40. Inductive reactance per single conductor, ohms per mile

From formula $x = 2\pi f\left(80 + 741.1 \log \frac{D}{r}\right) 10^{-6}$

Size A.W.G.	60 cycles per sec. — Spacing, in.															
	12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
0000	0.510	0.558	0.594	0.642	0.677	0.704	0.726	0.746	0.762	0.776	0.788	0.800	0.810	0.820	0.829	0.838
000	0.524	0.572	0.608	0.656	0.692	0.718	0.740	0.760	0.776	0.790	0.802	0.814	0.824	0.834	0.843	0.852
00	0.538	0.586	0.622	0.670	0.706	0.732	0.754	0.774	0.790	0.804	0.816	0.828	0.838	0.848	0.857	0.866
0	0.552	0.600	0.636	0.684	0.720	0.746	0.768	0.788	0.804	0.818	0.830	0.842	0.852	0.862	0.871	0.880
1	0.566	0.614	0.649	0.698	0.734	0.760	0.782	0.802	0.818	0.832	0.844	0.856	0.866	0.876	0.885	0.894
2	0.580	0.628	0.664	0.712	0.748	0.774	0.796	0.816	0.832	0.846	0.858	0.870	0.880	0.890	0.899	0.908
3	0.594	0.642	0.678	0.726	0.762	0.788	0.810	0.829	0.846	0.860	0.872	0.884	0.894	0.904	0.913	0.922
4	0.608	0.657	0.692	0.740	0.776	0.803	0.824	0.843	0.860	0.874	0.886	0.898	0.908	0.918	0.927	0.936
5	0.622	0.671	0.706	0.754	0.790	0.817	0.838	0.858	0.874	0.888	0.900	0.912	0.922	0.932	0.941	0.950
6	0.636	0.684	0.720	0.768	0.804	0.831	0.853	0.872	0.888	0.902	0.915	0.926	0.936	0.946	0.955	0.964
7	0.650	0.698	0.734	0.782	0.818	0.845	0.867	0.886	0.902	0.916	0.929	0.940	0.950	0.960	0.97[illegible]	0.978
8	0.663	0.712	0.748	0.796	0.832	0.859	0.880	0.900	0.916	0.929	0.943	0.954	0.964	0.974	0.984	0.992

To be used on all circuits with quantities measured *to neutral.*

41. Inductive reactance per single conductor, ohms per mile

Stranded conductor
25 cycles per sec.

Size cir. mils A.W.G.	Spacing, in. 12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
500,000	0.1885	0.208	0.223	0.243	0.258	0.269	0.279	0.287	0.293	0.299	0.304	0.309	0.313	0.317	0.321	0.325
450,000	0.1911	0.211	0.226	0.246	0.261	0.272	0.281	0.289	0.296	0.301	0.307	0.311	0.316	0.320	0.324	0.327
400,000	0.1941	0.214	0.229	0.249	0.264	0.275	0.284	0.292	0.299	0.305	0.310	0.315	0.319	0.323	0.327	0.330
350,000	0.1974	0.217	0.232	0.252	0.267	0.278	0.288	0.296	0.302	0.308	0.313	0.318	0.322	0.326	0.330	0.334
300,000	0.201	0.221	0.236	0.256	0.271	0.284	0.291	0.299	0.306	0.311	0.317	0.321	0.326	0.330	0.334	0.337
250,000	0.206	0.226	0.241	0.261	0.275	0.287	0.296	0.304	0.310	0.316	0.321	0.326	0.331	0.335	0.338	0.342
0000	0.210	0.230	0.245	0.265	0.280	0.291	0.300	0.308	0.315	0.320	0.326	0.330	0.335	0.339	0.343	0.346
000	0.216	0.236	0.251	0.271	0.286	0.297	0.306	0.314	0.320	0.326	0.331	0.336	0.341	0.345	0.348	0.352
00	0.222	0.242	0.257	0.277	0.291	0.302	0.312	0.320	0.326	0.332	0.337	0.342	0.347	0.350	0.354	0.358
0	0.227	0.248	0.262	0.282	0.297	0.308	0.318	0.326	0.332	0.338	0.343	0.348	0.353	0.356	0.360	0.364
1	0.233	0.254	0.268	0.288	0.303	0.314	0.324	0.331	0.338	0.344	0.349	0.354	0.358	0.362	0.366	0.370
2	0.240	0.260	0.275	0.295	0.309	0.320	0.330	0.338	0.344	0.350	0.355	0.360	0.365	0.368	0.372	0.376
3	0.245	0.265	0.280	0.300	0.315	0.326	0.336	0.344	0.350	0.356	0.361	0.366	0.370	0.374	0.378	0.382
4	0.251	0.271	0.286	0.306	0.321	0.332	0.342	0.349	0.356	0.361	0.367	0.372	0.376	0.380	0.384	0.387

To be used on all circuits with quantities measured *to neutral*.

41. Inductive reactance per single conductor, ohms per mile

Size cir. mils A.W.G.	60 cycles per sec. Spacing, in. 12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
500,000	0.451	0.500	0.535	0.584	0.619	0.647	0.669	0.688	0.703	0.718	0.730	0.742	0.752	0.762	0.771	0.780
450,000	0.458	0.506	0.541	0.591	0.625	0.653	0.675	0.693	0.709	0.724	0.736	0.748	0.758	0.767	0.777	0.785
400,000	0.464	0.514	0.548	0.598	0.632	0.660	0.682	0.700	0.716	0.731	0.743	0.755	0.765	0.775	0.784	0.793
350,000	0.472	0.522	0.556	0.606	0.640	0.668	0.690	0.708	0.724	0.739	0.751	0.763	0.774	0.783	0.792	0.800
300,000	0.482	0.532	0.566	0.615	0.650	0.677	0.699	0.718	0.734	0.748	0.760	0.772	0.783	0.792	0.801	0.810
250,000	0.493	0.542	0.577	0.626	0.661	0.688	0.711	0.729	0.745	0.759	0.772	0.783	0.794	0.804	0.812	0.821
0000	0.503	0.552	0.587	0.636	0.672	0.698	0.722	0.739	0.755	0.770	0.782	0.793	0.804	0.814	0.822	0.831
000	0.517	0.566	0.601	0.650	0.685	0.713	0.735	0.754	0.769	0.784	0.796	0.808	0.818	0.828	0.836	0.845
00	0.531	0.580	0.615	0.664	0.699	0.726	0.748	0.767	0.782	0.798	0.810	0.822	0.832	0.842	0.850	0.859
0	0.546	0.595	0.629	0.678	0.714	0.740	0.762	0.781	0.797	0.812	0.824	0.836	0.846	0.856	0.865	0.873
1	0.560	0.608	0.643	0.693	0.728	0.755	0.777	0.796	0.812	0.826	0.838	0.850	0.860	0.870	0.879	0.888
2	0.574	0.624	0.658	0.707	0.742	0.770	0.792	0.810	0.826	0.841	0.853	0.865	0.875	0.885	0.894	0.902
3	0.588	0.638	0.672	0.722	0.756	0.783	0.806	0.824	0.840	0.854	0.867	0.878	0.889	0.898	0.907	0.916
4	0.603	0.652	0.686	0.736	0.770	0.798	0.820	0.838	0.854	0.869	0.881	0.893	0.903	0.912	0.922	0.930

To be used on all circuits with quantities measured *to neutral.*

42. Charging current per single wire, amperes per mile, per 100,000 volts from phase wire to neutral

From formula $I = \dfrac{2\pi f \times 89.42 \times 10^{-9}}{\cosh^{-1}\left(\dfrac{D}{d}\right)}E = \dfrac{2\pi f \times 38.83 \times 10^{-9}}{\log_{10}\left(\dfrac{2D}{d} - \dfrac{d}{2D}\right)}E$

Solid wire
25 cycles per sec.

Size A.W.G.	Spacing, in.															
	12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
0000	0.355	0.322	0.302	0.278	0.263	0.252	0.244	0.238	0.233	0.228	0.224	0.221	0.218	0.215	0.213	0.211
000	0.345	0.314	0.295	0.272	0.257	0.247	0.240	0.234	0.228	0.224	0.220	0.217	0.214	0.212	0.209	0.207
00	0.335	0.306	0.288	0.266	0.252	0.242	0.235	0.229	0.224	0.220	0.216	0.213	0.211	0.208	0.206	0.204
0	0.326	0.298	0.281	0.260	0.247	0.238	0.230	0.225	0.220	0.216	0.213	0.210	0.207	0.204	0.202	0.200
1	0.318	0.291	0.275	0.255	0.242	0.233	0.226	0.221	0.216	0.212	0.209	0.206	0.203	0.201	0.199	0.197
2	0.310	0.284	0.269	0.249	0.237	0.229	0.222	0.217	0.212	0.209	0.205	0.203	0.200	0.198	0.196	0.194
3	0.302	0.278	0.263	0.244	0.233	0.224	0.218	0.213	0.209	0.205	0.202	0.199	0.197	0.195	0.193	0.191
4	0.295	0.272	0.257	0.240	0.228	0.220	0.215	0.209	0.205	0.202	0.199	0.196	0.194	0.192	0.190	0.188
5	0.288	0.266	0.252	0.235	0.224	0.216	0.210	0.206	0.202	0.198	0.196	0.193	0.191	0.189	0.187	0.185
6	0.281	0.260	0.247	0.230	0.220	0.213	0.207	0.202	0.198	0.195	0.192	0.190	0.188	0.186	0.184	0.182
7	0.275	0.254	0.242	0.226	0.216	0.209	0.203	0.199	0.195	0.192	0.189	0.187	0.185	0.183	0.181	0.180
8	0.269	0.249	0.237	0.222	0.212	0.205	0.200	0.196	0.192	0.189	0.186	0.184	0.182	0.180	0.179	0.177

E = volts to neutral; D = distance between wires; d = diameter of wires.

42. Charging current per single wire, amperes per mile, per 100,000 volts from phase wire to neutral

Size A.W.G.	60 cycles per sec.															
	Spacing, in.															
	12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
0000	0.852	0.773	0.725	0.667	0.631	0.606	0.587	0.571	0.559	0.548	0.539	0.531	0.523	0.517	0.511	0.506
000	0.828	0.753	0.708	0.652	0.618	0.593	0.575	0.560	0.548	0.538	0.529	0.521	0.514	0.508	0.502	0.497
00	0.805	0.734	0.691	0.638	0.605	0.582	0.564	0.550	0.538	0.528	0.519	0.512	0.505	0.499	0.494	0.489
0	0.783	0.716	0.675	0.624	0.593	0.570	0.553	0.540	0.528	0.519	0.510	0.503	0.497	0.491	0.486	0.481
1	0.763	0.690	0.660	0.611	0.581	0.559	0.543	0.530	0.519	0.510	0.502	0.495	0.488	0.483	0.478	0.473
2	0.763	0.682	0.645	0.598	0.569	0.549	0.533	0.520	0.510	0.501	0.493	0.486	0.480	0.475	0.470	0.465
3	0.725	0.667	0.631	0.586	0.558	0.539	0.523	0.511	0.501	0.492	0.485	0.478	0.472	0.467	0.462	0.458
4	0.707	0.652	0.618	0.575	0.548	0.529	0.514	0.502	0.492	0.484	0.477	0.470	0.465	0.460	0.455	0.451
5	0.690	0.638	0.605	0.564	0.538	0.519	0.505	0.494	0.484	0.476	0.469	0.463	0.458	0.453	0.448	0.444
6	0.674	0.624	0.592	0.553	0.528	0.510	0.497	0.485	0.476	0.468	0.462	0.456	0.450	0.446	0.441	0.437
7	0.659	0.611	0.580	0.544	0.519	0.501	0.488	0.477	0.469	0.461	0.455	0.449	0.444	0.439	0.435	0.431
8	0.645	0.598	0.569	0.533	0.510	0.493	0.480	0.470	0.461	0.454	0.448	0.442	0.437	0.432	0.429	0.425

43. Charging current per single wire, amperes per mile, per 100,000 volts from phase wire to neutral

From formula $I = \frac{2\pi f \times 89.42 \times 10^{-9}}{\cosh^{-1}\left(\frac{D}{d}\right)} E = \frac{2\pi f \times 38.83 \times 10^{-9}}{\log_{10}\left(\frac{2D}{d} - \frac{d}{2D}\right)} E$

Stranded conductor, 25 cycles per sec.																
Size cir. mils A.W.G.	Spacing, in.															
	12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
500,000	0.420	0.374	0.346	0.315	0.295	0.282	0.274	0.264	0.256	0.252	0.247	0.243	0.240	0.236	0.233	0.230
450,000	0.412	0.367	0.341	0.310	0.292	0.279	0.269	0.261	0.254	0.250	0.245	0.241	0.237	0.234	0.231	0.228
400,000	0.404	0.361	0.337	0.306	0.288	0.275	0.265	0.258	0.251	0.247	0.242	0.239	0.234	0.231	0.229	0.226
350,000	0.396	0.355	0.342	0.302	0.284	0.271	0.262	0.254	0.248	0.244	0.240	0.235	0.232	0.229	0.227	0.224
300,000	0.388	0.348	0.325	0.297	0.280	0.268	0.258	0.251	0.245	0.241	0.236	0.232	0.229	0.226	0.224	0.221
250,000	0.377	0.342	.0319	0.291	0.275	0.263	0.254	0.247	0.242	0.236	0.233	0.229	0.226	0.223	0.221	0.219
0000	0.370	0.334	0.312	0.286	0.269	0.259	0.250	0.243	0.239	0.233	0.229	0.226	0.223	0.220	0.217	0.215
000	0.357	0.325	0.304	0.280	0.264	0.253	0.246	0.238	0.234	0.229	0.225	0.222	0.219	0.216	0.214	0.212
00	0.349	0.317	0.296	0.273	0.259	0.248	0.241	0.234	0.229	0.225	0.211	0.218	0.214	0.213	0.211	0.208
0	0.339	0.308	0.290	0.267	0.253	0.243	0.236	0.230	0.225	0.221	0.217	0.214	0.210	0.209	0.207	0.204
1	0.329	0.300	0.282	0.261	0.248	0.238	0.232	0.225	0.221	0.216	0.213	0.211	0.207	0.205	0.203	0.201
2	0.319	0.291	0.275	0.255	0.243	0.233	0.227	0.221	0.216	0.212	0.209	0.207	0.204	0.202	0.1995	0.1974
3	0.311	0.285	0.269	0.250	0.237	0.229	0.223	0.217	0.213	0.209	0.206	0.203	0.201	0.1985	0.1965	0.1942
4	0.303	0.279	0.263	0.245	0.233	0.225	0.219	0.213	0.209	0.206	0.203	0.1995	0.1973	0.1953	0.1931	0.1910

E = volts to neutral; D = distance between wires; d = diameter of wires.

43. Charging current per single wire, amperes per mile, per 100,000 volts from phase wire to neutral

60 cycles per sec.

Size cir. mils A.W.G.	Spacing, in. 12	18	24	36	48	60	72	84	96	108	120	132	144	156	168	180
500,000	1.01	0.896	0.830	0.755	0.709	0.676	0.653	0.634	0.615	0.605	0.593	0.582	0.574	0.567	0.560	0.553
450,000	0.989	0.880	0.819	0.746	0.700	0.668	0.644	0.626	0.609	0.599	0.588	0.577	0.569	0.561	0.554	0.547
400,000	0.970	0.866	0.808	0.734	0.691	0.661	0.636	0.618	0.602	0.593	0.582	0.572	0.562	0.555	0.550	0.542
350,000	0.951	0.851	0.796	0.725	0.681	0.651	0.628	0.610	0.595	0.585	0.575	0.565	0.556	0.548	0.543	0.537
300,000	0.932	0.836	0.780	0.711	0.671	0.641	0.619	0.601	0.588	0.577	0.568	0.557	0.549	0.541	0.536	0.531
250,000	0.904	0.818	0.765	0.698	0.659	0.631	0.610	0.592	0.581	0.568	0.559	0.550	0.542	0.534	0.530	0.524
0000	0.887	0.800	0.749	0.686	0.646	0.620	0.600	0.583	0.572	0.560	0.549	0.542	0.534	0.527	0.522	0.516
000	0.857	0.780	0.730	0.671	0.633	0.608	0.590	0.572	0.562	0.550	0.539	0.532	0.524	0.520	0.514	0.508
00	0.836	0.760	0.712	0.656	0.620	0.595	0.579	0.562	0.550	0.539	0.529	0.523	0.514	0.510	0.506	0.499
0	0.813	0.740	0.695	0.640	0.608	0.583	0.568	0.551	0.539	0.529	0.521	0.514	0.505	0.502	0.496	0.490
1	0.789	0.719	0.676	0.626	0.595	0.570	0.556	0.540	0.529	0.519	0.512	0.505	0.496	0.493	0.487	0.482
2	0.765	0.699	0.661	0.613	0.582	0.560	0.545	0.529	0.519	0.509	0.502	0.496	0.489	0.484	0.480	0.474
3	0.747	0.683	0.646	0.601	0.570	0.550	0.534	0.520	0.510	0.501	0.494	0.488	0.483	0.476	0.471	0.466
4	0.726	0.668	0.631	0.588	0.560	0.540	0.524	0.512	0.502	0.494	0.487	0.479	0.474	0.469	0.463	0.458

To be used on all circuits with quantities measured *to neutral*.

GENERAL FEATURES OF DESIGN

44. The conductor for a given transmission system is influenced by such factors as climate, topography, length of span, reliability, amount of power, transmission distance and the economics of the problem. Copper and aluminum (see Sec. 4), except in special cases, are used exclusively for the conductors. Copper has high conductivity, is very ductile, is not easily abraded, has high tensile strength, a high melting point, and can be readily soldered. Aluminum has a conductivity about 60 per cent. that of copper. For the same conductance, it has only one-half the weight of copper. It is ductile and easily abraded; has 1.4 times the linear coefficient of expansion of copper, giving greater sag, and would therefore require higher towers for the same length of span. The tensile strength is much less than that of copper, though the ratio of tensile strength to weight is greater for aluminum. The melting point of aluminum is lower than that of copper, so that aluminum will be more easily burned by arcs and short-circuits. For the same conductance, aluminum offers a greater surface to wind-pressure, so towers must be designed with greater transverse strength. Neither copper nor aluminum is attacked by the atmosphere to any extent. In the United States, the price of aluminum is always held slightly below that of copper of the same conductance. In view of increased cost of pole line necessary to its employment, there is comparatively little incentive to use aluminum in small sizes of wire. In Canada and on the Continent of Europe, aluminum has found favor.

45. For extra long spans, it may be found economical to use either iron or steel as conductors, because of their much greater tensile strength. As these metals are subject to corrosion, they must either be galvanized or "copper-clad." Phosphor-bronze has been proposed, but its much higher cost for the same conductance practically prohibits its use. The table in Par. 46 shows a comparison of various conductor materials, and more complete tables may be found in Sec. 4.

46. Comparison of conductor materials on basis of equal conductance

Metal	Diameter	Weight	Strength	*Cost relation
Copper	1.00	1.00	1.00	1.00
Aluminum	1.27	0.485	0.65	2.06
Iron	2.72	6.36	5.30	0.157
Steel	3.41	10.00	41.5	0.100
Copper-clad steel	1.52	2.12	4.46	0.47

NOTE.—Skin effect has been neglected. Skin effect tables are given in Sec. 4. The relative resistances have been taken as follows: copper = 1; aluminum = 1.61; iron = 7.4; steel = 11.6; copper-clad steel = 2.3. The specific gravities are: copper = 8.89; aluminum = 2.68; iron and steel = 7.64; and copper-clad steel = 8.20. The elastic limits are: copper = 35,000 lb. per sq. in.; aluminum (stranded) = 14,000 lb. per sq. in.; iron = 25,000 lb. per sq. in.; steel = 125,000 lb. per sq. in.; and copper-clad steel = 68,000 lb. per sq. in.

47. Required size of conductor is determined by (a) mechanical strength; (b) permissible energy loss; (c) required voltage regulation; (d) corona; (e) cost; (f) current-carrying capacity.

(a) **Mechanical strength** is a primary consideration in any transmission line. It becomes especially important where long spans are necessary.

(b) **Permissible energy loss** is determined by such factors as the cost of generating power, selling price, load-factor, and other economic considerations. Where power is produced cheaply, it may be more economical to lose power in the line than to pay the fixed charges incident to heavier conductors and poles. (See Economics.)

(c) **Required voltage regulation** is, in general, not difficult to secure, as automatic regulators and synchronous apparatus may take care of any

* The last column in the table shows what *should* be the relation in cost per lb. of the various materials to result in the same total cost of conductor where the conductance of the line is fixed.

voltage fluctuations at the substations. If, however, the inductive line drop for a given cross-section of conductor is too great, two separate lines of half the cross-section may be used. The additional cost of insulators, poles and construction seldom justifies duplicate lines, where better regulation alone is the requirement.

(d) **Corona** may make the energy loss in excess of the permissible value, in which case, it will be necessary to increase the conductor diameter or the effective size of conductor. See Par. **48** to **53**.

(e) **Cost,** such as the relative cost of line, of plant, and of line maintenance may determine the size of line conductors. Since the salvage value of the line is in general low, whereas the engines and dynamos of the central station may be transferred without excessive loss to another plant and again used, it is advantageous to put more money into the generating station and to build the line as cheaply as possible if the system is a temporary affair. The amount of money available may make it necessary to build the system at a minimum cost, in which case the line conductors must be so chosen that the cost of the line plus the cost of the station, to supply both the net load and the line loss, shall be a minimum. The larger the line conductors, the smaller will be, the energy loss, but the fixed charges for the line will be increased. The conductors may be so chosen that the sum of these last two quantities is a minimum. See Par. **225**.

(f) **Current-carrying capacity** of the conductors under continuous operating conditions, is usually ample when the size of wire is determined by the permissible energy loss. An emergency demand, however, may overload the line for a short time, and where this is likely to occur, the conductor should be of such size as to operate within safe temperature limits. Tables of safe carrying capacity are given in Sec. 12.

CORONA

48. Corona, or the luminous discharge into the atmosphere from conductors at high voltage, may result in a considerable loss of power. H. J. Ryan, R. D. Mershon, J. B. Whitehead, and F. W. Peek have made studies of this phenomenon. *Peek's results are the latest obtained under actual operating conditions, and their accuracy is unquestioned. The relations may be expressed by the following formulæ:
The visual critical voltage is:

$$E_v = M_v \, g_o \delta r \left(1 + \frac{0.301}{\sqrt{\delta r}}\right) \log_e \frac{S}{r} \text{ kv. to neutral} \qquad (19)$$

$$P = \frac{k}{\delta} f \sqrt{\frac{r}{S}} (e - e_o)^2 10^{-5} \text{ (per kilometer of single conductor)} \qquad (20)$$

where $e_o = g_o M_o r \delta \log_e \frac{S}{r}$

e_o is the *disruptive critical voltage* to *neutral* and is always lower than E_v. The tables in Par. **49** and **50** give values of e_o.

(To obtain kw. per mile, multiply by 1.61)

Where E_v = effective kilovolts from phase wire to neutral at which corona becomes visible. $M_v = M_o = 1$ to 0.93 for wires, the higher value applying to a polished wire. $M_v = 0.72$, local corona all along conductor and 0.82, decided corona all along conductor for seven-strand cables; $g_o = 21.1$ kv. per cm., being the dielectric strength of air at 25 deg. cent. and 76 cm. pressure; δ = air density factor $= 3.92b/(273+t)$; $\delta = 1$ at 76 cm. pressure and 25 deg. cent. b = barometric pressure, in cm.; t = temperature deg. cent.; r = radius of conductor, cm.; S = distance between centres of conductors, cm.; $\log_e = 2.303 \log_{10}$; P = power per kilometer wire, kilowatts; $k = 344$; f = frequency cycles per sec.; e = effective kilovolts to neutral of conductor; M_o = irregularity factor of conductor; $M_o = 1$ for polished wires; 0.98 to 0.93 for roughened or weathered wires; 0.87 to 0.83 for seven-strand cable.

For three wires equally spaced in a plane, an exact calculation is too complicated for practical work. If the average spacings are assumed in calculating the critical voltage, corona will start on the centre conductor at a voltage about 5 per cent. lower than the calculated value, and on the two outside conductors at a voltage about 5 per cent. higher than the calculated value. For practical work it is sufficiently accurate to neglect this correction unless the spacing is quite uneven.

* Bibliography 25–30 in.

Smoke, fog, sleet, rain and snow all lower the critical and visual voltages, and increase the losses. Fig. 23 shows the increased loss due to snow.

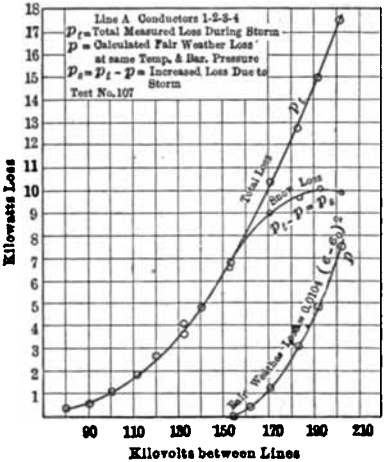


FIG. 23.—Corona loss during snowstorm.

In calculating corona loss, it must be remembered that the entire line is not at the same potential, and that a small change in e.m.f. above the critical value, e_o, makes a large percentage change in the loss. It has been suggested to make use of this last fact in dissipating energy associated with an abnormal rise of voltage due either to a line surge or to lightning.

The part of the loss curve between E_v and e_o is affected to a considerable degree by the conditions of the wire surface as to dirt, weather, etc., and hence varies from day to day. In practice it is generally not advisable to operate at a higher voltage than that corresponding to e_o, otherwise the loss would become very high during wet weather or when the conductor surface became roughened. Local brushes also occur which may cause deterioration of the conductor by nitric acid formation, especially at the points of support. The voltages in the tables (Par. 49) correspond to e_o voltages reduced to kilovolts between conductors at 25 deg. cent. and 76 cm. barometer.

49. Corona limits of voltage. Kilovolts between lines (three-phase) at sea level

(Cables)

From formula $e_o = \sqrt{3}\, g_o M_o r \delta \log_e \frac{S}{r}$ where $M_o = 0.87$

A.W.G.	Diam., in.	Spacing—feet									
		3	4	5	6	8	10	12	14	16	20
4	0.230	...	56	58	60	62	64	66	68	69	71
3	0.261	...	62	65	67	70	72	74	76	77	80
2	0.290	...	...	71	73	76	79	81	83	85	87
1	0.330	...	...	79	81	85	88	91	93	95	97
0	0.374	...	...	...	90	95	98	102	104	106	109
00	0.420	...	...	...	98	104	108	111	114	117	121
000	0.470	...	...	...	...	114	118	121	124	127	132
0,000	0.530	...	...	...	...	125	130	135	138	141	146
250,000	0.590	...	...	...	...	138	144	149	152	156	161
300,000	0.620	...	...	...	...	....	151	156	161	165	171
350,000	0.679	...	...	...	...	....	161	166	170	175	180
400,000	0.728	...	...	...	...	....	171	176	180	185	192
450,000	0.770	...	...	...	...	....	178	184	190	194	200
500,000	0.818	...	...	...	...	....	188	194	199	205	210
800,000	1.034	...	...	...	...	....	....	234	241	244	256
1,000,000	1.152	...	...	...	...	....	....	256	264	270	281

(Solid wires) $M_o = 0.93$

A.W.G.	Diam, in.	Spacing—feet									
		3	4	5	6	8	10	12	14	16	20
4	0.204	51	54	56	58	60	62	64	65	66	68
3	0.229	...	59	62	64	66	68	70	72	74	76
2	0.258	...	...	69	70	74	76	78	80	82	84
1	0.289	...	...	75	77	81	83	86	88	90	92
0	0.325	...	...	...	85	89	92	95	97	99	102
00	0.365	...	...	...	94	98	102	105	107	110	113
000	0.410	...	...	...	...	109	113	116	119	121	124
0000	0.460	...	...	...	...	120	125	128	131	134	138

To find the voltage at any altitude, multiply the voltage found above by the δ corresponding to the altitude as given in Par. 50.

For single-phase or two-phase circuits find the value of volts for the corresponding three-phase circuit above, and multiply by 1.16.

50. Altitude correction factor δ

Altitude, ft.	δ	Altitude, ft.	δ	Altitude, ft.	δ	Altitude, ft.	δ
0	1.00	2,000	0.92	5,000	0.82	9,000	0.71
500	0.98	2,500	0.91	6,000	0.79	10,000	0.68
1,000	0.96	3,000	0.89	7,000	0.77	12,000	0.63
1,500	0.94	4,000	0.86	8,000	0.74	14,000	0.58

51. To decrease corona loss, either the frequency or the voltage must be reduced. These, however, are usually fixed. The spacing may be increased, but this decreases the loss but slightly, and the increased conductor spacing would increase the line cost considerably. As the meteorological conditions cannot be controlled, the diameter of conductor must be increased. This may be done without increasing the conductor weight by using aluminum, hemp- or steel-cored cable, or hollow conductors. The first is the most practicable method and in future, it may become necessary to use aluminum for very high voltage lines. Hemp-cored cable has been tried, but the core soon rots and the conductor strands become disarranged. Hollow conductors reduce the skin-effect, but the cost of manufacture makes their use prohibitive.

52. Example of calculation of corona loss. Line, 3-phase; length of line, 120 miles; size conductor, 00 copper; e.m.f., 110 kv.; frequency, 60 cycles; spacing, 10 ft. Assume 20 deg. cent., 76 cm. barometric pressure, and a coefficient of roughness, $M_o = 0.95$. $d = (3.92 \times 76)/(2.73 + 20) = 1.01$; diameter of 00 wire = 365 mils; $r = 0.463$ cm.; $S = 10 \times 12 \times 2.54 = 305$ cm.; $e = 110/\sqrt{3} = 63.5$ kv.. to neutral; $e_o = 21.1$ kv.; $\log_{10} \dfrac{305}{0.463} = 2.82$; $P = \dfrac{344}{1.01} \times 60 \times 0.039\ [63.5 - (21.1 \times 0.95 \times 0.463 \times 1.01 \times 2.303 \times 2.82)]^2 \times 1.61 \times 10^{-5} = 797(63.5 - 60.9)^2 \times 1.61 \times 10^{-5} = 0.0864$ kw. per wire per mile; total corona loss $= 0.0864 \times 3 \times 120 = 31.1$ kw.

LINE INSULATORS

53. Requirements. The successful operation of a transmission system depends to a large extent upon the degree of insulation attained, and the most important factor is the insulator. Up to a few thousand volts, there is no difficulty whatever in maintaining good insulation, but as the voltage reaches higher values, the difficulties increase and factors such as leakage and capacity effects, which are entirely negligible in low-tension systems, become of major importance.

54. Insulators have appreciable capacity, and act like condensers of complicated construction. The dielectric is made up of alternate layers of air and porcelain or glass of varying thicknesses. Some of the charging current to the pin must pass over the surface of the insulator, which has a very high resistance, so the insulator may be represented by a resistance, shunted by a number of small condensers as shown in Fig. 24, where E is the voltage from the line to the pin, I the total current taken by the insulator, i_c the charging current, and i_r the leakage current. The vector diagram simply illustrates the theory, and no attempt has been made to give the proper relative values to the various quantities. *Measurements by C. E. Skinner

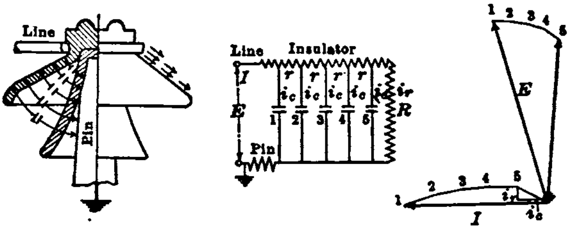


Fig. 24.—Insulator, equivalent circuits.

indicate that the ohmic resistance of porcelain insulators is practically infinite, and that whatever leakage takes place passes over the surface. The effect of capacity tends to increase this surface leakage, which ionises the air, and thereby decreases the leakage resistance. Insulators should, therefore, be designed with small petticoat areas; the material should have a low dielectric flux constant, and the capacity should be so distributed that there will be no local stresses tending to cause a breakdown. Flaring the petticoats increases the thickness of the dielectric and decreases its dielectric flux constant, since that of air is only about one-fifth that of porcelain; therefore, by flaring the petticoats the electrostatic capacity of the insulator is greatly decreased.

55. Insulator adapted to wet-weather conditions. A German firm has substituted a metal top for the topmost petticoat and found that the ability to stand up under high tension is increased, other things being equal. The substitution of metal for porcelain does away with the surface resistance to the charging current on the top petticoat, and equalizes the static strains when the insulator is wet. The tendency is to drive the water to the edge and repel it. This fact is borne out by test. When perfectly dry this type will break down at a slightly lower voltage than a similar one with a porcelain top; due to the extreme lightness of the top, it may be made very broad and its action in rain is to shield the porcelain part of the insulator. In this way the breakdown voltage is considerably increased over that of the ordinary all-porcelain insulator of the same weight.

56. The minimum arcing distance and leakage path are shown in Fig. 25, as $A+B+C$, and ab respectively. The resistance is directly proportional to the length and inversely proportional to the area of the path, so increasing the diameter of the petticoats does not increase the leakage resistance appreciably. Increasing the number of petticoats increases the length of path without necessarily increasing the area, so that a high leakage resistance is best secured by increasing the number of petticoats. Insulators are usually made of glass, porcelain, or patented compounds.

57. Glass is cheaper than porcelain and when properly annealed, has high dielectric strength and specific resistance. As it is transparent, flaws can readily be detected. On the other hand, moisture condenses on its surface; the action of rain destroys the smoothness of the surface and allows particles of dirt to accumulate diminishing the resistance of the leakage path.

* Measurements made for Ralph D. Mershon, *Trans.* A. I. E. E., Vol. XXVII (1908), p. 928.

58. Porcelain gives less leakage trouble, is stronger mechanically than glass, and is less affected by changes of temperature. On the other hand, it is more expensive, and slight imperfections in the glaze are common. As flaws, such as blow-holes, strata, or cracks cannot be readily detected by simple inspection, each section should be subjected to a voltage test before and after assembling.

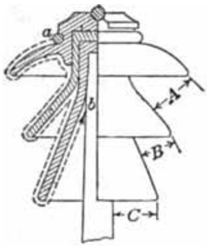


FIG. 25.—Arcing and leakage paths.

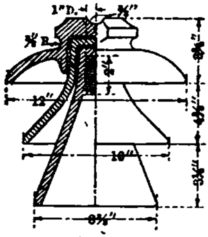


FIG. 26.—Pin-type insulator.

59. Patented compounds are on the market, possessing better mechanical characteristics than either porcelain or glass. It is somewhat doubtful, however, if these compounds can successfully withstand the effects of weather and the high electrostatic stresses incident to high-tension power transmission.

60. Pin-type insulators are made of either glass or porcelain. Glass insulators of this type are now being manufactured to operate at 50,000 volts pressure. Porcelain pin-type insulators can be used for pressures as high as 90,000 volts. (See Fig. 26.)

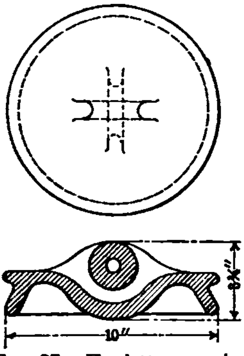


FIG. 27.—Hewlett suspension insulator.

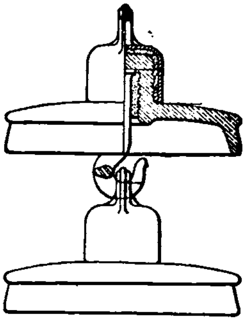


FIG. 28.—One-piece cemented insulator, suspension type.

61. Suspension insulators can be operated at about 20,000 volts per unit, and are used for voltages in excess of 70,000, as the pin-type insulator then becomes too large, heavy, expensive, and mechanically weak. When suspension insulators are used, the cost and weight are practically proportional to the line voltage, but beyond a certain point it is difficult, even with additional units, to secure increased insulation. There are two common types, the Hewlett, or interlinking type of insulator, shown in Fig. 27, where the two suspension cables loop through each other and are separated by a layer of porcelain; and the cemented type, in which the porcelain or glass is cemented into a metal cap, and the pin is cemented into the insulator. Fig. 28 shows a one-piece cemented unit and Fig. 29 shows a two-piece cemented unit. The Hewlett type has not as yet met the mechanical requirements of very heavy power work. It is probably more difficult to replace than the cemented type, and the electric stresses are not so well distributed. The cemented type has given trouble due to failures at the base of the cap, and in design this factor should be carefully considered. The present tendency in insulator design is toward smaller discs and closer spacing. This results in higher puncture strength for a given flash-over voltage.

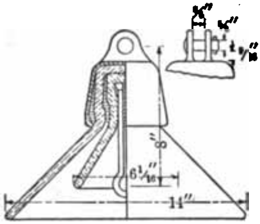


FIG. 29.—Two-piece cemented insulator, suspension type.

62. The string efficiency* of n suspension insulator units is the ratio of their total flash-over voltage, to n times the flash-over voltage of one insulator. Although certain unpublished 500,000-volt tests have shown this ratio to be practically unity, the majority of experiments show that the string efficiency decreases when the number of insulators is increased. Fig. 30 shows the results of the tests made by F. W. Peek, Jr. This lowering of flash-over voltage is due to the fact that each insulator has a certain capacity to ground, the insulator nearest the line carrying the charging current of the whole string of n insulators. The second insulator carries the charging current of $n-1$ insulators, etc., so the unit next the line is subjected to the greatest stress, the second unit to a lesser stress, etc. The string efficiency is nearer unity under the wet test, as the leakage current is then so increased that the effect of the capacity current is negligible. The string efficiency is increased by making the ratio of mutual capacity to ground capacity large; that is by hanging the insulator units near together but having each string at some distance from the pole or tower. (Par. 67.)

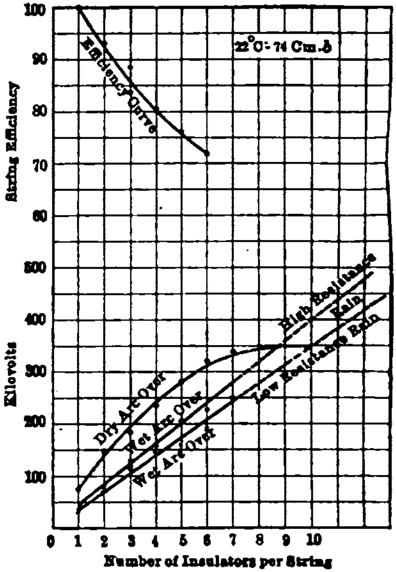


FIG. 30.—Insulator string efficiency.

63. The Watts insulator, shown in Fig. 31, proposed by *A. S. Watts, of Germany, is 1 ft. long and has withstood 100,000 volts. It is claimed that in so far as cost and weight go, this insulator is similar to the suspension type, in that the cost and weight are about proportional to the voltage. The small grooves are not so deep that they will collect dirt and foreign material which can-

* Bibliography 39.

not be removed by the action of the elements. If struck by lightning the charge can pass to ground by jumping from one ridge to another, and the insulator will remain unharmed.

64. Strain insulators are used when the line is dead-ended; at intermediate anchor towers; on sharp curves where the line would tend to overturn the insulator, break the pin, or pull a string of suspension insulators out of alignment; and on extra long spans, as at river crossings. For voltages up to

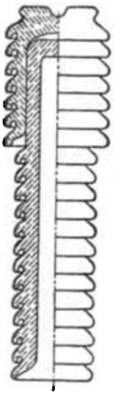


Fig. 31.—The Watts insulator.

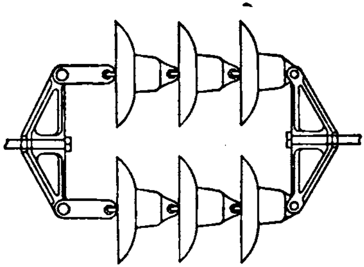


Fig. 32.—Strain insulator with yoke.

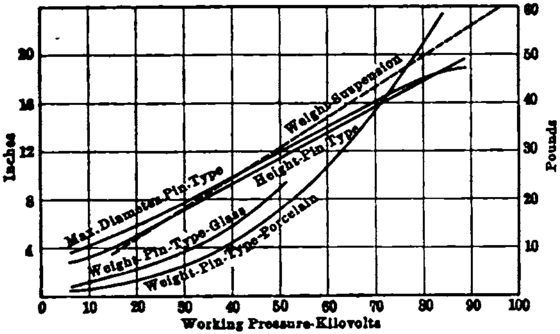


Fig. 33.—Weights and sizes of insulators.

30,000, a pin-type may be used. For voltages in excess of 30,000, either the link-type or the cemented type (Fig. 32) is used. Fig. 33 gives the approximate sizes and weights of the various types of insulators.

65. Insulators are usually designed to flash over, rather than to puncture. To assist in securing this result, particularly on high frequency impulses, arcing rods are used (Fig. 35). These have the further effect of

* Bibliography 35.

holding the power arc away from the insulator. Another type is the *Nicholson arcing ring. (Fig. 34.)

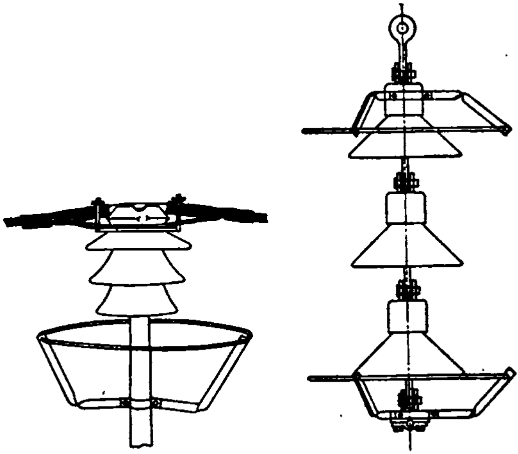
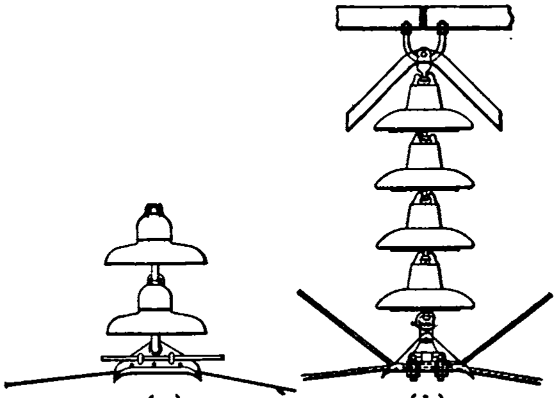


FIG. 34.—Nicholson arcing rings.



(a) (b)

FIG. 35.—Arcing rods.

66. The line conductor should also be protected from burning off, due to the heat of the arc. The arcing rods shown in Fig. 35, and the Thomas Line Protector shown in Fig. 36 may be used.

* Bibliography 36.

67. *Effect of high frequency on insulators. Insulators that only flash over at commercial frequencies may puncture at the same voltage if the frequency be high. This is probably due in part to the altering of stress distribution caused by the change in the ratio of susceptance to leakage conductance brought about by high frequency. It is also due in part to the corona not having time to form and relieve the stress by rupture of the air. To prevent puncture due to high frequency disturbances, the ratio of flash-over voltage to puncture voltage should be low.

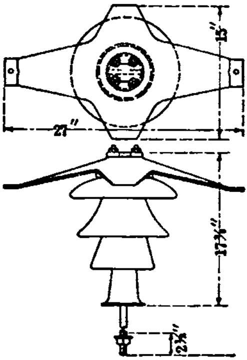


FIG. 36.—Thomas line protector.

68. Insulator testing† is of two kinds, design tests and routine tests. Design tests cover those features that are important to the purchaser, such as dry and wet flash-over, puncture voltage, tensile strength, and are usually made on the assembled unit or string. The insulator should be tested under conditions approximating those attained in service, such as mounting or suspending from a grounded pin and cross arm, well away from other objects. The potential should be applied between the pin, and a short length of cable, representing the line conductor, tied or clamped to the insulator. The standard wet test is to spray water over the insulator at an angle of 45 deg. and at a precipitation rate of 0.2 in (0.508 cm.) of water per min. As results are largely dependent on the electrolytic nature of the water, distilled water is to be preferred, as more uniform results are obtained by its use. Insulators, under ordinary conditions, flash over before puncturing, so in order to obtain the puncture voltage, the insulators must be immersed in oil.

Routine tests should be made on each part of every insulator before assembling, and also on the complete unit. The object is not to flash over the insulator but rather to detect existing faults before the insulator is put in service. The parts of pin and suspension type insulators are inverted in water thus forming one terminal. Water is also placed inside the insulator

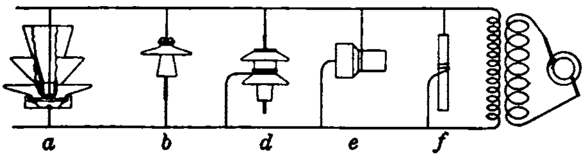


FIG. 37.—Insulator testing.

covering the threads in the threaded parts, and from 0.5 to 0.75 in. (1.27 to 1.9 cm.) deep in the other parts, thus forming the other terminal as shown in a, Fig. 37. Dry tests are often made on the assembled unit, b, c, d, e (Fig. 37) and are necessary on strain insulators and bushings. The *breakdown voltage of insulators* is a function of the time during which the voltage is applied, as has been shown by A. O. Austin.‡ A higher potential for a short time will eliminate poor insulators in the same manner as a lower potential for a longer time. Such curves for 100 kv. and 85 kv. are shown in Fig.

* See Bibliography 40.
† See Bibliography 34, 37–41 incl.
‡ See Bibliography 37.

38. Thus 100 kv. for one-half minute will eliminate 2.2 per cent., whereas 85 kv. must be applied 4.7 minutes to produce the same result.

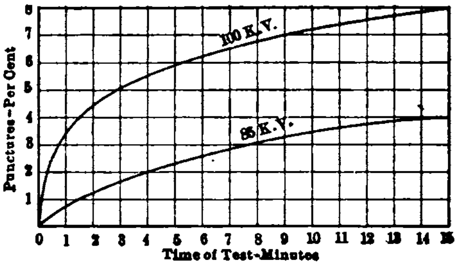


FIG. 38.—Insulator time-puncture curves.

SYSTEM DISTURBANCES

69. Surges* and disturbances occur in a transmission circuit, when circuit conditions are in any way altered. An **oscillation** is a recurring disturbance due usually to the oscillation of energy between the electrostatic and electromagnetic fields. An oscillation of low frequency, or one that is rapidly damped, is called a **surge**. Disturbances may be produced by causes within the system itself, such as switching, grounds, changes of load, or they may be produced by external causes, such as lightning.

In an oscillation, the energy passes from one form to the other, so that assuming no loss,

$$\tfrac{1}{2}Li^2 = \tfrac{1}{2}Ce^2$$

or

$$e/i = \sqrt{L/C} \qquad (21)$$

The term $\sqrt{L/C}$ is the *natural impedance* of the line.

From Eq. 21, the maximum voltage possible to occur on interruption of the current I is:

$$e = I\sqrt{L/C} \qquad (22)$$

This rise of voltage limits the current that may safely be interrupted and renders a short circuit dangerous.

Any change in load will alter either e or i and as the energy of the electrostatic and electromagnetic fields cannot change in zero time, e and i must pass through some transient values before the steady state is again reached.

If r, the resistance, is equal to or greater than $\sqrt{L/C}$, the transient is non-oscillatory, and quickly dies out. If r is less than $\sqrt{L/C}$, the transient is oscillatory. The energy is dissipated as heat in the resistance, in hysteresis losses in the fields themselves, or the insulation of the system may break down allowing the energy to manifest itself in an arc.

70. The frequency at which the transient oscillates is

$$f = 1/(4\sqrt{LC}) \qquad (23)$$

when the circuit constants are distributed, as in the case of a transmission line. f is the *natural frequency* of the circuit. The transmission frequency should be so chosen that the natural frequency is not exactly an odd multiple thereof.

71. Forced oscillations are produced by a source of energy external to the circuit, such as lightning, whose frequency has no relation to the circuit constants.

* Par. 247.

72. Effect of transients. When a traveling wave passes from one part of a circuit into another of different constants, the voltage wave, e_1, will change its magnitude to e_2, as follows,

$$e_2 = e_1 \frac{Z_2}{\left(\frac{Z_1 + Z_2}{2}\right)} \tag{24}$$

and the current

$$i_2 = i_1 \frac{Z_1}{\left(\frac{Z_1 + Z_2}{2}\right)} \tag{25}$$

where Z_1 and Z_2 are the natural impedances $\sqrt{L_1/C_1}$ and $\sqrt{L_2/C_2}$ of the two parts of the circuit, respectively. (See Par. 69.) Thus a wave passing from one part of a circuit to another having a greater ratio of inductance to capacity will develop an increased voltage and a decreased current. This explains the breaking down of transformer windings, due to surges entering them. On the other hand, if a wave passes from an overhead system into a cable, the voltage will be reduced, and the current increased. This explains the self-protecting quality of cables to surges.

73. A line whose length is a quarter wave is determined by

$$L = \frac{183{,}000}{4f} \tag{26}$$

where L is the length in miles, f the frequency in cycles per sec., and 183,000 the velocity of an electric wave in miles per sec. It can be shown that such a line, with constant generator voltage, tends to regulate for constant current at the receiving end, and the maintenance of constant voltage at the load therefore becomes difficult. The voltage may rise to dangerous values when the circuit is opened, though a transformer at the receiving end will practically neutralize this abnormal potential. The frequency corresponding to a quarter wave length of line is the lowest frequency at which the line can freely oscillate. It cannot oscillate at a frequency corresponding to either a half or a whole wave length when the circuit is open at one end.

74. Oscillations originating in the transformer. High voltage transformers have an appreciable electrostatic capacity between turns, and also to ground, together with a large equivalent reactance. This not only tends to create very high frequency oscillations in the transformer itself but also to produce voltage rises that may puncture the insulation. Protective apparatus must therefore be so designed that these oscillations may readily pass from the transformer to the line, and, at the same time, outside disturbances will be prevented from passing in the reverse direction.

75. Lightning disturbances* may be due to a charge induced on the line by a nearby cloud which discharges, thus allowing the line charge to flow suddenly to ground; to inductive action of a nearby discharge; to direct stroke. Such disturbances may be of high frequency and may either start a destructive arc to ground or shatter the insulators near the spot of original disturbance. Waves may be propagated in both directions, causing damage at some remote point.

76. Lightning disturbances may be minimized by the use of one or more overhead ground wires, grounded at very frequent intervals. Damage to apparatus may be practically prevented by installing arresters, preferably of the aluminum cell type, near the apparatus, for example, across the high-tension bus bars at the generating station, at substation entries, and near outdoor transformers and substations. Lines have been protected by operating them just below the critical corona voltage (see Par. 48 to 52). Any disturbance that tends to raise the voltage, immediately increases the corona loss to such an extent that the energy of the disturbance is thereby dissipated.

77. The selection of protective equipment is governed somewhat by local conditions. The degree of protection necessary depends largely upon the value of the power that is being transmitted, and the financial loss involved by a shut-down or by an interruption of the service.

* Bibliography 56.

78. Local short-circuits may be isolated from the rest of the system by properly selected automatic oil switches equipped with relays which are of either the instantaneous, reverse-energy, or inverse-time-limit types. Lightning arresters should be able to care for any abnormal voltage rise due to switching. (See Par. 69 and 92.) That the current flowing into a short circuit in one portion of the system may not rise to dangerous values, power-limiting reactances are interposed between the different sections of the system.

79. Detection and clearing of grounds. Grounds may be detected by some form of electrostatic detector, placed on the switchboard. An arcing-ground on an ungrounded system may be cleared by the **arcing ground suppressor,*** shown in Fig. 39. The selective relay may operate electrostatically, or electromagnetically by the use of potential transformers. When a ground occurs on any phase, that phase is temporarily grounded by the proper oil switch, selectively operated by the relay. This lowers the voltage across the arc, which therefore ceases, and the switch then opens (through a resistance to prevent oscillations) and the ground is thus cleared. In a cable system the grounded phase is permanently connected to ground, as otherwise the arc would immediately re-form when the switch opened, due to the short distance between core and sheath. Interlocking devices prevent the simultaneous operation of more than one switch at a time, thus avoiding a short circuit on the system.

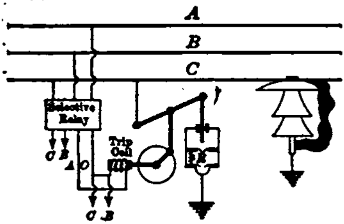


FIG. 39.—Arcing-ground suppressor.

A **short-circuit suppressor** throws a fuse directly between phases, shunting out a short-circuit arc. Subsequently the fuse automatically interrupts its own current. When these are used, power-limiting reactances are desirable in order to protect apparatus from mechanical injury.

80. Overhead ground wires unquestionably reduce the interruptions to service due to lightning, although there are no available data stating just how great the advantage is. It is estimated that one wire will reduce these interruptions about 50 per cent., and that two wires will make a still greater reduction. Galvanized iron and steel, because of their low cost and high tensile strength, have been commonly used for this purpose. Copper-clad conductors may have a lower impedance to the high-frequency discharges of lightning than have galvanised iron or steel.

SYSTEM CONNECTIONS AND SWITCHING

81. System connections should be made in such a manner that continuity of service, flexibility, and safety are secured without undue complications of wiring and switching.

82. Duplicate lines are usually necessary, where continuity of service is important. It is customary to run the two lines on the same poles or towers, especially if these are of steel or concrete, as the total cost of line supports is then much less than it would be for two individual pole lines. Where the power is especially valuable, the two lines may be run over two different routes, removed from each other. This lessens the chance of both lines being disabled at the same time by lightning or by other natural causes. The cost of two such lines is frequently prohibitive. When it is necessary to shut down a line for repairs, the service is interrupted if two lines are not available. Where the regulation would be impaired, or the overload capacity of one line is not sufficient to carry the entire load during such a shut-down, sectionalising switches may be provided. The section requiring repairs may be isolated and grounded, the two lines being in parallel for the remaining distance. This insures better and more continuous service, though frequently the advantage gained is more than offset by the added expense and

* See Bibliography 56.

switching complication. Fig. 40 shows the connections for a typical power system.

83. Substation connections are made as shown in Fig. 40 and Figs. 73 and 74. See also Sec. 10 and Sec. 12.

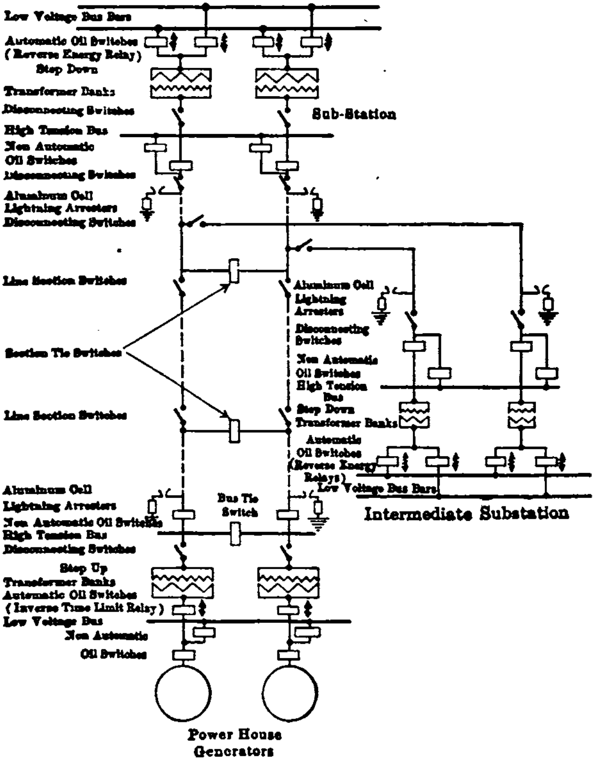


Fig. 40.—Typical system connections.

84. *Advantages of grounded systems are as follows: (a) Except under unusual transient conditions, the voltage from line wire to ground never exceeds the *Y* voltage, so the line insulation need not have so large a factor of safety, as with isolated systems; (b) a ground on one wire opens the breakers and warns the operator of trouble; (c) the dynamic arc to ground has but little tendency to create high frequency oscillations; (d) disturbances to the telephone system due to electrostatic unbalancing are a minimum.

85. Disadvantages of grounded systems are: (a) The line is inoperative if a ground occurs; (b) the short-circuit current may produce strong mechanical forces in generator and transformer windings, causing

* See Bibliography 67, 68.

serious damage; (c) the dynamic arc may shatter the insulators or burn off the conductors, because of the large amount of energy available; (d) inductive effects of the earth circuit may affect the telephone and telegraph circuits, though the earth current is practically negligible except in case of an accidental ground.

86. Conditions of advantageous grounding. A system in excess of 60,000 volts may well be grounded, unless absolute continuity of service is essential. A line connected as a part of a large system should be grounded. It will then be automatically disconnected and cannot subject the entire system to the delta voltage between line wire and ground. A cable system* should be grounded, as oscillations and transients are of common occurrence, and a ground in one part of the system may otherwise cause a breakdown in the insulation at some other point. To locate and repair a ground in a cable system is expensive, requiring considerable time.

87. The ground† connection may be made by connecting the neutral to a copper plate buried in charcoal; by connecting to a metal plate immersed in a nearby body of water; by connecting to metal work in contact with the earth or water; by driving iron pipes of about 1 in. (2.54 cm.) or so in diameter and 6 ft. (2 m.) length into the earth 6 ft. (2 m.) apart, and pouring salt water around them. To limit the short-circuit current, a resistance may be inserted in the neutral connection, though to secure one having the necessary resistance and carrying capacity is expensive. A reactance should not be used in the neutral as it may increase the probability of oscillations. The ground should be made at only one point of the system, at the power-house, as otherwise earth currents tend to flow and to disturb telephone and telegraph circuits in the vicinity of the line.

88. Ungrounded systems‡ have the following advantages: (a) an accidental ground does not shut down the system; (b) the earth may serve as a third conductor until the damage can be repaired; (c) an arcing ground may be cleared by the arcing ground suppressor; (d) under normal conditions, there is little effect on telephone and telegraph lines.

89. Disadvantages of ungrounded systems are as follows: (a) Though the neutral of the system should be at ground potential, experiment has shown that excessive voltage may exist between neutral and ground; (b) the insulation of the system must be designed to withstand the delta voltage, and therefore must have 1.7 times the insulation for the same factor of safety; (c) an arc to ground is in series with the line capacity, and therefore tends to set up destructive high-frequency oscillations; (d) any electrostatic unbalancing affects neighboring telephone and telegraph systems.

90. Ungrounded systems should be used where the voltage is moderate; where a shut-down would be a serious matter; where the apparatus may well withstand the full-line potential.

91. Transformer connections§ may be either delta or star. Transformers connected in delta must be able to withstand the total voltage between lines, hence their cost is greater than for star-connected transformers. They are more reliable than the star-connected, for if one transformer is disabled the system will continue to operate connected open delta. Transformers connected in delta may be heated by the third harmonic circulatory current. The star connection affords an accessible neutral, and the transformers need be designed to withstand only 58 per cent. of the line voltage. There is no third-harmonic circulatory current possible, and any third-harmonic voltage does not appear on the line. If one transformer goes out, the system must either be operated single-phase, or be shut down, unless a spare unit is available. Voltage taps are easily brought out from the transformer winding in the star connection. See Sec. 6.

92. Switching‖ a transmission line may give rise to transients causing

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* See Bibliography 46.
† See Bibliography 63.
‡ Bibliography 67, 68.
§ Bibliography 23.
‖ See Bibliography 48, 49.

serious damage to line and apparatus. The matter is further complicated by the characteristics of the oil switches themselves. When the switch contacts approach each other on closing the circuit, small arcs of decreasing magnitude are set up between them. These may result in high frequency oscillations corresponding in period to the natural frequency of the transformer windings. In a three-phase switch the three contacts may not close at the same instant which further complicates the problem. Similar phenomena occur when the switch opens the circuit, the arcs between contacts increasing in magnitude. The maximum possible voltage rise as the switch opens is given by

$$e = i\sqrt{L/C} \qquad (27)$$

where i is the current at the moment of break and L and C are the circuit inductance and capacity respectively. The voltage does not usually approach this limiting value as the arcs formed between the contacts introduce resistance which diminishes the voltage rise. The switch also absorbs some of the energy stored in the line. The voltage rise, under ordinary switching conditions, may not exceed the normal operating value more than from 50 to 75 per cent. The excessive rises in potential occur under short-circuit conditions, when the current may reach many times full-load value. Aluminum arresters and power-limiting reactances offer the best solution of the problem.

93. High-tension and low-tension switching are both extensively employed, there being no consensus of opinion as to which is more desirable. The following methods are used in switching on a substation.

(a) Connect the line to the high-tension bus at the generating station, and then switch the substation transformers.

(b) Connect substation transformers to the dead line, and then switch the line to the high-tension bus at the generating station.

(c) Connect the open line to the transformers at the generating station, switch these on the low side, and then connect the substation transformers at the end of the live line.

(d) Connect the substation transformers to the dead line and step up transformers and switch these latter on the low tension side.

(a) and (b) come under the classification of high tension switching and (c) and (d) low-tension switching. The reverse order may be followed, when switching off.

Transformer switching may result in abnormal current rushes, if the circuit is closed on a point of the e.m.f. wave, which does not correspond to the residual magnetic state of the transformer.

POWER-FACTOR CORRECTION

94. Power-factor correction* may often be made on transmission lines, whereby the voltage regulation may be materially improved, the generating capacity increased and the copper losses reduced. This correction may be made by the over and the under excitation of synchronous apparatus at the receiving end of the line. When used for this purpose exclusively, such apparatus is called a synchronous condenser. This synchronous apparatus may be a part of the receiver and used for further distribution of power, or it may merely float on the end of the line, its sole function being to regulate the power-factor, or the voltage. As synchronous motors are not wound for voltages much in excess of 13,000 volts, they must be connected to the low sides of transformers if the line voltage exceeds this value. When the motor is installed solely to improve transmission efficiency, the cost of the power required by the motor plus its maintenance and fixed charges, must not exceed the cost of the power saved, and must be less than the interest on the cost of installing more copper. As the synchronous apparatus may fall out of step, or be damaged by surges or short-circuits, it is generally desirable to install copper, which will give greater reliability, and has a better scrap value.

When improved regulation is the result desired, the installation of synchronous apparatus may be justified regardless of the energy saving. Where large amounts of power are concerned, it is impracticable to install synchronous condensers to take care of the entire quadrature current, although they may be used for purposes of improved regulation.

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* Bibliography 71–77 incl.

95. Calculations for power-factor correction. The per cent. quadrature current required for unity power-factor at the receiver may be determined from Fig. 41, or may be calculated for a three-phase system as follows:

$$I_1 = \frac{W}{3E} \tag{28}$$

$$I_2 = \frac{W}{3E} \tan \theta \tag{29}$$

where I_1 and I_2 are the energy and quadrature components of current respectively, W is the power, in watts, at the receiver, E is the voltage, from line wire to *neutral*, at the receiver, and θ is the angle between the current and voltage vectors. It will be noted, from Fig. 41 that it requires a much larger synchronous motor to bring the power-factor from 95 per cent. to 100 per cent., than it would require to bring it from 90 per cent. to 95 per cent. As a rule, it is not economy to install apparatus large enough to obtain the last 5 per cent.

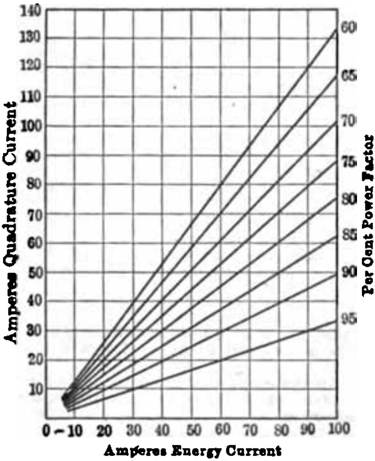


FIG. 41.—Energy and quadrature currents.

96. Constant receiver voltage* **may be obtained** by varying the excitation of the synchronous apparatus, either by use of an automatic regulator which acts on the exciter or by compounding, if the synchronous apparatus is a motor-generator or a rotary converter. When the variations in voltage are not severe, hand regulation may be employed. Machines cannot always be compounded to give constant voltage at all loads, though the condition of constant voltage may be approximated. As the voltage of a line may rise on open circuit to a value in excess of the generator voltage, due to the line charging current, the synchronous apparatus must be able to shift its phase from leading to lagging current. The power-factor being known, the quadrature current and the required capacity of synchronous apparatus may be determined by plotting Fig. 17 (Par. 28) to a large scale. For more complete discussion consult the bibliography references.

STRESSES IN SPANS

97. Mechanical stresses in a span are produced by: (a) the dead weight of the conductor, which acts vertically; (b) the weight of any ice, sleet, or snow that may cling to the wire; and (c) the wind pressure, which is assumed to act horizontally, at right angles to the line, and on the projected area of the conductor, and its sleet loads.

The weights of copper and aluminum conductors are given in Par. 99. The weight of ice is 57 lb. per cu. ft., or 0.033 lb. per cu. in. and the weight of sleet and snow is somewhat less than this. For the average climate of the United States, a layer of ice 0.5 in. (1.27 cm.) thick is assumed to be the worst condition of loading, though in the mountainous regions, sleet may form to a greater thickness than this. The table in Par. 99 gives the ice and conductor loads with 0.5-in. and 0.75-in. layers of ice, for both copper and aluminum conductors.

* Bibliography 73, 75, 77.

The wind pressure is a function of the wind velocity and may be expressed by Buck's* formula

$$p = 0.0025V^2 \qquad \text{(lb. per sq. ft.)} \qquad (30)$$

Where p is the pressure in lb. per sq. ft. and V is the actual velocity of the wind in miles per hr. Fig. 42 shows the relation between velocity and wind pressure. Buck gives the following as the relation between actual velocity and that indicated at the Government observation stations.

Indicated velocity...	10	20	30	40	50	60	70	80	90	100
Actual velocity......	9.6	17.8	25.7	33.3	40.8	48.0	55.2	62.2	69.2	76.2

Fig. 43 shows the wind pressure at different heights above ground, and Par. 99 gives the pressure for the various conductors and ice loads.

The resultant force acting on the conductor, is the vector sum of the horizontal and vertical forces shown in Fig. 44. The resultant loading for various conditions of component loading on line conductors is given in Sec. 4.

98. The general span formulæ, assuming that the span has the form of a parabola, and that the weight is uniformly distributed, are as follows:

$$t = \frac{S^2 w}{8d} \qquad \text{(lb.)} \qquad (31)$$

$$d = \frac{S^2 w}{8t} \qquad \text{(ft.)} \qquad (32)$$

$$l = S + \frac{8d^2}{3S} \qquad \text{(ft.)} \qquad (33)$$

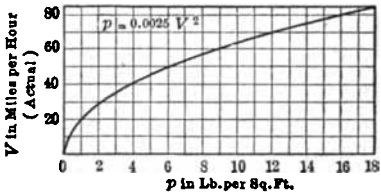


FIG. 42.—Wind velocity and pressure.

where t is the horizontal tension in lb., S is the span length in ft., d is the sag in ft., w is the weight in lb. per ft. of the conductor plus the sleet or snow, and l is the length of the conductor in ft. The total tension T in the conductor at the support, is the sum of the horizontal component t, and the vertical component due to the dead load.

$$T = t + wd \qquad \text{(lb).} \qquad (34)$$

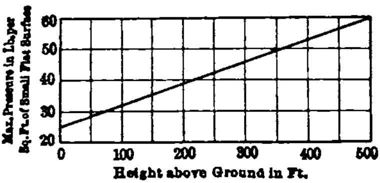


FIG. 43.—Wind velocity and height.

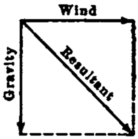


FIG. 44.—Resultant force on the wire.

The second term is usually very small, and for ordinary sags is negligible.

If in Eq. 32 the conductor is considered by itself, ignoring sleet and wind loads, then

$$d = \frac{S^2\left(\frac{w}{A}\right)}{8\left(\frac{t}{A}\right)} = \frac{S^2 W}{8F} \qquad \text{(ft.)} \qquad (35)$$

where W is the weight of the conductor per ft. of length and for 1 sq. in. cross-section, and F is the tension in lb. per sq. in. The required deflection may then be determined for the allowable unit stress.

* See Bibliography 82.

99. Loading tables*

Copper wire—stranded

Cir. mils and A.W.G.	Diam., inches	Area, sq. in.	Hard drawn: Ultimate tension, lb.	Hard drawn: Allow. tension	Soft drawn: Ultimate tension, lbs.	Soft drawn: Allow. tension	Load per lin. foot, vertical: Dead	Load per lin. foot, vertical: Dead + ½ in. ice	Load per lin. foot, vertical: Dead + ¾ in. ice	Load per lin. foot, horizontal: 15.0 lb. p. sq. ft.	Load per lin. foot, horizontal: 8.0 lb. p. sq. ft., ½ in. ice	Load per lin. foot, horizontal: 11.0 lb. p. sq. ft., ¾ in. ice	Max. load per lin. foot, plane of resultant: Class A load'g	Max. load per lin. foot, plane of resultant: Class B load'g	Max. load per lin. foot, plane of resultant: Class C load'g	EA: E(hard drawn) 16,000,000	EA: E(annealed) 12,000,000
500,000	0.819	0.3924	23,540	11,750	13,340	6,650	1.525	2.345	2.989	1.024	1.213	2.126	1.837	2.640	3.668	6,278,400	4,708,800
350,000	0.679	0.2750	16,500	8,250	9,350	4,650	1.068	1.801	2.401	0.849	1.119	1.997	1.364	2.120	3.123	4,400,000	3,300,000
0,000	0.530	0.1662	9,970	5,000	5,650	2,800	0.645	1.286	1.831	0.663	1.020	1.861	0.925	1.641	2.611	2,659,200	1,994,400
000	0.470	0.1318	7,910	3,950	4,480	2,250	0.513	1.116	1.651	0.588	0.980	1.806	0.780	1.485	2.446	2,108,800	1,581,600
00	0.420	0.1045	6,270	3,150	3,555	1,750	0.406	0.978	1.498	0.525	0.947	1.760	0.664	1.361	2.311	1,672,000	1,254,000
0	0.375	0.0829	4,970	2,500	2,820	1,400	0.322	0.866	1.372	0.469	0.917	1.719	0.569	1.261	2.199	1,326,400	994,800
1	0.330	0.0657	3,940	1,950	2,235	1,100	0.255	0.771	1.263	0.413	0.887	1.678	0.485	1.175	2.100	1,051,200	788,400
2	0.291	0.0521	3,130	1,550	1,770	900	0.203	0.695	1.174	0.364	0.861	1.642	0.417	1.107	2.019	833,600	625,200
3	0.261	0.0413	2,480	1,250	1,405	700	0.160	0.633	1.103	0.326	0.841	1.614	0.363	1.053	1.955	660,800	495,600
Copper wire—solid																	
0000	0.460	0.1662	8,310	4,150	5,650	2,800	0.641	1.238	1.770	0.575	0.973	1.797	0.861	1.575	2.522	....	....
000	0.410	0.1318	6,590	3,300	4,480	2,250	0.509	1.074	1.591	0.512	0.940	1.750	0.722	1.427	2.365	....	....
00	0.365	.1045	5,220	2,600	3,555	1,750	0.403	0.940	1.443	0.456	0.910	1.709	0.608	1.309	2.237	....	....
0	0.325	0.0829	4,560	2,300	2,820	1,400	0.320	0.833	1.323	0.406	0.883	1.673	0.517	1.214	2.133	....	....
1	0.289	0.0657	3,740	1,850	2,235	1,100	0.253	0.744	1.223	0.362	0.860	1.640	0.442	1.137	2.046	....	....
2	0.258	0.0521	3,120	1,550	1,770	900	0.202	0.673	1.142	0.322	0.838	1.611	0.380	1.075	1.975	....	....
3	0.229	0.0413	2,480	1,250	1,405	700	0.159	0.613	1.073	0.287	0.820	1.585	0.328	1.024	1.914	....	....
4	0.204	0.0328	1,960	1,000	1,115	550	0.126	0.564	1.016	0.255	0.803	1.567	0.284	0.981	1.863	....	....
5	0.182	0.0260	1,560	800	885	450	0.100	0.524	0.969	0.227	0.788	1.542	0.248	0.946	1.821	....	....
6	0.162	0.0206	1,240	600	700	350	0.079	0.491	0.930	0.203	0.775	1.524	0.218	0.917	1.785	....	....

99. Loading tables.—(*Continued*)

Aluminum wire—stranded

Cir. mils and A.W.G.	Diam., inches	Area, sq. in.	Hard drawn		Soft drawn		Load per lin. foot, vertical			Load per lin. foot, horizontal			Max. load per lin. foot, plane of resultant			*EA*	
			Ultimate tension, lb.	Allow. tension	Ultimate tension, lb.	Allow. tension	Dead	Dead + ½ in. ice	Dead + ¾ in. ice	15.0 lb. p. sq. ft.	8.0 lb. p. sq. ft., ½ in. ice	11.0 lb. p. sq. ft., ¾ in. ice	Class A load'g	Class B load'g	Class C load'g	E (hard drawn) 16,000,000	E (annealed) 12,000,000
																9,000,000	
500,000	0.814	0.3924	9,025	4,500	......	......	0.460	1.280	1.919	1.018	1.209	2.121	1.117	1.762	2.860	3,531,600	
350,000	0.679	0.2750	6,325	3,150	......	......	0.322	1.055	1.655	0.849	1.119	1.997	0.908	1.538	2.594	2,475,000	
0000	0.522	0.1662	3,820	1,900	......	......	0.195	0.831	1.382	0.652	1.015	1.853	0.681	1.312	2.312	1,495,800	
000	0.464	0.1318	3,160	1,600	......	......	0.155	0.755	1.288	0.580	0.976	1.800	0.600	1.234	2.213	1,186,200	
00	0.414	0.1045	2,510	1,250	......	......	0.122	0.691	1.208	0.518	0.943	1.754	0.532	1.168	2.130	940,500	
0	0.368	0.0879	1,990	1,000	......	......	0.097	0.637	1.140	0.460	0.912	1.712	0.470	1.112	2.057	746,100	
1	0.328	0.0657	1,575	800	......	......	0.077	0.592	1.082	0.410	0.885	1.676	0.417	1.065	1.995	591,300	
2	0.291	0.0521	1,250	600	......	......	0.061	0.533	1.032	0.364	0.861	1.642	0.368	1.023	1.939	468,900	
3	0.261	0.0413	990	500	......	......	0.049	0.522	0.992	0.326	0.841	1.614	0.329	0.990	1.894	371,700	
4	0.231	0.0328	790	400	......	......	0.039	0.494	0.954	0.289	0.821	1.587	0.292	0.958	1.846	295,200	

NOTE: Class A loading = dead load + 15.0 lb. per sq. ft. wind pressure. *E* = modulus of elasticity, in.-lb.
Class B loading = dead load + 0.5 in. ice + 8.0 lb. wind pressure. *A* = conductor area.
Class C loading = dead load + 0.75 in. ice + 11.0 lb. wind pressure. *EA* = product of modulus of elasticity and conductor area.

* Report of the Joint Committee on Overhead Line Construction, N. E. L. A.

100. Stresses at centres of spans resulting from a given deflection

Deflection in decimal parts of spans

Spans in ft.	0.001	0.002	0.005	0.010	0.015	0.020	0.030	0.040	0.050	0.060	0.070
	Multipliers										
10	1,250.001	625.003	250.008	125.016	83.358	62.533	41.716	31.316	25.083	20.933	17.973
20	2,500.003	1,250.006	500.016	250.033	166.716	125.066	83.433	62.633	50.166	41.866	35.947
40	5,000.006	2,500.013	1,000.033	500.066	333.433	250.133	166.866	125.266	100.333	83.733	71.895
50	6,250.008	3,125.016	1,250.041	625.083	416.791	312.666	208.583	156.583	125.416	104.666	89.869
70	8,750.011	4,375.023	1,750.058	875.116	583.508	437.733	292.016	219.216	175.583	146.533	125.816
100	12,500.016	6,250.033	2,500.083	1,250.166	833.583	625.333	417.166	313.166	250.833	209.333	179.738
120	15,000.020	7,500.040	3,000.100	1,500.200	1,000.300	750.400	500.600	375.800	301.000	251.200	215.685
140	17,500.023	8,750.046	3,500.116	1,750.233	1,167.016	875.466	584.033	438.433	351.166	293.066	251.633
150	18,750.025	9,375.050	3,750.125	1,875.250	1,250.375	938.000	625.750	469.750	376.250	314.000	269.607
170	21,250.028	10,625.056	4,250.141	2,125.283	1,417.091	1,063.066	709.183	532.383	426.416	355.866	305.554
200	25,000.033	12,500.066	5,000.166	2,500.333	1,667.166	1,250.666	834.333	626.333	501.666	418.666	359.476

Deflections in decimal parts of spans

Spans in ft.	0.080	0.085	0.090	0.095	0.100	0.110	0.120	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200
	Multipliers														
10	15.758	14.847	14.038	13.316	12.666	11.546	10.616	9.832	9.161	8.583	8.079	7.636	7.244	6.895	6.583
20	31.516	29.695	28.077	26.632	25.333	23.093	21.233	19.664	18.323	17.166	16.158	15.272	14.488	13.791	13.166
40	63.033	59.390	56.155	53.264	50.666	46.187	42.466	39.328	36.647	34.333	32.316	30.545	28.977	27.582	26.333
50	78.791	74.237	70.194	66.581	63.333	57.734	53.083	49.160	45.809	42.916	40.395	38.181	36.222	34.478	32.916
70	110.308	103.932	98.272	93.213	88.666	80.828	74.316	68.824	64.133	60.083	56.554	53.453	50.711	48.269	46.083
100	157.583	148.475	140.388	133.162	126.666	115.469	106.166	98.320	91.619	85.833	80.791	76.362	72.444	68.956	65.833
120	189.100	178.170	168.466	159.794	152.000	138.563	127.400	117.984	109.942	103.000	96.950	91.635	86.933	82.747	79.000
140	220.616	207.865	196.544	186.427	177.333	161.657	148.633	137.648	128.266	120.166	113.108	106.907	101.422	96.538	92.166
150	236.375	222.713	210.583	199.743	190.000	173.204	159.250	147.480	137.428	128.750	121.187	114.544	108.666	103.434	98.750
170	267.891	252.408	238.661	226.375	215.333	196.298	180.483	167.144	155.752	145.916	137.345	129.816	123.155	117.225	111.916
200	315.166	296.950	280.777	266.324	253.333	230.939	212.333	196.641	183.238	171.666	161.583	152.725	144.888	137.912	131.666

101. Total lengths of wires in spans

Deflections in decimal parts of spans

Spans in ft.	0.010	0.015	0.020	0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060	0.070	0.080
	Lengths of wires												
10	10.002	10.006	10.010	10.016	10.024	10.032	10.042	10.054	10.066	10.080	10.096	10.130	10.170
20	20.005	20.012	20.021	20.033	20.048	20.065	20.085	20.108	20.133	20.161	20.192	20.261	20.341
40	40.010	40.024	40.042	40.066	40.096	40.130	40.170	40.216	40.266	40.322	40.384	40.522	40.682
50	50.013	50.030	50.053	50.083	50.120	50.163	50.213	50.270	50.333	50.403	50.480	50.653	50.853
70	70.018	70.042	70.074	70.116	70.168	70.228	70.298	70.378	70.466	70.564	70.672	70.914	71.194
100	100.026	100.060	100.106	100.166	100.240	100.326	100.426	100.540	100.666	100.806	100.960	101.306	101.706
120	120.032	120.072	120.128	120.200	120.288	120.392	120.512	120.648	120.800	120.968	121.152	121.568	122.048
140	140.037	140.084	140.149	140.233	140.336	140.457	140.597	140.756	140.933	141.129	141.344	141.829	142.389
150	150.040	150.090	150.160	150.250	150.360	150.490	150.640	150.810	151.000	151.210	151.440	151.960	152.560
170	170.045	170.102	170.181	170.283	170.408	170.555	170.725	170.918	171.133	171.371	171.632	172.221	172.901
200	200.053	200.120	200.213	200.333	200.480	200.653	200.853	201.080	201.333	201.613	201.920	202.613	203.413

Deflections in decimal parts of spans

Spans in ft.	0.090	0.100	0.110	0.120	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200
	Lengths of wires											
10	10.216	10.266	10.322	10.384	10.450	10.522	10.6	10.682	10.770	10.864	10.962	11.066
20	20.432	20.533	20.645	20.768	20.901	21.045	21.2	21.365	21.541	21.728	21.925	22.133
40	40.864	41.066	41.290	41.536	41.802	42.090	42.4	42.730	43.082	43.456	43.850	44.266
50	51.080	51.333	51.613	51.920	52.253	52.613	53.0	53.413	53.853	54.320	54.813	55.333
70	71.512	71.866	72.258	72.688	73.154	73.658	74.2	74.778	75.394	76.048	76.738	77.466
100	102.160	102.666	103.226	103.840	104.506	105.226	106.0	106.826	107.706	108.640	109.626	110.666
120	122.592	123.200	123.872	124.608	125.408	126.272	127.2	128.192	129.248	130.368	131.552	132.800
140	143.024	143.733	144.517	145.376	146.309	147.317	148.4	149.557	150.789	152.096	153.477	154.933
150	153.240	154.000	154.840	155.760	156.760	157.840	159.0	160.240	161.560	162.960	164.440	166.000
170	173.672	174.533	175.485	176.528	177.661	178.885	180.2	181.605	183.101	184.688	186.365	188.133
200	204.320	205.333	206.453	207.680	209.013	210.453	212.0	213.653	215.413	217.280	219.253	221.333

RULE.—To find stress in lb. on wire of given span and deflection, multiply numbers in column answering to span and deflection by the weight per ft. of wire.

102. Calculation of horizontal stress.* The foregoing tables give the factors by which the weight per ft. of conductor may be multiplied, in order to determine the horizontal stress in the span. Values are given up to 200 ft. (61 m.) spans, and to 20 per cent. deflections. For any span greater than 200 ft. (61 m.) the table may still be used, if it be remembered that for a given percentage deflection, the stress is proportional to the span. Thus for a 1,500-ft. (4.57 m.) span having 2.0 per cent. deflection, and a total weight of 0.5 lb. per ft. (1.64 lb. per m.) the horizontal stress will be (from 150-ft. span)

$$t = 938 \times 10 \times 0.5 = 4690 \text{ lb.}$$

In the same way, the length of this span wire (Par. **101**) will be (with 150-ft. span)

$$l = 150.16 \times 10 = 1501.6 \text{ ft.}$$

The tables were computed from formulæ given in Weisbach's "Mechanics of Engineering," page 297 (seventh American edition, translated by Eckley B. Cox, A.M.)

$$S \times W = \text{horizontal stress in wire at centre of span (lb.)} \quad (36)$$

$$S = y^2/2x + x/6 \text{ (ft.)} \quad (37)$$

$$l = y[1 + (2/3)\ (x/y)^2] \text{ (ft.)} \quad (38)$$

$$x = 3S - \sqrt{9S^2 - 3y^2} \text{ (ft.)} \quad (39)$$

$$y = \sqrt{(3yl - 3y^2)/2} \text{ (ft.)} \quad (40)$$

where y = one-half the span.
l = one-half the length of the span wire.
x = deflection at centre in same units as y.
w = dead weight per ft. of wire.

103. Temperature variations will change the length of the span, and as the sag and tension are very sensitive to changes in the length of span, the effect of change of temperature must be considered. With a change of tension, the length of the wire will be changed, due to stretching or contracting. As stretch and temperature change are inter-related and occur simultaneously, their combined effect must be determined. As an analytical calculation is difficult to make, the solution is better determined by graphical methods. For every degree fahr. change in temperature, the length of unstressed copper will change 0.00096 per cent., and of aluminum 0.00128 per cent. The following table gives stress and temperature data for both copper and aluminum conductors.

104. †Properties of conductor materials

Copper	Ultimate strength per sq. in.	Elastic limit	Mod. elasticity, E	Coef. expansion, θ
Solid, soft-drawn.	32–34,000	28,000	12,000,000	0.0000096
Solid, hard-drawn.	50–55–57–60,000	30–32–34–35,000	16,000,000	0.0000096
Stranded, soft-drawn.	34,000	28,000	12,000,000	0.0000096
Stranded, hard-drawn.	60,000	35,000	16,000,000	0.0000096
Aluminum				
Stranded........	23–24,000	14,000	9,000,000	0.0000128

105. The maximum stress in a span occurs when it has its greatest loading of ice or sleet, minimum temperature, and maximum wind velocity blowing at right angles to the line. The loading usually assumed is 0.5-in. layer of ice at −20 deg. fahr. (−29 deg. cent.) and a wind pressure of 8 lb. per sq. ft. (at a velocity of about 57 miles per hr.) The load under these conditions may then be determined from Par. **99**, and the stress from Par. **100**, or calculated from Eq. 31, Par. **98**.

106. Example of stress-sag calculation. Problem: Required to find the proper sag for a 600-ft. span of No. 0000 hard-drawn solid copper, at

* From "Wire in Electrical Construction" by John A. Roebling's Sons Co.
† Report of the Joint Committee on Overhead Construction, N. E. L. A.

maximum (summer), minimum (winter-loaded), and stringing (unloaded) temperatures.

From Par. 99 for 0.5-in. ice, and 8 lb. per sq. ft. wind pressure, the total load per lin. ft., w, is 1.575 lb. The allowable tension, t, is 4,150 lb. (corresponding to 25,000 lb. per sq. in.). The sag may be calculated from Eq. 32, Par. 98. $d = [(600)^2 \times 1.575]/(8 \times 4{,}150) = 17.08$ ft. at the assumed minimum temperature.

This is the sag under ice load at -20 deg. fahr.

The maximum sag will occur at $+120$ deg. fahr., the assumed maximum temperature, with no load other than the conductor itself and no wind.

To determine this sag first consider that all the stress is removed from the conductor, and determine its length under this condition.

The change of length due to removing the load, $\Delta l = \dfrac{tl}{EA}$ (41)

In this expression, t is the tension in lb., l, the length in ft., E, the modulus of elasticity, in-lb., A, the cross-section of the conductor, in sq. in. Values of EA are given in Par. 99.

The original length, from Eq. 33, Par. 98, is $l_1 = 600 + [8 \times (17.08)^2/(3 \times 600)] = 601.297$ ft. $\Delta l = 4{,}150 \times 601.297/2{,}659{,}000 = 0.939$ ft. The span, then, if all stress were removed, would have the hypothetical length at -20 deg. fahr., $601.297 - 0.939 = 600.358$ ft. This often results in a value less than the span length. At zero deg. fahr., the length would be given by

$$l = l_0(1 + \alpha t') \tag{42}$$

Where l_0 is the length at zero deg. fahr. α is the coefficient of expansion, t' is the temperature deg. fahr. $l_0 = 600.358/[1 + 0.0000096 \times (-20)] = 600.473$ ft. $d_0 = \sqrt{[3 \times 600(600.473 - 600)]/8} = 10.31$ ft. (Eq. 33, Par. 98.)

107. To obtain the sag at zero deg. fahr., no ice and no wind load, the sag-stress curve ab should first be plotted (Fig. 45), having $w = 0.641$ lb. per ft., weight of conductor with load removed (Par. 99). The table of Par. 100 is very convenient for this purpose. The sags for different tensions are then calculated, by finding, first, the length from Eq. 41, and then the sag from Eq. 32, Par. 98. These values are now plotted (curve cd); where this curve intersects the sag-stress curve ab will be the sag at zero deg. fahr., when the conductor has no load other than its own weight.

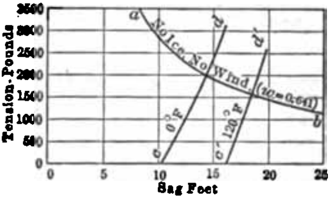


Fig. 45.—Stress-sag curves.

Thus, at a tension of 3,000 lb., $l_1 = 600.473 + [(600.473 \times 3{,}000)/2{,}659{,}000] = 600.473 + 0.678 = 601.151$ ft. (from Eq. 41). $d = \sqrt{[1{,}800(601.151 - 600)]/8} = 16.09$ ft. (from Eq. 33, Par. 98). From the intersections, sag at zero deg. fahr. = 14.4 ft. and tension at zero deg. fahr. = 2,000 lb.

108. The sag at another temperature may be found by increasing the absciss**a** by a distance, determined from Eq. 42 and Eq. 33, Par. 98. Thus, to find the sag and tension for 120 deg. fahr., $l = 600.472\ (1 + 0.0000096 \times 120) = 601.163$ ft. at 120 deg. fahr. and zero stress, $d = 16.18$ ft.

The sag and stress should then be computed as in Par. 107, and a new stretch line $c'd'$ plotted. The maximum sag (assumed at 120 deg. fahr.) occurs where $c'd'$ cuts ab. It is equal to 18.5 ft., and the corresponding tension 1,560 lb.

109. Data used when stringing. A set of stretch curves for several temperatures should be furnished the foreman in charge of stringing the wire, in order that he may adjust the sag, or tension (by means of a dynamometer) to their proper values for the temperature at the time of stringing. It must be remembered that the temperature of the wire, when the sun is shining, may be several degrees higher than that of the surrounding air.

110. With the supports at different levels, the line forms a catenary, the lowest point of which is no longer midway between supports. The curve can, however, be prolonged until it reaches a point which is at the same level as the higher support (Fig. 46) and the distance x_1 to the lowest point of the catenary will be equal to half the assumed span, S', and may be computed.

$$x_1 = \frac{S}{2} + \frac{ht}{wS}\text{*} \qquad \text{(ft.)} \qquad (43)$$

$$x_1 = S\frac{\sqrt{d}}{\sqrt{d-h}+\sqrt{d}} \qquad \text{(ft.)} \qquad (44)$$

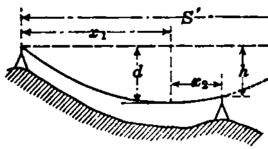


Fig. 46.—Supports at different levels.

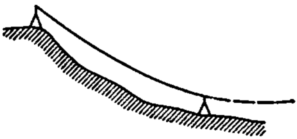


Fig. 47.—Condition for upward pull at lower support.

where S is the horizontal distance between supports, d the sag measured from the higher support, t the tension in the wire in lb. at the higher support, w the weight in lb. per unit length, h the difference in height of supports, all distances expressed in ft.

Eq. 43 is useful when the span and the allowable stress are given; and Eq. 44 when the span and sag are given. Eq. 43 is correct to within 2 to 4 per cent. when neither the sag nor difference in height of supports exceeds 15 per cent. of the span. Eq. 44 has an error of less than 1 per cent. under these conditions.

The sag d may be computed,

$$d = d'\left(1+\frac{h}{4d'}\right)^2 \qquad \text{(ft.)} \qquad (45)$$

where d' is the sag as determined by Eq. 32 for the same span, S, and the same loading.

also

$$x_2 = \frac{S}{2}\left(1-\frac{h}{4d'}\right) \qquad \text{(ft.)} \qquad (46)$$

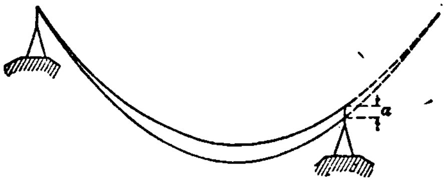


Fig. 48.—Error introduced by assuming constant equivalent span.

Having determined the distance x_1, the span may then be treated like a span S', where $S' = 2x_1$. From Eq. 46 if $h/4d'$ is greater than unity, the vertex of the line will lie outside the span, and there will be an upward pull on the insulator. This is shown in Fig. 47 and the span should be so designed that this condition does not occur.

Load and temperature changes may be computed as in Par. **107** and **108**, but a certain error is introduced in assuming that the length of equivalent span remains unchanged. Except for accurate work, this error is negligible. The error increases or decreases with the difference in height of supports by an amount, a, Fig. 48. For accurate work, however, the length of line in the span may be computed from Eq. 33 knowing x_1, x_2 and d (Fig. 46) and the effects of changes of load and of temperature may also be computed. The new distance x_1 is determined and the new equivalent length of span found.

* See Bibliography 88.

111. The Thomas chart* for sag and stress determinations is based on the following: Imagine a given span to be reduced to a length of 1 ft. without changing the shape of the curve. The percentage sag will remain the same, but the sag, stress and length of wire will be reduced in direct proportion. The stress for a definite sag is proportional to the weight per unit length of the wire including ice and wind loads. The curves, Fig. 49, show the relation

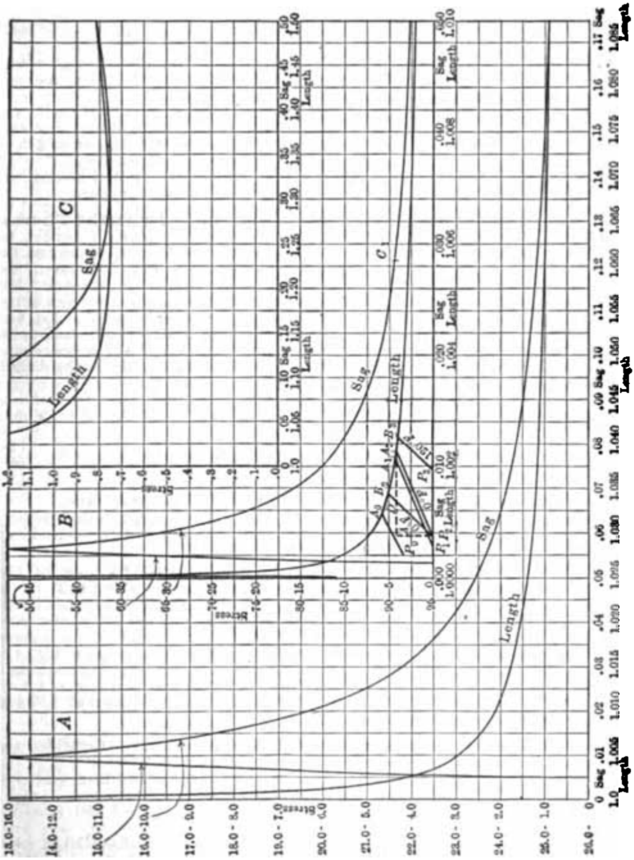


FIG. 49.—Thomas chart.

between sag, length of wire and stress, for a 1-ft. span loaded uniformly with 1 lb., and are based on the equation of the catenary. Three sets of curves, *A*, *B*, and *C*, are given, all plotted to different scales. Curve, *A*, is good for sags from 2 to 15 per cent.; curve *B*, for sags less than 2 per cent.; curve *C*, for very large sags, being especially useful for spans on steeply inclined slopes

* See Bibliography 88.

The chart in Fig. 49 is too small for accurate work but the data from which the curves were plotted may be obtained from the original paper (Bibliography 88).

112. Use of the Thomas chart. By means of these curves, the sag, stress, and length of any span may be easily determined. Divide the allowable stress in the wire, by the span and weight per unit length.

$$t = \frac{T}{w \times S} \qquad \text{(lb.)} \qquad (47)$$

where t is the tension in lb. in a 1-ft. span; T the allowable tension in lb. in the actual span; w the weight in lb. per ft. (wire, ice and wind); S the distance in ft. between supports.

From the chart, determine the length and sag corresponding to t, as A_1 and C_1 (Fig. 49). Then the sag and length in the actual span will be the values just obtained multiplied by the actual span in ft. If the sag, or length be given, the other quantities may be found by reversing the process.

With supports at different levels the span may be computed as outlined in Par. 110, and the chart then used for the total equivalent span.

113. The effect of temperature may be determined with the Thomas chart by finding the length of wire, with all stress removed, from Eq. 41, Par. 106, using the stress in the *actual* span, and marking this point on the chart (as P_1, Fig. 49). The elongation of the wire is proportional to the stress, so the straight line P_1A_1 will be the stress-length or "stretch" line for this load and temperature. If the sag is small, P_1 may be less than unity, but the line may be drawn by determining some other point P_e (Eq. 41), and drawing P_eA_e. To determine the sag and stress at any temperature, determine the length of the unstressed wire at zero deg. fahr. (−17.8 deg. cent.) by Eq. 42, Par. 106, as at P_2. For the same loading, the stress-length line at zero deg. fahr., P_2A_2, will be parallel to P_1A_1, and A_2 is the length at zero deg. fahr. of the 1-ft. span. Let this be l_1, and the corresponding stress and sag be t_1 and d_1 respectively. The values in the actual span may then be found.

$$\text{Actual length} = Sl_1 \qquad (48)$$
$$\text{Actual stress} = St_1w' \qquad (49)$$
$$\text{Actual sag} = Sd_1 \qquad (50)$$

Where S is the actual span in ft., and w' the load in lb. per ft. of line.

The length axis may then be marked off in divisions proportional to temperatures, and parallel lines drawn, from which the lengths, stresses and sags may be determined.

114. The effect of ice and wind is determined by use of the Thomas chart as follows: Suppose the values in Par. 113 to be computed for maximum loading (ice and wind). When these loads are removed, the weight per ft. is reduced to w (the weight per ft. of the wire) and the stretch in the wire will be w/w' of what it was before, for a given stress in the 1-ft. span. Therefore, along the abscissa, A_2, make $AD/AA_2 = w/w'$ and draw P_2B_2 through D. The intersection of this line with the length curve will give the results as obtained in Par. 113, substituting w for w'. The temperature lines may be found as before. P_3B_3 being drawn at 120 deg. fahr. (49 deg. cent.) and parallel to P_2B_2.

115. Example of calculation, using Thomas chart. Consider the problem of Par. 106 where $S = 600$ ft., $w' = 1.575$ lb., $T = 4{,}150$ lb.

S is the distance between supports; w' is the weight (including wire, ice, and wind) per unit length; T is the allowable tension.

The tension in a 1-ft. span, having a 1-lb. load, will be $t = 4{,}150/(1.575 \times 600) = 4.395$.

From curve B the sag will be 0.0286 ft. (C_1) and the length 1.00215 ft. (A_1). The true sag and length will be $S = 600 \times 0.0286 = 17.16$ ft. $l = 1.00215 \times 600 = 601.290$ ft. The length unstressed, may be found (Eq. 41, Par. 106).

$$\Delta l = (1.00215 \times 4{,}150)/2{,}659{,}000 = 0.00156 \text{ ft.}$$
$$l_1 = 1.00215 - 0.00156 = 1.00059 \text{ ft.}$$

A line P_1A_1 is drawn from P_1 (length = 1.00059) to A_1, the original point on the length curve. The length at zero deg. fahr. is found from Eq. 42, Par. 106. $l_0 = 1.00059/[1 + 0.0000096 \times (-20)] = 1.00078$ ft. A line P_2A_2 is drawn

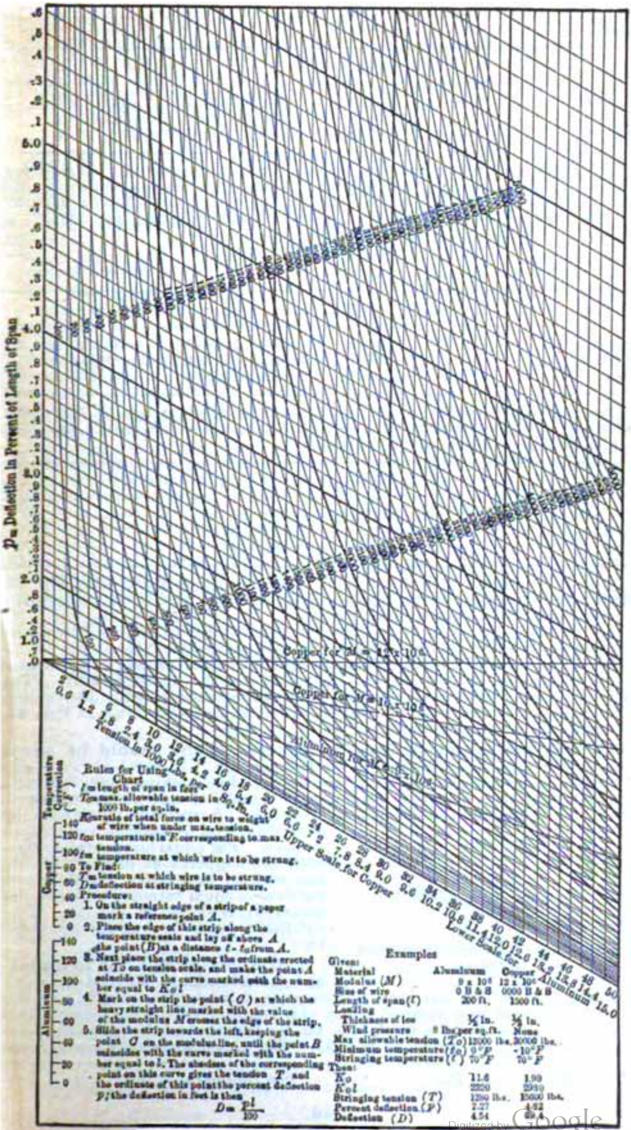


Fig. 50.—Pender and Thomson chart.

(where $P_2 = 1.00078$) parallel to P_1A_1. At zero deg. fahr., with wind and ice loads,

	Chart	Actual
Length................	1.00224 ft.	600 × 1.00224 = 601.344 ft.
Stress................	4.2 lb.	600 × 4.2 × 1.575 = 3,965 lb.
Sag................	0.0295 ft.	600 × 0.0295 = 17.70 ft.

To find the length, stress and sag when the loads are removed. At zero deg. fahr., no ice, and no wind, $w = 0.641$ lb. At the stress as now shown on the chart of 4.2 lb., the stretch will be $(1.00224 - 1.00078)0.641/1.575 = 0.00059$, and the length $1.00078 + 0.00059 = 1.00137$. Draw P_2B_2 through 1.00137 at the 4.2 lb. ordinate (at D). Graphically

$$AD/AA_2 = 0.641/1.575$$

Then, at zero deg. fahr., no ice or wind,

	Chart	Actual
Length................	1.0015 ft.	600 × 1.0015 = 600.90 ft.
Stress................	5.1 lb.	600 × 5.1 × 0.641 = 1,960 lb.
Sag................	0.0244 ft.	600 × 0.0244 = 14.6 ft.

The unstressed length at 120 deg. fahr. is found from Eq. 42, Par. **106**. $1.00078(1 + 120 \times 0.0000096) = 1.00193$ ft. At $P_3(l = 1.00193)$ draw P_3B_3 parallel to P_2B_2. Then, at 120 deg. fahr.,

	Chart	Actual
Length................	1.00234 ft.	601.40 ft.
Stress................	4.1 lb.	1,577 lb.
Sag................	0.031	18.6 ft.

These results check very closely with those already obtained using Fig. 45. The differences are due to errors in reading the charts, and to the assumption of a parabola rather than a catenary.

The distance P_1P_3 may be subdivided proportional to temperatures, and results may be found by drawing stretch lines parallel to P_2B_2.

116. Pender and Thomson tension and deflection chart.* By means of this chart, Fig. 50, the sag and deflection may be found directly. The rules for its use, together with examples, accompany the chart. The values of K_s in the examples given are slightly different from the values in Par. **99**. The problems are worked in lb. per sq. in.

117. The horizontal stresses in adjacent spans should be equal to minimize the longitudinal pull on the support. In level country and with equal spans this may be easily accomplished by making equal sags at a given temperature. Unequal spans can be equalized only at one temperature which should be the average temperature. Suspension insulators, by deflecting, tend to equalize unbalanced stresses. For equal horizontal stresses with the supports at different levels, the wire in each span should form portions of equal catenaries (parabolas assumed) as shown in Fig. 51. This condition holds for but one temperature.

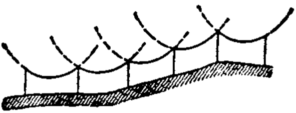


Fig. 51.—Balanced horizontal stresses.

118. Short-circuit due to unbalanced ice loads.† Ice loads on wires may drop from all but one span. If suspension insulators are used and the lines are arranged in a vertical plane, this span, aided by the longitudinal deflection of the suspension insulators, will sag heavily and the adjacent spans will be drawn up, as shown in Fig. 52. The phase wires may readily ap-

* See Bibliography 20. † See Bibliography 90.

proach within easy arcing distance of one another or even touch in all three spans, thus causing a short-circuit. Also, if one wire alone loses its ice load its whipping up may cause short circuit. This may be partlally overcome by the use of shorter spans, more anchor towers, or better, by offsetting the middle conductor, thus making an isosceles triangle arrangement (see Fig. 64, isosceles triangle).

STRENGTH OF SUPPORTING MEMBERS

119. Insulators and pins must be designed to withstand the weight of conductor and any ice, sleet or snow load; the wind pressure acting on the conductor, and any other transverse force produced by a change in direction of the line; the longitudinal force due to unbalanced horizontal stresses in adjacent spans; the longitudinal stress occasioned by the breaking of a line conductor. It is desirable that they withstand a stress equal to the elastic limit of the conductor, when exerted in any direction in a plane perpendicular to the axis of the pin.

120. The cross arms must be designed to withstand the resultant of the forces of Par. **119**, and the dead weight of insulators and attachment. In addition, the cross arms must be secured to the pole so that they will not be wrenched loose by the turning moment which follows the breaking of one or more conductors on the same side of the pole. The results of "Strength Tests of Cross Arms," made by T. R. C. Wilson, are published in U. S. Government Forest Service Circular 204.

121. The supporting structure must be designed to bear the compressive stress, due to its own weight and that of conductors, loads, insulators, cross arms and attachments; the transverse forces due to wind on conductors and supporting structure and also those occasioned by change in direction of the line; the longitudinal stresses due to unbalanced horizontal stresses in adjacent spans; stresses caused by the breaking of one or more conductors.

Wooden, steel, or concrete poles, designed to withstand the horizontal forces, will have the necessary compressive strength to bear vertical loads. With towers of the light wind-mill type, this matter should be carefully considered. Where extreme rigidity at small expense is desired, the structure must be made of many light members, resulting in a more complicated tower, and a shorter life, due to the greater proportionate corrosion. A less rigid tower made of fewer but heavier members will frequently answer the purpose, will be less expensive and of longer life.

122. The transverse force due to the wind on the conductors should be assumed as 8 lb. per sq. ft.* of the projected conductor and ice area. A 0.5-in. (1.27 cm.) layer of ice is usually assumed. Values of the resulting pressure may be found in Par. **99**. The pressure on the pole or tower may be

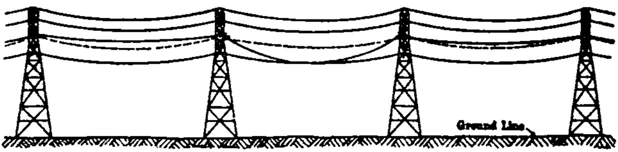


FIG. 52.—Ice loading on single span.

assumed to be 13 lb. per sq. ft. on one and one-half times the projected area of latticed structures. (Also see Sec. 12, Par. **166**.) The overturning moment may be greater without the ice load. Both conditions should be calculated. The stress due to an angle in the line may be readily computed by a simple resolution of the maximum stresses already calculated for the spans. The longitudinal forces due to unbalanced horizontal stresses in adjacent spans, should be small in a well-designed line, and may be determined if the stresses in each span at different temperatures are known. There is some question as to how many conductors may be assumed to be broken at one time. If

* Report of the Joint Committee on Overhead Line Construction, N. E. L. A.

a line is carefully strung with no kinks or abrasions in the wires, and if the ends of the insulator clamps are well rounded, there is small chance of a line conductor breaking under ordinary load conditions. As an extra precaution, however, anchor towers are used at frequent intervals, and are so designed as to safely withstand the simultaneous breaking of several conductors. Where suspension insulators are used, the insulator string is thrown in the unbroken side of the span, hence the increased sag decreases the ultimate pull. The force due to the jerk at the time of breaking is quite severe, and no reduction in the allowable stress should be made even if suspension insulators be used. The line structures should have a factor of safety of from 2 to 4, according to the importance of the line, the assumptions made in the design, and to the local conditions.

123. A wooden pole should be a cubic parabola, to use the material to the best advantage. As this would be impractical, a truncated cone, having the diameter of the top two-thirds of that of the bottom, is the best approximation. With this shape the pole will break theoretically at the ground line.

The allowable horizontal pull, P, on the pole may be calculated

$$P = \frac{T}{n}\,\frac{\pi d_2^3}{32l} \quad \text{(lb.) for a round pole.} \tag{51}$$

$$P = \frac{T}{n}\,\frac{d_2^3}{6l} \quad \text{(lb.) for a square pole.} \tag{52}$$

assuming that d_2, the ground diameter in inches, is one and one-half times the top diameter. In these formulæ n is the factor of safety, l the length of the pole in inches, and T the tensile strength or modulus of rupture of the pole material, values of which are given in Sec. 12, Par. 164. The factor of safety should be at least 5 or 6 for wood.

124. The stresses in steel poles cannot readily be calculated due to the complications introduced by lattice work, cross bracing, etc., and the engineer is more or less dependent upon actual tests and manufacturers' guarantees for data relative to the load that a given structure may be expected to carry safely. Steel poles, for the same weight and material, have much less torsional strength than steel towers. Although they may be satisfactory under normal conditions of balanced load, their factor of safety may be much reduced if one or more wires on the same side of the pole should break.

125. The stresses in concrete poles may be computed approximately, knowing the moment of inertia of the top and bottom sections, the cross-section and tensile strength of the reinforcing steel, and the compressive strength of the concrete. Up to the present time, however, very little has been done along this line, and purchasers and manufacturers have been dependent upon actual tests of full-sized poles. The usual mixture of Portland cement (1 : 2 : 4, cement, sand and gravel) has a compressive strength after 7 days of 900 lb.; after 1 month, 2,400 lb.; after 3 months, 3,100 lb.; after 6 months, 4,400 lb. all in lb. per sq. in.

126. Stresses in guys and anchors may be readily computed if the magnitude, direction, and point of application of the resultant force acting on the pole are known. The position of the anchor is determined, and the stress in the guy and anchor can be calculated by the well-known laws governing the composition and resolution of forces. The table in Sec. 4 gives the diameters, strengths and weights of 7-strand galvanized steel wire, such as would be used for guys.

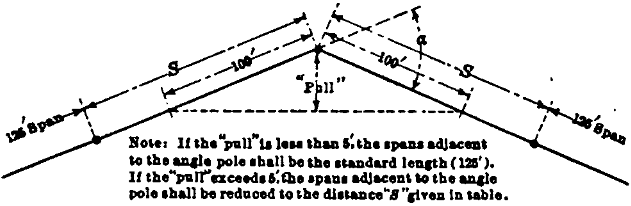
127. The stresses in towers may be computed by the well-known laws of statics. As steel fails in compression rather than in tension the compressive strength of the long unsupported members should be carefully checked by the well-known column formulæ. The ratio of l/r, where l is the length of the unsupported compression member, and r is the radius of gyration of its section, should seldom exceed 150. R. D. Coombs* shows, in the following table, that by using a different angle iron of less cross-sectional area the strength of the main compression members is nearly doubled. This should not be carried too far, however, if a reasonable life is expected. It is

* Letter to *Elect. World*, Vol. LVII (1913), p. 544.

generally conceded that ¼ in. for the legs and $\frac{3}{16}$ in. for the secondary members should be the minimum permissible thicknesses of metal.

Section	Area, sq. in.	Length, ft.	l/r	Breaking strength, lb./sq. in.	Total breaking strength, lb.
4 in. by 4 in. by ¾ in. angle.	5.44	13	202	12,000	65,200
5 in. by 5 in. by $\frac{9}{16}$ in. angle.	5.31	13	159	16,000	85,000
6 in. by 6 in. by $\frac{7}{16}$ in. angle.	5.06	13	131	20,000	101,200

128. Location of poles and side guys may be determined by use of the table given with Fig. 53. The term "pull" refers to the deviation of the line and is equal to the distance from the pole to the straight line joining points on the line 100 ft. each side of the pole.



Angle α	"Pull" in Feet	Span S	No. of 6000 Lb. Side Guys 1 Arm 6 Wires	2 Arms 12 Wires	3 Arms 18 Wires
Less than 6°	Less than 5'	125'	None	None	None
6°-11°	5'-10'	115'	None	1	1
11°-15°	10'-13'	105'	1	1	1
15°-22°	13'-19'	95'	1	1	2
22°-30°	19'-26'	85'	1	1	2
Over-30°	Over-26'	75'	1	2	2

Fig. 53.—Location of side guys.

129. Flexible towers* are used with a view to decreasing the line cost; their design is based on the fact that with equal spans and sags on both sides of the tower, the stresses in the direction of the line are balanced. The towers are not intended to carry longitudinal stresses but are designed to withstand any transverse stresses that may occur. They are held in position by the conductors, if pin insulators are used. When suspension insulators are used, a heavy steel galvanized ground wire is necessary to keep the towers in position. If a conductor breaks, the tower will deflect until the increased sag in the conductors and ground wire on the other side of the pole compensates for the unbalanced forces due to breaking. The towers should be designed to deflect from 12 in. to 24 in. without being permanently deformed. The unbalanced pull will not only be taken up by the tower at which the break occurs, but will be gradually absorbed by the other structures in the line. If a tower is actually pulled over, it is not a very serious matter because of its low initial cost, and ease with which another may be erected. About every mile there should be an anchor tower. Methods of computing the deflections and stresses in flexible towers have been published (see Bibliography 91 and 99). Such towers should be designed to carry from $\frac{1}{10}$ to $\frac{1}{20}$

* See Bibliography 91, 99.

the load for rigid towers and with this load should not be stressed beyond the elastic limit.

130. Anchor towers, when used in connection with flexible towers, should be designed to withstand the stress produced by the breaking of all the conductors on one side, even when the line is loaded under the most unfavorable conditions. Under these circumstances, there should be no yielding of the foundations, and the tower should not be stressed beyond the elastic limit. With a line constructed entirely of rigid towers, these conditions may be somewhat modified, as the intermediate towers themselves are designed to take care of one or two broken conductors.

FUNDAMENTAL CONSIDERATIONS OF LINE CONSTRUCTION

131. The line location should in general be direct. Detours are often necessary, to avoid sections subject to severe lightning, to avoid country that may be inaccessible, to avoid swamps or hills that will make the construction difficult and costly. It may be necessary to pass near towns or villages where connected load may be profitable.

The most direct right of way cannot always be obtained at a reasonable figure. County plat maps or U. S. Topographical Survey maps should be carefully studied with special reference to the villages along the route, the proximity of roads, hence accessibility, and the topography that will permit standard structures and spans. When the location is roughly determined, a small surveying party should go over the route, make a profile, locate swamps, streams, railroads, other power, telephone or telegraph lines, and should note the character of ground and probable location of supports. Profiles should be made 100 ft. on each side of the centre line, as well as at the centre line, since a supporting structure might be advantageously located a short distance from the centre, if an abrupt change in profile made an increased height of structure necessary to secure the proper clearance.

132. A private right of way is necessary for most high-voltage transmission lines, as the risk to life and property from high voltages is too great to permit circuits to be carried along highways. The width should be so chosen that no tree or other object located outside the right of way can fall across lines. Where very tall trees do occur, they should be bought and removed. It is advantageous to secure the right of way near a highway, as the construction materials can be easily hauled to the tower locations. The line will also be more accessible for repairs, and patrolling is facilitated. Where the line must pass over private property, if possible it should follow the division lines.

133. The proper form of contract should be executed, when the consent of the proper parties is obtained. In many cases, as in sparsely settled districts, the land may be bought outright. The best practice, however, is to acquire perpetual right under easement, or for a term of years, with the right to renew the contract at the expiration of this time. Legal questions of importance should be settled by counsel. (Also see Bibliography 113-115 incl.)

134. The conductor material will be either copper or aluminum and the relative advantages and disadvantages of these are described in Par. 44 to 47 incl.

135. The spans for any line will usually vary in length. For level or undulating country a standard span, ranging from 100 to 800 ft. may be used. In hilly or broken country the support must be erected at advantageous points regardless of the varied lengths of spans that may result. With increased length of span, the number of structures and insulators (hence maintenance charges) is decreased, but the height of tower is increased. The cost of the tower may vary as the cube of the height. Other things being equal, the span should be so selected that the total line cost is a minimum. (See Par. 224.)

136. Extra long spans must be anchored at each end. To secure sufficient tensile strength in the insulator, it is often necessary to connect a number of strings of suspension insulators in parallel. In order that each string may take its own share of the load, a *strain yoke* (Fig. 32) is used.

137. The conductor spacing should be such that the wires cannot swing within arcing distance of one another in the span. When suspension insulators are used, the wires at the insulators should not be able to swing within arcing distance of the pole or tower. Allow a 45-deg. deflection from the vertical for copper and 60-deg. deflection for aluminum under the worst conditions of loading. Assuming that one of the phase conductors hangs vertical and that the other swings to the above angle, no two conductors must come within arcing distance of each other. Fig. 54* shows the usual spacings employed.

138. Weighted conductors. Where small conductors are used with suspension insulators it may be impracticable to increase the spacing by an amount sufficient to prevent the wires swinging more than 60 deg. By hanging a weight on the end of the insulator string, the maximum swing may be kept within this limit. The table in Par. 139, presented by H. W. Buck,† gives the necessary weight per ft. of conductor to bring the deflection to 60 deg. Such weights also tend to prevent the propagation of mechanical waves longitudinally.

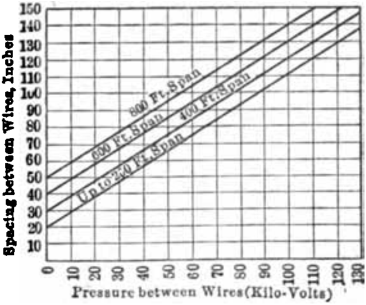


Fig. 54.—Approximate conductor spacing.

139. Deflections and counterweights at various wind pressures

Size conductor A.W.G.	Wind pressure lb. per sq. ft.	Angular deflection without weight	Auxiliary weight per ft. conductor necessary for 60 deg. deflection
	Stranded copper		
4	15 lb.	66 deg.	0.041 lb.
3	15 lb.	63 deg.	0.028 lb.
2	15 lb.	60 deg.	0.000 lb.
	Stranded aluminum		
2	15 lb.	81 deg.	0.156 lb.
1	15 lb.	79 deg.	0.161 lb.
0	15 lb.	78 deg.	0.171 lb.
00	15 lb.	77 deg.	0.182 lb.
000	15 lb.	75 deg.	0.186 lb.
0000	15 lb.	74 deg.	0.196 lb.
250000	15 lb.	72 deg.	0.190 lb.
300000	15 lb.	71 deg.	0.177 lb.
400000	15 lb.	68 deg.	0.158 lb.
500000	15 lb.	66 deg.	0.125 lb.

140. The type of line construction should be decided upon after the location of the line has been determined. The choice lies between wooden poles, steel poles, concrete poles, rigid steel towers, and the flexible tower system.

When selecting the type of line, the locality through which the line passes, the initial cost, the reliability, the ultimate life, and the maintenance should all be carefully considered.

141. The poles or towers should be staked out by the surveying party; following should come a digging party provided with a steel or wooden template by which the corner holes may be located. This party should be followed by another to install the concrete foundations, if such are to be used, and then by the erecting gang.

* Bibliography 3. † Bibliography 43.

POLES

142. Wooden poles, though apparently the cheapest form of construction, should seldom be used, except on short or relatively unimportant lines. The life of untreated poles (Par. **143**) ranges from 6 to 15 years, depending on the type of wood and the climatic conditions. When treated, their life may reach 20 years or more. Though wooden poles and cross arms give better insulation (per pole) to the system, they may be charred or badly burned by leakage currents or by conductors that fall from insulators. Although less likely to be struck by lightning, they are usually shattered or badly damaged when struck. The large number of poles required per unit length of line, decreases the (total) insulation of the system and increases the number of insulator troubles in direct proportion.

Wooden poles are still used to a considerable extent in transmission. Sixty per cent. of the wooden poles used in the United States are cedar and 20 per cent. are chestnut. On the western coast, redwood is used to a great extent; other woods, such as pine, cypress, juniper, Douglass fir, tamarack, and oak are occasionally used. Cedar, owing to its lightness and to its long life, which varies from 10 to 30 years depending on the climate and soil, is the most common pole timber, although the supply in the eastern states is practically exhausted. Chestnut, though heavy and not as long-lived as cedar, is used in the eastern and middle states. Redwood poles have a long life, and are usually sawed from large trees. Pine, though heavy in resinous products, rots very rapidly and does not last more than 4 or 5 years unless treated. Cypress stands very well in its native climate, but is short lived in the north. The other woods are used only occasionally though the present methods of pole treatment will widely increase the timber available for poles.

143. Average life of untreated poles.

Cedar	15 years	Juniper	8.5 years
Chestnut	12 years	Pine	6.5 years
Cypress	9 years		

144. Preservative treatment of poles is attracting much attention among large users, as the available supply of timber is constantly decreasing and the price rising. Two preservatives are in general use: creosote and zinc chloride, though copper sulphate has also been used to some extent. Creosote, though expensive, is the most satisfactory preservative, as it does not contain water nor is it affected by water, and has valuable antiseptic properties. Zinc chloride is far cheaper, but as it is carried into the wood poles in a water solution, the water must be dried out again, and the pole will readily absorb moisture later.

145. Brush treatment of seasoned poles consists of two applications of hot creosote (220 deg. fahr.) about 24 hr. apart. The treatment should extend at least 2 ft. above the ground line, and the pole should be very dry at the time of application. This is the simplest form of treatment; it costs from 15 to 40 cents per pole, and increases the life 2 to 3 years.

146. In the open tank method of pole treatment the dry pole butts are placed in tanks containing hot creosote at 220 deg. fahr. (105 deg. cent.), for from 4 to 8 hr., and are then allowed to stand in a "cold" bath between 100 and 150 deg. fahr. (38 and 66 deg. cent.) from 2 to 4 hr. Where the top of the pole is subject to rot, as in the south, the whole pole may be treated by this process. The penetration is about three times as great as with the brush treatment, and the cost per pole ranges from $0.75 to $1.25, depending on the absorbent properties of the wood. The estimated increase of life is 20 to 25 years. (See Par. **230**.)

147. In the full-cell (Bethel) process of pole treatment, the poles are placed in an iron cylinder, about 125 ft. long and 8 or 9 ft. in diameter. Live steam at 20 lb. pressure is admitted and maintained for several hours. The steam is then blown out of the cylinder, and pumps exhaust as much of the air as possible. At the end of the vacuum period, the preservative at about 150 deg. fahr. (66 deg. cent.) is admitted and is forced into the wood under pressure. This insures a deep penetration of the preservative and a long life to the pole. No data as to the life of such poles are available, but poles in England under similar treatment are still in service at the end of 60 years. The cost is estimated at $1.10 for a 25-ft. pine pole and $2.45 for a 35-ft. pole, depending upon the amount of liquid absorbed.

148. The burnettized creosoted butt process of pole preservation is similar to the full-cell method, except that zinc chloride is always used in the tank. The butt, to a foot or two above the ground line, is then impregnated to a slight depth with creosote under pressure. This prevents the zinc chloride from leeching out, and is much cheaper than a complete treatment of creosote.

149. Tabulation of pole cost, per-annum pole cost, and cost of butt treatment—western red cedar*

Price of pole	8 in.-35 ft.	8 in.-40 ft.	8 in.-45 ft.	8 in.-50 ft.	8 in.-55 ft.	8 in.-50 ft.
F.O.B. Central Iowa........	8.75	10.15	13.20	15.45	17.70	19.90
Cost of setting............	3.89	4.77	6.05	6.85	7.61	9.08
Total................	$12.64	$14.92	$19.25	$22.30	$25.31	$28.98
Using U. S. Aver. 12 yrs. life..	......	......	......	......	......	......
Cost per annum............	1.05	1.24	1.60	1.86	2.11	2.42
Cost of Butt treatment.....	......	......	......	......	......	......
†Specification "A".........	1.50	1.75	2.00	2.50	3.00	3.50
‡Specification "AA"........	1.20	1.35	1.60	1.85	2.00	2.50
No. years added life to pay entire cost of treatment....	......	......	......	......	......	......
†Specification "A".........	1.4	1.4	1.2	1.3	1.4	1.4
‡Specification "AA"........	1.1	1.08	1.0	1.0	0.9	1.0
Probable increase of life................10 to 15 years.						

150. Char and tar the butts of poles before setting if they are not creosoted. This is done by placing the pole upon a skid over a slow fire, gradually revolving it until the butt to about 1 ft. above ground level is thoroughly charred. While hot it is given two or three coats of tar with a stiff brush and is then set. This will increase its life perhaps a year.

151. Wooden pole specifications. Each pole should be of good quality of live growing timber free from knots and shakes, and sound in all respects; the grain should be close and hard with the annular rings closely pitched and with a sound heart. Each pole should be straight and well proportioned, free from all objectionable bends; should have the natural butt of the tree and should be squarely sawn, without trimming. Poles should vary in size by lengths of about 5 ft.; they should be cut between the first of November and the first of March, and after being felled they should be carefully trimmed, the bark removed and the butt squared. The poles should be piled with open spaces between, raised from the ground and allowed to season for at least a year or more. After seasoning, the top of each pole should be roofed and the suitable number of gains cut for the cross arms. The specifications vary with the kind of wood.

152. §Depth of wooden poles in the ground

Length over all (ft.)	Depth for straight line (ft.)	Depth curves, corners and points of extra strain (ft.)	Length over all (ft.)	Depth for straight line (ft.)	Depth, curves, corners and points of extra strain (ft.)
30	5.0	6.0	60	7.0	7.5
35	5.5	6.0	65	7.5	8.0
40	6.0	6.5	70	7.5	8.0
45	6.5	7.0	75	8.0	8.5
50	6.5	7.0	80	8.0	8.5
55	7.0	7.5			

* Page & Hill, Minneapolis, Minn.
† Specification A. High grade of carbolinium.
‡ Specification AA. Highest grade of creosote oil.
§ Report of Committee on Overhead Line Construction, N. E. L. A.

153. Wooden-pole settings. All holes should be dug large enough to admit the pole without forcing, and should have the same diameter at the top as at the bottom. The pole may be "piked" into position, but it is usually much cheaper to employ a gin wagon, and to use the team for raising the pole. Forty to fifty poles per day can be thus raised, with only two linemen and a teamster. Poles should be set to stand perpendicular when the line is completed, but at terminals and curves the pole can be slightly inclined against the pull. When the pole is in position, only one shovel should be used in filling the hole, while three tampers pack the earth. The earth should be piled about a foot higher than the ground level.

154. Crib-bracing can be used, where the poles are set in loose, or marshy soils. For further discussion see Sec. 12, Par. 173.

155. The sand barrel is a useful expedient in digging holes or setting poles in sandy or loose soils. See Sec. 12, Par. 173.

156. A concrete foundation may be used for wooden poles where exceptional stability is desired. This concrete filling should extend at least a foot from the pole on all sides, should be carried above the ground line and bevelled to shed water, and should consist of one part Portland cement, three parts sand, and six parts broken stone or clean gravel, mixed wet. (See Fig. 47, Sec. 12.)

157. Special pole settings. In marshy ground, more elaborate devices, as shown in Fig. 47, Sec. 12, are often required for a satisfactory foundation.

158. Pole repairs. Wooden poles usually fail by decay at the ground line. If they are long enough, they may be sawed off and set again. A very satisfactory way of repairing such poles without disturbing them is to drive U-shaped rods in the poles at the ground line, as shown in Fig. 55, and fill the space with concrete. Poles reinforced in this way are said to be stronger than when new, and their life is greatly prolonged.

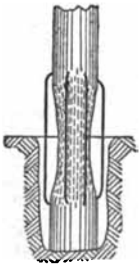


FIG. 55.—Pole repairing at ground line.

159. Steel poles cost but little more than wooden poles, when the erection and labor costs are considered, require no assembling at the point of erection, are not injured by fire, birds and insects, and are not damaged by lightning. Their field is the moderate line, with spans from 250 to 350 ft. in length running along roadways, or where space is limited. Their life is from 25 to 50 years, depending upon their upkeep.

For heavier circuits, they lack the necessary horizontal and torsional strength. The more common types are the tubular, made in sections, the diamond, the latticed-girder type, and the patented types, of which the tripartite is an example. Of these, the low weight efficiency of the first two and the difficulty with which the insides are protected from corrosion make them doubtful for high voltage transmission. The last two are extensively used. Steel poles have reached a much higher state of development abroad than in the United States.

160. The tripartite steel pole, shown in Fig. 78, consists of three continuous U parts, the dimensions of which are given in Par. 234. These are held together by "spreaders" and "collars" bolted together. The strength and rigidity of the pole can be increased by increasing the number of these members, and the pole is everywhere accessible, so that it can be readily painted and inspected. Tripartite poles may be shipped either assembled or "knocked down." They can be assembled by unskilled labor. In ordinary soil, and with a concrete foundation, it has been asserted that the poles need only be buried for one-tenth their length.

161. Steel poles should invariably have a concrete foundation, in order to obtain adequate bearing area. Steel-pole foundations are shown in Fig. 56.

162. Concrete poles are coming to be used for high-voltage transmission. Their first cost and maintenance are very low, they are not injured by the attacks of insects, fire, etc., and, apparently, are not damaged by lightning. They can be used in the most accessible places only, as they must be constructed, in most cases when erected. Their weight results in high transportation costs. Though there are as yet no data regarding their life, it is probably considerable. Two poles, 150 ft. (45.8 m.) high, 11 in. (28.0 cm.) square at the top, 31 in. (78.7 cm.) square at the bottom, and capable of withstanding, without guys, a 2,000-lb. horizontal pull at the top, have been successfully installed by the Hamilton Power, Light and Traction Co., at the Welland Canal Crossing.

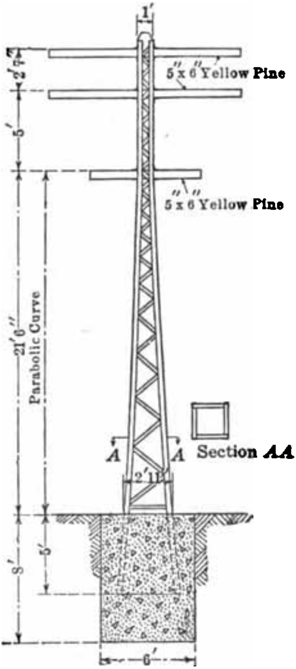


Fig. 56.—Typical steel pole.

STEEL TOWERS

163. Advantages. Steel towers in the open country, and for trunk lines of large capacity and long spans, are unquestionably the best type of construction. The two systems, the rigid and flexible, are both in general use, ard the latter is becoming more used. The flexible system compares favorably even with wooden poles, as far as first cost is concerned, since most of the work on it can be done by unskilled labor. The flexible towers as a rule come all assembled.

Towers are the strongest of all supports for their weight, not only under direct horizontal pull, but under torsion as well. They are free from injury by fire, attacks of insects, birds, etc., and are not wrecked by lightning. They have a life of from 25 to 50 years and possibly longer, when properly maintained.

164. The design of a steel tower is largely the work of the structural engineer, but the electrical engineer should be able to specify the various stresses that the tower must withstand, the height, length of cross arm, etc., and be able to check the design by calculating the stresses in the various members. Towers made with members which are too light, deteriorate very rapidly when corrosion once begins, and the cost of painting such towers, should this form of protection be found necessary, will be high. Members should never be much less than 3/16 in. (0.48 cm.) thick. Fig. 57 shows a standard tower, Ontario Hydroelectric Commission, and Fig. 58 shows a flexible tower.

165. Protection against corrosion is obtained by painting, galvanizing and sherardizing. For proper protection, paint must be applied every 2 or 3 years, and if the tower consists of a large number of small members, the expense of painting may be prohibitive. Where the structures consist of a few members, painting may be economically used. One coat of hot dip galvanizing well applied offers protection, for perhaps 30 years, except at the ground line. A shell of concrete at the ground line may increase the life of the tower materially. Sherardizing or "dry galvanizing," gives a uniform coating at a low cost, and offers a high resistance to wear and abrasion. If the zinc is removed by abrasion or bending, the zinc-iron alloy still offers protection.

166. Erection of the tower is ordinarily by gin poles or by shear poles. The former device consists of a wooden mast or a frame which must be set outside the tower base. The butt must be firmly anchored, and the pole strongly guyed, especially in the direction of the back line.

The shear pole supports the raising line and affords a means of raising the tower by a straight away pull. The straight shear pole has a groove at the top, over which the raising line passes. The shear pole may be lowered to the ground when the raising line clears the top.

Heavy towers must often be braced at the base by some form of strut, to reinforce the tower against the stresses due to erection.

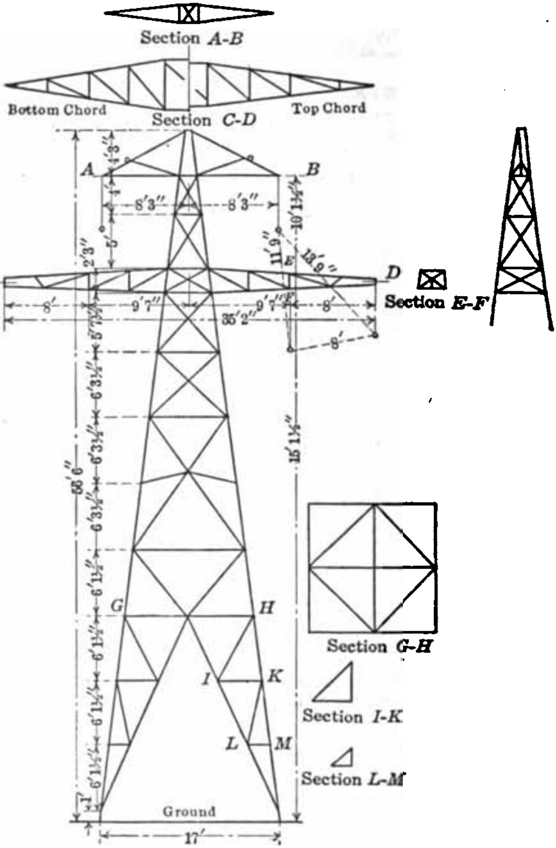


Fig. 57.—Rigid steel tower.

167. Special structures are often required for transpositions, and at points where the line crosses a river, a bay, or a railroad. They are also used where the line makes a sharp angle; where the line is dead-ended; and to allow the installation of line switches, protective apparatus, or outdoor substations or switching stations. Special structures are usually very expensive as compared with the standard towers, and where one of the latter will answer the purpose, it should be used.

168. Steel towers may be set directly in the ground, in which case, the steel should be well protected by galvanizing. The footings are usually made by bolting an angle or channel iron directly to the bases of the anchor stubs. For the heavier structures, a built-up grillage is necessary. Fig. 59 shows a concrete anchor.

POLE ACCESSORIES

169. Wooden cross arms may be of either Norway or yellow pine, long-leaf yellow pine, Washington fir, though other woods such as cypress, oak, spruce and cedar are used to a limited extent. Long-leaf yellow pine, and Washington fir are the best woods for high-class construction, the average life untreated being 8 and 11 years. Wooden cross arms are being used in connection with steel or concrete poles. In certain localities, cross arms are being treated to prevent decay. The full-cell treatment (see Par. 147) is usually employed, although the initial treatment by live steam is found unnecessary if the arms have been well seasoned. Cross arms should be seasoned for at least 3 months and painted with two coats of white lead paint, unless properly treated with a suitable preservative. For the voltages employed in transmission work, there has been no standard size of cross arm adopted. In the

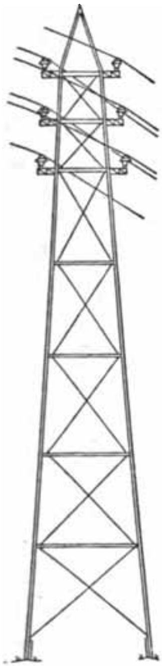


Fig. 58.—Flexible tower.

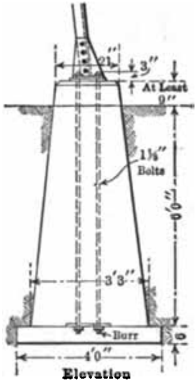


Fig. 59.—Concrete anchor for steel tower.

lighter construction, the standard electric light cross arm, 3¼ in. × 4¼ in. (8.25 cm. × 10.8 cm.) often answers the purpose. For heavier work, sizes ranging from 4 in. × 5 in. (10.2 cm. × 12.7 cm.) to 5 in. × 7 in. (12.7 cm. × 17.8 cm.) are used.

Cross arms should be snugly fitted into a 0.75-in. (1.9 cm.) gain. Unless the pole previous to erection has been treated by some preserving process, the gain should be given a good coat of mineral paint. Cross arms may be secured to the pole by two lag bolts, though in the best construction the cross arm is supported with a through bolt and braces. The cross arms on alternate poles should face in opposite directions.

170. Cross-arm braces are discussed in Sec. 12, Par. 179.

171. Double cross arms should be used where excessive stresses may occur such as at line terminals, corners, curves, and where extra precautions against life or property hazard are required, as at railroad, highway, or low-voltage line crossings. See Sec. 12, Par. 178.

172. The wish-bone and bo-arrow cross arms, made of angle iron, are used for wooden-pole, single-circuit construction. The ground wire is carried on the bayonet, at the tip of the pole. See Fig. 60.

173. Insulator pins are made of wood, of steel and of steel in combination with porcelain. Although the wooden pin adds to the insulation, the dielectric stress in the insulator is so localized, especially in wet weather, that little is gained; wood deteriorates rapidly, being carbonized by leakage currents, and eaten by nitric acid which forms in the presence of high voltages. Furthermore, a wooden pin is weaker mechanically than a steel pin, hence requires a larger hole in the cross arm, and thus decreases the mechanical strength of the arm. **Wooden pins** should be used only for the lightest construction, and with voltages not exceeding 20,000. They are made from locust, oak, maple, hickory and eucalyptus, and should have a fine straight grain, free from knots.

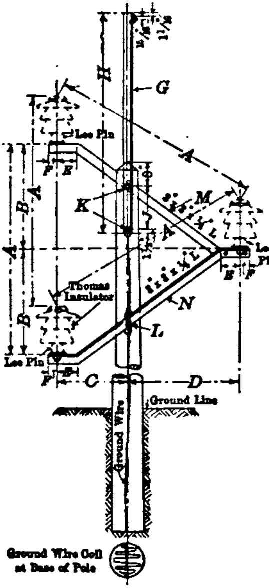


Fig. 60.—Wish-bone cross arm.

174. A wooden pin with a centre bolt is common. The bolt serves as a cross-arm fastening and the wooden portion holds the insulator. The advantage of this over a straight wooden pin is that a much smaller cross-arm hole is required.

175. Steel pins may be of steel, malleable iron, cast iron, cast steel, or combinations of these. They are much stronger than wood pins, and when well galvanized have a much longer life. They are either cemented directly into the insulator, with Portland cement, or capped with either a wooden or a lead thimble, which is screwed into the porcelain. The difficulty of replacing such insulators has been obviated by providing a steel thimble, threaded inside, which is cemented directly into the insulator, and to which the metal pin is screwed. A steel pin designed with a large shoulder which rests on the cross arm, decreases the size of cross-arm hole necessary.

176. Clamp pins are designed to eliminate the weakening of the cross arm due to removal of valuable material when holes are drilled for the insulator pins. Furthermore, they reduce the concentration of leakage current, and hence the burning and charring of the wood.

177. Insulator pins with a porcelain base (lead or wood thimble) prevent an arc from striking from the conductor to the pin, have a long life, and are mechanically strong. Even though the porcelain cracks, the pin will only bend and the insulator will not fall.

178. Method of hanging suspension insulators. When suspension insulators are used, the breaking of a conductor pulls the string into a nearly horizontal position. The tower connection at top of suspension string should be made as snug as possible to the under side of the cross arm, to avoid torsion on the arm.

179. A tie wire or a clamp may be used to fasten the conductor to the insulator. The main function of a tie is to hold the conductor securely to the insulator, and prevent it from creeping from one span to the next. Its form depends largely on the type of insulator used. Aluminum tie wires should be used with aluminum conductors, as contact with other metals may form a galvanic couple and produce corrosion. Furthermore, harder metal will injure the soft aluminum. A large bearing area must be allowed where aluminum is used, as it is softer than iron or copper

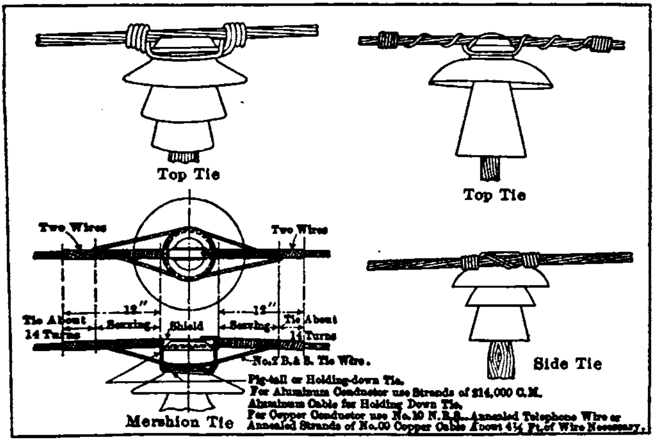


FIG. 61.—Insulator ties.

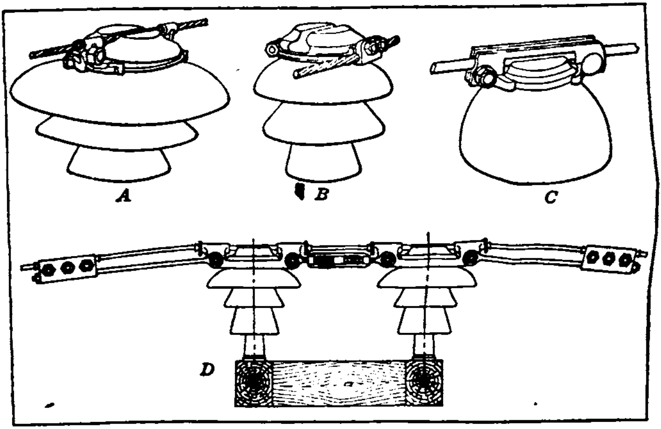


FIG. 62.—Insulator clamps.

No. 2, No. 3 and No. 4 A.W.G. have been found most satisfactory for aluminum ties. A few typical insulator ties are shown in Fig. 61, and Fig. 62 shows two Clarke insulator clamps.

180. Cable clamps for suspension insulators may be designed either to allow the cable to slip through and equalize the horizontal stresses in adjacent spans, or to hold the cable to approximately breaking loads, in case of a broken span. The clamp should be designed with a liberal cable seat and long, free, well-rounded approaches, so that the conductor will not be permanently injured if a span breaks, and the string is thus thrown temporarily into use as a strain insulator.

181. Suspension strain or anchorage clamps should admit the wire from the span without producing any kinks, or sharp bends, and should have a long, liberal bearing surface. The cable should not be held by such devices as U or J bolts, but rather by flat smooth surfaces.

POLE BRACES, GUYS, AND ANCHORS

182. Pole braces consist of shorter and lighter poles bolted against the main pole. They are sometimes preferable to guying, especially where a narrow right of way does not allow a guy wire to be used. The brace can be designed to take tension and compression; assist the main pole to resist the stresses in the direction of the line, and is not easily damaged maliciously. Owing to the increasing cost of poles, the cost of erection, and the liability of destruction by grass fires, guys are ordinarily to be preferred. Fig. 63 shows standard methods of bracing. The bearing area of

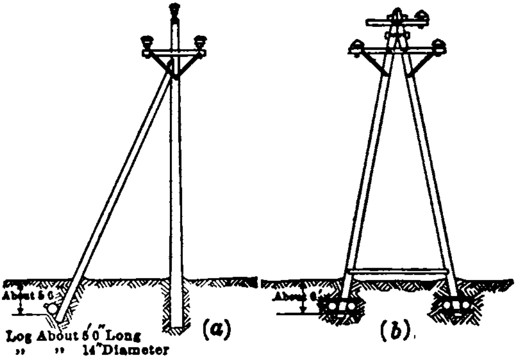


Fig. 63.—Pole brace. A-frame.

the soil can be increased by fastening planks to the base, or by placing a flat rock under the butt. A log bolted to the butt also permits the brace to take tension. An A frame, or double-pole shown in Fig. 63b may be substituted for the braced pole.

183. Guys are necessary to assist the supporting structure in resisting such unbalanced stresses as are produced at angles, terminals or on sloping ground. They are also used to give the line increased stability in places where a failure is very undesirable, where a hazard to life or property must be avoided, as at a railroad crossing, or where a line runs parallel to or crosses a highway. Steel towers are seldom guyed, their resistance to overturning being sufficiently large (also see Sec. 12, Par. 174, 175, 176).

Well-galvanized steel strand, a table concerning which is given in Sec. 4, should be used for guys.

184. Straight-line guying is used to give increased stability to the line. Approximately every twentieth pole should be guyed, in the direction of the line, either by head or anchor guys, and, if possible should be side guyed as well. Head guys should be used when a line runs over abruptly sloping ground, in order to give the line increased longitudinal stability.

185. Guy anchors are necessary where there are no trees, poles, or rocks to which the guy line may be conveniently attached. The simplest and most reliable form of anchor is the so-called "dead man" which consists of a log, 8 to 15 in. (20 to 38 cm.) diameter and 5 to 12 ft. (1.5 to 3.7 m.) long. A guy rod is passed through and held by a nut and washer. The log is buried to a depth of from 4 to 7 ft. (1.2 to 2.1 m.), depending on the load it must carry, and the character of the soil. Malleable iron plates may serve the same purpose.

186. Patent anchors. The many types of patent anchors depend for their holding power upon projections that are brought into play upon reversal of stress. The anchors are placed into position by being driven, screwed, or buried in the ground.

187. Rock anchors are often desirable where ledges or large boulders are encountered. They are made by setting an eye-bolt into the rock with or without cement, depending upon the character of the rock.

CONDUCTOR CONSTRUCTION

188. Wire stringing may be accomplished either by securing the end of the wire and carrying the reel forward, or by maintaining the reel stationary and carrying the end of the wire forward. The former method is best adapted to light construction and long lengths, whereas the fixed reel is best adapted to heavier and shorter lengths. The conductors are drawn up by means of a team, and when the proper sag and tension are obtained, the wires are attached to the cross arms by snub-grips, thus making temporary dead-ends which remain until the lineman can attach the clamps or make the tie. Where flexible or light structures are used, these must be guyed temporarily until a permanent line anchorage is made.

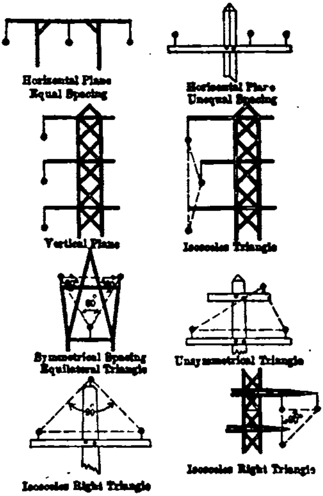


Fig. 64.—Grouping of phase wires.

189. Phase wires may be arranged (Fig. 64) (a) in a horizontal plane; (b) in a vertical plane; (c) at the vertices of an equilateral triangle; (d) at the corners of a square (quarter-phase); and (e) at the corners of an isosceles triangle. Only in (c) are the conductors symmetrical with respect to one another. In the other cases except (d) the inductive drop and charging current are unbalanced, but these effects are so slight that they can be neglected. The arrangement of circuits on a pole will be determined by mechanical considerations and the type of construction employed. When making inductance and capacity calculations, the *average distance* between wires, or the cube root of the product of all three of the actual distances may be used. Either method introduces only a slight error. For spacing and clearances see Fig. 54.

190. Cable splicing. The insulation should be carefully removed from the ends of the cable to be spliced, close attention being given to getting the copper perfectly clean. A copper sleeve of the proper size may be used to make the joint. The joint should be left smooth and free from any little points of solder or sharp edges, as these factors tend to produce abnormal dielectric stress.

All burned or imperfect material in the insulation should be removed. The braid and tapes should be taken back far enough to allow the splices to be completed without touching them; this is very necessary owing to their low insulating properties.

The insulation should be beveled down to a very thin edge until it has the appearance of a well-sharpened lead pencil; this bevel or taper should be very gradual. If the taper is too short, it will be difficult to put the splicing compound on with sufficient density where the insulation stops at the joint, or at the end of the scarf. More high-tension joints break down at this point than at any other one place. The remedy is a very long gradual taper or scarf.

When possible, a good rubber cement should be used, smearing the taper as far up on the insulation as the splicing compound is to go, keeping it off the copper. The cement should be allowed to dry out until all moisture has disappeared, leaving it firm and sticky. Enough pure rubber should be put on to cover the copper, running about one-third of the way up on the taper. This should be covered with a good rubber splicing compound until it is somewhat larger than the rest of the cable. Care should be taken to put as much tension on the splicing compound as it will stand in order to get it on tight, to exclude all air and make the whole a solid, dense mass. In the case of submarine cables, the vulcanising of all patches and splices is recommended.

On small stranded joints which must be kept flexible and which cannot be soldered, a layer of tin-foil over the joint is recommended; this should be laid on before the rubber is applied, and will prevent any corrosive action of the sulphur in the rubber on the unsoldered joint. (Also see Sec. 12, Par. 219.)

191. Joints in transmission lines are seldom made up from the conductor itself but are almost entirely patented devices. Aluminum is not readily soldered and hard-drawn copper becomes annealed when soldered. The Western Union joint is used only for small wires. The so-called dovetail splice is made by fitting the strands of one cable between those of the other and wrapping one strand at a time tightly around the others and around the cable.

Patented joints that are satisfactory for inside wiring or short spans may give trouble when subject to the stresses incidental to the long spans employed in transmission work, unless installed with considerable care. The parallel-groove clamp is used where a jumper connection or station connection is to be made.

192. The McIntyre joint is used chiefly on small sizes of cable, although it has been used on sizes as large as 650,000 C.M. It is made of seamless copper or aluminum tubing, oval in section, into which each conductor is pushed from opposite ends, until the conductors project about 2 in. beyond the ends of the sleeve. The tube is then twisted three or four complete turns by special tools. This joint is efficient both electrically and mechanically.

193. Ground-wire construction. See Par. 80, 87. Ground wires are designed primarily to protect the line from lightning disturbances, hence should be placed well above the line conductors. With wooden poles, the so-called "bayonet" shown in Fig. 60 is commonly used. This may be a piece of angle iron or a pipe properly drilled and fitted to be fastened to the pole top to receive the ground wire. Where steel towers or poles, and consequently long spans, are used, the ground wire is often depended upon to take up some of the unbalanced stress due to the breakage of a line conductor. This is especially true when flexible towers with pin insulators are used. A ground wire is absolutely necessary to hold these towers in the correct longitudinal position, if suspension insulators are used. The ground wire should be held securely to the pole top by a clamp which is slightly flexible, has a grip of several inches, and flaring, well-rounded approaches. The use of J bolts or U bolts should not be allowed, as they will crush and weaken the cable at a point where mechanical strength is most necessary. Taps to ground connections for the same reason should not be soldered, but rather fastened by well-designed clamps. Some companies mount the ground wire on insulators as an extra conductor during the winter. The wire should be grounded at every steel pole or tower by contact with the metal work. If the metal work is completely imbedded in concrete at the base the ground should be made by driving an iron pipe, about 6 ft. (2 m.) long and 1 in. (2.5 cm.) diameter, into the ground, and connecting it to the metal work with a copper wire.* If the soil is dry, the ground can be made more permanent by pouring salt water around the pipe. When wooden poles are used, the ground connection should be made at every pole, by running a copper wire down the pole and grounding to a pipe driven in the ground, or by coiling the wire (bare) in a flat helix and placing it under the pole-butt.

194. Transpositions† are made to eliminate electrostatic and electromagnetic unbalancing of the various phases; to eliminate mutual induction between parallel lines; and to prevent disturbances in neighboring telephone and telegraph circuits. The distance between power-line transpositions is a matter of judgment, and may vary from 10 to 40 miles. Many engineers question the value of transpositions, and lines are operating satisfactorily without them. Fig. 65 shows the transposition of a section of three-phase line and a telephone circuit.

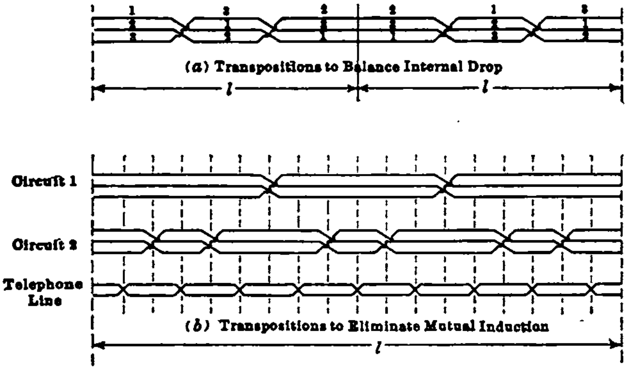


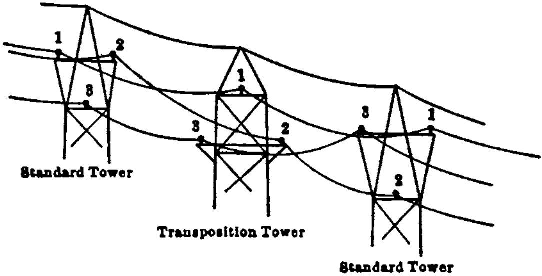
Fig. 65.—Transpositions.

195. Transpositions are commonly made by rotating the delta; by gradually changing the relative positions of the wires; by dead-ends and jumpers, similar to the method employed in telephone work. The first method requires special structures that are usually interspersed between the standard towers. When the wires are arranged at the corners of a triangle, the delta is rotated through 60 deg. in one span, and through the other 60 deg. in the next span. This is shown in Fig. 66 (*a*). When the wires all lie in the same plane, resort to an intermediate triangular arrangement must be made, as shown in Fig. 66 (*b*). Both of the above methods require special structures, and the transposition spans are usually about one-half the length of standard spans, in order that proper clearance between conductors may be maintained. The jumper method, shown in Fig. 66 (*c*), requires only a standard strain tower, which may be slightly modified if the conductors happen to lie in a vertical plane.

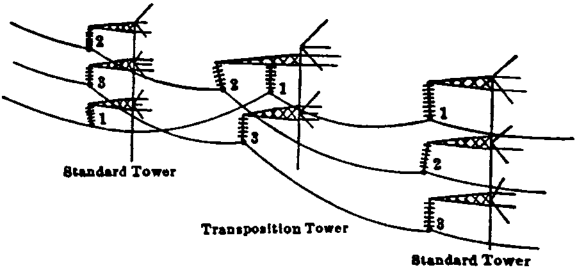
196. A telephone line is essential to the satisfactory operation of every transmission system, as a means of communication between generating stations, substations and patrolmen. When possible, the telephone wires should be run on a separate pole line to eliminate disturbances and trouble caused by the high-tension circuit. The cost of an extra pole line is often prohibitive, so it then becomes necessary to carry these wires on the power line poles or towers. In this case they should be at least 8 ft. (2.44 m.) beneath the nearest power wire, and in as protected a position as possible, otherwise the telephone may be rendered useless when trouble occurs on the power line—a time when the telephone is most needed. Small telephone

* See Bibliography 63. † Bibliography 69, 70.

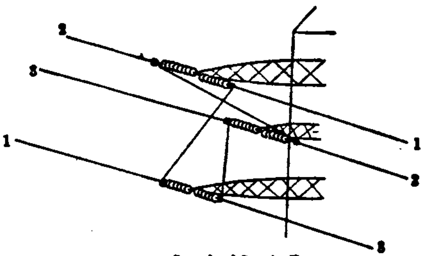
wires may be unable to withstand the stresses in occasional long spans. In this case they may be supported by a steel messenger wire, and if this latter is grounded, it helps to shield the telephone from inductive effects.



(*a*) Single Circuit Construction-Symmetrical Spacing



(*b*) Vertical Spacing



(*c*) Dead-end Jumper Method

Fig. 66.—Methods of transposition.

197. Induced electrostatic charge may raise the potential of the telephone circuit to a dangerous value. This potential can be greatly reduced by connecting coils of low reactance to ground, known as *drainage coils*, across the telephone line at intervals, and grounding their middle points. For further protection to the user, vacuum lightning arresters, horn-gaps, fuses and well-insulated transformers are used. Fig. 67 shows the connections ordinarily employed.

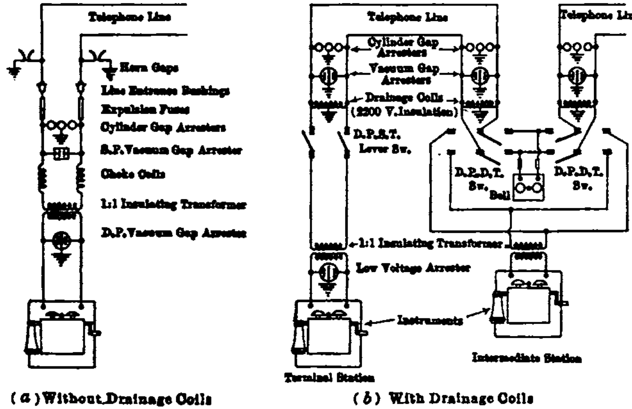


FIG. 67.—Telephone protection.

198. Where overhead crossings are made as over railroads or highways, extra precautions are necessary to protect life and property. In the past, a grounded cradle or basket-work beneath the lines, or some other grounding device, has been used to catch and ground the falling conductor. Patent wire clamps and hooks, out of which the conductor drops when broken, have been more or less used. Present-day practice rests on the principle that the less there is to come down, the better, and further assumes that there shall be no broken conductors. Safety is now procured by the use of short well-supported spans, having a liberal factor of safety.

199. Extra precautions in overhead-crossing construction.* Long spans shall be avoided; the supports at the crossing and adjacent spans shall be in a straight line; the power wires shall cross *over* the telegraph and telephone wires, whenever practicable; cradles shall in general not be used; but where the power lines run beneath the others, a cradle or bridge of adequate strength may be required; a 12-ft. (3.66 m.) side clearance to the nearest rail, a 7-ft. (2.14 m.) clearance to siding rails, and a 30-ft. (9.15 m.) headroom to the top of the rail under the most unfavorable loading conditions, is allowable practice; the clearance above the other wires shall be not less than 8 ft. (2.44 m.).

When suspension insulators are used, the crossing span shall be dead-ended, or else the maximum sag in the crossing span shall not exceed 30 ft. (9.15 m.) in case of failure in the adjacent span; the normal tension shall be allowed in the crossing and adjacent spans (see Par. 99), and no splices or taps shall occur in these spans; the pins, insulators, and attachments shall be able to hold the conductor under the greatest stress with the designated factor of safety, and the insulators shall be such that if shattered the conductors will not fall.

Wooden poles supporting the crossing span shall be side-guyed in both

* Report of the Joint Committee on Overhead Line Construction, N. E. L. A.

directions if practicable, and shall be head-guyed away from the crossing span; the next adjoining poles shall be guyed toward the crossing span.

Assumed loads shall be the resultant of dead-load, ½ in. of ice, and wind pressure of 8 lb. per sq. ft. on the ice-covered diameter at zero deg. fahr. The stresses and clearances shall be calculated for a temperature variation of from − 20 deg. fahr. to + 120 deg. fahr., except in those regions where this range is not representative. Towers or poles shall withstand a wind pressure of 13 lb. per sq. ft.

Factors of safety, or ultimate unit stress divided by allowable unit stress, shall be not less than the following:

Wire and cables	2
Pins	2
Insulators, conductor attachments, guys	3
Wooden poles and cross arms	6
Structural steel	3
Reinforced concrete poles and cross arms	4
Foundations	2

HIGH-TENSION CABLES

200. Underground and submarine cables are often used for transmission purposes and pressures up to 60,000 volts are successfully used.

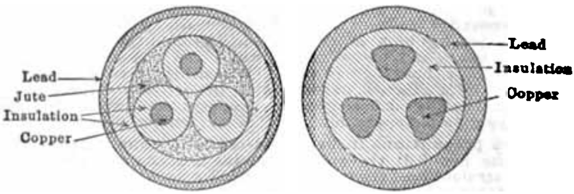
201. Three types of insulation are in common use, rubber compounds, varnished cambric, and impregnated paper.

(a) **Rubber compounds** consist of pure Para rubber and such mineral ingredients as sulphur, whiting, talc and litharge, which are thoroughly mixed together; the compounds are forced upon the conductors and then vulcanised.

(b) **Cambric insulation** consists of cotton cloth and a viscous filler. Each surface of the cloth is covered with multiple films of insulating varnish. The cloth is then applied to the conductor in the form of tape wound on spirally, the filler being applied between the successive layers.

(c) **Impregnated paper** insulation consists of Manila paper tapes applied spirally and evenly to the conductor, and then thoroughly impregnated with an insulating compound.

202. Cable insulation. In underground practice it has been found necessary to protect the insulation by a lead sheath. For submarine



(*a*) American Three-Phase Cable. (*b*) Clover Leaf Three-Phase Cable (English)

Fig. 68.—High-tension cables.

installations, cambric and paper-insulated cables have lead sheaths usually armored with steel for protection. When rubber is used, the lead sheath is unnecessary. Varnished cambric will resist water to a certain extent. Paper is worthless as an insulator if moisture is allowed to enter the cable.

Sometimes two or more of the insulations classified in Par. **201**, are used in the same cable to good advantage. For alternating-current transmission it is advisable to have all the conductors of the circuit in one cable, as the tendency to set up currents in the sheath is then practically neutralised. In all high-tension cables, the sheath should be well grounded to allow the high-voltage static charge to pass readily to earth. Where high-voltage conductors pass from the air into the cable, or from the cable into air, a large pot-head should be used, thus reducing to a minimum the high potential gradient that would otherwise occur at this point. Fig. 68 shows sections of three-conductor high-voltage cables; (*b*) is the clover-leaf type used in Europe.

203. Electrical disadvantages of a cable system. A cable system differs from an overhead system in that the electrostatic capacity is much greater while the linear inductance is negligible. Hence the charging current may be equal to or even greater than the load current itself. Surges* and transient phenomena are much more common than on an overhead line of the same length.

204. Underground cables for high-tension work are ordinarily installed in standard ducts (see Sec. 12). All underground cables should be **lead covered.** The rubber covering may last for years after the lead sheath has been eaten away by electrolysis or has been injured mechanically.

205. High-voltage cables† should be tested at a potential from 2 to 2.5 times their working pressure, depending upon the system to which they are connected.

The factory test voltage E, which should be applied between the core and sheath of a single conductor concentric cable, having homogeneous insulation, is

$$E = Kd \log_{10} D/d \tag{53}$$

where D is the diameter over insulation, d the diameter of the copper and K is a constant depending on the insulating material. If d is expressed in mils, K is about 250 for 30 per cent. Para rubber, cambric, and paper. From this formula the proper test voltage or the proper thickness of wall for a given test voltage may be determined.

SUBSTATIONS‡

206. The building is intended to shield the apparatus and equipment from the weather, as well as to furnish a shelter where repairs may be quickly made. A low-voltage station may have a fairly low initial cost. On the other hand, the large clearances required by overhead bus bars, connecting-leads, arrester equipment, etc., make the high-voltage substation a rather expensive affair.

207. The transformers should be installed in separate fireproof compartments which should be of such construction as to prevent burning oil from flooding the station, in case of trouble. Provision should be made for easily moving the units, so that repairs and replacements can be quickly made. Each transformer is often installed on wheels and rails, and trucks are provided in order that the large units may be readily moved.

208. Protective equipment is often placed indoors. The larger sizes of aluminum arresters and the large overhead clearances required for the horn-gaps often necessitate that these as well as the aluminum arresters, be placed out-of-doors. Where there are no overhead busses or inflammable material, the following clearances from the top of the horns should be allowed:§ for pressures up to 16,100 volts, 3 ft. (1 m.); from 16,101 to 37,900 volts, 4 ft. (1.2 m.); from 37,901 to 70,000 volts, 6 ft. (2 m.). At pressures above 70,000 volts, the horn-gaps should never be placed indoors. The auxiliary charging gaps for the aluminum arresters should always be in sight of the operator.

209. Choke coils are often mounted on post insulators on the outside of the building, especially where very high voltages are employed. For the lower voltages they may be conveniently installed on the inside wall, or directly in the switch leads.

210. High-tension bus bars are hung from the ceiling by suspension insulators, are suspended by ceiling insulators, or are mounted on post insulators. Owing to their low cost it is desirable to utilize suspension insulators whenever possible. Fig. 69 shows typical high-tension bus construction. (See Sec. 10, Par. **369.**)

* See Bibliography 45–55 incl.
† See Bibliography 33.
‡ See Sec. 12, Par. **51.**
§ See Bibliography 64.

211. Entrance and outlet for lower voltages are as shown in Fig. 70. Plate glass with a central hole, slightly larger than the conductor, is often used, as it keeps the weather out. Where high-voltage must be carried into a station, great care should be used in the design and selection of suitable bushings. A simple entrance for a 110,000-volt line consists of a 5-ft. (1.5 m.) slab of glass or marble, with a small hole sufficient to admit the conductor without undue corona discharge. In Fig. 71 are shown typical wall bushings.

The condenser type* of bushing is built up by placing thin layers of tin foil between concentric layers of insulation, and making the areas of the foil equal, irrespective of the diameter, thus giving uniform potential distribution. Such a bushing is shown in Fig. 70 (c).

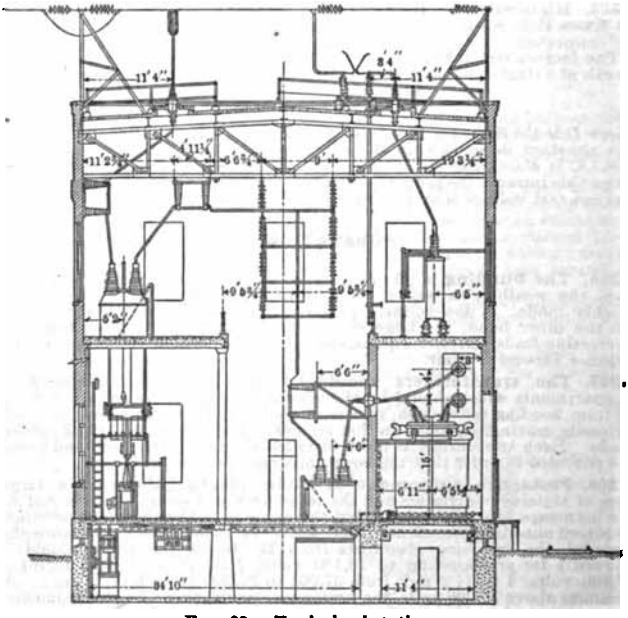


FIG. 69.—Typical substation.

212. Roof entrances and horn-gap outlets require a petticoated insulator in addition to a wall bushing in order to prevent trouble which might arise from rain and condensed moisture. The ratio of wet to dry flash-over should be very high. Fig. 138, Sec. 10, shows a typical roof insulator, and Fig. 72 shows standard roof construction.

213. A Substation wiring diagram is shown in Fig. 73, and Fig. 74 shows a typical meter panel. Meter leads A and B (Fig. 74) correspond to instrument transformer leads A and B (Fig. 73).

214. Outdoor switching stations are often installed at points where the amount of switching actually done does not warrant the expense of a building for housing the equipment. In such cases, a safe and economical

* Bibliography 44.

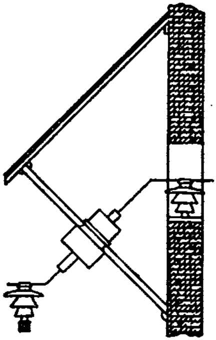
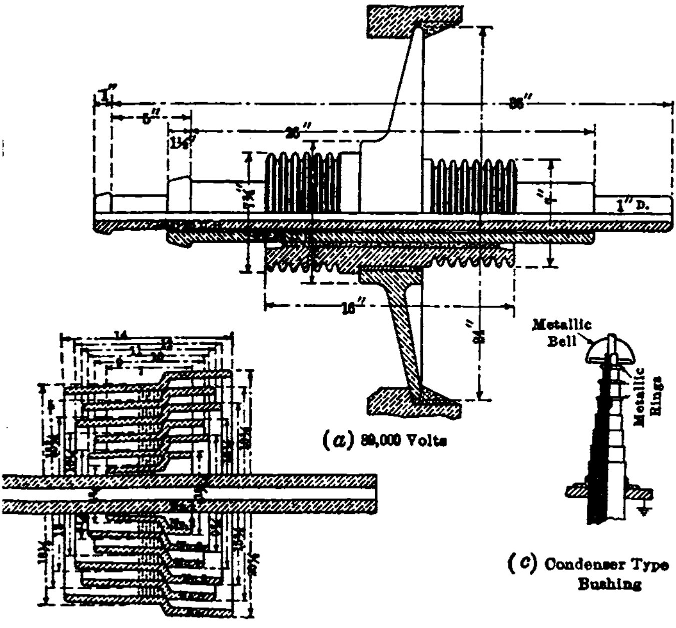


FIG. 70.—80,000 volt entrance.



(a) 80,000 Volts

(b) 90,000 Volts

(c) Condenser Type Bushing

FIG. 71.—High-tension bushings.

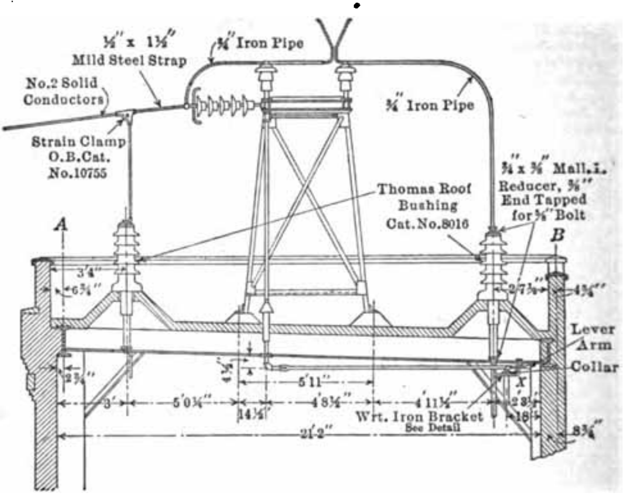


FIG. 72.—Typical roof construction showing horn gaps and roof insulators.

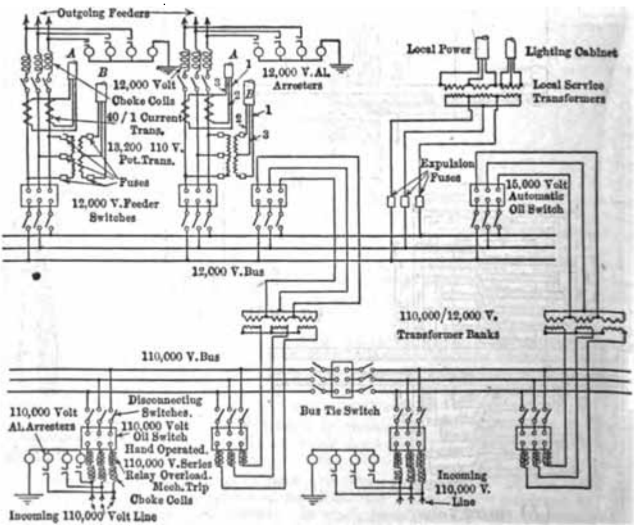
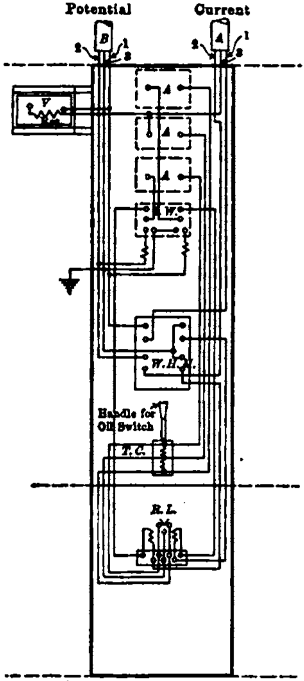


FIG. 73.—Substation wiring.

construction is to erect a platform on a special structure, upon which the switch-handles, transformers and other equipment are placed.

215. Outdoor substations* are rapidly coming into use, since the large clearance necessitated by high voltages would require a very large building. They are also used where small loads are tapped from the main line, requiring only one transformation from line to consumer. Switches, arrester equipment, power and instrument transformers have been developed to such a point that little deterioration occurs due to the weather. The outdoor equipment should be installed on paved, well-drained ground, and should be enclosed by a fence to exclude intruders. A small building may be necessary for making repairs, as well as to protect the operator and the switchboard and meter equipment. Climate, location, comparative costs of building and ground, the voltage and method of operation, are factors which largely determine the type of station. The transformers and arresters should be shielded from the hot sun and in winter the electrolytes and cooling water must be prevented from freezing. Painting the arrester tanks white tends to prevent the absorption of heat and cold. Transformer oil thickens and loses its insulating properties under extreme conditions of cold. An outdoor substation can be enlarged or modified with but little expense.



A Ammeter
V Voltmeter
I.W. Indicating Wattmeter
W.H.M. Watthour Meter
R.L. Inverse Time Limit Relays
T.C. Trip Coils

FIG. 74.—Instrument panel for substation.

OPERATION

216. A chief operator should be in absolute control of the system and should have direct telephone connection with every part of it, not only over the company's private line, but over a leased wire as well, as in times of emergency the private telephone line may be crippled. Likewise the chief operator and the substation operators should be in telephone connection with all linemen and patrolmen. In the chief operator's office there should be a dummy board showing the position of every line and switch on the system and whether each switch is opened or closed. No switch should be operated, no generator connected to or disconnected from the system, no water taken from a flume, unless the chief operator is notified and sanctions the operation. All communications should be repeated to the sender in order to prevent any misunderstandings and should be written in the log book to reduce mistakes to a minimum.

217. A complete log should be kept, not only by the chief operator, but by switchboard operators as well, of every transaction, loads carried, shutdowns, causes of trouble, and times of connecting or disconnecting motors and generators on the system.

* Bibliography 105, 106, 107.

A *multi recorder** for lightning and switching phenomena has been devised, whereby the exact time of switching, shut-downs and disturbances are automatically recorded.

218. A periodic line inspection should be maintained over all lines, the frequency of inspection depending on the country and the importance of the lines. A patrolman should be assigned to about 20 miles of line, as one man is then always within 10 miles of each section of the line. The patrolmen may cover the ground on foot, on horse-back, or with a horse and team, depending entirely upon the nature of the right of way, his duties and the distance he must travel. He should be furnished with a telephone test set and sundry tools and materials whereby he is able to make repairs, replace insulators, pins or cross arms. Some companies provide small booths every 2 or 3 miles along the line, where a small stock of insulators, pins, cross arms, wire and clamps is kept, so that material for repairs is always within a comparatively short distance. The pole switches and line sectionalizing switches should be inspected at least once a month, to insure proper alignment of parts and proper operation in times of need. The patrolman should be held responsible for the proper operation of his particular section of the line.

Defective insulators which cannot be detected by inspection may be located by the use of a megger. A sound insulator should have a resistance greater than 1,000 megohms, whereas, if the porcelain or glass is injured or cracked, the resistance will drop below 500 megohms.

219. Line repairs and replacements should be made only after the line is "dead." The lineman or patrolman should notify the chief operator when a particular line or section is desired. The line should then be cleared, not merely through the oil switches, but should be opened by disconnecting switches as well. Before a lineman is allowed to work the line should be well grounded, in order to eliminate the electrostatic charge. If the line closely parallels another, both ends should be grounded to eliminate any dangerous induced potential.

220. Aluminum arresters† should ordinarily be charged at least once a day, under normal conditions of temperature. In hot weather, or if exposed to a higher temperature, they should be charged two or three times a day. After passing a heavy discharge, and undergoing a high temperature rise, they should be charged intermittently while cooling, in order to re-form the film, which dissolves very quickly when the temperature is above normal. The charging current should be about 0.4 amp. The auxiliary or charging gap should be closed three or four times or until the arc ceases to flare. Ammeter jacks are now available for convenience in measuring the charging current. An abnormal charging current may denote trouble within the arrester, such as carbonized oil between the cones. It is desirable to charge the arresters individually, not all at the same time. (Also see Sec. 10, Par. **362**.)

221. Short circuits may open the line when a station is provided with automatic breakers. Where non-automatic switches are used, the operator should decrease the voltage, rather than open the circuit, waiting for the line to clear. If the line does not then clear, the load should be thrown over to a spare line until repairs can be made. Where it is essential that the service shall not be interrupted, resort may be had to such expedients as operating single phase, with a ground return, etc., until the line is again in its normal condition.

TRANSMISSION ECONOMICS

222. Value of continuity of service. No system should be equipped with expensive automatic control devices, duplicate lines, liberal protective equipment, and spare generating plants in order to insure continuity of service, unless the cost of an interruption or a shut-down justifies the expenditure of such capital. The line should be constructed as cheaply as is consistent with the required standard of service, without endangering life or property. Further, a system should not be extended to a distance greater than that at which there is a reasonable prospect of selling sufficient power to pay the development and operating costs of the extension.

223. The type of line must be decided upon after considering the reliability desired, the character of the country, transportation facilities, availability of timber, etc. Although steel construction, as an engineering

* Bibliography 58, 59.

† Bibliography 64, 65.

proposition, is far superior to wood, there are many instances where the low first cost of wood alone makes a transmission project economically feasible.

224. The length of span should be so chosen as to have the line cost a minimum. As the length of span increases, the number of supports and insulators decreases, but the height of the support and the conductor spacing must be increased to allow for the greater sag. The effect of these changes on cost is shown in Fig. 75 (see Bibliography 79). Under these conditions the most economical span for steel towers is about 700 ft. Other factors, such as the decreased cost for pole or tower rights on private right of way, the lesser number of insulators, with the decreased possibility of failure with the longer span, should receive due consideration.

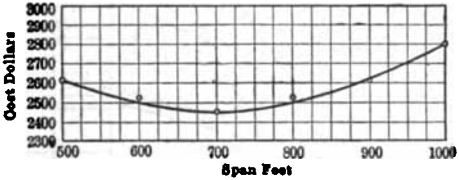


FIG. 75.—Span length and cost.

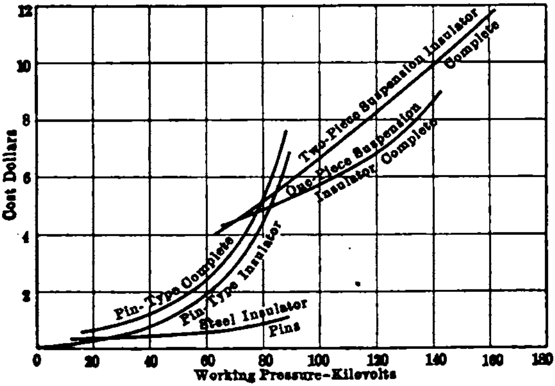


FIG. 76.—Cost of insulators.

225. The choice of conductor material lies between copper and aluminum, except for a few special spans. Although aluminum is about 10 per cent. cheaper than copper for the same conductance, its greater temperature coefficient of expansion and lower tensile strength demand greater sags, hence more expensive structures.

226. The size of conductor is influenced by mechanical considerations and by the amount of energy that it is permissible to waste in transmission. Line regulation may require a larger conductor than is economically demanded. When energy may be generated and sold at a low rate per kw-hr., a much smaller conductor is justified than if the reverse be true.

227. The choice of voltage is determined by the amount of power and the transmission distance. The conductor cross-section varies inversely as the square of the voltage, but the cost of insulators, supporting structures, stations, protective equipment and transformers increases as the voltage is increased. These last three items are independent of the length of the line, so would make a higher voltage on a long line economically desirable, neglecting other considerations. Roughly, a thousand volts per mile seems to be the criterion adopted by engineers. An 80,000-volt line presents no greater operating difficulties than a 30,000-volt line. Surge voltages are, however, dependent upon the current and systems have been designed to operate at a higher voltage than is economically demanded, in order to secure greater freedom from surges.

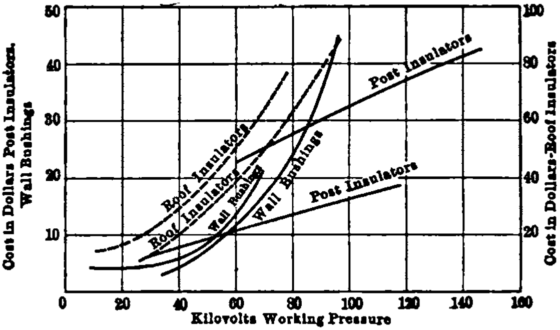


Fig. 77.—Cost of station insulators.

COST DATA†

228. Preliminary and right of way*

	Minimum cost per mile	Maximum cost per mile
Surveying	$5.00	$10.00
Right of way, perpetual easement, 50 poles per mile.		
Along highways $0.50 to $2.00 per pole	25.00	100.00
Along section lines $0.50 to $5.00 per pole	25.00	250.00
Through fields, $2.00 to $10.00 per pole	100.00	500.00
Towers, 10 per mile, $9.00 to $20.00 per tower	90.00	200.00

229. Cost of wooden poles

Length, ft.	Top diam., in.	Approx. butt diam., in.	No. per carload	*Cost Northern Cedar f.o.b., Minneapolis, per pole	*Cost Western Cedar, f.o.b., Spokane, per pole	Cost Chestnut f.o.b., Western Mass., per pole	*Cost Cypress f.o.b., St. Louis, per pole	Cost per pole unloading, cents
30	7	11	55–95	$4.60	$2.50	$3.25	$1.20	5–8
35	7	12	50–70	6.70	3.25	4.00	2.00	8–12
35	8	13	40–60	6.95	3.75	5.25	2.30	8–12
40	7	14	40–55	7.50	3.75	6.25	2.35	12–15
45	7	15	60–70	10.25	4.25	7.75	2.85	15–18
50	7	16	48–55	11.90	5.00	10.50	3.30	22–25
55	7	17	39–42	15.10	5.50	14.00	3.50	25–30
60	7–8	18	30–33	22.50	7.00	20.00	3.90	30–35
65	7–8	19	28–25	29.00	8.50	30.00		35–40

* Bibliography 78.

† Cost data should be used merely as suggestive, the data here given being thout reference to special conditions.

230. Cost of Butt treatment by open-tank method*

Species	Size of pole		Amount creosote applied		Cost of treatment		Total
	Top diam., in.	Length, ft.	Lb. per cu. ft.	Lb. per pole	Preservative	Operation	
Chestnut..........	7	30	.....	25	$0.30	$0.45	$0.75
Northern white cedar	7	30	.....	50	0.60	0.45	1.05
Western yellow pine	8	40	6	37.5	0.90	0.45	1.35
Western yellow pine	7	40	10	62.5	1.45	0.45	1.90
Western red cedar...	7	40	6	39	0.90	0.45	1.35
Lodge pole pin......	7	35	.....	35	0.80	0.45	1.25

231. Unit labor costs

	Cost per mile	
	Minimum	Maximum
Cost of hauling, 10-20 cents per pole per mile of line per mile hauled	$5.00	$10.00
Cost of framing and attaching fittings $0.25 to $1.00 per pole	12.50	50.00
Cost of digging holes $0.50 to $2.50 each........	25.00	125.00
Cost of rock holes, $2.00 to $4.50 each	100.00	225.00
Cost of raising and setting with pikes. $0.35 to $1.00 per pole	17.50	50.00
Cost of raising and setting with gin wagon $0.35 to $0.60 per pole	17.50	30.00

232. Cost of long-leaf, yellow-pine cross arms, middle west†

3.25 in. × 4.25 in. per lin. ft.	$0.0375
4 in. × 4 in. per lin. ft.	0.055
4 in. × 5 in. per lin. ft.	0.075
4 in × 6 in. per lin. ft.	0.0825
4.5 in. × 5.75 in. per lin. ft.	0.089
5 in. × 7 in. per lin. ft.	0.12

Fir 5 to 15 per cent. higher.
Cost of steel cross arms 2.5-3 cents per lb.

233. Approximate prices each of high-voltage insulator pins‡

Insulator voltage	Wood pins paraffined	Steel pins galvanized	Iron pins with separable thimble; galvd.	Steel pins with porcelain base; bolt galvd.
80,000	$0.65	$0.85	$0.80	$0.85
66,000	0.50	0.65	0.75	0.75
60,000	0.40	0.60	0.68	0.65
50,000	0.35	0.60	0.68	0.65
45,000	0.35	0.60	0.68	0.65
40,000	0.30	0.50	0.48	0.22

Wood pins with steel bolt not used for these high voltages.
* Steel pipe, forged.

* Abeles & Taussig, Spokane, Wash.
† Bibliography 78.
‡ Locke Insulator Mfg. Co.

234. Tripartite steel poles. (Fig. 78)

Length overall	Type of arming	U-bar section	Weight complete	Depth of set in concrete	Average cost of setting	Cost comp. at Franklin, Pa.
SINGLE CIRCUIT—NO GROUND WIRE Design used to carry three No. 4 A.W.G. H. D. copper conductors in 300-ft. spans						
30 ft.	Fig. A	No. 2	447 lb.	4 ft.	$5.00	$12.77
35 ft.	Fig. A	No. 2	508 lb.	4 ft.	5.25	14.07
40 ft.	Fig. A	No. 2	595 lb.	4 ft.	5.50	16.90
45 ft.	Fig. A	No. 2	675 lb.	4½ ft.	6.00	19.32
SINGLE CIRCUIT—WITH GROUND WIRE Design used to carry a ¼-in. steel strand ground wire three No. 4 A.W.G. H. D. copper conductors and a No. 10 steel phone circuit in 300-ft. spans						
32 ft.	Fig. B	No. 2	553 lb.	4 ft.	$5.25	$16.58
37 ft.	Fig. B	No. 2	631 lb.	4½ ft.	5.50	18.01
42 ft.	Fig. B	No. 2	714 lb.	5 ft.	5.75	21.65
47 ft.	Fig. B	No. 4	886 lb.	5½ ft.	6.25	24.16
SINGLE CIRCUIT—NO GROUND WIRE Design used to carry three No. 1 A.W.G. equivalent copper strand and 2 phone wires in 350-ft. spans						
41 ft.	Fig. C	No. 6	1,197 lb.	4 ft.	$7.10	$32.08
46 ft.	Fig. C	No. 6	1,372 lb.	4½ ft.	8.40	37.28
51 ft.	Fig. C	No. 6	1,548 lb.	5 ft.	10.95	42.68
SINGLE CIRCUIT—WITH GROUND WIRE Design used to carry a ⅜-in. steel strand ground wire three No. 0 conductors and a phone circuit in 350-ft. spans						
54 ft.	Fig. D	No. 6	1,757 lb.	5½ ft.	$13.97	$50.41
59 ft.	Fig. D	No. 6	2,012 lb.	6 ft.	16.00	58.71
65 ft.	Fig. D	No. 6	2,235 lb.	6½ ft.	18.20	65.86
DOUBLE CIRCUIT—WITH GROUND WIRE Design used to carry a ¼-in. steel strand ground wire and six No. 4 A.W.G. copper conductors in 300-ft. spans						
35 ft.	Fig. E	No. 4	853 lb.	4 ft.	$6.00	$24.28
40 ft.	Fig. E	No. 4	977 lb.	4½ ft.	7.05	28.41
45 ft.	Fig. E	No. 6	1,327 lb.	4¾ ft.	9.15	33.15
DOUBLE CIRCUIT—WITH GROUND WIRE Design used to carry a ⅜-in. steel strand ground wire, six No. 0 A.W.G. copper-clad conductors and a phone circuit in 440-ft. spans						
40 ft.	Fig. F	No. 6	1,800 lb.	4 ft.	$8.70	$50.64
50 ft.	Fig. F	No. 6	2,162 lb.	5 ft.	11.70	61.51
60 ft.	Fig. F	No. 6	2,529 lb.	7 ft.	16.85	72.33

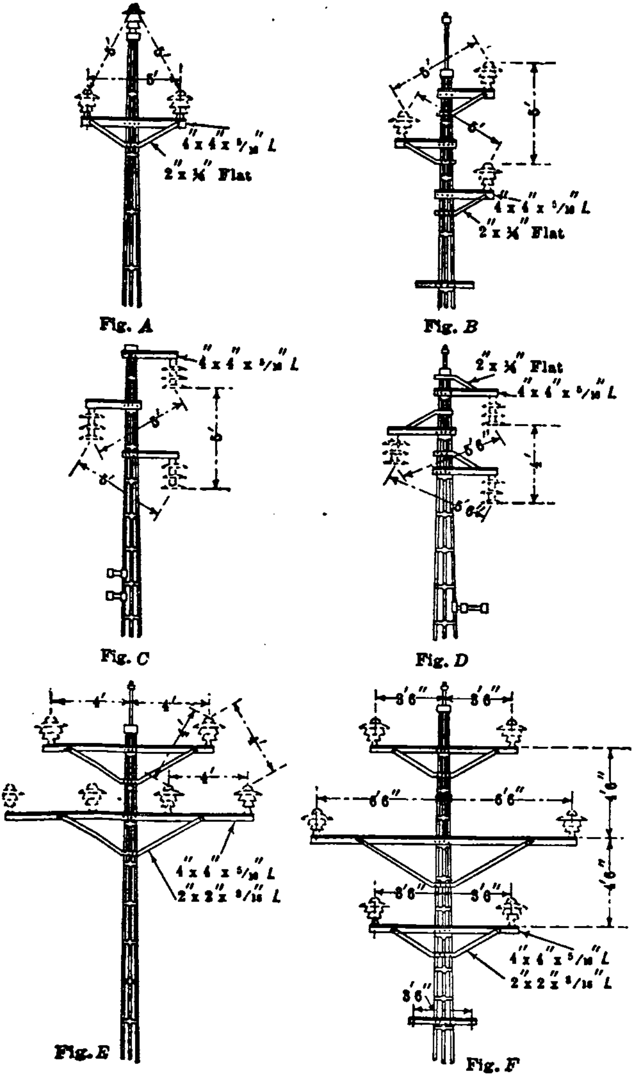


FIG. 78.—Tripartite pole.

235. Cost of steel towers

3.25 to 4.25 cents per lb. galvanized. 0.5 to 1 cent cheaper, painted

Height, ft.	Weight, lb.	Number per mile	Cost each at 4 cents, lb. Minimum	Cost each at 4 cents, lb. Maximum	Cost per mile Minimum	Cost per mile Maximum
Single circuit						
40	1600–2500	12	$64.00	$100.00	$768.00	$1200.00
50	1800–3000	9	72.00	120.00	648.00	1080.00
60	2200–3500	7	88.00	140.00	616.00	980.00
Double circuit						
40	2200–3500	12	$88.00	$140.00	$1056.00	$1680.00
50	2600–4200	9	104.00	168.00	936.00	1512.00
60	3200–5000	7.	128.00	200.00	1152.00	1800.00

236. Cost of placing steel towers in position, 8 and 12 towers per mile

	Per mile Minimum	Per mile Maximum
Labor cost of distribution at $2.00 to $2.50 each..	$16.00	$30.00
Digging holes, earth setting at $4.00 to $6.00 each..	32.00	75.00
Digging holes, and concrete foundation at $10.00 to $20.00 each.	80.00	250.00
Digging holes and concrete foundation anchor towers (1 per mile)	30.00	90.00
Assembling at $7.50 to $25.00 each..............	60.00	300.00
Raising at $3.00 to $10.00 each.................	24.00	120.00
Total cost per mile of placing towers in position — earth setting	$162.00	$615.00
Total cost per mile of placing towers in position — concrete foundation	210.00	795.00

237. Semi-flexible steel towers vs. wooden poles*

Cost of transmission line per mile, wooden poles

Specifications:

33,000 volts working pressure, No. 2 B. & S. copper wire
120-ft. pole spacing, one pole line
44 poles per mile
Pin type insulators
"Bo-Arrow" cross arms
35-ft. poles, 7-in. top diameter
⅜-in. ground wire (standard galvanized wire)

Material, labor, etc.

44	Poles, 35-ft., 7-in. top diameter @ $8. f.o.b., Ohio	$ 352.00
44	Cross arms "Bo-Arrow" galvanized complete @ $3.79	166.76
44	Telephone brackets @ 10 cents	4.40
	Bog shoes @ 15 cents per pole, average	6.60
	Guying material @ 50 cents per pole	22.00
	Pole steps and hardware @ 75 cents	33.00
	Framing and trimming of poles @ 50 cents	22.00
	Creosoting of poles @ 20 cents	8.80
	Cartage @ 70 cents per pole	30.80
	Hauling (railway) @ $1.20 per pole	52.80
	Digging of holes @ 1.20 per pole	52.80
	Setting of poles @ $1.80 per pole	79.20
3	Miles hard drawn copper strand No. 2 B. & S. @ $181.20 per mile	543.60
1	Mile ⅜-in. Siemens-Martin steel strand wire	54.00
2	Miles Tel. wire No. 10 B. & S. copper clad 30 per cent. @ $25.00 per mile	50.00
44	Ground wire connections @ 35 cents per pole	15.40
132	Porcelain petticoat insulators @ 50 cents	66.00
	Tie wire	4.50
88	Telephone insulators @ 2 cents	1.76
	Stringing 3 miles No. 2 B. & S. strand @ $15.00	45.00
	Stringing 2 miles No. 10 copper clad wire @ $10.00	20.00
	Stringing ground wire	18.00
	Soldering materials	5.00
	Miscellaneous material	10.00
	Damage, expense to property of owners	5.00
	Clearing of branches and trees	4.50
	Tools	3.00
	Camp expenses	18.00
	Materials deposited along the lines for repairs	19.20
	Wasted materials	18.00
	Contingencies and incidentals, 7 per cent	121.25
	Supervision and inspection, 5 per cent	92.67
	Total construction cost per mile with wooden poles exclusive of right of way	$1,946.04
	Right of way @ $8.00 per pole	352.00
	Total cost including right of way	$2,298.04

*From *Lefax*, by Frank G. Nagele.

Cost of transmission line per mile, semi-flexible steel structures.

Specifications:

33,000 volts working pressure, No. 2 B. & S. copper wire
400-ft. pole spacing, one pole line
13 poles per mile
3-disc suspension type insulators
$\frac{7}{16}$-in. ground wire (standard galvanized wire)

Material, labor, etc.

13	Towers (steel frames) 43-ft. high with cross arms, telephone clips and pole steps, complete, f.o.b. Central Ohio @ $53.00 per tower	$ 689.00
	Cartage @ 80 cents per frame	10.40
	Hauling (railway) @ $1.25 per frame	16.25
	Digging of holes @ $1.50 per frame	19.50
	Erecting of frames, @ $2.00	26.00
	Concrete foundations for curve frames and frames in swampy ground	40.00
	Guying of poles	30.00
	Crushed stone for regular foundations	6.00
3	Miles No. 2 B. & S. copper wire @ $181.20	543.60
2	Miles No. 10 B. & S. copper clad @ $25.00	50.00
1	Mile $\frac{7}{16}$-in. S.-M. steel strand wire	75.00
39	Suspension insulators, porcelain 3-disc unit sets including suspension hooks and wire clamps @ $3.50	136.50
26	Telephone insulators and pins @ 20 cents	5.20
	Stringing 3 miles No. 2 B. & S. @ $18.00	54.00
	Stringing 2 miles No. 10 B. & S. @ $12.00	24.00
	Stringing ground wire	20.00
	Miscellaneous material	10.00
	Painting of structures @ $1.60 each	20.80
	Soldering material	5.00
	Clearing and trimming of trees	4.50
	Damage, expense to property owners	20.00
	Camp expenses	16.00
	Wasted materials	5.00
	Contingencies and incidentals, 6 per cent	100.61
	Supervision and inspection, 5 per cent	96.82
	Total construction cost per mile with steel towers exclusive of right of way	$2,033.18
	Right of way @ $15.00 per frame	195.00
	Total cost including right of way	$2,228.18

238. Cost of galvanized steel wire (*Roebling*)

(*7-strand*)

Dollars per 1,000 ft.

Diam., in.	Single galvanized	Double galvanized	*Siemens-Martin	*High strength	*Extra high strength
$\frac{5}{8}$	....	....	$32.60	$46.90	$65.60
$\frac{1}{2}$	$18.00	$22.50	21.00	29.60	41.25
$\frac{7}{16}$	15.00	18.75	17.25	25.90	34.50
$\frac{3}{8}$	11.00	13.75	13.50	20.25	26.60
$\frac{5}{16}$	9.00	11.25	11.10	15.75	20.25
$\frac{9}{32}$	....	....	8.25	13.10	15.75
$\frac{1}{4}$	7.00	8.75	7.50	11.25	14.25
$\frac{7}{32}$	6.00	7.50	....	....	....
$\frac{3}{16}$	5.00	6.25	6.38	9.75	12.00
$\frac{5}{32}$	4.60	5.75	....	....	....
$\frac{1}{8}$	4.00	5.00	4.13	6.00	7.88
$\frac{3}{32}$	3.20	4.00	....	....	....

* Double galvanized.

239. Cost of substations*

Kw. capacity		Water cooled				
†Oil cooled	Water cooled	Cost of building		Cost of equipment		Total cost per kw.
		Total	Per kw.	Total	Per kw.	
3,650	4,325	$12,490	$2.89	$29,670	$6.87	$9.76
2,400	3,075	9,152	2.97	30,534	9.92	12.89
1,500	1,875	10,979	5.85	23,774	12.65	18.50
1,500	1,875	7,236	3.86	19,023	10.15	14.01
1,500	1,875	7,344	3.92	14,732	7.87	11.79

240. Comparison costs of indoor and outdoor types of substation‡

Transformer substation			600-volt motor-generator substation		
2,000 kva., 25,000-volt, 60 cycles			3,000 kva., 22,000–3,000-volt, transformers 25 cycles		
	Indoor	Outdoor		Indoor	Outdoor
Building	$ 5,400	$ 1,020	Building	$ 21,835	$ 7,480
Transformers	7,200	7,800	Transformers	15,000	16,000
Switchboard	2,500	2,625	Motor-generators	48,000	48,000
			Exciters	4,500	4,500
Total	$15,100	$11,445	Switchboard	20,000	20,200
				$109,335	$96,180
Per kva	$7.55	$5.72	Per kva	$36.45	$32.00

241. Cost of cables per 1,000 ft.

2/0 stranded, 3-conductor, lead-covered						
	Underground			Submarine		
Volts	Insulation			Insulation		
	Rubber	Cambric	Paper	Rubber	Cambric	Paper
6,600	$1,040	$ 700	$ 620	$1,110	$1,180	$ 920
13,000	1,840	1,150	780	1,810	1,490	1,220
25,000	2,210	1,520	1,090	2,740	2,180	1,690

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SECTION 12

DISTRIBUTION SYSTEMS

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CONTENTS

(Numbers refer to Paragraphs)

SECTION 12

DISTRIBUTION SYSTEMS

CLASSIFICATION OF SYSTEMS

1. Distributing circuits may be classified as to the nature of the current—direct or alternating; as to method of connection—series or multiple; and further as to phase, number of conductors, voltage and frequency. The following is a statement of the field of application of the principal kinds of distributing circuits.

2. Direct current is best adapted to use: (a) where the distances are small, (b) where there is variable-speed machinery, and (c) where there is an area of congested load for which storage-battery reserve is necessary to insure continuous service.

3. Alternating current is best adapted to use where the distances are greater and the density of the load not sufficient to justify low-tension distribution without transformation from a higher voltage.

4. The use of series systems is limited almost entirely to street and other lighting which is all in use at the same time. These systems are inherently high-tension in character and are, therefore, not suitable for general purposes. They are operated by direct current or alternating current at a constant current of 5 amp. to 10 amp. in American practice. In Europe there are several direct-current series power transmission systems in operation utilizing a series of motor generators as the converting medium (Sec. 11).

5. Multiple or parallel systems are used for general purposes almost exclusively. When **direct current** is used a nominal voltage of 110, 220, or 550 is employed, the last named being used only for power distribution. The Edison three-wire system at 220 and 110 volts is common in large installations.

When **alternating current** is used, the primary mains are operated at a nominal voltage of 2,200. Single-phase, two-phase, and three-phase circuits are in general use, with frequencies of 25 or 60 cycles. In general, single-phase distribution is used for lighting and small power service, and two-phase or three-phase distribution is used for larger power loads.

6. Frequency. Twenty-five cycles is standard where most of the energy is converted to direct current for lighting and railway service or other purposes. Sixty cycles is standard where the energy is delivered for retail consumption as alternating current. Other frequencies such as 30, 33, 40, 50 and 133 cycles are in use in some of the older installations in America and in Europe. Sixty-two and one-half cycles is used in some modern systems where the supply is derived from a 25-cycle system, this frequency giving a better design of frequency-changer apparatus.

GENERAL APPLICATIONS

7. The single-phase system, requiring only the simplest form of electric circuit, has the advantage of a minimum number of conductors, and hence the minimum first cost for distributing mains. The feeders, however, require 33 per cent. more copper than equivalent three-phase feeders. Single-phase motors are more complicated and cost more than polyphase motors, and usually produce more disturbance of pressure, in starting, than three-phase machines. The distribution of energy by single-phase circuits is, therefore, usually limited to motor units of less than 10 h.p., although motors up to 35 h.p. are used in single-phase systems with good success. This system is used very generally for lighting circuits, in both single-phase and polyphase systems.

8. Two-phase systems. Two-phase distribution is effected by the use of two single-phase circuits in a quarter-phase relation, making a **four-wire** system; or by means of a **three-wire** system in which one conductor of each phase is common.

The four-wire system is substantially the same as a single-phase system, except that two-phase motors may be used. The principal advantages of two-phase systems are that there are only two phases to keep balanced and only two transformers are required to supply polyphase energy to motors.

In a three-wire, two-phase system, the current in the common or neutral conductor is 1.414 times the current in the outer conductors, with balanced load. When all conductors are the same size, the copper required is 75 per cent. of that needed for a four-wire system. When the neutral is 40 per cent. larger than the outer conductors, the amount of copper required is 85 per cent. of that needed for a single-phase system or a four-wire, two-phase system. In the primary mains, which are all the same size, the three-wire two-phase system is as economical of copper as the three-wire, three-phase system. The line drop in this system is such that even with balanced load the drop in the two phases is not the same, making voltage regulation difficult, unless line-drop compensators are employed. The three-wire circuit cannot be used where the mid-points of the quarter-phase generator windings are tied together, as is the case in some machines.

9. Three-phase, three-wire system. This system is commonly employed for general distribution, since it is readily derived from a three-phase transmission system; it is also well suited to power distribution, and requires but 75 per cent. as much copper in the feeder-system as an equivalent single-phase system. The three-wire distributing mains are usually carried only where motor service is required, the lighting service being taken on single-phase branches from the three-phase main. Users of small motors, up to about 5 h.p., are generally supplied from a single phase; while the larger motors, up to 30 h.p. or 40 h.p., are supplied from two phases with the open-delta connection.

10. Three-phase four-wire system. In primary distribution this system is usually operated at 3,800 volts between phase wires and 2,200 volts between any phase wire and neutral. This gives the advantage of 3,800-volt distribution in the feeder system and permits the supply of energy over a radius about twice as great as with 2,200-volt systems, with the same regulation. Standard 2,200-volt transformers and other accessories are used, and the lighting branches are single-phase. The unbalanced load is carried by the neutral wire, and with the use of line-drop apparatus, good pressure regulation is possible with any proportion of unbalanced load.

The four-wire distributing mains are carried only where there are motors or large loads to be served, and but three wires are needed for installations of less than 30 to 40 h.p., which may be served by two transformers connected in open delta. The wide range permissible has led to the adoption of this system in many of the larger cities of the United States. It is also well suited to the supply of suburban districts and rural communities, where double-voltage, 4,400–7,600 volts may be used to supply a group of towns and villages, the pressure being regulated independently on each phase at the source of supply.

11. Direct-current low-tension systems find their principal field of application in important parts of cities where the protection of the storage battery reserve is of great value, and where there are many elevators, printing presses and other variable-speed machines, and where space for transformers would be difficult to secure in public thoroughfares. The principal limitations of direct-current distribution are the small radius of distribution, and the necessity for rotating machinery to transform the energy from an alternating-current source of supply. This requires a greater number of substations to cover a given area, and these are more expensive both in first cost and operation than alternating-current substations.

12. Two-wire, 500-volt, direct-current systems are operated in some cities where they were originated to supplement single-phase systems in the early period of development. The duplication of mains necessitated by a separate power-service results in an excessive investment and 500-volt systems are being eliminated wherever possible.

13. Combination systems. Various combinations of alternating-current, and direct-current, or 25-cycle and 60-cycle systems, are necessary in the larger cities. The direct-current supply is usually derived through synchronous converters or motor-generators from an alternating-current generating system. The 60-cycle supply is sometimes derived from a 25-cycle system by the use of synchronous motor-generators called frequency changers. In some cases both 25-cycle and 60-cycle generating systems are maintained, and the frequency changers are used as a connecting link between the two systems.

TYPES OF CIRCUITS

14. Series circuits. Two general types of arrangement are employed in laying out series circuits, the "open loop," and the "parallel loop." In the **open-loop** circuit (Fig. 1) the lamps are connected by following the shortest available route, without reference to the separation from the return conductor. This permits a minimum length of circuit, but makes it difficult to test for a break, or open circuit in the line. In alternating-current circuits it also tends to increase interference with telephone systems.

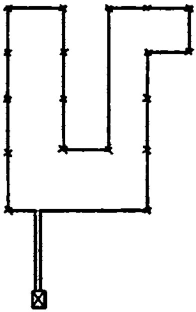


Fig. 1.—Open-loop series circuit.

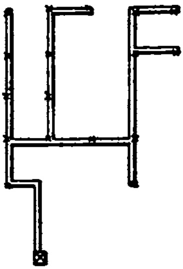


Fig 2.—Parallel-loop series circuit.

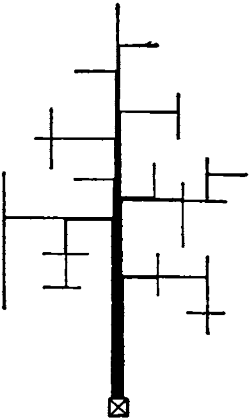


Fig. 3.—Tree-system of distribution.

The **parallel-loop** circuit (Fig. 2) is laid out in such a way as to be near the return conductor at many points. This affords frequent opportunity for test and minimizes inductive disturbances, but usually requires a greater mileage of conductor than the open-loop circuit. A combination of parallel loops with small open loops may often be used to advantage.

15. Multiple circuits. The arrangement of multiple circuits may take any one of a number of forms as conditions require. The simplest and least expensive circuit is that commonly known as the "tree" circuit (Fig. 3); it is thus named because it is branched off in various ways, and has its heaviest branches nearest the source of supply. The tree system is not adapted to supplying a uniform distribution pressure and is only suited to short branches and those branches in which the current values are small as compared with the conductor capacity.

16. A system of feeders and mains is the arrangement most commonly employed in city distribution for lighting and power-service. This takes the form of a network in low-tension systems (Fig. 4), and an isolated or dead-ended main system in primary distribution (Fig. 5). In the low-tension network the system of mains is designed to be of such capacity as to carry the load units which are tapped off from house to house, and the feeders are provided in such number, of such size and at such points as will maintain an even distribution of pressure, within a few per cent., over the entire system of mains.

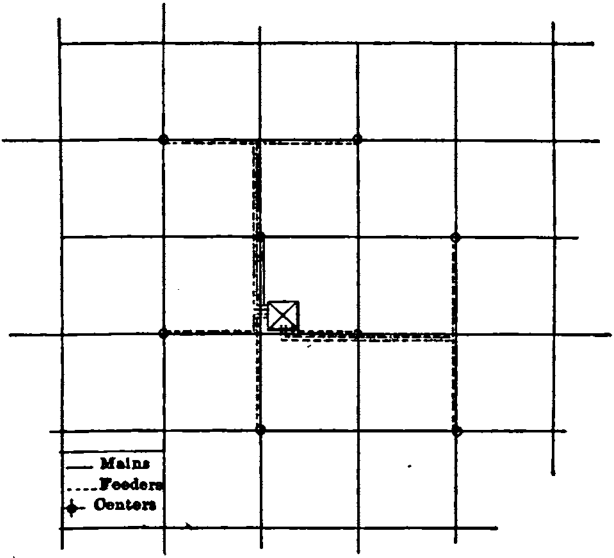


FIG. 4.—Feeders and mains in a direct-current network.

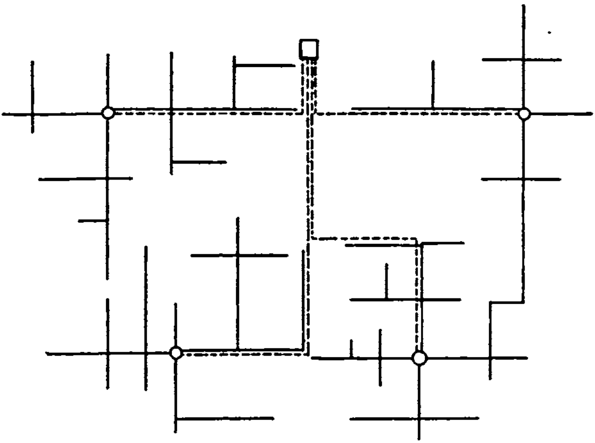


FIG. 5.—Feeders and mains in alternating-current distribution.

17. Primary-main systems are usually supplied by a feeder at a **centre of distribution,** this point being a junction from which the load is distributed in four or more directions. These mains are not interconnected, because it is not practicable to provide fuse protection, and in most cases not much is to be gained by such connection.

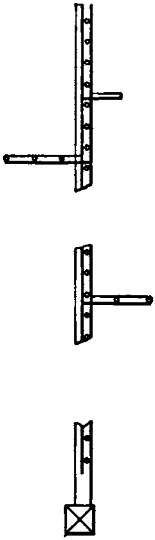


Fig. 6.—Loop feeder.

18. The loop feeder (Fig. 6), is used where the load is distributed in a long continuous line with few side branches. This arrangement distributes the pressure more evenly along the line than is possible with other types of circuit.

19. Ring feeders. Where it is desired to provide emergency supply to units of load in one general direction from the point of supply, the most economical means often consists of the type of feeder known as a ring circuit (Fig. 7). The capacity of the ring must be sufficient to carry the combined load of all the units, in case either of the links adjacent to the point of supply should fail.

20. Urban transmission systems. In cities having too large an area to permit an economical distribution of electrical energy from a single point, it becomes necessary to transmit energy from a generating station (located at a point convenient to coal and water supply) to substations centrally located with reference to the districts served. This transmission system, in the larger cities, becomes practically a bulk-supply distribution system. The same condition exists where hydroelectric energy is brought from a distance for distribution in a large city. These urban transmission systems are universally three-phase; where two-phase energy is generated, it is converted to three-phase energy for transmission.

21. Pressures and frequencies in urban transmission. The pressures in common use are 6,600, 9,000, 12,000, and 13,200 volts, and the standard frequencies are 25 and 60 cycles. The use of 25 cycles is preferable where the principal portion of the energy is converted to direct current for lighting and railway service, because the synchronous converter is more economical in operation and in first cost, at 25 cycles, than at 60 cycles. The use of 25-cycle energy for general lighting purposes is not satisfactory, and the transformers, motors, etc., are more expensive; hence it is necessary to convert the retail supply of alternating current to 60 cycles, to put it into form which is readily saleable.

The use of 60 cycles is desirable where the major part of the energy is to be distributed as alternating current. This permits the use of transformer substations, instead of frequency-changing motor-generators which are necessary for securing 60-cycle energy from a 25-cycle supply.

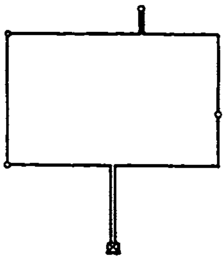


Fig. 7.—Ring feeder.

22. Underground urban transmission. Urban transmission lines are necessarily placed underground to a large extent. This involves the use of paper-insulated lead-sheathed cables, which are made up with the three conductors of the circuit under one sheath. With standard 3.5-in. ducts, the largest size of cable which can be drawn into the duct is about 3 in. outside diameter, and this limits the maximum size of the conductor which can be used with a given thickness of insulation. At pressures of 6,600 volts, 400,000-cir. mil sector-shaped conductors are the largest in use. At 9,000 to 13,000 volts, about 300,000 cir. mils is the maximum size. This fixes the maximum load which can be carried continuously on such cables at from 4,500 to 6,000 kv-a.

In the larger cities where certain substations distribute loads of 8,000 to 15,000 kw., several cables are required to supply each substation, and it is desirable to have cables of the maximum size.

23. Reserve cables. A reserve cable must be provided for use in case of the failure of any of the cables which normally carry the load. This reserve may be secured by having a spare cable direct from the power-station, or by means of a **tie line** from a neighboring substation, or by the use of a ring system. When substation loads are small as compared with the cable capacity, the ring system is often found to be the most economical (Fig. 7). After the combined loads of the substations exceed the capacity of one side of the ring, additional capacity may be secured by adding **radial** feeders (Fig. 8). This is the situation in the larger cities where substation loads run from 2,000 kw. upward.

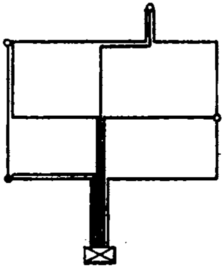


FIG. 8.—Radial feeders.

DESIGN OF CIRCUITS

24. General. The function of a conductor being to convey electrical energy from the source of supply to the consuming device, it must be of such size that it will not absorb too great a percentage of the energy or become overheated. The problem of designing a circuit is, therefore, one of determining what size of conductor should be used to limit the loss of voltage to a specified amount, when distance and current-strength are known, and also determining whether the size needed for the specified voltage drop is sufficient to carry the current safely.

25. Direct-current circuits. In direct-current circuits the current and the resistance are the only factors affecting the drop in voltage. The resistance of a mil-foot of pure annealed copper at 68 deg. fahr. being 10.4 ohms, that of a conductor D ft. long and M cir. mils in area is $R=(D\times 10.4)/M$. The drop with current I, therefore, is

$$E=IR=\frac{I\times D\times 10.4}{M}\text{ (volts) or } M=\frac{I\times D\times 10.4}{E}\quad\text{(cir. mils)}\qquad(1)$$

If both conductors are of the same size the total drop is twice the drop in one conductor, as found by Eq. 1; if they are not of the same size, the drops in the different sizes must be computed separately and added together.

Example. A two-wire circuit is to carry a load of 100 amp. a distance of 300 ft. with a drop of 5 volts. What size of conductor must be used?

$$M=\frac{2D\times I\times 10.4}{E}=\frac{2\times 300\times 100\times 10.4}{5}=124{,}800\text{ cir. mils.}$$

The nearest size is No. 2/0, A.W.G., which should be used.

26. The calculation of direct-current drop at any load is readily determined, where the size of the conductor is already fixed, by the use of the formula, $E=2IDR/1{,}000$, in which R is the resistance per 1,000 ft. of conductor, the formula gives the total drop in the two wires of the circuit.

Example. A circuit of 4/0 cable, 500 ft. in length, is to carry a load of 190 amp.; what will be the line drop? The resistance of No. 4/0 conductor is 0.049 ohm per 1,000 ft. (Par. **31**); $D=500$ ft. The drop is

$$E=\frac{2\times 190\times 500\times 0.049}{1{,}000}=9.3\text{ volts.}$$

27. Three-wire direct-current circuits. In making calculations for a **three-wire Edison circuit,** separate computations are made for each conductor if the load is appreciably unbalanced.

Example. A circuit having two No. 4/0 A. W. G. outer wires and a No. 0 neutral, 1,000 ft. long, carries a load of 150 amp. on the positive side and 110 amp. on the negative side; what is the drop on each side of the circuit?

The resistance of 1,000 ft. of No. 4/0 = 0.049 ohm, and that of No. 0 = 0.098 ohm, per 1,000 ft. (Par. 31).

$E = IR = 150 \times 0.049 = 7.35$ volts drop on positive wire;
$E = IR = 110 \times 0.049 = 5.4$ volts drop on negative wire;
$E = IR = 40 \times 0.098 = 3.92$ volts drop on neutral wire.

The drop in the neutral wire is added to the drop on the "heavy" side and subtracted from that on the "lighter" side, making the total drop $7.35 + 3.92 = 11.27$ volts on the "heavy" side, and $5.4 - 3.92 = 1.48$ volts on the other side.

28. Alternating-current circuits. In an alternating-current circuit, voltage drop is caused by the combined effect of (a) resistance, (b) inductance, and (c) capacity. **The component of drop due to resistance** is governed by the same laws which govern direct-current circuits, and is in phase with the current. **The component due to inductance** (reactance drop) is a counter e.m.f. set up by the magnetic field as it reverses with each alternation; this back e.m.f. is a quarter cycle behind the current wave, and the component of impressed e.m.f. required to overcome it is a quarter cycle ahead of the current. The resistance drop and the reactance drop may be represented, therefore, by two sides of a right triangle.

The reactance of a circuit is ωL, where $\omega = 2\pi n$ and n = frequency in cycles per second; L = inductance in henrys. The inductance is a measure of the number of lines of force per ampere linked with the circuit; it increases, therefore, as the separation of the conductors of the circuit is increased, or with the introduction of iron into the magnetic field, since either of these increases the number of lines of force linked with the circuit.

29. Table of wire resistance and reactance. The table in Par. 31 gives the reactance drop in volts per ampere, for 1,000 ft. of conductor, for the distances of separation and sizes of wire commonly used in transmission and distribution work. It should be noted that the *reactance increases as the separation is increased.*

30. Example of calculation of resistance and reactance drops. A single-phase circuit 10,000 ft. long operates at 60 cycles and carries a load of 100 amp., with No. 0 wires 12 in. apart. What are the values of the inductive and the ohmic components of drop, and the impedance drop? The reactance per 1,000 ft., per amp. per wire, for No. 0 wires 12 in. apart is $X = 0.1043$. The resistance is 0.098 ohm. per 1,000 ft. The inductive component of the impedance of the circuit is

$X = 2D \times I \times 0.1043/1{,}000 = 2 \times 10{,}000 \times 100 \times 0.1043/1{,}000 = 208.6$ volts.

The ohmic component is $R = 2 \times 10{,}000 \times 100 \times 0.0981/1{,}000 = 196.2$ volts.

The impedance drop in the circuit is

$$\sqrt{(209)^2 + (196)^2} = 286 \text{ volts.}$$

The length of the line OA in Fig. 9 is proportional to the resistance component, that of AB represents the inductive component and OB the resultant of the two. If the circuit consisted of two No. 6 wires the resistance component would be 788 volts, the inductive component 241 volts, and the impedance drop would be

$$\sqrt{(788)^2 + (241)^2} = 824 \text{ volts.}$$

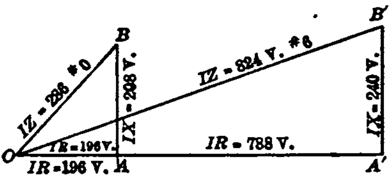


Fig. 9.—Resolution of ohmic drop and inductive drop to obtain total or impedance drop.

The e.m.f. diagram for the latter case, in Fig. 9, is $OA'B'$. It is apparent that the ratio of resistance to inductance decreases as the size of wire is increased, so that increasing the size for the purpose of reducing the pressure-drop becomes less effective in the larger sizes. It is preferable to install an additional circuit if facilities will permit.

31. Table of Resistance Drop and Reactance Drop in Volts per Amp., per 1,000 ft., per Wire, at 60 Cycles

Size in cir. mils or A.W.G.	Lb. per 1,000 ft. bare.	Lb. per 1,000 ft. T. B. weatherproof.	Resistance, ohms per 1,000 ft. at 68 deg. fahr.	Volts drop per amp. per 1,000 ft. of (one) wire at 60 cycles										
				Distance between centres										
				½ in.	1 in.	2 in.	3 in.	6 in.	12 in.	18 in.	24 in.	36 in.	48 in.	60 in.
1,000,000	3,050	3,610	0.01035	......	......	......	......	0.063	0.0784	0.0877	0.0943	0.1036	0.1102	0.1153
500,000	1,525	1,870	0.0207	......	......	......	......	0.071	0.0864	0.0957	0.1023	0.1116	0.1182	0.1233
350,000	1,068	1,320	0.0296	......	......	......	......	0.0746	0.0905	0.0998	0.1064	0.1157	0.1223	0.1274
0000	640.5	754	0.0489	0.0328	0.0394	0.0553	0.0646	0.0805	0.0964	0.1057	0.1123	0.1216	0.1282	0.1333
000	508	614	0.0617	0.0355	0.0421	0.058	0.067	0.0832	0.0991	0.1084	0.1150	0.1242	0.1308	0.1360
00	402.8	486	0.0778	0.0381	0.0447	0.060	0.070	0.0858	0.1017	0.1110	0.1176	0.1269	0.1335	0.1386
0	319.5	388	0.0981	0.0408	0.0474	0.0633	0.0726	0.0885	0.1043	0.1136	0.1202	0.1295	0.1361	0.1412
1	253.3	312	0.1237	0.0435	0.0501	0.0659	0.0752	0.0911	0.1070	0.1163	0.1229	0.1322	0.1388	0.1439
2	200.9	254	0.156	0.0461	0.0527	0.0686	0.0779	0.0938	0.1097	0.1190	0.1256	0.1348	0.1414	0.1466
4	126.4	163	0.248	0.0514	0.0580	0.0739	0.0832	0.0991	0.1150	0.1243	0.1309	0.1402	0.1468	0.1519
6	79.46	112	0.394	0.0567	0.0633	0.0792	0.0885	0.1044	0.1203	0.1296	0.1362	0.1455	0.1521	0.1572
8	49.98	73.8	0.627	0.0621	0.0687	0.0845	0.0938	0.1097	0.1256	0.1349	0.1415	0.1508	0.1574	0.1625
10	31.43	50.2	0.997	0.0674	0.074	0.0898	0.0991	0.1151	0.1309	0.1402	0.1468	0.1561	0.1627	0.1678

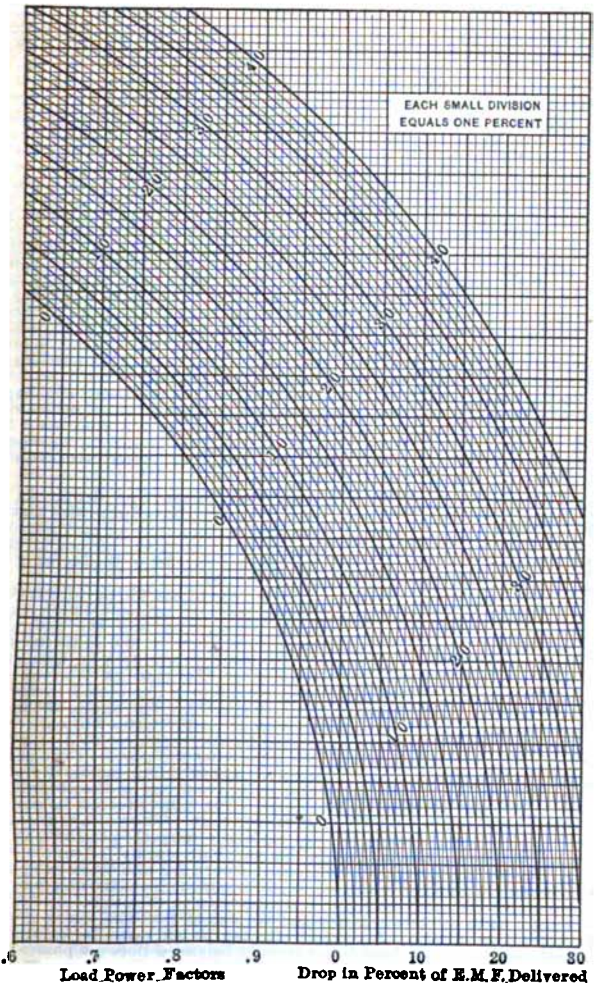


FIG. 11.—Mershon chart for calculating drop in alternating-current lines.

The net line drop is, therefore, 127 volts or 5.8 per cent. of the receiver voltage.

If a lighting load of 100 amp. at 100 per cent. power-factor were being carried, the inductance factor ER would be zero and ON would be

$$\sqrt{(2,288)^2+(94)^2}=2,290 \text{ volts.}$$

At 100 per cent. power-factor, therefore, the drop is 90 volts.

35. Mershon diagram. R. D. Mershon has devised a diagram by means of which **line-drop calculations,** which do not involve charging-current effects, may be made with facility and yet with sufficient accuracy for all ordinary purposes. This diagram,* Fig. 11, is based on the principles of the diagram of Fig. 10. The concentric circles are described about a centre, to the left of the diagram, which corresponds to the point O in Fig. 10. The divisions are made in percentages so that the scale may be applicable to any voltage. The use of the chart may be illustrated by the example of the circuit of No. 0 wire carrying a load of 100 amp. at a distance of 4,500 ft. (Par. 34). The ohmic drop is 88 volts, or 4 per cent., while the inductive drop is 4.3 per cent. The power-factor is 0.8. The base of the 0.8 power-factor line in Fig. 11 is the point R in Fig. 10. The point where the 0.8 power-factor line intersects the first circle is the point E in Fig. 11. Passing from this point to the right, 4 divisions, and then upward, 4.3 divisions, a point is reached which is a little below the 6-per-cent. circle; this point is equivalent to the point P in Fig. 10. The net line drop is 5.8 per cent. of 2,200 = 128 volts, compared with 127 volts by calculation.

If the load on the circuit has a power-factor of 100 per cent., one begins at the base of the 100-per-cent. power-factor line, passes to the right 4 divisions and then up 4.3 divisions. The drop is found to be about 4.1 per cent., or 90 volts, as compared with 90 volts calculated.

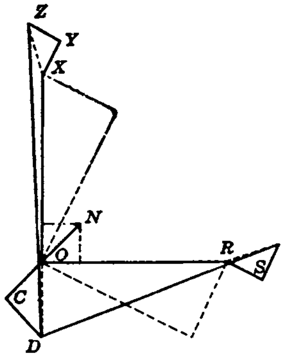


Fig. 12.—Diagram of potential drop on two-phase three-wire circuit.

36. Two-phase line drop. In the case of a **two-phase four-wire circuit** the drop is computed for each phase independently, using the method given in Par. 33 and Par. 34, or the Mershon diagram, Par. 35.

In a two-phase three-wire system having the load connected between the outer phase wires and the neutral or common phase wire, the inductive drop on the neutral produces an unbalanced pressure at the load or receiver end. This condition is illustrated in the diagram in Fig. 12. The ohmic and inductive drops on the outer wires are represented by the triangles XYZ and RST. ON represents the phase of the neutral current and OCD represents the ohmic and inductive drops on the neutral conductor. The power-factor is assumed at 90 per cent. The voltage necessary to maintain normal pressure at the feeder end is represented by line DZ on one phase and by DT on the other phase. The net line drop is the difference between DZ and OX in one phase, and between DT and OR in the other. It is evident from the diagram that the drop on one phase is considerably greater than on the other. The difference varies with the power-factor and the size of the wire, being greater with larger sizes of wire. No simple rule can be laid down for calculating such problems, when the load is not equally balanced between phases, and a graphical solution is usually the most practical.

37. Drop in three-phase three-wire symmetrical circuits. In a three-phase three-wire circuit with conductors symmetrically arranged and carrying a balanced load, the inductive effect is the same in each wire and

* *American Electrician*, June, 1897.

the calculation of drop may be made exactly as it would be for a single-phase circuit carrying one-half the load.

As the currents in the three wires are 120 deg. apart in time phase, the ohmic drop for the two wires making up any one phase is not twice that of one wire, as it is in a single-phase two-wire circuit, but is 1.73 times this drop. The inductive component of drop is also 1.73 times that of a single wire, for the loop. If the load on a three-phase circuit were the same as on the single-phase circuit in the previous example (Par. 34), the current per wire in the three-phase circuit would be

$$\frac{100\times 1.732}{3}=57.7 \text{ amp.}$$

The drop at 100 amp. on the three-phase circuit would be $(5.8/2)\times 1.73 = 5.0$ per cent., and at 58 amp. the drop would be 58/100 of 5 per cent., or 2.9 per cent. The single-phase drop at the same load was found to be 5.8 per cent., or twice the three-phase drop.

Therefore, for the same load and equal line drop, the size of the conductor in a three-phase circuit may be one-half that of a single-phase circuit. There being three wires in the three-phase circuit, it follows that the *weight of copper which is required for a three-phase circuit is three-quarters of that required for single-phase* transmission, with equal pressures between phase-wires, equal loads and equal line drops.

38. Drop in three-phase three-wire unsymmetrical circuits. When the arrangement of conductors is not symmetrical, the inductive component of drop is different among the different pairs of wires, on account of the different distances between centres. The most common case is that in which the wires are arranged on a cross-arm in the same horizontal plane. In such cases the equivalent of a symmetrical arrangement can be secured by **transposing** the conductors at proper intervals. This is not necessary in 2,200-volt distributing feeders which are equipped with line-drop compensators, as they can easily be adjusted to correct the unbalanced conditions.

The calculation of drop in an unbalanced three-wire three-phase circuit is somewhat complicated and such problems are most readily solved graphically. Loads which are not unbalanced more than 10 per cent. to 15 per cent. may usually be averaged and considered as balanced for practical purposes. In systems where the lighting service is all on one phase, and the third phase wire carries a small scattered load of three-phase motors, the lighting phase may be considered as a single-phase circuit in computing the drop. However, as the motor load increases, the drop in the lighting phase becomes less for a given current value, until, when the current in the other phases equals that in the lighting phase, the drop in the latter is but 86.6 per cent. of what it would be with the same current carried for lighting service only.

39. Drop in three-phase four-wire circuits. The pressure at the transformer, on such systems, is the pressure between phase wires and neutral; when the latter is 2,200 volts, the pressure across phase wires is $2,200\times 1.732 = 3,810$ volts. With **balanced load** the neutral conductor carries no current and the drop is that in the phase wires only. The resistance drop at 100 amp. on a No. 0 circuit 9,000 ft. long is $100\times 9\times 0.0981 = 88$ volts. This is 4 per cent. of 2,200 volts. Assuming a 12-in. spacing, single-phase, the inductive component of drop is $100\times 9\times 0.1043 = 94$ volts, or 4.3 per cent. At 80 per cent. power-factor, by the Mershon diagram (Fig. 11), the total drop is 5.8 per cent. The size of wire for a given load and drop, three-phase, is one-half what it would be for a single-phase circuit, or, assuming wires of equal size, the distance may be doubled for the same drop as compared with a single-phase circuit.

In the case of an **unbalanced four-wire circuit**, which is the more usual condition, the effect of the drop on the neutral wire must be taken into consideration. In general, the effect of the unbalance is to increase the drop on the more heavily loaded phases and decrease it on the lightly loaded phases, in comparison with the drops at balanced load, as shown in the case of the three-wire two-phase circuit above. A graphical solution of the problem of determining line drop in unbalanced three-phase four-wire circuits is shown in Fig. 13. This diagram is constructed on a principle similar to that used in Fig. 12 for a two-phase circuit.

The load on *A* phase is heavier than that on *B* and *C*, and the drop *OE* due to the neutral current is added almost directly to the drop XZ on the A-phase conductor.

The net drop on A phase is EZ-OX, that on B phase is ET-OR and on C phase it is EW-OU.

Where line-drop compensators are employed in each conductor, only the individual calculations for the four conductors are required, as the compensator corrects for the effect of the neutral drop.

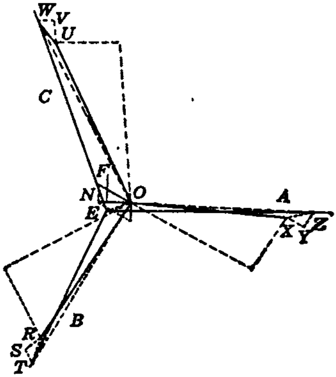


Fig. 13.—Diagram of drops in a three-phase four-wire circuit.

40. Skin effect is an alternating-current phenomenon (Sec. 2, and Sec. 4, which materially affects cables of large cross-section, due to the fact that the currents passing through the strands around the outer surface of the cable encounter less inductance and impedance than the strands near the centre, thus causing the outer strands to carry more current, proportionately, than the inner strands. It is desirable, therefore, to build up large cables about a core of non-conducting material. Cables of over 500,000 cir. mils are often made in this manner where they are to be used in 60-cycle systems, and cables of more than 1,000,000 cir. mils for 25-cycle systems.

The increase in effective resistance due to skin effect is approximately proportional to the product of the frequency and the circular mils, as shown in the following table in Par. **41**.

41. Table of Skin-effect Coefficients

Cir. mils × frequency	Coefficient	
	Copper	Aluminum
10,000,000	1.000	1.000
20,000,000	1.008	1.000
30,000,000	1.025	1.006
40,000,000	1.045	1.015
50,000,000	1.07	1.026
60,000,000	1.096	1.04
70,000,000	1.126	1.053
80,000,000	1.158	1.069
90,000,000	1.195	1.085
100,000,000	1.23	1.104
125,000,000	1.332	1.151
150,000,000	1.433	1.206
175,000,000	1.53	1.266
200,000,000	1.622	1.33

To determine the skin effect of a copper cable having an area of 1,000,000 cir. mils, carrying current at 60 cycles, refer to the table, opposite the product 60,000,000. The coefficient is 1.096. The resistance of a 1,000,000-cir. mils cable per 1,000 ft. being 0.01035, the effective resistance at 60 cycles is $0.01035 \times 1.096 = 0.01134$, or 9.6 per cent. more than with continuous current. The resistance of a 1,500,000-cir. mils cable is increased 19.5 per cent. at 60 cycles. The current-carrying capacity of large cables is reduced in proportion to the reciprocal of the skin-effect coefficient; that is, if the coefficient is 1.096, the capacity is only $1/1.096 = 91.2$ per cent. of that with continuous currents.

42. Effect of electrostatic capacity. At ordinary distributing voltages and frequencies the capacity effect is too small to be of any consequence in the solution of line-drop problems and need not be considered. At transmission voltages it is a matter of considerable importance in many cases (Sec. 11). The electrostatic capacity of an overhead circuit is fixed by the distance between the conductors and by their size; with insulated conductors (aerial or in cable), the capacity is further affected by the dielectric constant (Sec. 4), of the insulating material. The mutual capacity of a single-phase uninsulated circuit strung in the open air, per 1,000 ft. of circuit, is given by

$$C = \frac{0.003677}{\log \frac{d}{r}} \qquad \text{(microfarads)} \qquad (2)$$

where d is the distance between centres of conductors and r is half the diameter (radius) of the conductor. The logarithm used is the *common logarithm.*

43. Charging current. The charging current of a single-phase circuit is given by

$$I = \frac{6.284DnCE}{1{,}000{,}000} \qquad \text{(amp.)} \qquad (3)$$

where D is the length of circuit in thousands of feet, n is the frequency, C is the capacity in microfarads, and E is the effective voltage between conductors. The charging current of a symmetrical three-phase circuit, between phase wires, is $2/\sqrt{3} = 1.155$ times that of a single-phase circuit with equal spacing between phase wires.

When an inductive load is carried on the line, the lagging component of the load current tends to offset the leading current required to charge the line. The tendency of the charging current to raise the power-factor of the line current thus results in a corresponding tendency to reduce the line drop where the load is of an inductive character. (For full treatment of the effect of capacity on line drop, see Sec. 11.)

44. Electrostatic capacity of cables. In underground cable work the effect of charging current is greatly increased by the reduced separation of the conductors. The charging current cannot be determined so easily, however, since the dielectric constant of the insulation must be taken into account. The mutual capacity of a three-phase three-conductor cable between conductors, per 1,000 ft., is given by

$$C = \frac{0.00735\ K}{\log \frac{3a^2\ (R^2 - a^2)^3}{r^2\ (R^6 - a^6)}} \qquad \text{(microfarads)} \qquad (4)$$

When K is the dielectric constant, a is the distance from the centre of the cross-section of the cable to the centre of the conductors, R is the radius of the inside of the lead sheath, and r is the radius of the conductors. The *common logarithm* should be used.

45. Dielectric constants of cable insulation. The value of K, the dielectric constant, is determined by tests on samples of cable. It varies with different materials, and with variation of temperature with the same material. The general effect of increase in temperature is to decrease the dielectric constant, and increase the dielectric loss. The length and the voltage of cable systems are usually such that the charging current is not sufficient to cause any operating inconvenience.

46. Current-carrying capacity of conductors. The energy absorbed by a circuit, I^2R, is dissipated in the form of heat, and tends to raise the temperature of the conductor. The maximum current-carrying capacity of a conductor is dependent upon whether it is installed in open air, in conduit or underground. The character of the insulation is also a factor, since certain kinds of insulation may be safely operated at higher temperatures than others.

The insulation of rubber-covered conductors should not be operated regularly at temperatures above about 50 deg. cent. (122 deg. fahr.). Weatherproof and other fibrous types of insulation may be operated at temperatures as high as 65 deg. to 70 deg. cent. (149 deg. to 158 deg. fahr.). Conductors used inside of buildings are subject to the requirements of the National

Electrical Code, which limits the current in rubber-covered cables to values such that the temperature rise will not exceed about 15 deg. cent. (59 deg. fahr.). This represents a temperature of about 40 deg. cent. (104 deg. fahr.) during summer months, or in parts of buildings such as engine rooms which are normally above outside air temperature. Slow-burning insulation is accordingly required in places where the temperature is likely to be above 45 deg. cent. (113 deg. fahr.).

47. Table of Current-carrying Capacity of Wires and Cables Under Various Conditions

Size, A.W.G. or cir. mils	National electrical code		Lead-covered cables		
			Single conductor		Three conductor paper ins. 45 deg. cent. rise. (amp.)
	Rubber ins. (amp.)	Slow-burning ins. (amp.)	Rubber 30 deg. cent. rise (amp.)	Paper or cambric, 40 deg. cent. rise (amp.)	
14	15	20	....	....	....
12	20	25	....	....	....
10	25	30	20	22	....
8	35	50	30	34	26
6	50	70	50	56	48
4	70	90	78	87	68
3	80	100	98	110	81
2	90	125	121	134	93
1	100	150	145	160	110
0	125	200	169	187	132
00	150	225	192	210	150
000	175	275	245	270	190
0000	225	325	285	315	225
250,000	235	350	320	360	255
300,000	275	400	370	415	300
400,000	325	500	460	515	370
500,000	400	600	550	605	....
750,000	525	800	750	830	....
1,000,000	650	1,000	900	1,030	....
1,500,000	850	1,360	1,200	1,450	....
2,000,000	1,050	1,670	1,400	1,590	....

48. Current-carrying capacity of underground cables. The rise of temperature of underground cables depends upon the amount of energy liberated by all the cables in the duct line, and upon the ability of the cables and ducts to radiate the heat to the surrounding earth. The laws governing the radiation of heat from cable conductor to lead sheath and thence to earth have been studied by various investigators. S. Dushman* has derived a a formula by which the temperature of the copper may be calculated from observations taken on the lead sheath, as follows:

$$t = K \log \frac{D}{d} \frac{(I^2 \times 1{,}000)}{(\text{cir. mils})} \text{ (deg. cent.)} \qquad (5)$$

in which t is the fall of temperature in deg. cent. from copper to sheath, D is the inside diameter of sheath in inches, d is the diameter of the conductor (inches), I is the current (amperes) and K is a constant varying with the type of cable. For single-conductor cable, $K = 0.27$; for two-conductor cables $K = 0.6$; and for three-conductor cable, $K = 0.9$. The *common logarithm* is used.

The temperature of the conductor may thus be calculated from sheath

* Dushman, S. *Trans.* A. I. E. E.; Vol. XXXII, 1913, p. 165.

measurements without taking resistance measurements of the copper. This formula is of great practical value where cables cannot be taken out of service to make resistance measurements. Tests made on cables in service verify Dushman's formula with sufficient accuracy for practical purposes.

49. The radiating capacity of cables in the central ducts of a large underground line is less than that of the cables in the peripheral ducts, and the temperature of the former tends to become higher when the ducts are well filled. The effect of the position of cables in a duct line has been studied by H. W. Fisher.* The results of his tests indicate that with a nine-duct line the rating of a cable should be reduced about 15 per cent. from its capacity in a four-duct line; while in a sixteen-duct line it should be reduced about 40 per cent. This is true only when there are working cables in all the ducts of the line.

50. The carrying capacity of multiple-conductor cables is less than single-conductor cables of the same size, because of the larger energy loss in proportion to the radiating surface. Duplex cable has about 90 per cent. of the carrying capacity of single-conductor cable; concentric cable, 80 per cent.; and three-conductor cables, 75 per cent. The maximum temperature at which paper or cambric should be operated is about 65 deg. cent. (149 deg. fahr.). The temperature may be pushed above this figure occasionally for a short time, but if operated continuously above 65 deg. cent. the paper will be injured.

SUBSTATIONS

51. The function of a substation is to convert energy received from a bulk-supply system, at the transmission voltage and frequency, to energy suitable for distributing purposes. The energy distributed may be in the form of direct current at the voltage at which it is utilized, or in the form of alternating current at a voltage suitable for general distribution through step-down transformers located at suitable points in the district served. The expense of installing and operating a substation must be justified by the saving made by the shortening of distributing feeders and the reduction in feeder losses incident thereto.

52. Substation location. The distance between substations depends upon the voltage of distribution and the density of the load. The average length of the distributing feeders should be such that the total investment in feeder conductors and substation equipment is a minimum.

In low-tension systems it is usually found desirable to locate substations approximately 1 mile apart, except in very congested districts where they are sometimes located less than 0.5 mile apart, on account of the very large loads to be carried.

In 2300-volt alternating-current distribution, substations may be spaced from 2 to 3 miles; in four-wire systems operating at 2,300–4,000 volts, they may be located from 4 to 6 miles apart, in scattered districts. In the outlying parts of the larger cities they are usually found from 2 to 3 miles apart on account of the density of the load.

53. Substation classification. Substations may be divided into three principal classes: (a) those in which transformers change the pressure from that used in transmission to the distribution voltage; (b) those in which frequency changers convert energy from one frequency to another and from the transmission voltage to the distributing voltage; and (c) those in which the transmitted energy is converted by synchronous converters to continuous current at low voltage.

54. General features. Each of these classes of substations (Par. 53) has certain elements which are common to all. Each is served by incoming transmission lines which are terminated in oil switches and connected thence to a high-tension bus system. One side of the converting apparatus is connected to the high-tension bus and the other side to two or more distributing busses. From these busses the outgoing feeders are taken off through suitable feeder switches, in conjunction with regulating apparatus.

55. Substation building. The size of the lot and the dimensions of the building should be such as to permit an arrangement of apparatus which will not be unduly crowded, and which will permit the installation,

* Fisher, H. W. *Trans.* A. I. E. E.; Vol. XXII, 1903, p. 440.

repair and maintenance of the equipment at minimum cost. Where further growth is probable, due regard must be had for subsequent extensions of building and equipment. Fireproof construction is warranted where continuous service is important.

56. Bus-bar arrangement. Fig. 14 shows a simple arrangement for a substation having one main line and one reserve line. Where the load is such that several direct lines are required, a **transfer bus** (Fig. 15) is very desirable. This permits the operation of any machine from any line and makes the reserve line available in case of the failure of any of the main lines.

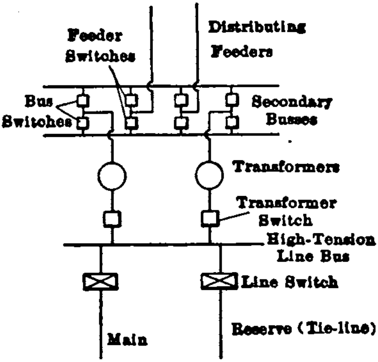


Fig. 14.—High-tension bus arrangement in a small substation.

57. Duplicate distributing busses are provided both as a means of operating the longer feeders at a higher bus pressure, and as a means of facilitating repair and maintenance work without interrupting service.

58. In continuous-current systems, two busses are required in practically all cases for **pressure control** during the heavy-load period, and in the larger substations it is sometimes necessary to provide **three busses** to take care of certain feeders which are exceptionally long or very short.

59. Transformer substations. The simplest type of substation is that which transforms alternating-current energy from one voltage to another

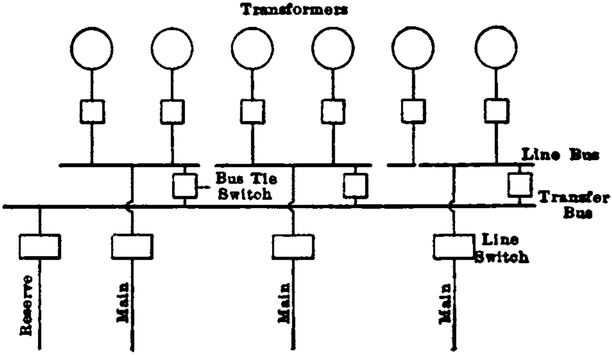


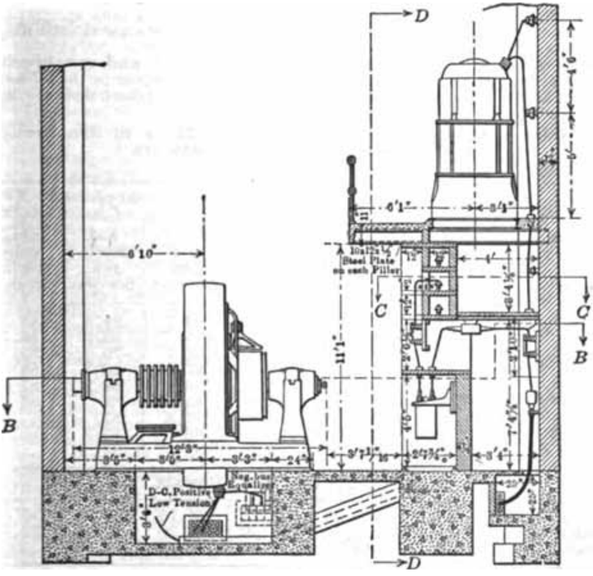
Fig. 15.—Bus arrangement in a large substation.

and requires, therefore, only transformers for the converting equipment. Both oil-cooled and air-cooled types of transformers are used for this purpose, with either single-phase or three-phase units. Oil-cooled units are preferable where the substation may be left without attendance during certain hours of the day. Oil-insulated, water-cooled transformers are used quite generally where there is an ample supply of cooling water.

Single-phase units are commonly employed where capacities of less than 1,000 kw. are required, although there is no settled practice in this regard.

Three-phase units are less expensive than single-phase units, particularly in the larger sizes, and require considerably less floor space.

60. Frequency-changer substations. Where the transmitted energy is converted to another frequency, the equipment consists of a motor generator, usually of the synchronous type; the motor is usually wound for the transmission voltage, to avoid the investment in transformers, where the voltage is less than 15,000 volts. This type of apparatus requires an exciter equipment, which may be driven by the machine itself, or by a separate motor. There should be at least one separately driven exciter equipment in a station where the exciters are direct connected.



Section A-A Incoming Line

FIG. 16.—Synchronous converter substation.

61. The synchronizing equipment of frequency-changer sets must be so arranged that synchronizing can be done at both frequencies. When the machine is brought into step on the transmission side, the arrangement of the poles is such that the generator end is held with a fixed angle of phase displacement from the supply system, except for one particular (and correct) position of the motor fields. In a 25-cycle to 60-cycle frequency changer having ten and twenty-four poles respectively, there are *five* positions in which the 25-cycle machine may come into synchronism, only *one* of which will permit the 60-cycle (generator) end to be synchronized with another frequency changer already in operation. The 60-cycle end must be synchronized by slipping poles until it comes into phase. Where the frequency changer is being synchronized with a generating system, it is necessary to advance or retard the phase of the 60-cycle generators.

62. Continuous-current substations. A continuous-current supply is usually derived from transmission systems by the use of synchronous converters, or motor-generators. The synchronous converter is universally employed where the transmission system is operated at 25 cycles, as the converter is less expensive in first cost and more efficient in operation than a motor-generator. Converters have been little used in 60-cycle systems until recent years. The development of the interpole converter has minimised the tendency of 60-cycle converters to hunt and flash over.

Where motor-generators are employed both synchronous and induction types of motors are in use. The induction motor has the advantage of greater stability than the synchronous motor in times of disturbance to the frequency or the voltage of the system. The induction motor, however, has a power-factor (lagging) of about 85 per cent., whereas the synchronous motor has an adjustable field and may be operated (overexcited) with a leading power-factor, thus raising the power-factor of the generating system. It has become customary, therefore, to employ both synchronous and induction types of motors in converting 60-cycle energy to continuous-current energy, in order to secure the advantages of both.

Efficiencies and first costs of motor-generators and synchronous converters at one-half, three-quarters, and full load appear in the following table (Par. 63), compiled from a paper read by E. W. Allen before the Association of Edison Illuminating Companies, 1908.

63. Tables of Efficiencies, Cost and Floor Space of Synchronous Converters and Motor-generators

Efficiencies

Rating, kw.	Per cent. load	25 cycles			60 cycles		
		Syn. mot.-gen. per cent.	Ind. mot.-gen., per cent.	Syn. converter, per cent.	Syn. mot.-gen., per cent.	Ind. mot.-gen., per cent.	Syn. converter, per cent.
300	100	84	85.3	89.5	86.7	84.8	88
300	75	82.3	83.3	88.5	85	82.3	86.7
300	50	77	79.8	86.5	81.7	79	82.5
500	100	85.5	86.8	90.8	87.8	86.3	89
500	75	83.7	84.8	90.3	86	84.3	87
500	50	79.5	82	88.3	83	81	83
1000	100	87.5	87	91.8	87.8	87	....
1000	75	86	85.8	90.5	86	85.3	....
1000	50	82.2	82.3	90	83	82	....

Approximate Cost per Kilowatt

300	......	$26.20	$26.35	$25.15	$25.75	$25.85	$25.00
500	......	24.70	24.35	22.00	23.20	23.40	22.70
1000	......	20.25	19.85	19.80	19.45	19.50	....

Floor Space, Square Feet

300	......	80	80	91	67	67	96
500	......	122	122	131	110	110	150
1000	......	136	136	170	140	140	.....

64. Motor-generator sets are commonly wound for the transmission voltage, and are started by the use of a compensator at fractional voltage. A single compensator is sufficient for a substation if a starting bus is provided, through which the same compensator can be used to start any of the units; a spare compensator should be in reserve.

65. The synchronous-converter substation, Fig. 16, is provided with transformers stepping down to the proper voltage for the alternating-current side of the converter. The transformers are commonly of the air-blast, three-phase type, as this form of equipment can be placed in a minimum of space.

66. Connection of neutral for three-wire continuous-current system.—The six-phase type of converter, wound for 250 volts, with a diametrical connection in order to provide for the neutral conductor, Fig. 17, is commonly employed for machines of 1,000 kw. and larger. Motor-generators are also designed for 250 volts, a small **balancer-set** being used to take care of the unbalanced load.

67. The regulation of pressure on the bus supplied by a synchronous converter is accomplished by the use of an induction regulator placed between the transformers and the converter. Some variation in pressure can be secured by manipulation of the converter field-rheostat, but this affects the power-factor and it is not depended upon for pressure control.

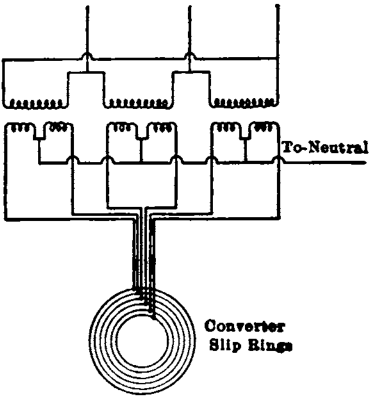


FIG. 17.—Six-phase diametrical connection for synchronous converter.

68. In the split-pole type of converter, which has been introduced in recent years, considerable range of **pressure regulation may be secured** by variation of the field rheostat without serious interference with the power-factor, and with this type of machine regulators are sometimes omitted.

69. Synchronous converters may be started in various ways, and it is usual to provide for at least one method of starting from both the alternating-current and the continuous-current sides. The converter may be started from the continuous-current side by the use of a starting rheostat in practically the same manner as that used in starting a continuous-current motor.

The converter may be started from the alternating-current side with the field open, by impressing approximately half the normal pressure, derived from a starting compensator or half-taps on the secondary of the transformer. The latter method is usually preferable. After the machine has come up to speed, the fields are excited and the polarity corrected, if necessary, by reversing the field, and slipping back one pole.

The current required in starting from the alternating-current side is from one and one-half to twice full-load current, while 25 per cent. to 30 per cent. of full-load current is sufficient for starting from the continuous-current side. The normal method of starting is, therefore, preferably from the continuous-current side.

70. Low-tension switchboards. The operation of distributing systems at low pressure involves very large currents and for that reason the most important part of a low-tension switchboard is the arrangement of heavy bars of copper, 3 in. to 6 in. wide and 0.25 in. to 0.5 in. thick, required for the safe handling of such currents. The important features of the design are to maintain sufficient clearance between bars of opposite polarity and to make the connections as short as possible consistent with accessibility for repair and maintenance work.

71. Feeder panels. The switchboard shown in Fig. 18 is based upon a vertical arrangement which permits ample separation of opposite polarities and minimum length of the bus-bar copper per feeder. Each vertical section comprises a set of switches and instruments for one three-wire feeder, the neutral not being brought into the main board. The neutrals are commonly carried to a separate bus in the basement, where they are connected without disconnecting switches other than removable copper links.

72. Switchboard voltmeters. It is customary to provide a single voltmeter with a multiple-point switch so arranged that one voltmeter can

79. End-cell switches for battery reserve. The tendency of the battery pressure to fall off at the time of discharge is provided for by the use of end-cell switches which are under the control of the operator, so that additional cells can be connected in series in sufficient number to hold the pressure up to the desired value. Normally, the end-cell switches are set so that the battery floats on the system. In any emergency which causes the bus pressure to drop, the battery immediately begins to supply energy, thus tending to maintain the bus pressure. A diagram of a battery, equipped to act as a reserve on two sets of busses, is shown in Fig. 19.

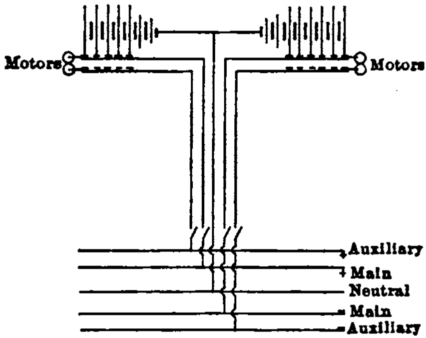


FIG. 19.—Arrangement of battery end-cells.

80. High-tension switchboards (up to 15,000 volts). In the design of high-tension switchboards, the space required for proper separation and insulation of the bus bars, and for the installation of oil-switches, necessitates an arrangement in which the busses and oil-switches are installed in some remote location such as a basement, the control panels being located at a point convenient to the operator.

Ammeters, voltmeters and wattmeters are operated with series (current) and shunt (potential) transformers, and oil-switches are usually of the remote-control type, so that the switchboard panel carries only low-tension apparatus. In smaller substations and in cases where only a few switches are installed, hand control is sometimes employed for the oil-switches on outgoing feeders.

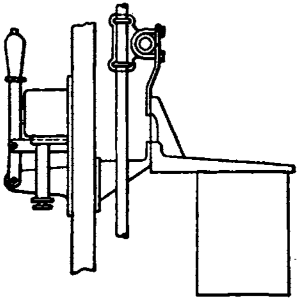


FIG. 20.—Tank-type of oil-switch.

81. High-tension bus bars commonly consist of cable or copper tubing mounted on suitable insulating supports, carried on a skeleton frame of pipe or angle iron. Oil-switches for distributing feeders are commonly mounted on the same framework in such a way as to provide an orderly system of connections from the busses to the switch terminals. Bus bars operating at voltages of 6,600 and upward are commonly installed in compartments, so arranged as to reduce to a minimum the probability of an arc between conductors of opposite polarity; this is very important where large amounts of energy are available to supply a short-circuit in case it should occur.

82. Disconnect-switches should be provided to permit oil-switches to be taken out of service during repair and maintenance work.

83. Two general types of oil-switches are employed, the **tank type** (Par. 84) for distributing-feeders and for the control of converters or transformers, and the **compartment type** (Par. 85) which is used for the control of transmission lines and at other points in the transmission system where the switch may be called upon to open automatically under short-circuit.

tive section *B* and the non-inductive section *A* in proportion to the load on the feeder. The secondary winding is divided into four sections of 5 volts each, and four sections of 1 volt each. The 5-volt terminals are connected to the contacts numbered 1, 2, 3, 4, and 5, and the one-volt terminals to the contacts numbered 6, 7, 8, 9, and 10. The arms may be independently adjusted, thus permitting any setting from 1 volt to 24 volts. The current from the shunt (potential) transformer *C* passes through the feeder voltmeter and the two movable arms to 3, thence through the portion of the non-inductive section, which is included between 3 and 5, and the portions of the inductive section between 6 and 9 and between 4 and 5, back to the transformer *C*. In completing this circuit, the impressed pressure has been opposed by a counter-e.m.f. of 10 volts in the non-inductive section and by 8 volts in the inductive section. The reading of the voltmeter is thus made

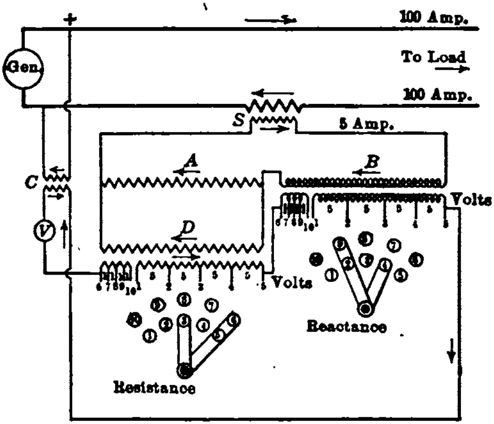


Fig. 22.—Circuits of Westinghouse line-drop compensator.

the same as it would be at the end of a feeder (in the secondary) having a resistance-drop of 10 volts (secondary) and a reactance-drop of 8 volts (secondary) at 100-amp. load.

89. In the General Electric line-drop compensator, Fig. 23, there is but one movable arm on each section, with eight points per section. Each point represents 3 volts when 1 amp. is flowing in the compensator circuit. The compensator shown (Fig. 23) is set so as to introduce in the voltmeter circuit an inductive counter-e.m.f. of 9 volts and a non-inductive counter-e.m.f. of 12 volts, when the feeder is carrying 100 amp.

90. Calculation of compensator setting for a single-phase feeder. Given a 60-cycle feeder of No. 0 A.W.G. copper wire, 5,000 ft. long, single-phase, wires 12 in. apart, series (current) transformer ratio 100 amp. to 5 amp., shunt (potential) transformer ratio 2,200 volts to 110 volts, how should the compensator be set?

The resistance drop on No. 0 wire, from Par. **81**, is 0.0981 volt per amp. per 1,000 ft.; hence the drop at 100 amp., for 5,000 ft., will be $2\times 100\times 5\times 0.0981 = 98$ volts $= 4.5$ per cent. The inductive drop of No. 0, at 12-in. spacing, being 0.1043 volt per amp. per 1,000 ft., the drop at 100 amp. will be $2\times 100\times 5\times 0.1043 = 104$ volts $= 4.7$ per cent. The resistance and the reactance should each be set at 5 volts ($= 0.045\times 110$), to give constant pressure at the end of the feeder at all loads.

91. Calculation of compensator setting for two-phase feeders. In the case of **a two-phase, four-wire feeder,** the method of connection is similar to that used for a single-phase feeder, except that separate equipment is required for each phase, and hence the calculations are similar.

A **two-phase, three-wire feeder,** with unbalanced load requires one compensator in each wire, with connections as shown in Fig. 24. The values of resistance and inductance per 1,000 ft. used in the case of a single-phase feeder are based on the use of two wires, whereas in a three-wire feeder each compensator corrects the drop in one wire only.

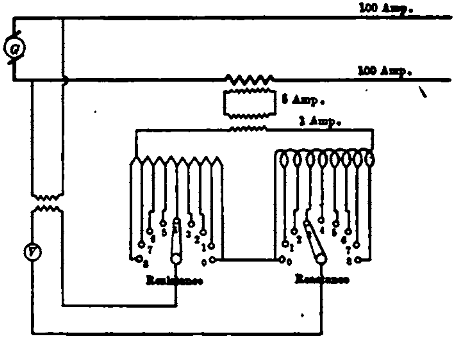


Fig. 23.—Circuits of General Electric line-drop compensator.

92. Calculation of compensator setting for three-phase feeders. In the case of a **three-phase, three-wire feeder** carrying unbalanced load, a compensator is required in each wire. For instance, if the feeder previously used for illustration were a three-phase, three-wire feeder (with symmetrical spacing of phase wires) carrying 100 amp. per wire, the ohmic drop in each wire would be $5 \times 100 \times 0.0981 = 49$ volts, and the inductive drop 52 volts.

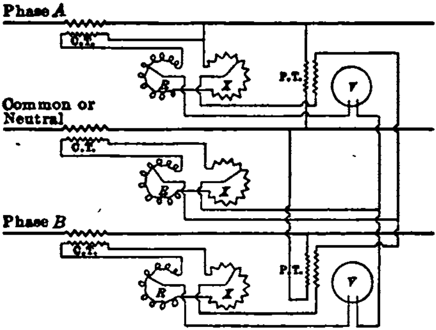


Fig. 24.—Compensator connections for two-phase three-wire system.

These values are respectively 3.8 per cent. and 4.1 per cent. of the pressure to neutral, 1.270 volts ($= 0.577 \times 2,200$).

In a **three-phase, four-wire feeder** operating at 2,200 volts between phase wires and neutral, the method of calculating the drop is as follows: Given a feeder of four No. 0 wires (12-in. spacing) running 5,000 ft. from the station as a three-phase feeder, the drop in each phase wire at 100 amp.

will be 49 volts, ohmic, and 52 volts, inductive. The working pressure being 2,200 volts, this is about 2.5 per cent. If the entire load of the feeder is delivered from this centre of distribution, the compensator on each phase wire

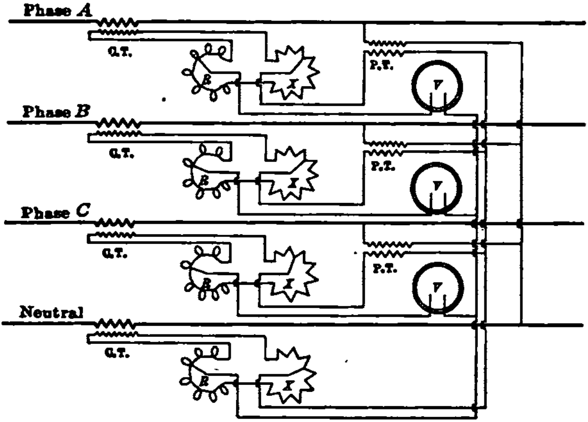


Fig. 25.—Compensator connections for three-phase four-wire system.

should be set at 2.5 per cent. on each dial; that on the neutral should be set at 2 per cent. on each dial, to take care of unbalanced load. If, however, the A-phase branches off with a neutral to a single-phase centre of a distribution 2,500 ft. beyond, there must be added to the A-phase setting, $2\times100\times2.5\times0.098=49$ volts $=2.2$ per cent., making the new setting $2.5+2.2=4.7$ per cent. If the other phases branch to similar centres of distribution, at different distances, the drops must be computed similarly, and added to the three-phase drop. The connections of the compensators for a three-phase, four-wire feeder are shown in Fig. 25.

93. Automatic regulation of feeder voltage. In connection with automatic regulation the General Electric Co. has developed a device which serves as a line-drop compensator combined with a relay. This device, known as a **"contact-making voltmeter,"** is shown in Fig. 26. It consists of a solenoid having windings which are tapped at various points and brought out to adjustable switches, as in the line-drop compensator. One winding produces a magnetic flux proportional to the pressure; another carries current in proportion to the load and opposes the flux due to the feeder pressure. This counter-

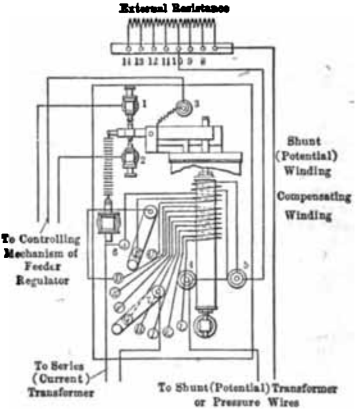


Fig. 26.—Automatic regulators for controlling feeder voltage.

magnetomotive force may be adjusted roughly by setting the proper switch on the points *A*, *B*, or *C*, and the finer adjustments are made by the points *D* to *L*. The pivoted bar carries the contacts which control the supply of energy to the feeder regulator.

As the load increases, the plunger falls until the contact is made which raises the pressure on the feeder. This increases the flux due to the pressure and the plunger rises sufficiently to stop the movement of the regulator until a further change in load or bus pressure occurs. This device gives very satisfactory results at all power-factors from 75 per cent. to 100 per cent.

94. Bus-bar voltage regulation. Where there is a variable motor load supplied by motor-generator converting equipment, it is desirable to maintain a constant bus pressure, in order to prevent the load variations from affecting the bus pressure and thus impairing the steadiness of voltage on the feeders supplying the lighting service. The automatic regulator devised by Tirrill has been successful in accomplishing this purpose.

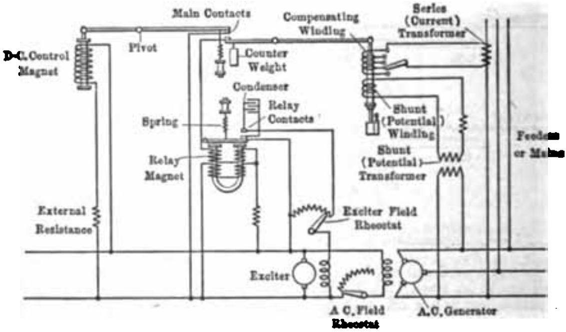


FIG. 27.—Connections of Tirrill regulator.

95. Tirrill regulator. The general scheme of connections is shown in Fig. 27. The secondary circuits of the shunt (potential) and series (current) transformers in the generator leads are connected through a solenoid in a compounding relation. The series section is subdivided so that different rates of compounding may be secured. A movable plunger is actuated by this solenoid, which in turn actuates a counterweighted lever, the opposite end of which is equipped to make electrical contact in a relay circuit. The other contact terminal of this relay circuit is carried on a similar lever which is actuated by the plunger of a direct-current solenoid. This solenoid receives current in proportion to the pressure at the exciter terminals. The relation of these contact-making levers is such that increased pressure at the exciter brushes tends to open the relay circuit, while increased pressure at the main generator terminals tends to close it.

This closing of the circuit demagnetizes the relay, which is differentially wound, and its armature is withdrawn by a spring. This shunts the field rheostat of the exciter, increases its terminal pressure, and opens the relay circuit, thus weakening its pull.

Where there are several units in parallel in a station, the regulator may be applied to the exciter for a portion of them and the bus regulated for constant pressure with the series coil of the alternating solenoid cut out. With this arrangement, the bus pressure may be maintained constant at any desired value by the insertion of an adjustable resistance in the pressure circuit of the alternating solenoid.

SECONDARY DISTRIBUTION

96. The secondary mains of an alternating-current system serve users in a local area, while the primary mains supply larger areas. The standard system of secondary distribution in America is the **single-phase,**

three-wire Edison system at approximately 110-220 volts for lighting and small motor service, and 220-volt two-phase or three-phase for general motor service; 440 volts and 550 volts are also used to some extent for power systems in industrial plants. For the supply of mixed service of lighting and motors from a secondary network, the **four-wire, three-phase system** at 115-200 volts or 120-208 volts, approximately, is sometimes used.

97. The voltage of general distribution systems must be low enough to be adapted to incandescent lamps, fans, heating devices and other small accessories, which are preferably made for the voltages around 110. Motor voltages are higher in order to secure economy of conductor investment; this is especially true with large installations.

98. Transformers are usually wound for a ratio of 2,200 to 110-220 volts, though some of the systems where 115-230 volts are standard are using a ratio of 2,080 to 115-230 volts. This secondary voltage permits a spacing between transformers of 600 ft. to 800 ft.

99. In laying out secondary systems for lighting service, it is usual to limit the drop from transformer to consumer to about 2 per cent. where first-class service is required. In scattered districts where secondaries are too small and remote to warrant interconnection, the problem of design consists in striking a balance between the cost of conductors, and the cost of transformers and their losses.

By reaching out farther from the transformer with the secondary mains, the number of transformers is reduced, and, their average size being larger, their total cost is smaller. This is true because the cost per kilowatt is less for the larger sizes, and because the kilowatt capacity required per kilowatt connected is less for a large number of users than for a few.

100. Minimum annual cost. As the radius of distribution from the transformer becomes more than 500 to 600 ft., the cost of conductors increases very rapidly, and it becomes more economical to provide additional transformers. On the other hand, if too many transformers are used, the iron loss which goes on 24 hr. a day becomes excessive, and the investment per kilowatt in transformers is high. The minimum annual cost of a secondary system is that at which the fixed charges on conductors and transformers, plus the value of the iron loss, is a minimum. The iron and copper losses of standard American transformers appear in the table in Par. **101** (also see Sec. 6).

101. Losses and Efficiencies of Standard Transformers for Alternating-current Distribution

2,200 to 110-220 volts, 60 cycles

Rating kv-a.	Watts loss		Per cent. efficiency, full load	Per cent. regulation		Per cent. charging current.
	Core	Copper at 125 deg. fahr.		100 per cent. p-f.	80 per cent. p-f.	
1	20	26	95.8	2.61	3.18	5.5
1 1/2	25	37	96.2	2.47	3.10	4.0
2	30	46	96.5	2.33	3.00	3.6
3	34	70	96.8	2.36	3.01	3.0
5	40	82	97.2	2.08	3.12	2.5
5	45	102	97.3	2.08	3.10	2.3
7 1/2	62	137	97.6	1.84	2.93	2.2
10	80	163	97.8	1.66	2.85	1.9
15	105	233	97.9	1.58	2.80	1.6
20	131	295	98.0	1.52	2.96	1.5
25	147	351	98.2	1.47	2.90	1.3
30	163	411	98.2	1.46	2.90	1.2
40	205	476	98.3	1.30	2.80	1.2
50	240	605	98.4	1.20	2.70	1.0

Also see Sec. 6.

102. All-day efficiency of transformers. In a distribution transformer, the iron loss may reach a considerable percentage of the daily consumption of energy. A 5-kw. transformer which carries full-load 4 hr. a day delivers 20 kw-hr. per day, and has a copper loss of about 102 watts at full-load, while the iron loss would be about 45 watts. The copper loss per day would be about 410 watt-hr., while the iron loss would be $24 \times 45 = 1{,}080$ watt-hr. The total loss being 1.5 kw-hr., the all-day efficiency is $20/21.5 = 93.0$ per cent., and the full-load efficiency is $5{,}000/5{,}150 = 97.1$ per cent. It is apparent that the all-day efficiency varies with the **load factor** or hours' use of the maximum load.

103. Calculation of secondary mains. The most economica size of conductor and spacing between transformers for secondary mains may be determined approximately as follows:* assuming a load density per 1,000 ft. and an allowable pressure drop, determine the distance between transformers which will result in that drop with several sizes of conductor.

The investment in wire and transformers may then be found. The fixed changes in the investment plus the annual value of the iron losses in the transformer constitute the annual cost of this secondary main (exclusive of pole line or conduit). The minimum annual cost will be found to work out approximately as in the curves shown in Fig. 28.

104. Curves of cost variation, overhead distribution. The variation of the elements of cost as the spacings between transformers and the size of wire are changed, is illustrated by the curves in Fig. 28, which are based upon a load density of 50 kw. per 1,000 ft., with overhead lines. It is apparent from this curve that the minimum cost is found with No. 2 wire at a spacing of 600 ft. between transformers. The curves of total cost at other load densities are shown in Fig. 29.

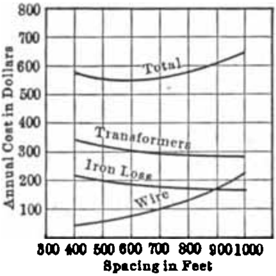


Fig. 28.—Elements of cost of secondary main.

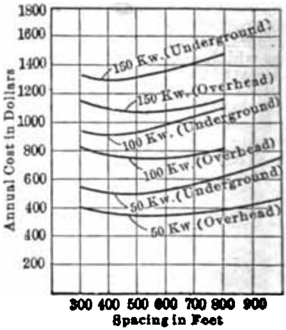


Fig. 29.—Economical spacing of transformers.

Where energy may be charged at less than 1 cent per kw-hr., or with water power, the decreased value of core loss tends to permit the use of smaller transformers, shorter spacings and a smaller size of wire.

105. Curves of cost variation, underground distribution. The curves for underground lines also appear in Fig. 29. The spacing for minimum cost is not materially changed, being about 500 ft. for each load density.

The flatness of the curve of total cost allows considerable flexibility in spacing, and it is generally preferable to use as few transformers as possi-

* Gear and Williams. "Electric Central Station Distributing System," '08.

ble with the larger sizes of conductor, so as to reduce the number of units to a minimum. Furthermore, it is usually desirable to **anticipate an increase in load** by installing a larger conductor than is required for immediate needs. The size of transformers is then gradually increased, from time to time, as the load increases.

106. Uneven load density. The curves (Figs. 28 and 29) are based on an assumption that the load is uniformly evenly distributed along the line throughout its length, but such is rarely the case in practice. At occasional intervals, department stores, churches or other large customers of energy throw heavy loads upon the line. It is necessary, therefore, to locate transformers near such large consumers' premises and design the mains between them to carry the scattered load.

107. Secondary networks. The gradual extension of mains on all streets results in a system of lines which is interconnected and becomes a network. **Transformers are preferably located** at intersections where they feed in all directions with the best economy of copper. In the design of such networks the sizes of secondary cable are fixed by the local conditions. The smaller consumers distributed along the routes are carried from mains of proper size, and the larger consumers such as theatres and department stores are cared for by a separate installation of transformers in the immediate vicinity of the consumers' premises.

108. Underground construction is often required in networks and this necessitates **manholes** of ample size for large transformers and such junction boxes as are necessary for operation. The space required is somewhat difficult to secure on account of pipes and other underground systems which limit the available space. In some cases it has been found desirable to install the transformers in a substation, supplying the network through low-tension feeders; this arrangement permits a saving in transformer investment and iron losses, as the diversity factor is better and the units are larger, but the cable investment is considerably greater.

109. Separate transformers for large motor loads. The design of secondary systems is subject to restrictions when **inductive loads,** such as arc lamps and motors, must be served along with incandescent lighting. The heavy starting-current required by induction motors may momentarily overload the transformer and the secondary main. This causes a flickering of incandescent lamps served in the vicinity. It is necessary, therefore, to install separate transformers for installations of motors if the best regulation is required for incandescent lighting. Motors larger than 10 h.p. can not usually be supplied from a lighting network without interfering with the service.

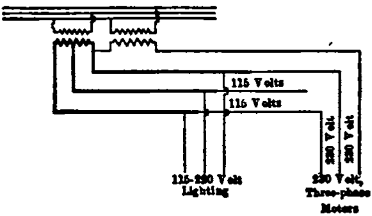


FIG. 30.—Three-phase secondary system, with single-phase lighting service.

110. Three-phase supply for mixed loads. In three-phase systems several methods of carrying mixed lighting and motor loads are in use. The most common method consists of **star-connected transformers supplying a four-wire main** operated at about 115 volts from phase to neutral and 200 volts across phase wires. The smaller lighting services are made three-wire and connected to two phases and neutral, and large services are balanced on three phases. Four-wire service is required wherever both lighting and motor service are supplied.

In another method, illustrated in Fig. 30, all the lighting is carried single-phase from a three-wire Edison main. Motors are served by the installation of additional smaller transformers and a fourth secondary (phase) wire. The lighting load is easier to keep balanced, and the higher diversity factor requires somewhat less transformer capacity for lighting.

111. Determination of transformer capacity. The selection of the size of transformers for various classes of consumers is important, since excess capacity involves idle investment and unnecessary core losses. Very few consumers use their entire connected loads at any one time. Where a number of consumers are served by one transformer, the various *maximum demands do not occur simultaneously* and therefore the resultant maximum demand is less than the sum of the individual demands. The demand must be ascertained by measurements which may be made by means of an ammeter or by a **Wright demand** indicator (Sec. 3).

Certain **ratios of maximum demand to connected load** may be established by a series of such measurements for the various classes of consumers for which it is necessary to select transformers. These ratios or **demand factors** (Par. **112** to **118**) may then be applied with reasonable accuracy to the transformers for new consumers. The results of tests made on various groups of consumers in Chicago appear in Par. **112**.

112. Table of Demand Factors in Lighting Service
(Based on Chicago Experience)

Description of load	Number of customers	Kilowatts connected	Kilowatts demand	Demand factor (%)
Residence	137	84.7	18.9	22.3
Residence	68	126.6	15.75	12.4
Residence (119 kw.; stores 11 kw.)	196	129.5	28.85	22.3
Residence (1 customer, 7.5 kw.)	5	10.3	9.45	92.0
Residence 70 kw.; stores 7 kw.	77	77.0	21.0	27.3
Residence (59.7 kw.; hotel 48 kw.)	66	107.7	26.25	24.3
Residence (1 30-amp. rectifier)	121	183.5	30.5	16.6
Residence	34	47.5	10.5	22.2
Residence (2 30-amp. rectifiers)	19	79.2	15.7	19.8
Residence (1 30-amp. rectifier)	21	67.7	13.6	20.2
Residence (1 30-amp. rectifier)	21	54.1	13.1	24.3
Residence	47	68.7	8.4	12.2
Residence	144	129.95	22.6	17.4
Residence (4 30-amp. rectifiers)	43	59.0	26.6	42.0
Residence	85	99.65	16.1	16.1
Residence	84	112.5	14.7	13.2
Residence, 20 kw.; Stores 15.7 (hotel 25 kw.)	38	60.7	27.3	45.0
Residence	99	59.0	8.4	14.2
Residence	89	100.45	13.7	13.6

113. In store lighting the maximum demand for window lighting, signs and other display lighting is from 90 per cent. to 100 per cent. of the connected load. The demand on interior store lighting is from 50 per cent. to 70 per cent.

114. In residence lighting where the connected load is fifty lamps or less, the average demand factor of a group of residences is from 15 per cent. to 20 per cent. of the connected load; small residences and apartments having connected loads of forty lamps or less, average about 20 per cent. of the connected load.

115. In theatre lighting the border lamps and foot lamps, of several colors, are not used simultaneously; and the stage and the auditorium are not lighted simultaneously except for a very few minutes at a time. In a small theatre the demand factor may be from 70 per cent. to 85 per cent., while in a large theatre it frequently runs as low as 50 per cent.

116. Influence of number of consumers on demand factor. In general, a higher ratio must be used where but few consumers are served from one transformer, than where there are more, as the occasional maximum demands of individual consumers are proportionately much larger.

117. The selection of transformers for motor loads is more difficult, as the maximum load may vary greatly from day to day or from month to month. Elevator and crane motors require transformers having 100 per cent. to 125 per cent. of the rated motor capacity, unless there are several motors supplied by one unit. This is necessary in order to hold up the pressure in starting. The average demand factors in motor service in Chicago are given in Par. **118.** These figures were made up from several thousand installations of continuous-current motors in Chicago, which were equipped with maximum-demand meters.

118. Table of Demand Factors in Motor Service
(Based on Chicago Experience)

Total installation in h.p.	Number of customers	Total h.p. connected	Average maximum h.p.	Ratio of max. to conn. h.p.
1 motor,				
1 to 5........	1177	2165	1862	86.1
6 to 10........	124	1036	676	65.3
11 to 20........	32	492	303	61.6
above 20........	17	686	366	53.2
Total........	1350	4379	3207	73.3
2 motors,				
1 to 5........	177	412	285	69.1
6 to 10........	51	387	261	67.4
11 to 20........	30	438	288	65.9
above 20........	6	203	74	36.5
Total........	264	1440	908	63.0
3 to 5 motors,				
1 to 5........	150	381	314	82.5
6 to 10........	42	290	238	82.1
11 to 20........	33	475	329	69.3
above 20........	14	1245	657	52.7
Total........	239	2391	1538	64.3
6 to 10 motors,				
1 to 5........	42	121	80	66.0
6 to 10........	21	157	98	62.4
11 to 20........	10	155	98	63.1
above 20........	19	931	417	44.7
Total........	92	1364	693	50.8

SPECIAL METHODS OF TRANSFORMATION

119. General. The use of various primary and secondary voltages and systems gives rise to situations, at times, which require the distribution engineer to make use of special methods of transformation. Some of the combinations of apparatus and connections which are most likely to be used are presented herewith.

120. The connections of standard transformers are made with two primary and two secondary coils, which permits their use on 2,200-volt or 1,100-volt circuits. The secondary may be connected for 110 volts or 220 volts, or on the three-wire Edison system at 110–220 volts. Some systems use a transformer having windings for 1,040–2,080 to 115–230 volts.

121. Booster transformers. Where it is desired to raise or lower the pressure by a fixed percentage, as when line drop is excessive, this may be accomplished by a transformer used as a booster. This is a transformer so connected that the secondary is in séries and in phase with the main line and thus the primary pressure is raised by the amount of the secondary voltage, as shown in Fig. 31.

When the secondary is reversed, the transformer becomes a "choke," or **negative booster** depressing the line pressure instead of raising it. The connections for 5 per cent. and 10 per cent. "boost" are shown in Fig.

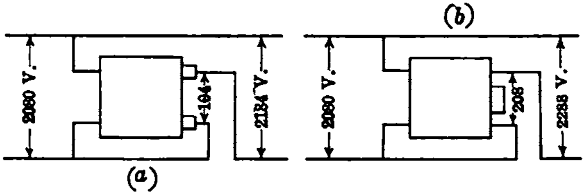


FIG. 31.—Booster transformer connection for positive boost.

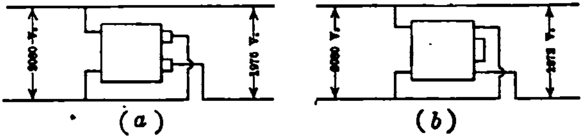


FIG. 32.—Booster transformer connections for negative boost or choking.

31, at *a* and *b* respectively. The corresponding connections for 5 per cent. and 10 per cent. choke (negative boost) are shown in Fig. 32.

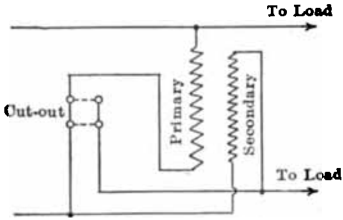


FIG. 33.—Connections of booster cut-out.

It is to be noted that the transformers used in these illustrations have a ratio of 10 to 1 or 20 to 1, and these percentages apply only to boosters having this ratio of transformation. If boosters having a ratio of 2,080 to 115–230 are used, the percentages are increased to about 5.5 per cent. and 11 per cent., respectively.

122. Precautions when installing boosters. If the primary of the booster is opened while the secondary is carrying the line current, the booster acts as a series transformer. The primary coils then generate a potential of 10,000 volts to 20,000 volts, or more, depending upon the load carried by the main circuit at the time. If a fuse is used in the primary, the blowing of the fuse will create this condition and the arc will hold across the terminals of the block, and is quite sure to break down the insulation of the primary coil.

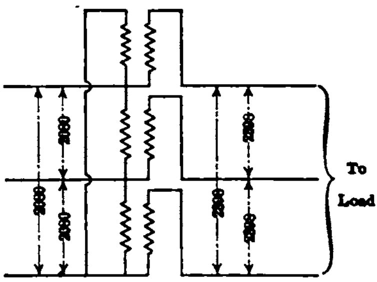


FIG. 34.—Connections of boosters in three-phase circuit.

The safest method of connecting or disconnecting a booster is to have the main line open while connecting it in or out of circuit. If the service cannot be interrupted, or if it is desired to switch the booster in or out at certain times, this may be accomplished by the use of a **series cut-out**, connected as shown in Fig. 33. The cut-out simultaneously opens the primary and short-circuits the secondary of the booster. Standard series-arc cut-outs should not be used where the line current is likely to be over 25 amp.

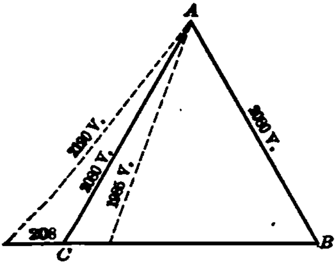


Fig. 35.—Effect of booster in one phase of three-phase circuit.

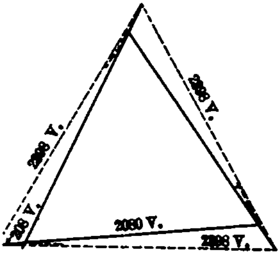


Fig. 36.—Effect of boosters in each phase of a three-phase circuit.

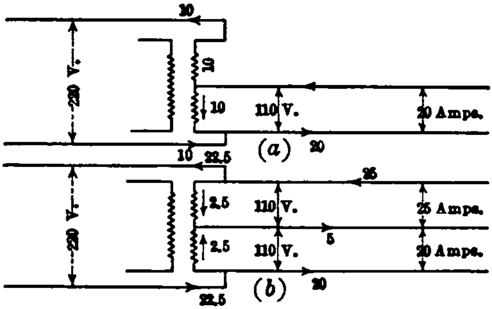


Fig. 37.—Connections of auto-transformers for 110-volt lighting.

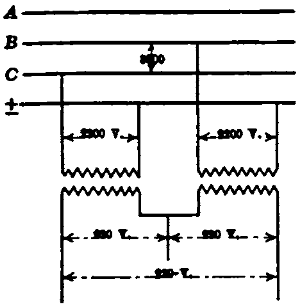


Fig. 38.—Open-delta connection of two transformers supplied from a three-phase four-wire system.

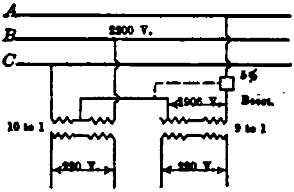


Fig. 39.—Transformation from three-phase to two-phase, or *vice versa*, with tee-connection.

123. The use of boosters in a delta-connected three-phase system is not so simple as in single-phase circuits. The booster secondary is looped into the line and pressure is taken for the primary from an adjoining phase, as in Fig. 34. The insertion of a booster on one phase affects the pressure on two phases, as shown diagrammatically in Fig. 35. The effect of a booster in each phase is shown in Fig. 36. Three boosters are required, therefore, to keep conditions in balance, in a three-phase three-wire circuit.

124. Auto-transformers. The use of 110-volt incandescent lamps in a 220-volt or 440-volt alternating-current system may be accomplished quite readily by the use of standard transformers used as auto-transformers. The connections in Fig. 37 show the methods of deriving two-wire and three-wire 110-volt distribution from a 220-volt system. When the lighting service is handled on a three-wire basis at 110–220 volts, the transformer carries only the unbalance of current; the primary winding is not used. Where 110-volt service is desired from a 440-volt plant, it may be secured from two transformers connected in series on the 220-volt side and in parallel on the primary side.

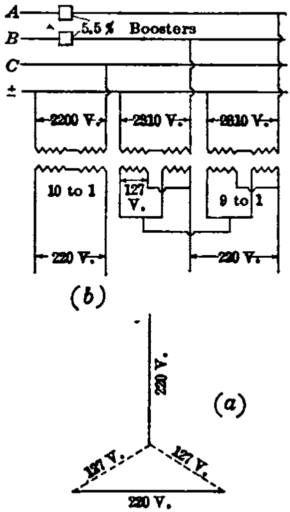


Fig. 40.—Two-phase service derived from a three-phase four-wire system with three transformers.

125. Three-phase conversion with two transformers. The cost of transformers for small three-phase motor service makes desirable the use of schemes of connections by which the three-phase secondary service may be derived from two transformers. Two schemes of connections are possible for this purpose, one known as the open delta and the other as the tee-connection.

The **open-delta connection** is merely an ordinary delta connection with one transformer left out (Sec. 6). Fig. 38 shows the open-delta connection supplied from a **three-phase four-wire** system. In this case the primaries are connected to two-phase wires and the neutral wire. In the open-delta connection the current in the transformer coils is 15.4 per cent. larger than with three transformers.

In the **three-phase three-wire** system, service may be given from two transformers with the **tee (T) connection** (Sec. 6). The current overload is 15.4 per cent.; as with the open-delta connection. This scheme cannot be used with standard 2,200-volt transformers on a four-wire system, as the principle of operation requires that the current divide and pass each way from the midpoint of the winding of one of the transformers, so that the magnetic field of one part balances the other.

126. Conversion from three-phase to two-phase, or vice versa. The **tee-connection** may be used in transforming from three-phase to two-phase, or *vice versa*, as shown in Fig. 39. with standard transformers having ratios of 9 to 1 and 10 to 1 respectively. If transformers having a ratio of 10 to 1 are available only, the right-hand transformer (Fig. 39) should be given a positive boost of 15 per cent. instead of 5 per cent. When using transformers having ratios of 9 to 1, the left-hand unit should be given a 10 per cent. negative boost, and the right-hand unit a 5 per cent. positive boost, in order to give 220-volt two-phase service from 2,200-volt primary mains.

127. Two-phase 220-volt service from a three-phase four-wire system may be secured with three standard transformers, connected as shown in Fig. 40. The unit at the left has a ratio of 10 to 1, and is connected from phase to neutral. The other two have ratios of 9 to 1, with their secondary coils in multiple, and are arranged as two limbs of a star-connection (Y), to give 220 volts across the outer wires. The three-phase system is therefore unbalanced by this arrangement, since half the energy is taken from one phase. The capacities of the transformers should be selected accordingly.

It is possible to use transformers with ratios of 10 to 1, but if this is done each of the phases supplying the right-hand transformer must be provided with a boost of 15 per cent.

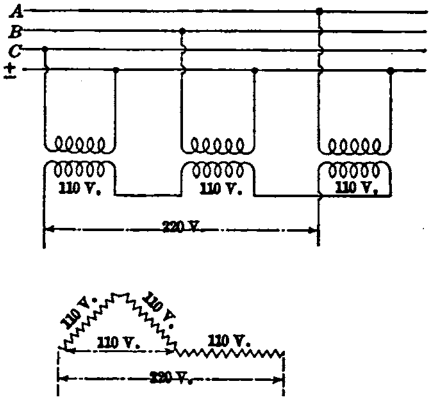


FIG. 41.—Conversion from three-phase to single-phase, with balanced load.

128. Conversion from three-phase to single-phase. In connection with electric welding and other work requiring single-phase energy in amounts so large that the unbalanced load is serious, the load may be equally distributed among the three phases by the scheme of connections shown in Fig. 41. Equal currents are drawn from the three phases to supply 220-volt single-phase energy. Each transformer must have capacity to carry the entire secondary single-phase current, so that the total transformer capacity must be 1.5 times the load.

PROTECTIVE APPARATUS

129. The insertion of fuses for protection in low-tension lighting systems has become universal, because of the low cost of fuses as compared with circuit breakers. In power systems where the circuits are opened frequently, the circuit-breaker is found preferable.

130. Plug-fuses. The fire hazard from the flash which occurs at the melting of a fuse led to the development of **enclosed fuses**, the earliest of which was the Edison plug-fuse, which is used very generally on circuits up to 20 amp.

131. Cartridge fuses. Cartridge fuses, consisting of a tube of fibrous material in which the fuse is mounted, with a **filler** of fire-resisting powders are used largely on circuit operating at 250 to 600 volts. Cartridge fuses have been fully standardized by the National Electrical Code as to voltage and current as follows: 250-volt: 0–30 amp., 31–60 amp., 61–100 amp., 101–200 amp., and 201–500 amp.; 600-volt: 0–30 amp., 31–60 amp., 61–100 amp., and 101–200 amp.

132. The law of the operation of fuses was discovered by Preece in 1888. It may be stated in the form,

$$\text{Current} = a\sqrt{d^3} \qquad (6)$$

On low-potential circuits the circuit-breaker consists of a switch of suitable design, with which is combined a series coil so arranged that it lifts a movable core and releases a spring-actuated mechanism which opens the switch. Circuit-breakers are designed so that they may be adjusted to operate at any point between 80 per cent. and 150 per cent. of their rated capacity.

In **high-potential systems** a series transformer may be installed at a convenient point to operate the tripping-coil of the circuit-breaker. On circuits operating at pressures above 600 volts the switch is designed to break in oil.

141. The operating mechanism of the circuit-breaker may be controlled by hand, or electrically by means of solenoids. In **hand-operated breakers** the energy required to open the circuit is stored in springs compressed during the act of closing. In **electrically operated breakers** the power for both closing and opening the circuit is supplied through solenoids or motors.

The larger sizes of circuit-breakers and those operating at the higher voltages are usually controlled electrically, on account of the power required, and because of the greater facility of operation. Continuous current is usually available in generating stations and substations, from the exciter system, and is therefore used for the operation of solenoid-controlled breakers where possible. Motor-operated breakers are often equipped with alternating-current motors.

142. Relays. It is usual to design relays for operation with an **inverse time element**; that is, with a relay set to operate at 100 amp. after 10 sec., it will operate at about 300 amp. in 5 sec. and almost instantaneously at 1,000 amp. This characteristic gives prompt action in opening the line under short-circuit, while reducing the likelihood of unnecessary interruption under brief overloads.

143. The arrangement of relays must be such that a short-circuit between any two wires will operate the breaker. On single-phase circuits

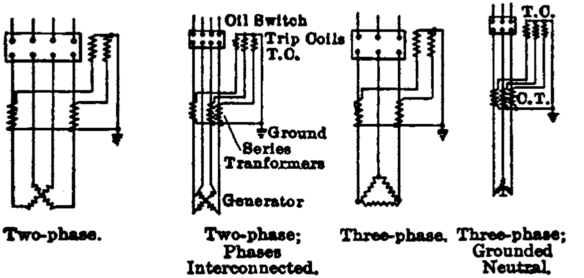


FIG. 42.—Relay arrangements for two-phase and three-phase circuits.

one relay is sufficient to accomplish this. On two-phase systems supplying lighting and motor service it is desirable to provide separate relays and circuit-breakers for each phase. In the three-phase, three-wire system without grounded neutral, relays are required in two of the three wires; the three-pole type of circuit-breaker is used. In the three-phase, four-wire system having the neutral point grounded, it is essential that relays be installed in each phase wire, with single-pole breakers; in case of a ground on one phase the corresponding circuit-breaker opens without interrupting the lighting service on the other phases (Fig. 42).

144. Relays on three-phase transmission lines. It is customary to provide relays at the point of supply, commonly called **overload relays**. Where several lines are operated in parallel, further protection is necessary. When the lines are connected to the same bus at each end, a short-circuit will draw energy from both ends and circuit-breakers must be provided at both busses. The relays at the receiving end must, however, be of a type which will operate only on reversal of the flow of energy. The converting equipment is provided with reverse-power relays on the secondary side.

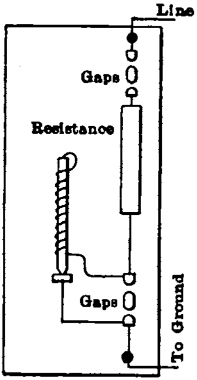


FIG. 43.—Solenoid type of lightning-arrester.

145. Speed-limiting devices. It is important that synchronous converters be protected by speed-limiting devices designed to operate the direct-current circuit-breaker when the speed exceeds a safe value.

146. Lightning Protection. Overhead distributing lines are susceptible to the effects of lightning. A discharge among the clouds causes an abrupt discharge of potential on the wires, which must be given an opportunity to escape to earth without injuring the insulation of the apparatus.

147. The function of lightning-arresters is to protect apparatus by passing the discharge of lightning to ground, without permitting the arc thus established to be maintained. This may be accomplished on potentials up to 600 volts by a short gap of non-arcing metal. At 2,200 volts or higher, several gaps in series are necessary, with a resistance to limit the current. Since each wire of the circuit is affected, discharge gaps must be provided between each wire and ground.

In systems having one side grounded, every discharge is likely to be followed by the generator current, as there is a fixed difference of potential between the circuit and earth. Arresters on grounded systems must, therefore, meet more severe requirements than those on ungrounded systems.

The problem of protection of transmission lines becomes more complex as the voltage is increased, and the study of protective methods for lines operating at 20,000 volts and upward is leading to new developments every year. The discussion in this Section will be restricted to alternating-current distributing systems operating at less than 5,000 volts.

148. Types of Arresters. The wide range in severity of lightning flashes makes it well-nigh impossible to design an arrester which will protect apparatus and yet withstand the effects of a direct stroke at any point nearby. The arresters described in the succeeding paragraphs (Par. **149** to **152**) include the leading commercial types which have been used in distribution work.

149. The Garton-Daniels arrester, Fig. 43, consists of air gaps and resistances, with a solenoid so arranged that the plunger is raised by the passage of the generator current, thus placing additional gaps in series and rapidly diminishing or stopping the flow of energy. The lightning discharge passes across the shunted gaps to ground owing to the inductance of the solenoid.

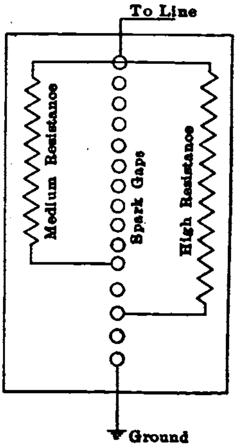


FIG. 44.—Multi-gap lightning-arrester.

150. Multi-gap arrester. A modification of the spark-gap and resistance type of arrester has been employed quite extensively. This is illustrated in Fig. 44, as made for 2,300 volts, and consists of three paths of discharge, one of which has a high resistance (100,000 ohms), another a resistance of about 300 ohms, and a third which consists of 13 or 14 gaps without resistance. The impedance of the unit is such that discharges of very high frequency pass over the 13 gaps, while those of lower frequency pass over the smaller number of gaps through one of the resistances. A slightly modified form is shown in Fig. 45.

151. The aluminum-cell arrester has given good results because of its ability to stop the flow of current promptly and safely. It has been found especially valuable at transmission voltages where its expense is justified by the importance of the service. It is not suited for outdoor distribution work, since it requires daily charging and supervision and cannot be left continuously in circuit.

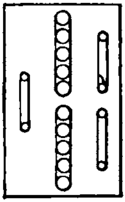


FIG. 45.—Westinghouse low equivalent arrester.

152. The compression type of arrester, Fig. 46, consists of a series resistance with air-gaps, assembled inside of a porcelain tube, the top of which is capped and sealed. The air-gaps are surrounded by a grounded strip of iron outside of the tube, which acts as a means of equalizing the potential gradient. The discharge of the arrester expands the air and compresses it, since the tube is sealed; hence the name compression type. This arrester, having but one path to ground, is of limited capacity.

153. Location of arresters. All of the above-described types of arresters are in general use on distributing systems in America, and each gives reasonably good protection to apparatus when placed in its immediate vicinity. Experience has fully demonstrated that lightning discharges do not travel any great distance along a line, owing to the very high frequencies of this form of energy. The arrester must, then, be located as near the apparatus as practicable, and preferably on the same pole. Complete protection of distributing transformers would require that an arrester be placed on every transformer pole.

The experience of large companies, however, has been that the cost of the damage to apparatus from lightning is not as large as the fixed charges on the arrester equipment, when complete protection is provided. The exact point at which these two elements of cost become a minimum varies with the value and the size of the transformers, since it costs as much to protect a 1-kw. unit as a 50-kw. unit. Practice has not yet become standardized, as the subject is still being studied and reliable conclusions can be reached only after a number of years' further experience.

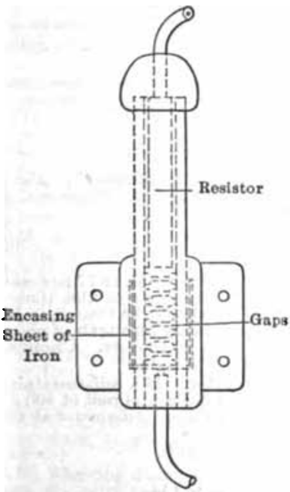


FIG. 46.—Compression lightning-arrester.

154. The use of lightning-arresters on transformer poles has been found to materially diminish the number of interruptions of service due to blowing of transformer fuses, and this tends to make the more liberal use of arresters desirable.

OVERHEAD CONSTRUCTION

155. General. Overhead construction is an economic necessity in a large part of every city. The **investment** for overhead lines in outlying districts usually is from 15 per cent. to 30 per cent. of that required for underground construction, and it is obvious that overhead construction must be used wherever feasible, to keep the investment within profitable limits.

In many cases the objection to overhead lines is minimized by locating them in alleys.

156. Poles. Distribution lines are necessarily carried on wooden poles. Iron poles are objectionable on account of the risk to linemen in handling "live" primary circuits. Iron poles are used in some cases for street-lighting circuits which are so operated that it is not necessary to do any work on them while they are "alive." The **cost** of iron poles is about **twice** that of wooden poles.

157. Concrete poles are being used increasingly in sections where the ravages of insects and the nature of the soil make the life of wooden poles very short. They are also being introduced for transmission work in places where iron poles would otherwise be required.

158. The woods which are best suited for pole work are Michigan cedar, Western cedar, chestnut, pine, and cypress.

159. The Michigan cedar grows with a natural **taper** of about 1 in. in diameter to every 5 ft. or 6 ft. of length, making a very substantial and rigid pole.

160. The Western cedar, which grows in Idaho and Oregon, has a natural **taper** of about 1 in. in 8 ft. to 10 ft. of length. For the same size of top the diameter of the butt is, therefore, smaller than that of the Michigan cedar. The surface of Western cedar is smoother than that of the Michigan cedar and the poles are very straight and neat in appearance. It is necessary on important lines to use nothing smaller than 8-in. tops with these poles, in order to secure adequate diameter at the ground line.

161. The chestnut pole is quite different from the cedar poles. The specific gravity of the wood is high and the surface is irregular and knotted, making the appearance of the chestnut pole not as good as that of cedar.

162. Pine and cypress poles are more like cedar in their general characteristics of weight and strength. Their use is limited to sections of the country where the timber is native, as their life is comparatively short.

163. On the Pacific coast, California redwood and some other native woods are used very generally.

164. Pole stresses. The stress acting on a pole at the top causes a tension in the fibre of the wood on one side of the pole and a compression on the opposite side. For a round pole the maximum fibre stress is:

$$f = \frac{384\,PL}{3.14\,(d)^3} \quad \text{(lb. per sq. in.)} \qquad (7)$$

in which P is the pull at right angles, in pounds, at the distance L ft. above ground, and d is the diameter at the ground line, in inches. Expressed in another form, Eq. 7 becomes,

$$d = \sqrt[3]{\frac{384PL}{3.14f}} \quad \text{(in.)} \qquad (8)$$

The unit stress f should be taken at not more than 10 per cent. to 12 per cent. of the ultimate breaking strength, as determined by tests of the timber in the form of poles; that is, the **factor of safety** should be from 8 to 10. Cedar, redwood and pine have an **ultimate breaking strength** of about 7,000 lb. per sq. in. when tested in the form of large timbers. Chestnut is slightly stronger, having a strength of 8,000 lb. per sq. in.

165. Example of calculation of pole diameter. If a self-sustaining (unguyed) pole is to support a line which exerts a horizontal pull of 800 lb. at a height of 30 ft. above the ground, what should be its diameter at the ground line to safely carry the load?

$$f = \tfrac{1}{10} \text{ of } 7{,}000 = 700;\ P = 800,\ L = 30 \text{ ft.}$$

$$d = \sqrt[3]{\frac{384 \times 800 \times 30}{3.14 \times 700}} = \sqrt[3]{4{,}193} = 16.1 \text{ in.}$$

This would call for the use of a 35-ft. pole with a butt-diameter of 16 in. at the ground line. The top-diameter of a Michigan cedar pole of this size would be from 8 in. to 9 in. In city practice where turns are made at right angles, which cannot be supported by a guy, the use of such poles is often necessary.

166. Wind pressure. The design of pole lines to withstand wind pressure must be considered where they are exposed, though the average pole-line distribution is so protected by buildings and trees that it is not subject to the full force of windstorms. The wind pressure on a normal flat surface is

$$p = 0.004\ V^2 \qquad \text{(lb. per sq. ft.)} \qquad (9)$$

where V is the velocity in miles per hr.; if Weather-Bureau observed velocities are used, they should be corrected.* Thus $p = 40$ lb. per sq. ft. at 100 miles per hr., 22.5 lb. at 75 miles, 10 lb. at 50 miles, and 2.5 lb. at 25 miles. The pressure on a cylindrical surface whose axis is normal to the wind is one-half that on a plane surface equal in area to the projected area of the cylinder. Thus for round smooth wires:

$$p = 0.002\ V^2 \qquad \text{(lb. per sq. ft.)} \qquad (10)$$

For bare concentric strands H. W. Buck† found that the constant in Eq. 10 is 0.0025.

The wind pressure on a 40-ft. pole, of which 34 ft. is above ground, with 7-in. top and 14-in. butt, would be calculated as follows. Projected area $= \{(7+14)/2\} \times 34 \times 12 = 4{,}284$ sq. in. $= 29.75$ sq. ft. Assuming a wind velocity of 60 miles per hr., $p = 0.002 \times (60)^2 = 7.2$ lb. per sq. ft. Total pressure on pole $= 29.75 \times 7.2 = 214$ lb. This force acts at the centre of gravity of the projected area, which is a long narrow trapezoid; or 15.1 ft. from the ground-line. The moment of this force about the ground-line is therefore $214 \times 15.1 = 3{,}230$ lb-ft. Taking the diameter of No. 6 A.W.G. triple-braid weather-proof wire as 0.32 in., the total wind pressure at 60 miles per hr., on a 120-ft. span, would be 23 lb. and on twenty wires it would be 460 lb.; this resultant force would act at a point about 3 ft. below the top of the pole, or 31 ft. from the ground-line. The resulting moment would be 14,260 lb-ft. The sum of the wind pressures on pole and wires would be $3{,}230 + 14{,}260 = 17{,}490$ lb-ft. A rough-and-ready rule is sometimes used that the wind pressure on the pole itself is about equal to that on five No. 6 A.W.G. weather-proof wires.

High wind velocities are attained at times in nearly all parts of North America, and it is advisable, therefore, to provide pole braces or guys on exposed lines.

167. Selection of poles. It is usual to select poles with 7-in. tops for important distributing lines.

The **height** of the poles selected for distribution purposes must be governed by the clearance over local obstructions and also by the number of cross-arms to be carried on the poles. Clearance over trees is especially troublesome in residence sections where trimming will not be permitted. In general it is desirable to use poles not less than 30 ft. long where primary lines are carried, and in built-up sections a minimum size of 35 ft. is preferable.

168. Poles for joint-line construction. Where joint-line construction with standard cross-arms is used, it is not usually possible to employ poles shorter than 35 ft. In a few cases the lines have been placed in cable and carried on 25-ft. poles on rear-lot lines. The use of poles over 40 ft. long is to be avoided wherever possible, on account of the cost, the increased danger in storms and the difficulty of handling transformers and service connections.

169. Poles should be spaced in approximately equal span lengths of about 100 ft. to 125 ft., to keep the sag within safe limits and to provide a sufficient number of points at which service drops may be taken off. The spans near self-supporting corner poles should be about 75 ft. long in order to relieve the strain on the corner pole. **The poles should be placed** opposite lot-lines to avoid interference with the rights of abutting-property owners.

170. Shaving and painting. It is considered good policy to carefully shave all poles, trim the knots, and give them two coats of paint. A dark green color is very commonly used because of its harmony with foliage in residence districts.

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* Fowle, F. F. "A Study of Sleet Loads and Wind Velocities;" *Electrical World*, Vol. LVI, 1910, p. 995.

† Buck, H. W. "The Use of Aluminum as an Electrical Conductor;" *Trans.* International Electrical Congress, St. Louis, 1904.

171. Stepping. Transformer poles and others which are climbed at frequent intervals should be provided with pole steps. It is the practice in many of the large city systems to provide steps on all poles.

172. Gaining. The gains should be cut for the cross-arms before the poles are erected. The **distance between cross-arm centres** must be sufficient to give clearance for service drops and allow a safe working space for linemen. The space usually allowed is about 24 in.

173. Pole setting. Experience has proven that the following practice is conservative, as regards the depth of setting.

Size pole (ft.)...............	30	35	40	45	50	55	60	70
Depth (ft.).................	5	5.5	6	6.5	6.5	7	7	7.5

Corner poles should be set about 6 in. deeper than the above. In rocky soil where boulders may be tamped about the poles, they need not be set as deep.

The poles should be placed so as to bring their natural curvature into the plane of the line. At corners a slight **rake** may be given in a direction opposite to the pull of the load. Several tampers should be employed to one shoveler, in **back-filling**, in order to insure the stability of the pole. Water may be used to advantage, where available, in settling the back-fill. In swampy soil, the digging of holes is greatly facilitated by the use of a **sand-barrel.** This consists of a sheet-iron cylinder about 30 in. in diameter and 3 ft. long, which is separable into two parts lengthwise, and is readily removed after the pole is in place. Various methods of setting are shown in Fig. 47.

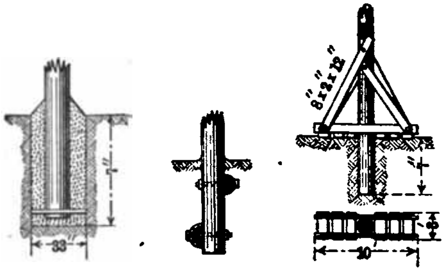

FIG. 47.—Methods of setting self-sustained poles.

174. Guying and bracing. Where the direction of a line changes, the tension of the wire should be supported by guying or bracing. The bracing method requires considerable space, and is more unsightly than a guy. Guys are secured in various ways, depending upon the space and the clearance required. Where nothing prevents, the guy cable may be secured to an **anchor** of timber or some form of patent anchor (Fig. 48). On public thoroughfares guys cannot be run directly to anchors without interfering with traffic, and the guys must be run to **stubs** at such height as to permit free passage of traffic beneath. Guys over roadways should clear about 25 ft., and those over pathways about 12 ft. (Fig. 48).

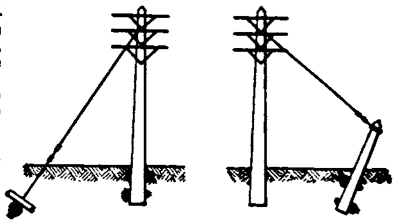

FIG. 48.—Anchor and stub guy.

Where side-arm construction is used it is necessary at corners to guy the cross-arms as well as the poles. At heavy corners a "head" guy is run from the base of the corner pole to the upper part of the next pole in the line.

The tension in the corner spans may thus be reduced, relieving the strain on the corner pole. In straight-away lines the head guy is used to limit the extent of damage in case several poles go down; this is sometimes called "storm guying."

175. Galvanized steel cable is generally employed for guying purposes because of its high tensile strength. Such cable is made in sizes varying in diameter by steps of $\frac{1}{16}$-in., from $\frac{1}{4}$-in. up. The **ultimate breaking strength of $\frac{1}{4}$-in. cable** is about 3,000 lb.; $\frac{5}{16}$-in., 4,500 lb.; $\frac{3}{8}$-in., 6,000 lb.; and $\frac{1}{2}$-in., 12,000 lb. Having calculated the tension, the size of guy cables should be such that the strain will be from one-fourth to one-fifth the ultimate breaking strength of the cable, or the **factor of safety of the steel cable,** from 4 to 5. Anchors should be placed at a distance from the pole not less than one-quarter the height of the guy attachment. In general, $\frac{1}{4}$-in. cable is used for the smaller loads, while the $\frac{3}{8}$-in. size is standard for corner poles where the load of the ordinary two-arm to three-arm distribution line is to be supported.

176. Strain insulators. It is important that guy cables attached to stubs be equipped with strain insulators not less than 8 ft. from the ground. This precaution is advisable for the protection of the public and of linemen.

177. Cross-arms. Southern pine and **Oregon fir** are the best woods for cross-arms because of their straight grain, high tensile strength, and durability. The **cross-section** should be such that the arm will safely bear

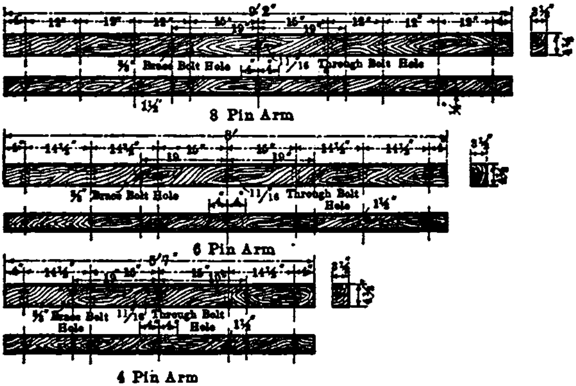

FIG. 49.—Dimensions of standard cross-arms.

the weight of a lineman in addition to that of the wires. Experience indicates that a cross-section 3.5 in. wide by 4.5 in. high is ample for the average requirements of distributing lines. For transformers of 20 kw. and larger it is usual to provide arms of a larger cross-section. Main lines are commonly built of six-pin arms, with four-pin arms on the smaller distributing lines. Where secondaries for both lighting and motor service must be carried on the same arm, it is usually necessary to employ six-pin arms.

The **spacing of pins** should provide safe working room for linemen and should take into account the average sag of the wires. Under the usual working conditions of distributing lines, it is not safe to attempt to use spacings less than 12 in. The spacing of the pole pins must give sufficient room for the men to climb to the upper arms, at least 30 in. being required for safety. The dimensions and spacings of standard cross-arms are shown in Fig. 49.

178. Double cross-arms. At corners, terminals, and other points where any unusual load is to be supported, the poles should be fitted with double arms. In turning corners on a single pole, the double-arming of in which T is the tension in pounds, L is the span length in feet, w is the weight per foot of conductor and S is the sag in feet at the centre of a horizontal span. If the span length is doubled, the tension must be quadrupled in order to keep the sag the same. If the tension is the same on several spans of different lengths, the sag is different in each span. The sag of any span when the tension is known is found by changing Eq. 11 to the form, $s = L^2w/8T$.

183. The maximum tension in a span is limited by the strength of the wire and supports. The **ultimate breaking strength of annealed copper wire** is about 34,000 lb. per sq. in., but the working stress should not be over one-fourth of this. The **ultimate tensile strength of hard-drawn wire** is about 60,000 lb. per sq. in. Such wire is left in the hardened condition in which it comes from the wire-drawing dies, which gives it greater strength and stiffness. The hard-drawn wire, however, should not be scratched in handling, as any injury to the surface increases the likelihood of fracture. If it is heated for soldering, its strength is reduced. Hard-drawn wire, therefore, is not adapted to general distribution work where taps must be made with soldered connections at frequent intervals, but for transmission lines and series-arc circuits it has advantages which are generally recognized.

184. The sag and tension of weather-proof, annealed wire and bare, hard-drawn wire may be readily determined from the tables in Par. **185** and Par. **186**.

185. Sag Table for Weather-proof Annealed Copper Wire

Size A.W.G.	10	8	6	4	2	1	0	2/0	3/0	4/0
Tension at 1 ft. sag (lb.)	62	92	140	204	318	390	486	607	767	942
Sag at 100 lb. tension (ft.)	0.62	0.92	1.40	2.04	3.18	3.9	4.86	6.07	7.67	9.42
Weight of wire, lb. per 1,000 ft.	50	74	112	163	254	312	388	486	614	754
Breaking stress (lb.)	283	440	700	1114	1772	2234	2818	3553	4480	5650

186. Sag Table for Bare Hard-drawn Copper Wire

Size A.W.G.	10	8	6	4	2	1	0	2/0	3/0	4/0
Tension at 1 ft. sag (lb.)	39.3	62	99	157	161	202	400	505	636	800
Sag at 100 lb. tension (ft.)	0.393	0.62	0.99	1.57	1.61	2.02	4.0	5.05	6.36	7.80
Weight of wire, lb. per 1,000 ft.	31.4	50	79.5	126	201	253	320	403	508	640
Breaking stress (lb.)	500	778	1240	1960	3120	3743	4560	5271	6590	8310

187. Use of sag tables. The tension at any other sag, or the sag at any other tension, or the sag or tension in any other length of span, may be readily found from the Tables (Par. **185** and **186**) as follows:

The tension at any other sag is $T' = T/S$, in which S is the sag in feet at which the tension is desired and T is the value at 1-ft. sag in the table. For example, the tension in a 100-ft. span of No. 0 weather-proof wire at a deflection of 2 ft. is

$$T' = \frac{T}{S} = \frac{486}{2} = 243 \text{ lb.}$$

Similarly, the sag at any other tension is $S^1 = S \times 100/T$, in which T is the assumed tension and S is the value of sag at 100 lb. tension in the table. For example, with No. 0 weather-proof wire the sag at 300 lb. is

$$S' = \frac{S \times 100}{T} = \frac{4.86 \times 100}{300} = 1.62 \text{ ft.}$$

For spans of other lengths, the sag or tension varies in proportion to the square of the length of the assumed span. That is,

$$S' = \left(\frac{L'}{100}\right)^2 S, \text{ and } T' = \left(\frac{L'}{100}\right)^2 T. \qquad (12)$$

For example, with No. 4/0 bare wire the tension with a span of 150 ft., at 1-ft. sag, would be

$$T' = \left(\frac{150}{100}\right)^2 \times 800 = 1{,}800 \text{ lb.}$$

Or if the tension of the line were 100 lb. in all the spans, the sag in a 150-ft. span would be

$$S' = \left(\frac{150}{100}\right)^2 \times 8 = 18 \text{ ft.}$$

188. Expansion and contraction of spans with temperature changes. The changes in sag due to expansion and contraction under varying temperatures are of much importance in the erection of the conductors. Lines erected during the winter months are likely to be too slack during the summer, and allowance should be made accordingly. The length of wire in a span, disregarding the elastic stretching due to the load, varies in proportion to the coefficient of expansion and the range of temperature:

$$L_t = L_o(1 + \alpha_o t) \qquad (13)$$

in which α is the coefficient of expansion, t is the temperature in deg. fahr. and L_o is the length of wire at zero temperature. When the length L_{t1} is known at some other temperature t_1, the formula becomes

$$L_t = L_{t1}\left(\frac{1 + \alpha_o t}{1 + \alpha_o t_1}\right) \qquad (14)$$

The linear coefficient of expansion of copper is 0.000017 per deg. cent. or 0.0000094 per deg. fahr. P. H. Thomas has worked out a graphical solution* of sag problems which is very useful where accurate results, with considerable variation of temperature and load, are required.

In practice the pole supports have a certain degree of flexibility which tends to take up part of the slack caused by expansion and to prevent excessive strains being placed on the wires by contraction during cold weather.

189. Table of sags recommended by National Electric Light Association. The following table, adopted by the N. E. L. A., represents good practice in wire-stringing at various temperatures, the deflection at the centre of the (horizontal) span being given in inches.

190. Table of Standard Sags Recommended by the National Electric Light Association

Deflection (sag) in inches

Span in feet	Temperature in deg. fahr.						
	30	40	50	60	70	80	90
50	8	9	9	10	11	11	12
60	10	11	11	12	13	14	14
70	11	12	13	14	15	16	17
80	13	14	15	16	17	18	19
90	14	16	17	18	19	20	21
100	16	17	19	20	21	23	24
110	18	19	21	22	24	25	26
120	19	21	23	24	26	27	28
130	22	24	26	28	30	32	33

191. Transformer installations. Transformers are usually supported on cross-arms by means of iron hangers. This class of construction is suitable for transformers of capacities up to 20 kw. For larger units the cross-arms should be double, and heavier than the standard arm. Large transformers which cannot be placed inside the building are often installed on a platform between two poles.

192. Grounded secondaries. To protect life and property in case a primary circuit becomes crossed with a secondary, it is very important

* Thomas, P. H. "Sag Calculations for Suspended Wires;" *Trans.* Amer. Inst. of Elec. Eng.; Vol. XXX, 1911; p. 2229.

that the secondary be grounded. This is preferably done by connecting the secondary circuit to **water pipes** where these are accessible. Where the ground must be made outdoors, the most practicable method is to drive a galvanized **iron pipe** into the ground to a depth of about 8 ft. The points to be grounded in various kinds of secondary mains are indicated in Fig. 52.

193. The grounding of secondaries up to 150 volts has been required by the National Electrical Code since 1913. There is some doubt as to the advisability of grounding secondaries when the difference of potential between any wire and ground is higher than 250 volts, owing to the possibility that shocks from such a system may prove fatal.

194. When the ground connection is made to a pipe at the pole, the ground-wire is preferably brought down the pole in half-round wooden moulding. The ground-wire may be soldered to the pipe about a foot above the ground, or may be attached by means of a pipe cap as shown in Fig. 53.

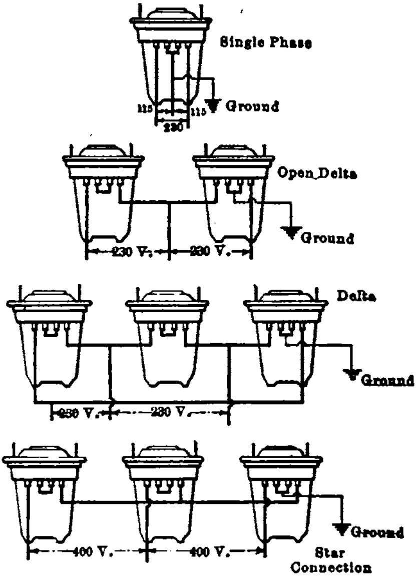

Fig. 52.—Connections for grounded secondary.

195. Arrangement of wires. The position of wires on the cross-arms should be assigned according to a systematic plan. Circuits should be kept on the same pins throughout their course, to facilitate maintenance work. In general, through lines should be carried on the upper arms and local distributing lines at the bottom. All the wires of a circuit should be carried on adjacent pins. Connections carried across the pole for transformers or service drops should leave one side of the pole free for climbing.

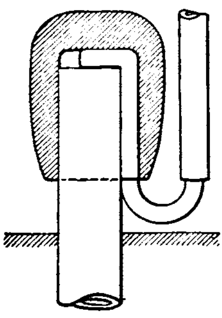
Fig. 53.—Ground-pipe cap.

196. Joint occupancy of pole lines. The use of a joint line of poles is preferable to separate lines, on thoroughfares where there are many service drops, as it avoids much confusion. Where poles are occupied jointly by both electric-light and telephone companies, *the lighting wires should always occupy the upper position.* A clearance of about 4 ft. should be maintained between the lower lighting wires and the telephone wires. Joint-line construction is the rule in most of the larger cities. For details of recommended forms of joint-line construction, see the "Report of Committee on Overhead Line Construction," *Trans.* N. E. L. A., 1911.

UNDERGROUND CONSTRUCTION

197. Edison tube system. The underground system devised by Edison consisted of 20-ft. lengths of iron pipe inside of which were copper rods imbedded in compound to exclude moisture. These lengths were made with various sizes of conductor from No. 4 A.W.G. up to 500,000 cir. mils for mains and up to 1,000,000 cir. mils for feeders. Feeder tubes were provided with three pressure wires to indicate at the station the pressure at the end of the feeder.

198. Arrangement of Edison tube system. Edison tube is joined by stranded connectors enclosed in cast-iron couplings which are filled with hot compound. At intersections the tubes are interconnected through fused junction boxes. Such tube lines are carried along each side of the street near the curb except where consumers are scattered or where an alley is used. The Edison tube system was the standard method of distributing low-tension energy underground until about the year 1897. The change to cable was made on account of the inability of the tube feeders to carry overloads without causing burn-outs. The necessity of opening street pavements in each case where repairs were made, also involved considerable expense.

199. Conduit systems. The early alternating-current and series-arc systems which were installed underground were unable to use a system similar to the Edison tubes because of the higher voltages employed. They were compelled to devise a drawn-in conduit system with manholes for handling the cables. Creosoted wooden pump log was tried and was satisfactory for some classes of work, but was too short-lived and inflammable.

Other systems were devised in which the ducts were intended to provide insulation, but experience proved that it was not practicable to maintain such a system. This led to the development of methods in which the insulation was applied to the conductor and the conduit was of some durable fire-proof material.

200. Modern standard conduit systems. Various forms of duct were tried out, but the most suitable were found to be those of fire-proof material such as terra cotta and clay tile.

A conduit made entirely of concrete and known as **stone pipe** has been used to some extent instead of clay tile. This is made in 5-ft. lengths and jointed with metal ferrules to preserve the alignment, single duct only being used. The conduit is laid in concrete, making a solid and durable duct system. The concrete pipe is fragile, however, and the breakage is likely to be greater than with the tile duct, if not carefully handled.

Various forms of **fibre conduit** have also been used to some extent. These are laid with concrete around and between them, so that if the fibre disintegrates in after years there will remain a concrete duct system. The principal advantage is in the ease of handling and lack of breakage.

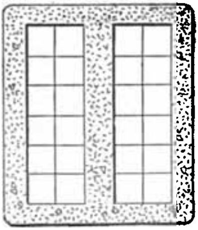

Fig. 54.—Arrangement of ducts for a large line.

201. Laying out a conduit line. In the design of a draw-in duct system, the number of ducts, the size of manholes and their location are the important considerations. The number of ducts must be sufficient to care for the local distribution, for feeders, for transmission lines and for future requirements. It is desirable to lay sufficient reserve ducts to care for probable requirements for about 5 years ahead.

The **maximum number of ducts** which it is advisable to put into a line is governed chiefly by the safety of the cable equipment. The space available for training the cables is limited, and if more than twenty to twenty-five cables are carried through a manhole, a large part of the load is endangered by a failure of any of the cables. Where conditions are such that a very large line must be used, protection may be had by separating one-half of the duct line from the other by a 6-in. concrete barrier and by building double manholes. A line having more than four ducts in each layer is to be avoided where possible on account of the difficulty of properly training the cables. The arrangement shown in Fig. 54 is a desirable one where [illegible] or more ducts are laid.

202. Manholes. Manholes must be provided in sufficient number to permit the drawing in of cable without overstraining the insulation. Thus the **manhole spacing** should be not over 500 ft., with large cables 400 ft. is a safer limit. Where distribution by overhead lines in alleys with underground lines on the street is used, manholes should be put opposite alley intersections as far as possible. The number of manholes required where numerous underground service connections are needed must usually be sufficient to enable services to be brought in at intervals of 25 ft. to 100 ft. In distribution by means of subway-type transformers and a secondary network, it is usually necessary to build extra large manholes for the transformers in order to get sufficient room and proper ventilation.

Manholes should be so designed that the cables may be trained with a minimum of waste and with sufficient space to enable a jointer to work efficiently, as in the oval-shaped manhole shown in Fig. 55. At intersections a square design is preferable, as shown in Fig. 56. In practice it is usual to provide manholes 5 ft. by 5 ft. at **junctions** where there are eight ducts, that is, where two four-duct lines cross; 6 ft. by 6 ft. where there are twelve to eighteen ducts; 7 ft. by 7 ft. where there are twenty or more, and larger as the needs of the case may require.

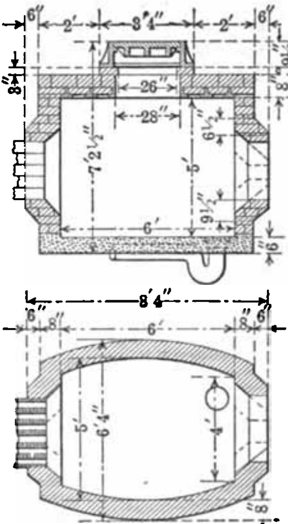

FIG. 55.—Oval manhole.

The size and the shape of manholes are often governed by local obstructions such as gas or water pipes, or conduit lines of other companies. The depth must be sufficient to give head room, and yet should not be so great as to carry the floor of the manhole below the sewer level. Service manholes may be 5 ft. high inside but junction manholes should be 6 or 7 ft. from roof to floor. In some cases a shallow form of manhole known as a **handhole** is used for distribution laterals. These are made about 3 ft. by 4 ft., and 4 ft. deep. They are placed above the conduit line so that only the top row of ducts enters the handhole. The distributing mains are thus accessible for service taps, and the through lines in the lower ducts are not in the way.

203. Forms of duct. Tile conduit is made in single- and multiple-duct pieces, single-duct pieces being about 18 in. in length, and multiple-duct 36 in. long. The dimensions of ducts in general use are shown in Fig. 57. Multiple-duct is somewhat cheaper than an equal number of single ducts and requires less labor. In a large system it is considered preferable to use single-duct to secure the advantage of having two thicknesses of tile between adjacent ducts. The single-duct also has the further advantage that the joints may be staggered, thus making it less likely that the heat of a burn-out may damage the cables in adjoining ducts.

204. Installation of conduit system. In laying a line of ducts the grades must be carefully established so that no pockets are formed where standing water may freeze and injure the insulation of the cables and break the tile. It is important that manholes where work must be done frequently, or where transformers or junction boxes are installed, be provided with sewer connections. The conduit line is protected from future excavators, and made secure against the possibility of getting out of alignment, by surrounding it with 3 in. of concrete on all sides. The con-

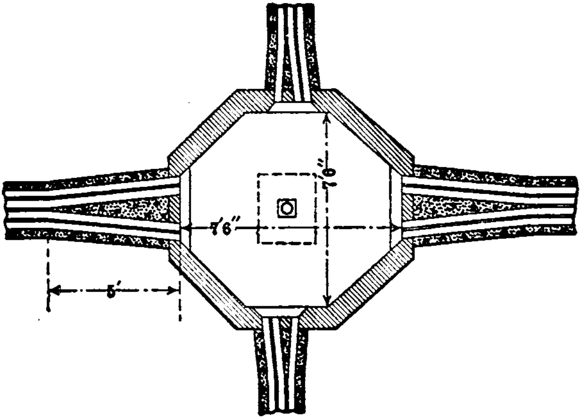

FIG. 56.—Square manhole.

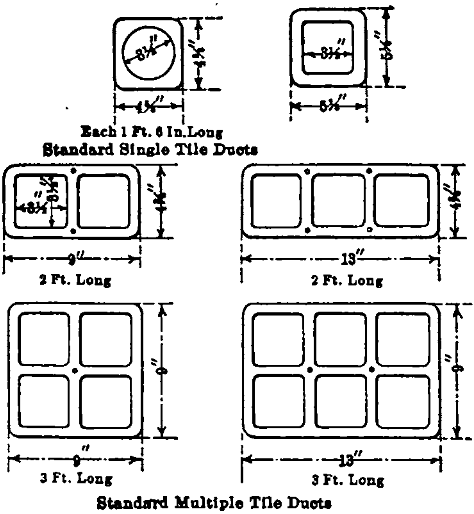

FIG. 57.—Forms of tile duct.

crete further acts as a water shed and minimizes the leakage of gas into the conduit system.

Manholes are constructed with brick walls and concrete floor and roof. Concrete walls may be used where there are no pipes to interfere with the use of the forms. The brick should be sewer brick, laid up with a good cement mortar, with an 8-in. wall. The roof must have sufficient strength to support the heaviest street traffic and its design, therefore, varies with the size and shape of the manhole. **Manhole covers** are made of cast iron, the upper surface of the cover being roughened or scored to prevent accidents to teams or pedestrians. It is desirable to provide openings in the covers for purposes of ventilation.

205. Cost of fifteen-duct line. The items of cost in constructing a fifteen-duct line as given by W. P. Hancock* are as follows:

	Per duct-foot	
Lumber at $15.00 per M ft	$0.0105	
Concrete at $4.85 per yd	0.0231	
Mortar at $3.98 per yd	0.0026	
Tile at $0.05 per ft	0.0502	
Total material		$0.0864
Excavation and filling at 15 cents per hr	0.0266	
Placing lumber at 20 cents per hr	0.0004	
Placing concrete at 15 cents per hr	0.0029	
Placing mortar at 25 cents per hr	0.0016	
Laying tile at 50 cents per hr	0.0040	
Hauling away dirt at 50 cents per hr	0.0047	
Total labor		0.0402
Inspection, 50 cents per hr		0.0033
Engineering expenses		0.0214
Incidentals, 5 per cent		0.0116
Grand total per duct-ft		$0.1629

206. Cost per duct-foot for duct-lines of various sizes. The cost per duct-foot of various sizes of duct-lines without manholes, at various costs of paving per sq. yd., as given by Hancock,* are as follows (Par. **207**):

207. Table of Costs of Duct-lines per Duct-foot
Cents per Duct-foot

No. of ducts	Cost of repaving per square yard						
	None	$0.50	$1.00	$1.50	$2.00	$3.00	$3.50
2	24	29	34	38	43	52	56
4	22	25	27	30	33	38	41
6	20	22	24	26	28	32	34
9	19	21	22	24	25	28	30
12	19	20	21	23	24	26	28
16	18	19	20	21	22	24	25
20	17	18	19	20	21	22	23
24	17	18	18	19	20	21	22
30	16	17	17	18	19	20	21
40	16	17	17	18	18	19	20
50	16	16	17	17	18	19	19

208. Cost of manholes. The costs of certain sizes of manholes as built under conditions existing in the City of Chicago are given in the following table, in Par. **209**. The cost of paving is not included. The dimensions are those inside the manhole, the last being depth.

* Hancock, W. P. *Trans.* National Elec. Light Association, 1904.

209. Table of Costs of Manholes
(Based on Chicago Experience)

	3×3×4 ft.		4×5×5 ft.		5×5×6 ft.		6×6×6 ft.		8×8×6 ft.	
	Quan.	Cost	Quan.	Cost	Quan.	Cost	Quan.	Cost	Quan.	Cost
Excavation at $1.00 per cu. yd.	3.70	$3.70	7.77	$7.77	16.30	$16.30	19.00	$19.00	29.63	$29.63
Brickwork at $10.50 per cu. yd.	1.67	17.55	2.92	30.50	4.17	43.80	4.50	47.30	5.83	61.20
Concrete bottom at $7.00 per cu. yd.	....	....	0.37	2.49	0.56	3.92	0.67	4.69	1.18	8.26
Concrete top at $10.00 per cu. yd.	0.56	7.00	0.96	7.68	1.35	10.80	1.55	12.40	2.50	20.00
Roof-iron at 3 cents per lb.	105 lb.	3.15	129 lb.	3.87	153 lb.	4.59	178 lb.	5.34	227 lb.	6.81
Sewer connection at $20.00 each	....	....	1	20.00	1	20.00	1	20.00	1	20.00
Frame and cover at $15.00 each	1	15.00	1	15.00	1	15.00	1	15.00	1	15.00
Supervision and incidentals	....	2.25	....	2.25	....	2.25	....	3.25	....	3.25
Totals	....	48.65	....	89.56	....	116.66	....	126.98	....	164.15
Square yards repaving required	4.00	....	8.9	....	10.7	....	12.00	....	16.00	....

210. Types of cables. Cables for underground electric light and power circuits are made up in single, duplex, concentric, triplex, etc. Duplex and triplex cables are those in which two conductors are enclosed in one lead sheath side by side, while concentric cable is made up with the conductors concentrically disposed.

In general, single-conductor cable is used when frequent taps are required, as in distributing mains, while multiple-conductor cables are used for through lines. Duplex cable has been used quite extensively in series-arc systems. It is difficult to train, and susceptible injury from bending at too small a radius. Duplex and triplex cables are somewhat less expensive than their equivalent in single-conductor cables with the same insulation.

The concentric arrangement is employed for large low-tension feeders in some cases. This arrangement is advantageous as it permits the use of a single duct for the feeder.

Low-tension distributing mains having three conductors of the same size are preferable of single-conductor cable, to facilitate making service taps. This work must be done while the lines are alive, and is much more easily accomplished when one polarity may be dealt with at a time. The same is true of service cables.

Transmission cables are almost universally of the three-conductor type. Insulation is placed on each conductor sufficient for the voltage between phases, and then a layer is placed over all three conductors in addition, as shown in Fig. 58, to provide insulation to ground.

211. Cable insulation. Cables are insulated with rubber, varnished cambric, or oiled paper. Rubber insulation is used where frequent taps are made, as on distributing mains, but not generally for feeders and transmission lines. Varnished cambric has been used to some extent in recent years as a substitute for rubber. Oiled paper is used almost exclusively for feeders and transmission lines, and can be used for primary distribution if the joints are well made and the ends are protected by suitable potheads.

212. Thickness of cable insulation. The smaller low-tension cables are provided with about $\frac{4}{32}$-in. insulation between conductors and lead; this is the least which it is advisable to use for mechanical reasons and is sufficient for 600 volts. In cables of 350,000 cir. mils to 1,500,000 cir. mils, it is customary to provide $\frac{5}{32}$ in. to $\frac{6}{32}$ in. of insulation, to insure sufficient mechanical strength to stand handling during installation. A thickness of $\frac{6}{32}$ in. is found sufficient for 2,000-volt to 6,000-volt single-conductor cables up to No. 4/0 A.W.G., while $\frac{10}{32}$-in. is required for potentials from 9,000 volts to 13,000 volts.

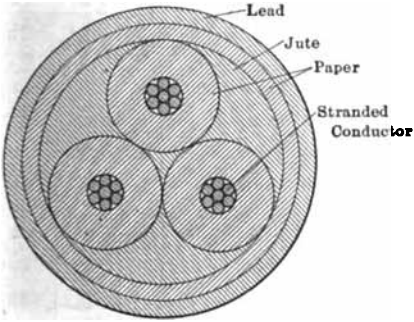

FIG. 58.—Cross-section of high-tension cable.

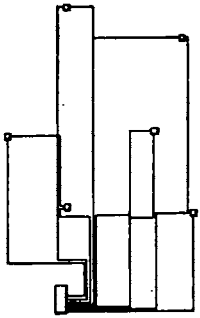

FIG. 59.—Lay-out of through cable lines to avoid the same routes.

213. The insulation provided in transmission cables in large transmission systems varies from 66 mils per 1,000 volts between conductors, at 6,600 volts, to 22 mils at 25,000 volts; and from 52 mils per 1,000 volts between conductor and ground, at 6,600 volts, to 16 mils at 25,000 volts.

214. Selection of duct position for cables. In placing cables in the duct-system a uniform method of selecting ducts should be followed as far as possible. Cables used in local distribution should be given a place, preferably in the top row, so that manholes can be built for service laterals without sinking them below the top row of ducts. Ducts should be selected for through lines so that they may be trained with the least interlacing with other cables. Lack of attention to this detail may result in a tangled condition of cables which greatly impedes any repair or reconstruction work.

215. Routing of cable lines. Through lines should be so routed as to utilize different duct lines to the best advantage. The service is better assured if transmission lines are separated as much as possible. This can be done by routing lines running to the same substation through different conduits, as indicated in Fig. 59.

216. Installation of cable. Cables are drawn into ducts by a line attached to a source of power. This line is put through the duct by the use of detachable rods of wood, which are pushed into the duct as they are joined together. They are then drawn through with the pulling-line attached, and disjointed as they come out. The cables are secured to the pulling-line by exposing the copper and making a secure mechanical connection, or by means of patent cable-grips, which are more quickly attached and removed.

The cable-pulling line is run over pulley-wheels leading out of the manhole to the source of power. Small-sized cable is wound on reels and cut to the be allowed to cool before it is moved, so that the compound will hold the parts rigidly in place.

In jointing three-conductor cables, the lead must be removed about 10 in. to facilitate the taping of the conductors (Fig. 60). In making joints for voltages of 6,600 volts and higher, it is important that as little air remain in the taping as possible. If paper tape is used, each layer should have compound poured over it before the next is applied.

The jointer requires the services of a helper in preparing the lead sleeves, heating solder and compound, and guarding the entrance to the manhole. A three-conductor high-tension joint in a paper cable usually requires about 4 hr. to complete, two joints a day being a fair rate of progress in such work.

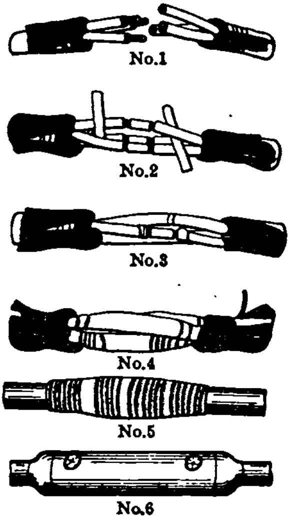

Fig. 60.—Cable splicing.

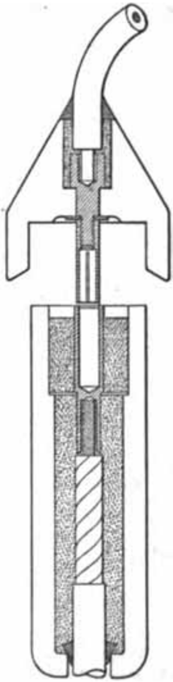

Fig. 61.—Porcelain pothead; single conductor type.

220. Pole terminals. In many primary distributing systems, it is usual to run feeders and important mains underground for some distance from the station, and connect with overhead lines in the more scattered areas. This class of distribution requires that the cable ends which are brought up the pole to the overhead lines be properly protected by **cable terminals or potheads.** Various types of terminal are in use, some of which include means for connecting and disconnecting the overhead line. Many such distributing systems have been equipped with porcelain potheads which have been very successful in protecting cables. The first such device was designed for a single-conductor cable, as illustrated in Fig. 61. The insulation is hermetically sealed by filling the porcelain sleeve with compound. The cap sheds all water and may be safely handled by a lineman when the line is alive. The connectors provide means for readily opening and closing the circuit when necessary for repair or alteration work. Other forms have been devised for multiple-conductor cables, in which there is a pot of cast iron with porcelain tubes set into the cover (Fig. 62).

221. Subway junction boxes. The arrangement of junction boxes and similar accessories in manholes should be worked out so as not to obstruct the space needed for the cables. Low-tension junction boxes are of two types, one of which is mounted on the wall in a vertical position, while the other is placed in the roof of the manhole so that it is accessible for replacing fuses or cleaning contacts from above ground. The surface type has its advantages in districts where the drainage of manholes is not perfect.

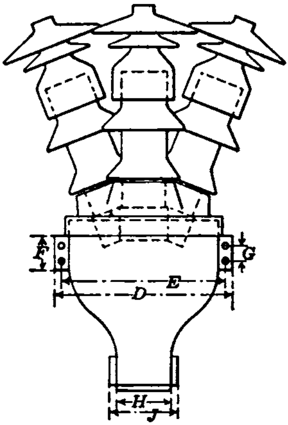

Fig. 62.—Cable pothead; triplex type.

222. Branch-line junction boxes. In a primary distributing system in which mains are underground, it is necessary to have means by which branches may be disconnected, without shutting down the circuit, when a transformer is to be connected or a cable repaired. Subway junction boxes with copper connections have commonly been applied to this work. The parts of the cable from which the lead has been removed are sealed in from moisture by wiped sleeves, or by filling the lower part of the box with hot compound. The **porcelain pothead** (Par. 220) has also been found convenient for this purpose, in manholes, as the cap may be submerged without permitting water to reach the live parts.

DISTRIBUTION ECONOMICS

223. General criterion for most economical size of conductor. The loss of energy in a conductor diminishes as the size of the conductor is increased, and *vice versa*. The generating capacity required to supply the energy loss follows the same law. The size of conductor with which the sum of the fixed charges on conductor and generating capacity, plus the value of energy loss, is a minimum, is the one which it is the most economical to employ.

224. Fixed charges consist of interest, depreciation, taxes and insurance. These are computed at different rates, depending upon the character of the equipment. **Interest** should be figured at not less than the rate paid on the bonded debt, which is about 5 per cent. (Sec. 25).

225. Depreciation is based upon the working life of the equipment, allowing for changes in the state of the art, and the scrap value of the equipment when taken out of service.

Weather-proof wire consists of about 80 per cent. copper and 20 per cent. insulation. It is conservative to figure 7 per cent. on the insulation, or 1½ per cent. of the whole wire, with 1 per cent. added for the labor of replacing, making a total of 2½ per cent. of the original cost of the wire. **Poles** have a life of about 15 years, with little salvage value. Other **overhead line material** must be replaced at intervals of 5 to 10 years. The average rate for **overhead lines** may thus be taken at about 5 per cent.

The life of lead-sheathed paper or rubber **cables** is indeterminate, but this may be conservatively taken at 15 years. The junk value is comparatively high, as the copper and the lead sheath constitute a considerable percentage of the cross-section of the cable. It is, therefore, safe to estimate depreciation at 3 per cent. for cables of No. 4/0 A.W.G. and larger, and at 5 per cent. for the smaller sizes.

226. Taxes and insurance must be considered as fixed charges of the same class as interest and depreciation. They vary somewhat with the locality, but are usually from 1.5 per cent. to 2 per cent., total.

227. The total fixed charges on underground cable and conduit may be taken at 5 per cent. interest, 4 per cent. depreciation, and 1 per cent. taxes, a total of 10 per cent. The total rate on the average overhead system may be taken at 5 per cent. interest, 5 per cent. depreciation, and 1 per cent. taxes, a total of 11 per cent.

228. General formula for annual conductor costs. The cost of a conductor varies inversely as its resistance per unit length, and the value of energy and generating capacity to supply it vary directly as the resistance per unit length. The total annual cost is

$$Y = \frac{a}{R} + bR + cR \qquad \text{(dollars)} \qquad (15)$$

in which a, b and c are constants depending on the cost of the conductor and the cost of energy. These are determined as follows: Par. **229** to **239**.

229. Formula for annual fixed charges on wire. The cost of insulation varies approximately with the size of the conductor. For bare wire the product of weight per 1,000 ft., W, by resistance per 1,000 ft., for all sizes, is $WR = 32$; with weather-proof insulation $WR = 38$ for the sizes No. 4 to No. 0 A.W.G., or 36 for sizes from No. 2/0 to 350,000 cir. mils. The value of 1,000 ft. of conductor at 15 cents per pound is $0.15W$ dollars. Hence, when $W = 38/R$, the cost per conductor of a circuit L thousand feet long is

$$C_1 = 0.15WL = \frac{0.15 \times 38L}{R} \qquad \text{(dollars)} \qquad (16)$$

Taking the fixed charges at 9 per cent., the annual cost is

$$C_1 = \frac{0.09 \times 0.15 \times 38L}{R} = \frac{0.513L}{R} \qquad \text{(dollars)} \qquad (17)$$

Thus $a = 0.513L$, in this case (Eq. 14).

230. Formula for annual fixed charges on single-conductor cable. With underground conductors a change in the size of the conductor does not make a proportionate change in cost. The table in Par. **232** gives the cost per 1,000 cir. mils of various sizes of single-conductor and three-conductor lead-sheathed cables. The resistance per 1,000 cir. mils per 1,000 ft. of copper at ordinary temperatures is about 10.4 ohms. If M is the number of 1,000 cir. mils and P is the price per 1,000 cir. mils, the cost of a single-conductor cable is MP. $M = 10.4/R$ and the cost of the cable is $10.4PL/R$, where L is the number of thousands of feet.

For **single-conductor low-tension cable** the value of P averages \$1.20 for cables from No. 2/0 A.W.G. to 500,000 cir. mils, and the value of each conductor is

$$C_2 = \frac{10.4 \times 1.2L}{R} = \frac{12.48L}{R} \qquad \text{(dollars)} \qquad (18)$$

Taking the fixed charges at 9 per cent., the annual conductor cost is

$$C'_2 = \frac{0.09 \times 12.48L}{R} = \frac{1.12L}{R} \qquad \text{(dollars)} \qquad (19)$$

and in this case $a = 1.12L$ (Eq. 14).

231. Formula for annual fixed charges on three-conductor cable. In the case of three-conductor cables the cost per 1,000 cir. mils in Par. **232** is based on the total cross-section of the three conductors. The cost of three-conductor cable is

$$C_3 = \frac{3 \times 10.4PL}{R} \qquad \text{(dollars)} \qquad (20)$$

and the annual charges are

$$C'_3 = \frac{0.09 \times 3 \times 10.4PL}{R} = \frac{2.8PL}{R} \qquad \text{(dollars)} \qquad (21)$$

and $a = 2.8PL$. Thus the value of a may be derived for different kinds of cable and at various values of copper, lead and insulation. Where a circuit is composed of more than one cable, this must be taken into account in figuring the total annual cost for the circuit; that is, for a two-wire circuit the value of "a" is doubled and for three cables it is trebled.

232. Cost of Lead-sheathed Cables

Size conductor A.W.G. or cir. mils	Cost per 1,000 cir. mils per 1,000 ft.			
	Single-cond. 3,000 volts	Three-cond. 10,000 volts	Single-cond. 300 volts	Three-cond. 300 volts
No. 2	2.20	2.80	1.90	1.85
No. 0	2.00	2.00	1.80	1.60
No. 00	1.70	1.85	1.60	1.50
No. 000	1.55	1.65	1.40	1.40
No. 0000	1.45	1.50	1.30	1.30
Cir. mils				
250,000	1.30	1.40	1.25	1.25
350,000	1.20	....	1.10	....
500,000	....	....	1.00	....
750,000	....	....	0.90	....
1,000,000	....	....	0.80	....
1,500,000	....	....	0.75	....

233. Fixed charges on generating equipment. Where conditions are such that generator capacity could be released for commercial load by the use of larger conductors, the fixed charges on generating equipment should be considered one of the elements of annual cost of a circuit. The station capacity required to supply the energy loss at the time of the maximum load I is $I^2RL/1{,}000$, in kw. The value of station capacity required to supply the loss on a feeder, when the cost is $100 per kw., is

$$C_4 = \frac{100 \times I^2RL}{1{,}000} \qquad (22)$$

and the fixed charges per conductor at 12 per cent., are

$$C'_4 = 0.12 \times 0.1I^2RL = 0\ 012I^2RL \qquad \text{(dollars)}$$

and $b = 0.012I^2L$ (Eq. 14).

234. Energy loss. The loss of energy on a circuit during a year is dependent upon the annual load factor of the load carried. In Fig. 63 typical load curves are shown for a lighting feeder which carries some day motor-load, for the months of March, June, September, and December. The energy losses will evidently be different on this feeder each month in the year, being less during the summer months than during the winter months.

The annual loss on a circuit may be computed with sufficient accuracy for practical purposes as follows: Take an average day in March, and compute the value of I^2R for each hour. Repeat this operation for the June, September and December curves. Multiply the sum of the losses on the four curves by 91, this being the number of days in each quarter of the year. This total is the annual loss in kilowatt-hours.

235. Loss factor. The ratio of the loss as thus calculated, to the value of the loss if the feeder had carried the maximum load of the year every hour of the year, may be called the loss factor, just as the ratio of the actual output for the year, to the possible output at the rate of the maximum load, is called the load factor of a circuit. If the loss factor of the feeder is 20 per cent., the annual loss is

$$\frac{I^2R \times 0.2 \times 365 \times 24}{1{,}000} = 1.752I^2R \qquad \text{(kw-hr.)} \qquad (23)$$

The loss factor for a load having the characteristics illustrated in Fig. 63 is about 16 per cent.

236. Calculation of loss. Given the character of the load curve, the loss factor may be determined in the manner described (Par. **234** and **235**) and the annual loss of energy calculated from the maximum load I, in terms of R, the resistance per 1,000 ft. of conductor. The loss at the time of the annual maximum load being I^2RL, the annual loss is

$$\frac{I^2RL \times 8{,}760 \times F}{1{,}000} \qquad \text{(kw-hr.)} \qquad (24)$$

where F is the loss factor. The loss equals $1.40I^2RL$ kw-hr. when the loss factor is 16 per cent. The value of this energy may be taken at about 1 cent per kw-hr. in the smaller plants, 0.7 cent in the larger engine-driven plants and 0.5 to 0.3 cent in the turbine-driven plants. At 1 per cent. per kw-hr. the value of the annual energy loss per conductor, at 16 per cent. loss factor, is

$$C_3 = 0.0140I^2RL \qquad \text{(dollars)} \qquad (25)$$

and the constant c is equal to $0.0140I^2L$.

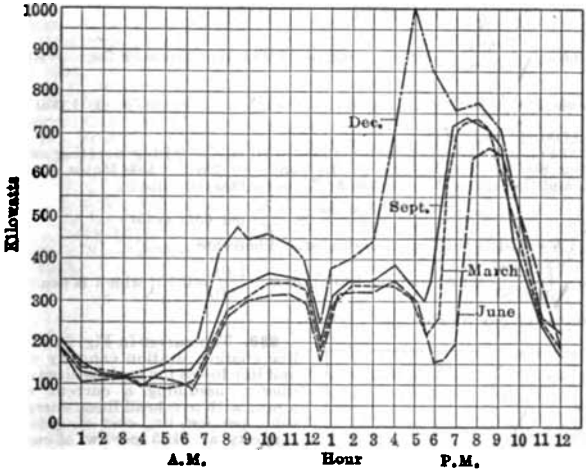

FIG. 63.—Typical load curves.

237. Summary of annual conductor costs; condition for minimum. The total annual cost is, therefore, the sum of the three quantities a/R, bR, and cR (Eq. 14). For weather-proof wire, with station capacity at $100 per kw., a loss factor of 16 per cent., and energy at 1 cent per kw-hr., the annual cost is

$$Y = \frac{a}{R} + bR + cR = \frac{0.513L}{R} + 0.012I^2RL$$
$$+ 0.014I^2RL = \frac{0.513L}{R} + 0.026I^2RL \quad \text{(dollars)} \qquad (26)$$

It is desired to ascertain at what value of R the sum of these three elements will be a minimum for a given current, at the time of the annual maximum load. The only variable in the equation being R, the value of Y will be a minimum, according to the rule of the calculus, when $\partial Y/\partial R = 0$.

If $Y = \frac{0.513L}{R} + 0.026I^2RL$, then $\frac{\partial Y}{\partial R} = \frac{0.026I^2R^2L - 0.513L}{R^2} = 0$. Therefore, $0.026I^2R^2L = 0.513L$, and $I^2R^2 = 0.513/0.026 = 19.7$; whence $IR = \sqrt{19.7} = 4.44$. For instance, if $I = 100$ amp., $R = 0.0444$ ohm, which is about the resistance per 1,000 ft. of a No. 4/0 conductor.

238. Examples of calculation of most economical size of conductor. Assume generating capacity costing $80 per kw., energy at 0.4 cent per kw-hr. and the loss factor at 25 per cent. With single-conductor low-tension cable of 500,000 cir. mils to 1,000,000 cir. mils, the cost per 1,000 cir. mils averages 90 cents per 1,000 ft., Par. 232.

Hence $\frac{a}{R} = \frac{0.09 \times 10.4 \times 0.9L}{R} = \frac{0.84L}{R}$,

$$bR = \frac{80 \times 0.12 I^2RL}{1,000} = 0.0096 I^2RL,$$

$$cR = \frac{0.004 \times 8,760 \times 0.25 I^2RL}{1,000} = 0.0087\ I^2RL.$$

$$Y = \frac{84\ L}{R} + 0.0183 I^2RL.$$

and $IR = \sqrt{\frac{0.84}{0.0183}} = \sqrt{46} = 6.7$ per 1,000 ft. of conductor. With 600 amperes $R = \frac{6.7}{600} = 0.011$, which is about the resistance of 1,000 ft. of 1,000,000-cir. mil cable.

In the case of three-conductor, 10,000-volt cables, with generating capacity costing $80 per kw., energy at 0.4 cent per kw-hr., loss factor at 25 per cent. and the cost of No. 0 cable $1.75 per 1,000 cir. mils,

$$aR = \frac{\$2 \times 0.09 \times 10.4L}{R} = \frac{1.87}{R} \text{ per conductor.}$$

$(b+c)\ R = 0.0183\ C^2RL$ per conductor. Therefore

$CR = \sqrt{\frac{1.87}{0.0183}} = 1.01$ and for 100 amp. $R = \frac{1.01}{100} = 0.101$ which is nearest the resistance of No. 0 cable, per 1,000 ft.

239. The curves in Fig. 64 show the line charges, station capacity charges and line losses for various sizes of conductor, assuming a current of 100 amp., with overhead lines, energy at 1 cent. per kw-hr., cost of generating capacity at $125 per kw. of capacity, and loss factor 12 per cent.

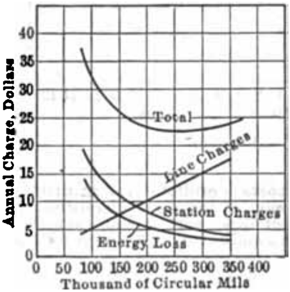

Fig. 64.—Elements of annual cost of a circuit.

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SECTION 13

INTERIOR WIRING

BY TERRELL CROFT

Consulting Engineer, Author American Electricians' Handbook

CONTENTS

(*Numbers refer to Paragraphs*)

SECTION 13

INTERIOR WIRING

RELATION OF WIRING TO FIRE RISK

1. The National Electrical Code was originally drawn in 1897, as the result of the efforts of the National Conference on Standard Electrical Rules, which comprised delegates from the various insurance, electrical, architectural and allied interests of the United States. The object of the conference was to formulate a set of rules for the installation and construction of electrical apparatus *in a manner free from fire hazard.* The *National Electrical Code* was the result of their work. This was immediately accepted as a standard and adopted by the National Board of Fire Underwriters. It at once placed electric lighting on a safe basis. At present practically all wiring is in accordance with Code rules; the fire insurance policies in some states and communities expressly provide that the Code shall be followed in detail. The National Conference on Standard Electrical Rules has disbanded and the work of the Underwriters' National Electrical Association and the National Conference has been taken over by the National Fire Protection Association, in which are represented the following organizations: American Electric Railway Association; American Institute of Electrical Engineers; Associated Factory Mutual Fire Insurance Cos.; National Board of Fire Underwriters; National Electric Light Association; National Electrical Contractors Association; National Electrical Inspectors Association.

Periodically the National Fire Protection Association convenes and makes such revisions or additions to the Code as are required by advances in the art. The *National Electrical Code* is revised every 2 years and a supplement and a "List of Approved Fittings," are issued semi-annually. Either of these can be obtained gratis on application to any of the Underwriters' Association offices or to any local inspection bureau.

2. Legal status of the Code. The Code has no statutory force, but merely comprises the rules and requirements of the National Board of Fire Underwriters. However certain cities have passed ordinances providing that all work installed in such cities shall be in accordance with the Code, which gives it a legal status in these cities. Moreover, other cities have legalized requirements of their own, which are, usually, essentially the same as the Code requirements. Where requirements are authorized by ordinance or statute they, of course, take precedence over the Code rules.

3. The National Code rules are of great economic importance in relation to fire hazard and fire insurance; without question fire loss amounting to many thousands of dollars has been averted by their use. When installing any electrical equipment, the first step should be to ascertain whether there are local installation rules (ordinances) in force in the community. If there are such rules, they should be followed; if there are none, the *National Electrical Code* rules should be followed.

4. Inspection. All electrical installations should be inspected, whenever an experienced inspector is available, to insure that they comply with either local or Code rules. In cities where rules have been adopted by ordinance, such inspection is usually mandatory. Where inspection is not mandatory, it is always advisable to retain an inspector from the most convenient Underwriters' Bureau to examine the work while it is being installed. Nominal fees are charged for such inspection.

All fittings and materials used in wiring installations should be approved by the Underwriters' Laboratories. Practically all standard equipment now being marketed is so approved and, usually, is so marked. When in doubt one should consult the "List of Electrical Fittings" referred to above.

METHODS OF WIRING

5. Wiring methods may be classified thus: (a) open or surface wiring; (b) concealed knob and tube wiring; (c) wooden-moulding wiring; (d) metal-moulding wiring; (e) flexible-tubing or circular-loom wiring; (f) rigid iron-conduit wiring; (g) flexible metallic conduit wiring; (h) flexible steel-armored cable wiring.

6. Open wiring on knobs and cleats (Fig. 1) is a cheap and satisfactory method if installed in compliance with Code requirements, and is largely used in industrial plants and in mercantile establishments where appearance is of small moment. Single-braid, rubber-covered or slow-burning weatherproof wire may be used. Wires having slow-burning insulation must not be used in damp places. The wires must be supported every 4.5 ft. (1.37 m.) except in buildings of "mill" construction where, if an inspector's authorization is secured, they may be supported at every beam, provided that the wires are No. 8 or larger and are carried at least 6 in. (15.2 cm.) apart. In dry places for voltages below 300, the wires must be separated at least 2½ in.

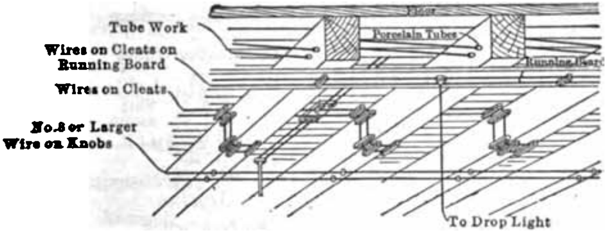


FIG. 1.—Methods of supporting open wiring.

(6.35 cm.), and they must be at least 0.5 in. (1.27 cm.) from the surface wired over. For voltages between 300 and 550, wires must be at least 1 in. (2.54 cm.) from the surface and must be separated 4 in. (10.2 cm.). In damp places, for voltages below 300, wires must be held 1 in. (2.54 cm.) from the surface. Where wires are exposed to mechanical injury protection must be afforded as specified by the Code. Wires must also be protected by porcelain tubes where they pass through walls, timbers or partitions. See the *National Electrical Code* for other minor requirements.

7. Knob and tube wiring (Fig. 2) is used in frame buildings, and is the cheapest method of concealed wiring. Although it has given fair satisfaction, it is being superseded by rigid conduit in progressive communities. In some cities only rigid iron or flexible conduit or flexible steel-armored cable is approved for concealed work.

The single-braid, rubber-insulated conductors are carried within the floors, walls and partitions of the building. Where passing through timbers they must be insulated with porcelain tubes. On a vertical run the wires must be protected from plaster droppings by tubes which extend at least 4 in. (10.2 cm.) above the horizontal timbers which have been pierced.

In structural-steel mill-type buildings, open wiring is carried on porcelain knobs or cleats which may be secured with stove bolts at points where there are spaces between the members or where holes are already punched. Sometimes it is desirable to screw the cleats to blocks which are clamped to the members with hook bolts.

Open work is especially suited to locations which are damp or hot such as dye works, breweries, dry kilns, metal refineries and the like. In such

9. Dimensions and capacities of wooden mouldings. Below are given the dimensions of standard two-wire wooden mouldings; the products of various manufacturers vary somewhat. All dimensions are given in inches (Fig. 3). (Kirkpatrick Mfg. Co.)

A Size of groove	Will accommodate wires		B	C	D	E	F
	Solid	Stranded					
0.250	14 to 12	.....	1[illegible]	[illegible]	1[illegible]	$\frac{3}{16}$	[illegible]
0.375	10 to 8	8	1[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]
0.500	9 to 4	5 to 6	2[illegible]	1	1[illegible]	[illegible]	1
0.625	3 to 0	4 to 1	2[illegible]	$1\frac{1}{16}$	1[illegible]	$\frac{7}{16}$	1[illegible]
0.750	....	0 to [illegible]	2[illegible]	1[illegible]	$2\frac{3}{16}$	[illegible]	1[illegible]
0.875	....	[illegible] to 250,000	3[illegible]	1[illegible]	$2\frac{7}{16}$	[illegible]	1[illegible]
1.000	....	250,000 to 500,000	3[illegible]	1[illegible]	2[illegible]	[illegible]	1[illegible]

10. Metal moulding, which can be used only for exposed circuits, is now largely employed in the place of wooden moulding (Par. 8). It also finds application in new construction in commercial buildings and in industrial plants, being substituted for the open wiring method. This moulding occupies little space (see Fig. 4), is very neat in appearance and being sherardised, will take paint readily. The conductors in the moulding can be taken out for inspection at any time with little trouble. Alterations in or additions to the moulding system can be very easily and neatly made. Fittings are manufactured, whereby almost any possible wiring arrangement can be effected. See *National Electrical Code* and manufacturers' catalogues for further information. Metal-moulding wiring costs somewhat less than conduit and. for exposed work, provides a neater ap-

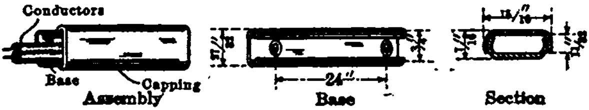


FIG. 4.—National metal moulding.

pearance. It can be used only where the potential difference does not exceed 300 volts and the power 660 watts. It must be continuous from outlet to outlet or to approved fittings. It should not be used in damp places.

Single-braid, rubber-insulated wire can be used in metal moulding. Wires must be laid in—not fished. The moulding shown in Fig. 4 has a capacity for four No. 14 wires. All wires of an alternating-current circuit must be in the same moulding, and it will be found advantageous to treat direct-current circuits likewise.

11. Flexible tubing (circular loom, duraduct, etc.) is now seldom used except in combination with other methods of wiring. However, it is very useful and finds wide application for furnishing additional insulation and protection to conductors. It cannot be used in damp places. See *National Electrical Code* for further information. Where metal outlet boxes or switch boxes are used, flexible tubing must extend from the last porcelain support into the outlet box. It is used for encasing wires fished between walls and ceilings, each wire being separately encased. It is also used in open work where wires, are nearer each other than 2.5 in.; on wires crossing other wires, gas pipes, water pipes, iron beams, wood work, brick or stone; on wires at chandeliers and bracket outlets; on gas pipe back of insulating joints; on wires under the edges of canopies: Where space is limited and the 5-in. separation required between wires cannot be maintained, each wire must be separately encased in a continuous length of flexible tubing. Flexible tubing may also be employed as an added protection to wires; as for instance on portable wires around machinery and in show windows, etc., where added protection, although not required, is often desirable.

17. Standard Sizes of Conduits for the Installation of Wires and Cables (*As adopted, recommended and copyrighted by The Natl. Electrical Contractors Assn. of the U. S.*)

Conduit sizes based on the use of not more than three 90-deg. elbows in runs taking up to and including No. 10 wires, and two elbows for wires larger than No. 10. Wires No. 8 and larger are stranded. Special permission is required of the inspection department having jurisdiction for the installation of more than nine wires in the same conduit. The wires used by the telephone companies of various cities differ as to thickness of insulation. The table "A" gives values satisfactory for both light and heavy insulation. For explanation of column reference letters for table "A," see footnotes.

Size of wire		Single wires				Duplex wires		
A.W.G.	Circular mils	Single wire	Two-wire system	Three-wire system	Four-wire system	Size A.W.G.	Number of wires	Size of conduit
14	4,107	½	½	½	¾	14	1	½
12	6,530	½	¾	¾	¾	14	2	¾
10	10,380	½	¾	¾	1	14	3	1
8	16,510	½	1	1	1	14	4	1
6	26,250	½	1	1¼	1¼	12	1	½
4	41,740	½	1¼	1¼	1½	12	2	¾
3	52,630	½	1¼	1¼	1½	12	3	1
2	66,370	½	1¼	1½	1½	12	4	1¼
1	83,690	¾	1½	1½	2	10	1	¾
0	105,500	1	1½	2	2	10	2	1
00	133,100	1	2	2	2½	10	3	1¼
000	167,800	1	2	2	2½	10	4	1½
0000	211,600	1¼	2	2½	2½			
	300,000	1¼	2½	2½	3			
	400,000	1¼	3	3	3½			
	600,000	1½	3	3	3½			
	700,000	2	3½	3½				
	1,000,000	2	4	4				
	1,500,000	2½	4½	5				
	2,000,000	3	5	6				

(A) Conduit capacities for various wires

Conduit	*a*	*b*	*c*	*d*	*e*
½	3	10	18	5	3
¾	5	20	30	10	6
1	10	30	40	15	10
1¼	16	70	100	25	16
1½	24	90	130	35	25
2	40	150	200	50	35

Single wires — Convertible system

Number and size of wires, A.W.G.	Size of conduit
1– 10 2– 14	½
1– 8 2– 12	¾
1– 6 2– 10	1
1– 4 2– 8	1
1– 2 2– 6	1¼
1– 1 2– 5	1¼
1– 0 2– 4	1½
1– 00 2– 3	1½
1– 000 2– 2	1½
1– 0000 2– 1	2
1– 250,000 2– 0	2
1– 350,000 2– 00	2½

a. No. 14 R. C. double-braid solid wires. Based on straight run without elbows.
b. No. 16 light insulation fixture wires. Based on straight run without elbow.
c. No. 18 light insulation fixture wires. Based on straight run without elbow.
d. No. 20 braided and twisted pair. Switchboard or desk instrument wire. Based on not more than two 90-deg. elbows.
e. No. 19 braided and twisted pair. Standard $\frac{1}{32}$-in. insulation, telephone wire. Based on not more than two 90-deg. elbows.

18. Flexible steel-armored conductor (Fig. 6) has found considerable application during the last few years, due to its adaptability for electrical construction in finished buildings. It can be run with practically no regard for pipes or other grounded obstructions and can be fished long distances. It is more expensive than conductors in circular loom but it makes a thoroughly dependable job. Flexible steel-armored conductor consists of rubber-insulated wire or cable, protected from injury and to some extent from dampness by two layers of spirally wound flexible steel armor. It is manufactured "leaded" and "unleaded." The leaded conductor has

Rope-lay cable. A single-conductor cable composed of a central core surrounded by one or more layers of helically laid groups of wires. This kind of cable differs from the preceding in that the main strands are themselves stranded.

N-conductor cable. A combination of N conductors insulated from one another. (It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable," etc. In referring to the general case, one may speak of a "multiple-conductor cable," as in definition for "*Cable*" above.)

N-conductor concentric cable. A cable composed of an insulated central conducting core with tubular stranded conductors laid over it concentrically and separated by layers of insulation. Usually only 2-conductor or 3-conductor. Such conductors are used in carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.

Duplex cable. Two insulated single-conductor cables twisted together. They may or may not have a common insulating covering.

Twin cable. Two insulated single-conductor cables laid parallel, having a common covering.

Triplex cable. Three insulated single-conductor cables twisted together. They may or may not have a common insulating covering.

Twisted pair. Two small insulated conductors twisted together, without a common covering. The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord."

Twin wire. Two small insulated conductors laid parallel, having a common covering.

21. Specifications for insulated conductors are given in detail in the *National Electrical Code*. Since these specifications are subject to revision, it is inadvisable to repeat them here. Practically all rubber-insulated wire on the market is manufactured in accordance with Code requirements, and to each coil is fastened a tag indicating the approval of the Underwriters' Laboratories. Unapproved rubber-insulated wire should not be installed.

22. Allowable or Safe Current-carrying Capacities of Insulated Copper Wires

(1913 *National Electrical Code*)

Circular mils	A.W.G.	Table A Rubber insulation. (Amp.)	Table B Other insulations. (Amp.)	Circular mils	A.W.G.	Table A Rubber insulation. (Amp.)	Table B Other insulations. (Amp.)
1,624	18	3	5	200,000	......	200	300
2,583	16	6	10	300,000	......	275	400
4,107	14	15	20	400,000	......	325	500
6,530	12	20	25	500,000	......	400	600
10,380	10	25	30	600,000	......	450	680
16,510	8	35	50	700,000	......	500	760
26,250	6	50	70	800,000	......	550	840
33,100	5	55	80	900,000	......	600	920
41,740	4	70	90	1,000,000	......	650	1,000
52,630	3	80	100	1,100,000	......	690	1,080
66,370	2	90	125	1,200,000	......	730	1,150
83,690	1	100	150	1,300,000	......	770	1,220
105,500	0	125	200	1,400,000	......	810	1,290
133,100	00	150	225	1,500,000	......	850	1,360
167,800	000	175	275	1,600,000	......	890	1,430
211,600	0000	225	325	1,700,000	......	930	1,490
				1,800,000	......	970	1,550
				1,900,000	......	1,010	1,610
				2,000,000	......	1,050	1,670

24. Dimensions and Weights of Rubber-covered Wires and Cables for Voltages from 600 to 1,500

Size A.W.G.	Size Cir. mils	No. of wires in cond.	Diam. of wires comprising cable, mils.	Thickness of rubber in inches	Diameter over all, Single braid, Mils	Diameter over all, Single braid, 64ths	Diameter over all, Double braid, Mils	Diameter over all, Double braid, 64ths	Approx. weight per 1,000 ft., tape and braid
				Solid					
14	4,107	....	....	1/16	239	15.3	289	18.5	46
12	6,530	....	....	1/16	256	16.4	306	19.6	58
10	10,380	....	....	1/16	277	17.75	327	20.9	75
8	16,510	....	....	1/16	304	19.45	354	22.6	100
6	26,250	....	....	5/64	382	24.2	446	28.5	153
4	41,740	....	....	5/64	425	27.2	489	31.3	212
2	66,370	....	....	3/32	498	31.9	582	37.2	310
1	83,690	....	....	3/32	561	35.9	645	41.25	394
				Stranded					
1	83,690	19	66.4	3/32	604	38.65	688	44.0	405
0	105,500	19	74.5	3/32	645	41.25	729	46.6	490
00	133,100	19	83.7	3/32	691	44.25	775	49.6	595
000	167,800	19	94.0	3/32	742	47.5	826	52.8	715
0000	121,600	19	105.5	3/32	800	51.2	884	56.5	875
......	400,000	37	104.0	7/64	1,032	66.0	1,116	71.4	1,570
......	600,000	61	99.2	1/8	1,227	78.5	1,311	83.9	2,300

25. Dimensions and Weights of Rubber-covered Wires and Cables for Voltages from 1,500 to 2,500

Size A.W.G.	Size Cir. mils	No. of wires in cond.	Diam. of wires comprising cable, mils.	Thickness of rubber in inches	Diameter over all, Single braid, Mils	Diameter over all, Single braid, 64ths	Diameter over all, Double braid, Mils	Diameter over all, Double braid, 64ths	Approx. weight per 1,000 ft., tape and braid
				Solid					
12	6,530	....	....	3/32	318	20.4	368	23.55	85
10	10,380	....	....	3/32	339	21.7	389	24.9	100
8	16,510	....	....	3/32	380	24.3	444	28.4	130
6	26,250	....	....	3/32	414	26.5	478	30.6	175
4	41,740	....	....	3/32	456	29.2	520	33.3	240
2	66,370	....	....	3/32	509	32.6	573	36.65	330
1	83,690	....	....	7/64	592	37.0	676	43.25	420
				Stranded					
8	16,510	7	48.6	3/32	398	25.5	462	29.6	140
6	26,250	7	61.2	3/32	436	27.9	500	32.0	185
4	41,740	7	77.2	3/32	504	32.25	588	37.6	250
2	66,370	7	97.4	3/32	564	36.1	648	41.5	340
1	83,690	19	66.4	7/64	635	40.6	719	46.0	435
0	105,500	19	74.5	7/64	676	43.25	760	48.6	520

26. Current-carrying capacity of copper wires. If the current arried by a given conductor is too great, the conductor will become so hot hat it will be unsafe, or may, if insulated, damage its insulation. Certain afe current values have been determined for different sizes of conductor, nd are listed in Par. 22. Less current is permissible in rubber-insulated

34. Dimensions and Weights of Weather-proof and Slow-burning Solid Copper Wire and Cable
(General Electric Co.)

Size A.W.G. and cir. mils	Weather-proof: Approx. wts. per 1,000 ft. (lb.)		Weather-proof: Approx. overall diameters, in.		Slow-burning: Approx. weights per 1,000 ft. (lb.)			Slow-burning: Approx. overall diameters, in.			A.W.G. and cir. mils.
	Triple braid	Double braid	Triple braid	Double braid	Weather-proof white finish	Weather-proof black finish	Under-writers	Weather-proof or white	Weather-proof or black	Under-writers	
					Solid wire						
1	310	290	0.445	0.405	350	340	330	0.445	0.445	0.445	1
2	255	232	0.400	0.374	290	280	280	0.400	0.400	0.400	2
4	164	146	0.346	0.320	200	190	180	0.346	0.346	0.346	4
6	112	97	0.303	0.278	140	127	125	0.303	0.303	0.303	6
8	75	64	0.264	0.245	95	85	90	0.264	0.264	0.264	8
10	53	46	0.221	0.197	70	60	65	0.221	0.221	0.221	10
12	35	27	0.200	0.172	52	42	40	0.200	0.200	0.200	12
14	25	20	0.182	0.155	40	30	30	0.182	0.182	0.182	14
16	19	15	0.169	0.142	30	24	22	0.169	0.169	0.169	16
					Stranded						
1,000,000	3,478	3,360	1.451	1.365	3,880	3,980	3,578	1.451	1.451	1.451	1,000,000
750,000	2,615	2,551	1.300	1.210	3,020	3,100	2,720	1.300	1.300	1.300	750,000
600,000	2,113	2,060	1.190	1.105	2,370	2,460	2,204	1.190	1.190	1.190	600,000
500,000	1,781	1,740	1.108	1.027	2,010	2,080	1,858	1.108	1.108	1.108	500,000
400,000	1,445	1,405	1.020	0.940	1,670	1,700	1,509	1.020	1.020	1.020	400,000
300,000	1,126	1,090	0.930	0.846	1,290	1,310	1,170	0.930	0.930	0.930	300,000
250,000	937	905	0.862	0.780	1,080	1,120	981	0.862	0.862	0.862	250,000
0,000	806	753	0.785	0.708	910	960	844	0.785	0.785	0.785	0,000
000	655	610	0.728	0.648	745	785	686	0.728	0.728	0.728	000
00	515	470	0.662	0.599	590	625	550	0.662	0.662	0.662	00
0	420	382	0.605	0.555	485	510	449	0.605	0.605	0.605	0
1	328	300	0.518	0.470	360	380	360	0.518	0.518	0.518	1
2	267	251	0.440	0.415	300	335	294	0.440	0.440	0.440	2
4	173	153	0.379	0.353	205	230	196	0.379	0.379	0.379	4
6	117	103	0.327	0.305	145	165	135	0.327	0.327	0.327	6
8	75	69	0.290	0.270	97	105	94	0.290	0.290	0.290	8

voltages as high as 600. These include single-pole, double-pole and triple-pole switches; three-way or four-way switches, for the control of hall lamps from any one of several locations; and the electrolier switches. They can be obtained (for 250 volts) for currents as large as 30 amp. Snap

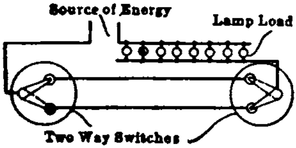


Fig. 7.—Control of circuit from two locations with two-way switches.

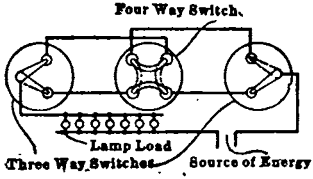
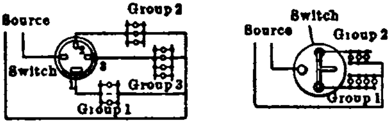


Fig. 8.—Control of circuit from any one of more than two locations.

switches are usually preferable to knife switches from an operating standpoint as any one can operate them, under normal conditions, without drawing a destructive arc. Indicating switches, which show by their appearance whether they are open or closed, should always be used. Flush snap switches are installed in pressed-steel switch boxes which are set in walls or partitions, so that only the plate and operating buttons are visable. Types can be obtained which will furnish practically the same service as surface snap switches. They are more expensive but present a neater appearance than surface switches.

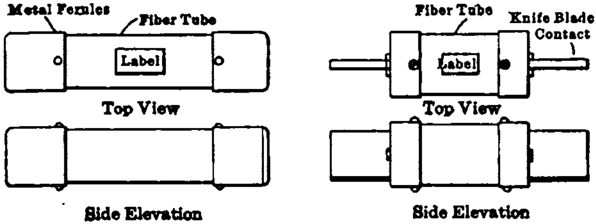


Three-Circuit Switch

Two-Circuit Switch

Fig. 9.—Wiring for electrolier switches.

40. Three-way and four-way switches. Switches for controlling a group of lamps from either of two locations are wired as indicated in Fig. 7. Two "three-way" snap switches are required. This scheme is largely used for the control of hall lamps. Switches for controlling a group of lamps from any one of more than two locations are connected as in Fig. 8. A "three-way" switch is used at each end of the circuit and as many additional "four-way" switches



A·Ferule Contact

B·Knife Blade Contact

Fig. 10.—National Electrical Code standard enclosed fuses.

are necessary as there are additional control locations. This arrangement is used for hall lamps so that they can be controlled from any floor.

41. Electrolier switches (Fig. 9) control lamps in independent groups such as would be used in an illuminated dome or of an electrolier. Switches

46. Cut-outs or fuse blocks are devices whereby fuses can be inserted in an electrical circuit. Detailed specifications covering cut-outs for all approved currents and voltages are given by the Code. A combination of the Edison plug cut-out, and the ferule fuse and fuse-plug casing that can be used in connection with it, constitutes a most satisfactory fuse arrangement. However, this arrangement is limited to a capacity of 30 amp. at 125 volts. The Edison plug cut-out, which has a right-hand thread, is approved only for 125 volts; the Bryant Electric Co. makes a similar cut-out having a left-hand thread, which is approved, under certain conditions, for 250 volts. The right-hand thread cut-out is approved for only 125 volts because the Edison fuse-plug, which is not safe at a greater voltage, can be used in it. Cut-outs for open-link fuses consist merely of slate blocks, having mounted on them the necessary terminals.

47. Diameters of Wires of Various Materials that will be Fused by a Current of a Given Strength

(Knox's "Electric Light Wiring." Derived from tables of W. H. Preece)

Current in amp.	Copper		Aluminium		German silver		Iron	
	Diam. in in.	Nearest A.W.G.	Diam. in in.	Nearest A.W.G.	Diam. in in.	Nearest A.W.G.	Diam. in in.	Nearest A.W.G.
1	0.0021	43	0.0026	41	0.0033	39	0.0047	37
2	0.0034	39	0.0041	38	0.0053	35	0.0074	33
3	0.0044	37	0.0054	35	0.0069	33	0.0097	30
4	0.0053	35	0.0065	34	0.0084	31	0.0117	29
5	0.0062	34	0.0076	32	0.0097	30	0.0136	27
10	0.0098	30	0.0120	28	0.0154	26	0.0216	24
15	0.0129	28	0.0158	26	0.0202	24	0.0283	21
20	0.0156	26	0.0191	24	0.0245	22	0.0343	19
25	0.0181	25	0.0222	23	0.0284	21	0.0398	18
30	0.0205	24	0.2500	22	0.0320	20	0.0450	17
35	0.0227	23	0.0277	21	0.0356	19	0.0498	16
40	0.0248	22	0.0303	20	0.0388	18	0.0545	15
45	0.0268	21	0.0328	20	0.0420	18	0.0589	15
50	0.0288	21	0.0352	19	0.0450	17	0.0632	14
60	0.0325	20	0.0397	18	0.0509	16	0.0714	13
70	0.0360	19	0.0440	17	0.0564	15	0.0791	12
80	0.0394	18	0.0481	16	0.0616	14	0.0864	12
90	0.0426	18	0.0520	16	0.0667	14	0.0935	11
100	0.0457	17	0.0558	15	0.0715	13	0.1003	10
120	0.0516	16	0.0630	14	0.0808	12	0.1133	9
140	0.0572	15	0.0698	14	0.0895	11	0.1255	8
160	0.0625	14	0.0763	13	0.0978	10	0.1372	7
180	0.0676	14	0.0826	12	0.1058	10	0.1484	7
200	0.0725	13	0.0886	11	0.1135	9	0.1592	6
225	0.0784	12	0.0958	10	0.1228	8	0.1722	5
250	0.0841	12	0.1028	10	0.1317	8	0.1848	5
275	0.0897	11	0.1095	9	0.1404	7	0.1969	4
300	0.0950	11	0.1161	9	0.1487	7	0.2086	4

WIRING CALCULATIONS AND LAYOUTS

48. The resistance of a circular-mil-foot of commercial copper wire (a wire 1 ft. long and having cross-sectional area of 1 cir. mil) is usually quoted as from 10.6 to 10.8 ohms, at 75 deg. fahr. (24 deg. cent.). For wiring calculations 11 ohms per mil foot is a sufficiently accurate assumption. (See Sec. 4 for the Annealed Copper Standard.) On this basis the resistance of any commercial copper conductor is:

$$R = \frac{11 \times l}{\text{cir. mils}} \quad \text{(ohms)} \qquad (1)$$

centages of the receiver voltage, a drop of from 1 to 3 per cent. is satisfactory and a 4.5 per cent. drop is the maximum. (See Par. 53.) The above values represent the voltage drops from the source of assumed constant voltage to the lamp. Because of the extreme sensitiveness of the incandescent lamp to variations in voltage, the lamps may be subjected to overvoltages if the drops suggested above are exceeded—which will materially decrease their life; they may also be subjected to undervoltages when the circuit is loaded—which will decrease their brilliancy (Sec. 14). Some central-station companies specify that the total drop in 110-volt, interior-wiring circuits shall not exceed 1 volt.

52. Allowable voltage drop in motor circuits. A 5 per cent. drop is in accordance with excellent practice and a 10 per cent. drop or even a slightly greater one is often considered satisfactory. The drop should be calculated on the basis of full-load motor current. Where incandescent lamps are on the same circuits with motors the drops suggested in Par. 51 should not be exceeded. In designing motor circuits the question of conductor economy (Par. 73) should be considered.

53. Apportionment of voltage drop. In circuit design it is necessary to apportion the total drop among the various component circuits—feeders, mains, sub-mains and branches. In incandescent lighting most of the drop is confined to the feeders because if there were excessive drop in the mains and branches, lamps located close together but served by different mains and branches might operate at decidedly different brilliancies.

With an isolated plant, that is where energy is generated on the premises, the drop may be apportioned exactly as indicated (Par. 54). Where the premises is served by a central station (Par. 55), the practice of the utility concern may allow 2 volts drop in its secondary mains and the service to the premises. In such a case, the total drop within the premises should not exceed 1 to 2 volts. Where a utility company is to give service, it should be consulted regarding its practice in this respect. Some central stations require that the voltage drop in interior wiring installations which they are to serve, shall not exceed a certain maximum. In any case, it is frequently the practice to allow one volt drop for the branches and to apportion the rest of the available drop to the main circuits and feeders.

54. Typical Apportionment of Drop in 110-Volt Lighting Circuits

Part of circuit	Proportion	4 volts total drop		3 volts total drop	
		Actual drop, volts	Per cent. drop	Actual drop, volts	Per cent. drop
Branches..........	1 volt.......	1	0.91	1	0.91
Mains..........	⅓ remainder.	1	0.91	⅔	0.60
Feeders..........	⅔ remainder.	2	1.82	1⅓	1.21
Total..........	....	4	3.64	3	2.72

55. Apportionment of drop on 2,400-volt distribution systems is often made under the assumption that the secondary voltage at the transformers remains practically constant. This will be found true in a well laid-out system, particularly if automatic feeder regulators are used.

56. Apportionment of drop in motor circuits is frequently made on the basis that 1 volt will be allowed in the branches, two-thirds of the remaining drop in the mains and one-third in the feeders. Most of the drop should be confined to the mains in order that a variation in the load on one motor of a group will affect the others as little as possible. Where motor circuits are fed by transformers, it is usually assumed that the voltage at the secondary side of the transformers remains practically constant, and therefore all of the allowable drop is apportioned to the secondary circuit. Where a group of motors is fed by a main circuit and branches, the drop in the branches, if they are not too long, is frequently 1 volt or less, under normal working conditions, because the insurance rules require that a branch conductor serving a motor be capable of safely carrying a current 25 per cent. greater than the normal full-load current of the motor.

Where circuits are long and the conductors lie far apart, the results given by the approximate formulas should be checked by the Mershon-Diagram (Sec. 12) which considers the effects of power-factor and reactance Although the Mershon method is a trifle tedious, it will be found the quickest and the best when all things are considered. The use of the tables, that are frequently given for the determination of alternating-current conductors, will probably lead to inaccurate results, unless the user is familiar with their derivation. The effects of electrostatic capacity are inconsequental and need not be considered in ordinary interior wiring calculations.

62. Line-reactance voltage drop may be decreased either by diminishing the distance between the wires, or by dividing the copper into a greater number of circuits. Reactance is little affected by changing the size of the conductor. In interior wiring installations the conductors can be no nearer together than certain minimum distances specified by the *National Electrical Code*. Where installed in conduit the conductors are so close together that their reactance is practically negligible. All the wires of any alternating-current circuit (two wires for a single-phase circuit, three wires for a three-phase circuit or four wires for a two-phase circuit) should be carried as close together as feasible or, in a conduit installation, should all be in the same conduit, in accordance with the Code.

63. Skin effect in interior wiring calculations is ordinarily of little consequence, and need not be considered unless conductors are larger than 600,000 cir. mils in area. (Sec. 2 and Sec. 12.) As a general proposition conductors larger than 600,000 cir. mils are very difficult to handle, and, hence, are uneconomical to install; therefore, when greater area is required it is usual to arrange several conductors in parallel. Some engineers will use no conductor larger than 300,000 cir. mils in interior wiring. Fiber-cored cables (Par. 36 and 37) should be used where conductors larger than 600,000 cir. mils are required.

64. Calculation of alternating-current circuits of high power-factor, such as are used for supplying incandescent lamps: in this case treat the circuits as if they were direct-current circuits, using Eq. 3, Par. 59. This method is not strictly accurate but is sufficiently so for ordinary conditions. If the circuits are long and the wires are widely separated, the conductor sizes obtained as above should be checked by the Mershon-diagram (Sec. 12).

65. To calculate single-phase, alternating-current circuits where line reactance may be neglected. The following formulas can be safely used for the calculation of branch circuits and also of feeders and mains where the conductors are carried in conduit or are not very long. Where the circuits are of considerable length the result given by the formula should be checked with the Mershon diagram (Sec. 12). The current may be found from the expression:

$$I_1 = \frac{Kw. \times 1{,}000}{E \times p.f.} \text{ (amps.)} \tag{4}$$

wherein, I_1 = current in amperes, $Kw.$ = kilowatts input of the load, E = voltage of circuit and $p.f.$ = power-factor of load.

$$\text{cir. mils} = \frac{22 \times I_1 \times L}{V}. \tag{5}$$

Wherein, *cir. mils* = area of conductor; I_1 = current in amperes; L = length (one way) of the circuit in feet and V = volts drop allowable.

66. Calculations of single-phase branches from three-phase circuits are made in the same way as those for any other single-phase circuit (Par. 65). However it must be remembered that if the branch is connected between one of the three phase wires and the neutral, the voltage impressed on the branch circuit will be 0.58 × the voltage across any two mains of the three-phase circuit

67. To calculate two-phase, four-wire, circuits where line reactance can be neglected the following formulas can be used. The limitations for this method are the same as those for single-phase circuits as outlined, Par. 65. As with the single-phase equations (Eq. 4 and 5, Par. 65), the Mershon diagram (Sec. 12) should be used for checking the conductors

For a four-wire, two-phase circuit (assuming balanced currents)

$$P = \frac{4 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{44 \times I^2 \times L}{\text{cir. mils}} \quad \text{(watts)} \qquad (12)$$

For a three-wire, three-phase circuit (assuming balanced currents)

$$P = \frac{3 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{33 \times I^2 \times L}{\text{cir. mils}} \quad \text{(watts)} \qquad (13)$$

Wherein, P = the power, in watts, lost in the circuit; I = the current in amperes which flows in each of the wires of the circuit; L = the length (one way) of the circuit; and *cir. mils* = cross-sectional area in circular mils of each of the wires. The above formulas can be used only when all of the wires of the line are of the same size.

73. Conductor economy in interior wiring installations always should be considered as a matter which is subordinate to the Code requirements. Obviously any conductor selected for a specific installation must fulfil the requirements of mechanical strength, ample carrying capacity (Par. **22** and **26**), and permissible voltage drop (Par. **51** and **52**). Frequently one of these three considerations will definitely determine the size of the conductor; however, a calculation of the resistance or I^2R (power) loss (Par. **72**) may indicate that it will be desirable to use a larger size than is otherwise necessary.

74. Annual charges may be considered, in connection with the economical selection of a conductor size, to be made up of two items: (*a*)

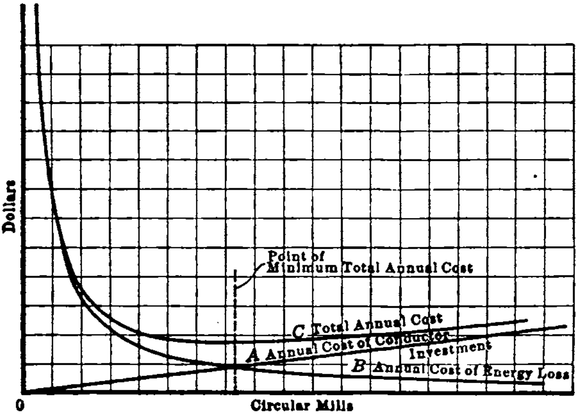


Fig. 14.—Graph illustrating Kelvin's law.

resistance-loss charges; (*b*) investment charges. Resistance-loss charges depend upon the resistance, the current and the unit cost of energy, and may be decreased by an increase of conductor size. This, however, calls for a greater investment with consequently larger investment charges. A conductor should be selected of such a size that the total annual charge (Sec. 25) will be a minimum.

In Fig. 14 the effect of a variation of conductor size on resistance-loss charge, investment charge, and total annual charge is shown graphically. The interest charges on the conductor increase directly with its cross-sectional area (curve *A*, Fig. 14). The resistance-loss charges decrease inversely as the cross-sectional area of the conductor (curve *B*, Fig. 14). The total annual charge (curve *C*, Fig. 14), the sum of curves *A* and *B*, is at its minimum value directly over the point where curves *A* and *B* intersect; that is, the conductor size that will have the least total annual cost is that

79. Factors for determining the mean annual current. To ascertain the mean annual current for substitution in Eq. 14, Par. 75, multiply the maximum current by the ratio applying to the conditions under consideration, given in the column headed "*Factor*" in the following table. The table is calculated on a basis of 24 hr. × 365 days = 8,760 hr. per year.

Example. If a maximum current of 1,000 amp. (I) flows ¾ of the time or 6,570 hr. per year and a current of 750 amp. (¾I) flows ¼ of the time or 2,190 hr. per year the factor "0.944" would be used; that is, the value 0.944 × 1,000 amp. = 944 amp. would be the mean annual current for substitution in the equation of Par. 75 (Eq. 14).

	Proportion of maximum current "I" carried				Factor
	¼I	½I	¾I	I	
Proportion of time current is carried	0	0	0	1	1.000
	0	0	¼	¾	.944
	0	¼	0	[illegible]	.901
	0	0	[illegible]	[illegible]	.844
	0	0	0	[illegible]	.866
	¼	0	0	[illegible]	.875
	0	[illegible]	[illegible]	[illegible]	.838
	0	0	[illegible]	[illegible]	.820
	¼	0	[illegible]	[illegible]	.810
	0	[illegible]	0	[illegible]	.790
	0	[illegible]	[illegible]	[illegible]	.771
	[illegible]	[illegible]	0	[illegible]	.760
	[illegible]	0	[illegible]	[illegible]	.744
	[illegible]	0	0	[illegible]	.729
	0	[illegible]	[illegible]	[illegible]	.718
	0	0	0	[illegible]	.707
	[illegible]	[illegible]	[illegible]	[illegible]	.685
	0	[illegible]	0	[illegible]	.661
	[illegible]	0	[illegible]	[illegible]	.650
	[illegible]	[illegible]	0	[illegible]	.611
	[illegible]	[illegible]	0	[illegible]	.586
	[illegible]	0	0	[illegible]	.545
	0	0	0	[illegible]	.500

80. Two-phase distribution may be effected with four or with three wires. In the former case there is a pair of wires for each phase, while in the latter there is one wire for each phase and a common wire for both phases. The circuits must be balanced on either side, just as in the case of a three-wire, direct-current system, the only difference being that where three wires are used, the common wire is 1.4 times as large as either of the other two, since it must carry 1.4 times as much current. Motors are connected to both phases and employ all three or all four wires as the case may be. With four wires, the lamps are connected to each phase as though the supply were single-phase and care should be exercised to balance each phase as nearly as possible.

81. The three-phase system is usually employed where motors form a greater part of the load. Three conductors are necessary. Where lamps are required they are either balanced on the three-phases or connected between each main conductor and a common conductor of smaller size usually connected to the middle point of the star-connected secondary. The e.m.f. between any one of the three wires and the neutral is 0.577 (or 0.58) times the e.m.f. between the mains.

82. Two-wire and three-wire systems. Most interior wiring follows the two-wire system, the three-wire system being used principally for feeders and mains. With the direct-current three-wire system, (lamps and motors) on the plans and then so locate the panel boxes that no lighting branch circuit shall be much over 100 ft. (30.5 *m*) in length, or have a load much greater than 440 watts. Panel boxes should be so located that they are accessible and that the circuits can be readily run to them. Compute the load on each panel box and indicate it, at the box, on the drawing. Lay out the mains and feeders (see Fig. 16). First decide whether the hall or public lights will be controlled separately or with the private lights from the main switchboard, because this feature affects the arrangement of the feeders and possibly that of the mains. Next decide whether there should be a separate feeder to each floor or whether several floors or portions thereof will be served by one feeder. Where it is not necessary to control the loads on the different floors separately, and where the resulting conductor size will not be prohibitively large, the cheapest and probably the best arrangement is to serve several or possibly all floors with one feeder. Usually, the only limit to the number of floors that may be served with one feeder is the re-

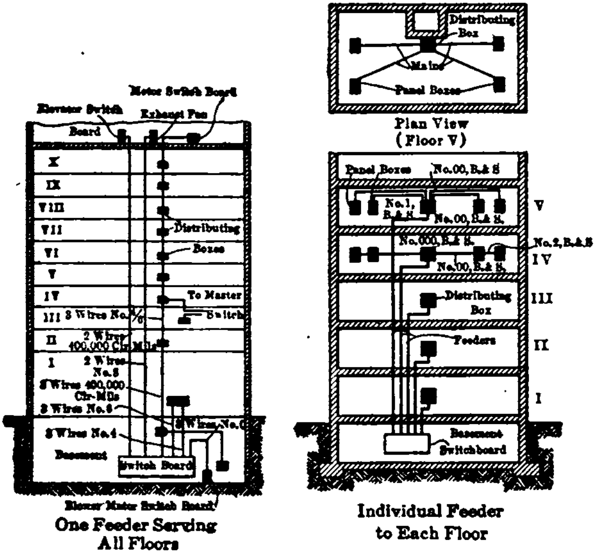


Fig. 16.—Wiring lay-outs in large buildings.

finement of control that is desired from the main switchboard. It is frequently necessary to make several tentative lay-outs and computations before the most desirable arrangement is found. Segregated motors and groups of motors, unless very small, should be served by independent feeders.

87. Arrangement of feeders. Solely on a basis of initial cost, it is usually cheaper to run a few large conductors than a number of small ones. It does not pay, however, to endeavor to install conductors larger than 1,000,000 cir. mils. When large capacity is necessary, use several conductors having the aggregate capacity required. For alternating currents, conductors larger than 700,000 cir. mils are not desirable because of skin effect. Often the space available for conductor runs necessitates small conductors (Par. 36 and 63).

88. Motor circuits are subject to many special Code requirements. One unfamiliar with its rulings should refer to the Code before he attempts

90. Compilation of estimates. Experience and a reliable note-book of labor costs applying to the community under consideration are the most valuable aids. Read the specifications or inspect the premises and make a wiring lay-out if there is none available. Make a list (Fig. 17) of all material required, following some definite system. A good method is to consider each distribution center—one at a time—and tabulate all the material required for the circuits feeding from it. Number or letter the distribution centers in accordance with a certain scheme and designate the branches with sub-notations. Indicate this notation on an estimating sheet similar to that of Fig. 17, in connection with your tabulation. Then proceed, tabulating panel-box, main, feeder and entrance material. After all is tabulated, the items can be totaled and these total values used for ordering material. Allow for some extra material for losses and breakages. Figure labor cost on a unit basis, that is, the cost of stringing wire being a certain value per 100 ft., the cost of erecting conduit being so much per unit length and so on through the entire list of materials. See cost data elsewhere for unit costs. A small job can be estimated with fair accuracy on a basis of so much per outlet, without the necessity of compiling a bill of materials.

INSTALLATIONS

91. Service entrances, (Fig. 19). A cut-out and a fuse block should protect the switch. The wall should be bushed where the conductors pass through unless they are in conduit, and the tubes or conduit should be cemented in the wall. Tubes should slant outwardly and downwardly to

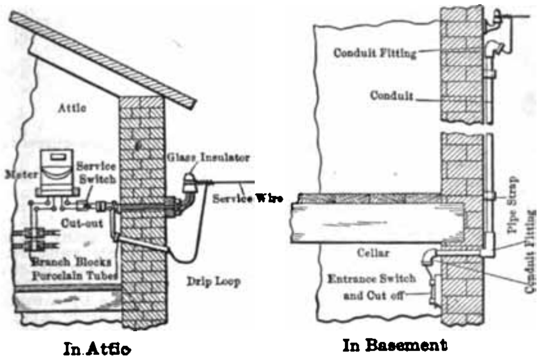
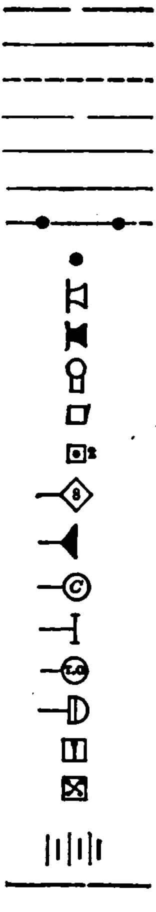


Fig. 18.—Service entrances.

prevent the entrance of moisture, and a drip loop should be formed of the service wires. The entrance switch should be so arranged that it will disconnect all of the equipment in the building except the main cut-out. Where conduit is used, the two or the three rubber-insulated wires should be carried in one conduit.

92. Panel-box panels may consist merely of porcelain cut-outs held to the back of the box with wood screws, or they may be more elaborate. The panel merely provides a convenient means of connecting the branch circuits to a main through fuses. Switches may be used in both main and branch circuits or they may be omitted entirely. Many satisfactory installations are in operation without switches, but switches are a great convenience for opening circuits when replacing fuses or for testing. In general, knife switches should not be used in branch circuits for the control of the lights, as they are frequently not of sufficiently strong construction to withstand permanently such service. Branch-lighting circuits should be controlled by either flush or surface snap switches mounted outside the panel box.



Main or feeder run concealed under floor.

Main or feeder run concealed under floor above.

Main or feeder run exposed.

Branch circuit run concealed under floor.

Branch circuit run concealed under floor above.

Branch circuit run exposed.

Pole line.

Riser.

Telephone outlet; private service.

Telephone outlet; public service.

Bell outlet.

Buzzer outlet.

Push button outlet. Numeral indicates number of pushes.

Annunciator. Numeral indicates number of points.

Speaking tube.

Watchman clock outlet.

Watchman station outlet.

Master time clock outlet.

Secondary time clock outlet.

Door opener.

Special outlet for signal systems, as described in specifications.

Battery outlet.

Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service wanted ascertained by symbol to which line connects.

Circuit for clock, telephone, bell or other service, run under floor above, concealed. Kind of service wanted ascertained by symbol to which line connects.

Heights of center of wall outlets (unless otherwise specified):

Living Rooms	5 ft. 6 in.
Chambers	5 ft. 0 in.
Offices	6 ft. 0 in.
Corridors	6 ft. 3 in.
Height of switches (unless otherwise specified)	4 ft. 0 in.

Fig. 19B.

fore, difficult to state even approximately what the cost of distributing systems for lighting should be. In large cities, these variations are not extreme and it is possible to state the limits within which the cost, expressed in terms of the usual contractor's price per outlet, should lie. The figures given below apply to interior wiring of all classes, from the small residence to the large hotel or office building. They cover the portion of the work from the main source of supply, assumed to be at the building line. In case the building is lighted from its own plant these figures will apply to the portion of the installation lying between the lamp and the plant switchboard. No lamps, fixtures or reflectors are included in these prices:

Exposed wiring, $1.50 to $1.60 per outlet.

Wire in wooden moulding, $2 to $2.50 per outlet.

Concealed knob and tube wiring, $2.50 to $3 per outlet, with $1 added per switch outlet.

Wiring in iron conduit and in new buildings, $4.50 to $5 per outlet.

Wiring in iron conduits in concrete buildings, $5 to $6 per outlet.

In the above, switches and base-board plugs are considered as outlets when the iron box is included. If the switch and plate are also to be furnished, approximately $1 per outlet of this nature should be added. For the larger installations in modern buildings the price of $7 per outlet, including all wiring and feeders up to the lighting fixture, has been found to be a fairly close figure.

98. Cost of Residence Wiring

Cost for Different Numbers of Outlets, Single Floor Construction, Concealed Knob and Tube Work in Finished Buildings

(Central Station Development Company, of Cleveland, Ohio)

No.	Cost	No.	Cost	No.	Cost	No.	Cost	No.	Cost
5	$15.85	17	$37.40	29	$57.20	41	$77.82	53	$100.82
6	17.85	18	39.65	30	58.85	42	79.75	54	102.85
7	19.85	19	40.70	31	60.50	43	81.75	55	104.77
8	21.85	20	42.35	32	62.15	44	83.60	56	106.70
9	23.85	21	44.00	33	63.80	45	85.50	57	108.62
10	25.85	22	45.65	34	65.45	46	87.45	58	110.55
11	27.50	23	47.30	35	67.10	47	89.37	59	112.47
12	29.15	24	48.95	36	68.75	48	91.30	60	114.40
13	30.80	25	50.60	37	70.40	49	93.22	....	....
14	32.45	26	52.25	38	72.08	50	95.15	....	....
15	34.10	27	53.90	39	73.97	51	97.07	....	....
16	35.75	28	55.55	40	75.90	52	99.00	....	....

Add as per following for outlets under other than single floors and for hardware and drop cords.

Under double flooring otherwise than hardwood. Second or third story.

Ceiling outlet	$1.00 extra.
Switch outlet for any center outlet	1.00 extra.

Under hardwood flooring, single, double or triple. Second and third story.

Ceiling outlet	$3.00 extra.
One switch outlet for any center outlet	3.00 extra.
Additional on same gang for same center outlet	1.50 extra.

Switches, hardware and drop cords as per following:

Push-switches, each	$1.00 extra.
Push-3-way switches, per set of two switches	2.75 extra.
Porcelain base switches, each	.35 extra.
Porcelain base Edison receptacles, each	.35 extra.
Baseboard flush plate receptacles, each	1.15 extra.
Drop cord, key sockets each	.60 extra.
Drop cord, chain sockets, each	.75 extra.

will be $20. The number of outlets upon which these figures are based does not include switch outlets, but only the actual lamp outlets. In old buildings the cost of the conduit and wiring work is $20 to $25 per outlet and $30 in the extreme West.

PROTECTION

103. General principles regarding the use of fuses. Fuses or some other form of overload protection should be used where the protection of conductors or appliances against overload is desirable. The *National Electrical Code* specifies in detail as to their application. Constant-potential generators should be protected against overload by fuses or their equivalent. Single-pole protection is acceptable under certain conditions for direct-current generators. Fuses should be placed at every point where a change is made in the size of wire, unless the fuse on the larger wire is of such capacity that it will protect the smaller one.

Fuses should be inserted in all service wires, and should be located in an accessible place as near the entrance to the building as possible. For three-wire systems, the neutral wire need not be fused, provided the neutral wire has a carrying capacity equivalent to that of the larger of the outside wires, and if the neutral is grounded. No group of small receivers, whether motors, incandescent lamps or heating appliances, requiring more than 660 watts should depend on one cut-out. The rated capacity of a fuse protecting any wire should not exceed the safe carrying capacity of that wire as specified in Par. 22. Each wire for a motor circuit, except at a switchboard, should be protected by a fuse whether or not circuit-breakers are used, except where the motor is of such large capacity that fuse protection cannot be obtained, in which case it is only possible to use circuit-breakers.

104. Fuses vs. circuit-breaker. Fuses possess a time element of operation (see Fig. 20) which circuit-breakers do not have unless specially designed therefor. Due to this property, fuses delay the opening of an over-loaded circuit, where the operation would be practically instantaneous with circuit-breakers; fuses, then, may be preferable for motor circuits and for circuits that are subject to very brief overloads, especially where expert supervision of electrical apparatus is maintained, as in large mills and factories. Where there are many fuse replacements, the cost of fuse renewals is considerable.

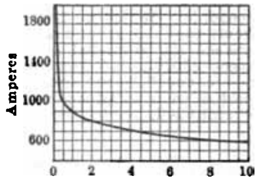


FIG. 20.—Typical performance curve of a 400-ampere, 500-volt, National Electrical Code standard fuse.

Circuit-breakers can be reset in less time and with less trouble than is required to replace blown fuses, and no spare parts are required. Circuit-breakers may, therefore, be preferable where the time saved by their use is an important consideration. The first cost of the circuit-breaker equipment is more than the cost of fuse equipment, but under severe service the circuit-breakers will prove less expensive in the end.

105. Grounding the neutral of three-wire circuits. It is important that the path through the neutral remain intact. Grounding promotes this condition, and the Code authorizes it, provided that: (a) the neutral is thoroughly grounded at the central station; (b) in underground systems the neutral is grounded at each distributing-box; and (c) in overhead systems, every 500 ft. Normally in a well-designed system, the neutral carries a minimum of current. Frequently, in underground systems, a bare copper wire drawn in the ducts constitutes the neutral. If the neutral becomes open, the pressure normally existing between the outer wires may be imposed on the equipment connected between the neutral and an outer wire; under these conditions the equipment may be ruined and a fire may result, since the voltage thus imposed will be twice that for which the equipment was designed.

106. Alternating-current, low-voltage, secondary circuits should be grounded. This is the recommendation of the *National Electrical Code* and is the practice of progressive central-station companies. Grounding prevents accidents to persons and damage, by fire, to property. If some point of a low-voltage secondary circuit is grounded, no point of the circuit can rise above its normal potential (except under unusual conditions) in case of a breakdown between primary and secondary windings of the transformer, or of other accidental connection between the primary and secondary circuits. See The *National Electrical Code* for further information regarding grounding.

The ground connection should be made at a neutral point or wire if one is

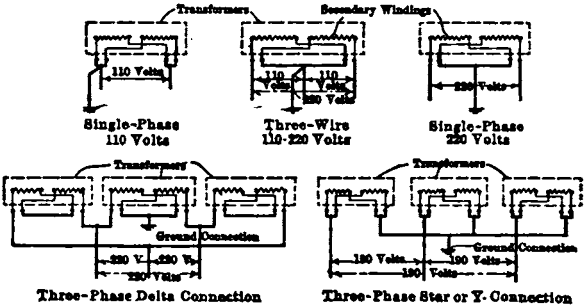


FIG. 21.—Ground connections to secondaries of commercial transformers.

accessible. Where no neutral point is accessible, one side of the secondary circuit may be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts (*National Electrical Code*). Fig. 21 illustrates how some of these connections are arranged with commercial transformers. The neutral point of each transformer feeding a two-phase, four-wire secondary, should be grounded, unless the motors taking energy from the secondary have

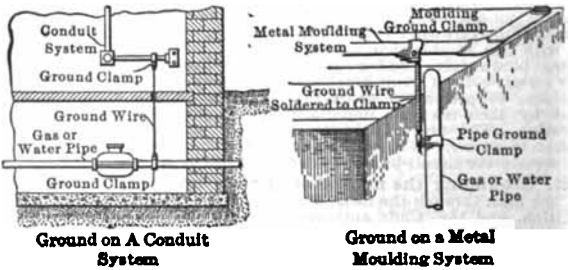


FIG. 22.—Methods of grounding.

interconnected windings. Where they are interconnected, the center or neutral point of only one transformer is grounded. No primary windings are shown in the illustration and the secondary winding of each transformer is shown divided into two sections, as in commercial transformers.

107. All metal conduit and metal-moulding systems must be grounded (see Fig. 22), by attaching an approved clamp (there are many on the market) to a conduit or moulding of the system and connecting it with a ground wire to another clamp attached to a water or gas pipe on the street side of the meter. The wire must be soldered in the clamps. All parts of the conduit or moulding system must be in good electrical contact. In an ungrounded system of conduit, "sneak" currents are possible. These leak from one wire to the conduit through an abrasion of insulation and reach the other side of the line through another ground. The resistance of the path may be sufficient to hold the "sneak" currents below the line fuse capacity, and yet these currents may be sufficient to start a fire. Grounding the conduit also eliminates the possibility of electrical shock to persons coming in contact with the conduit. In combination fixtures the gas pipe should be in thorough electrical contact with the conduit or moulding system at each outlet box.

Wire for grounding conduit or moulding must be of copper, at least No. 10 B. & S. gage, where the largest wire contained in system is not greater than No. 0 B. & S. gage. It need not be greater than No. 4 B. & S. gage where the largest wire contained in conduit is greater than No. 0 B. & S. gage. The wire must be protected from mechanical injury.

MISCELLANEOUS

108. Wire for bell signal work in dry places is usually No. 18 copper, double-cotton-covered and paraffined. Where more than two or three bells or similar devices are connected to the circuit, or where the circuits are long, No. 16 wire should be used. No. 14 is frequently used for battery wires. Rubber-covered, twisted-pair wires, like those used for interior telephone wiring, can often be used to advantage in damp places or where the circuits are exposed. No. 20 wire, although sometimes used, is too small for reliable work. Annunciator and twisted-pair wire is made with insulating coverings of different colors, so one can be selected that will match the surroundings, and be inconspicuous. Cables of annunciator wire, which can be obtained with practically any number of conductors from 2 up to 200, are very convenient and economical for large installations. In perfectly dry locations, a cable having a paraffined, braided-cotton covering can be used, but if it is to be exposed to dampness a lead-covered cable should be installed. By having the cable conductors covered with braids of different colors, the conductors can be readily identified. A kind of weather-proof wire called "damp-proof," is quite satisfactory for exposed wiring in damp places. It is more expensive than annunciator wire, but it has a better appearance when installed. See the *National Electrical Code*, the "Telephone" section in this book and the Western Electric Co. catalogue for further information.

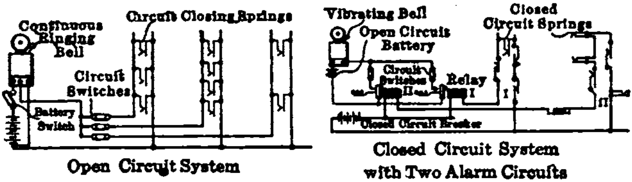


FIG. 23.—Burglar-alarm system.

109. Telephone wiring may follow the practice of the central-exchange or the intercommunicating system. In the former, single pairs of wires radiate from a switchboard to all stations. In an intercommunicating system, a cable of twisted pairs of insulated wires extends continuously through all the stations. This cable must contain at least one more wire than there are stations (Sec. 21). Conductors of No. 25 A.W.G. have been used; also No. 22 and No. 19, according to transmission requirements (Sec. 21).

110. Fire alarm wiring should be very carefully and substantially installed. As a general proposition, the wires should be heavier than would be used in ordinary signal practice; nothing smaller than No. 14 should be used indoors and nothing smaller than No. 8 out of doors. For interior lines, rubber-insulated copper should be used, while for outside construction, weather-

111. Electric gas-lighting wiring may follow the multiple system or the series system (Fig. 24). In the multiple system a spark is made by the breaking of an electrical circuit containing a reactance coil. One side of the circuit is usually grounded on the gas pipe. Electrically equipped burners of many types are obtainable. Certain spark coils are equipped with relays which sound an alarm if the system becomes short-circuited. Open circuit cells are used, a battery of 6 Leclanché cells in combination with a spark coil being usually sufficient.

In the series system, a spark gap is installed at each burner. The spark may be fed from induction coils or from frictional or static machines. The series system may be best adapted to large auditoriums, where many lamps are used in groups. It is now seldom used because such places are almost invariably lighted with electricity. See the "American Electricians' Handbook."

112. Electric bell and annunciator wiring. The possibilities for different circuit combinations are almost numberless. Those shown in Fig. 25 are typical. Two ordinary vibrating bells will not work well together in series; so when it is necessary to connect two bells in series, one should be a single-stroke bell. A multiple arrangement is preferable. The best arrangement of battery cells may be determined by trial. An ordinary bell requires about 0.1 amp. for its operation. Return call-bell circuits (*B*, Fig. 25) are so arranged that, when a station is signalled, the party called can respond by pressing his button. Ground return circuits may be used but are undesirable. Continuous-ringing bells are so arranged that, when the button is pressed, the bell continues to ring until reset. For elevator annunciators a cable is used, having as many conductors as there are buttons and one additional battery wire. If two annunciators are to operate simultaneously, their drops should be connected in series. See the "American Electricians' Handbook" for further information.

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SECTION 14

ILLUMINATION

BY PRESTON S. MILLAR

General Manager, Electrical Testing Laboratories; Past-President, Illuminating Engineering Society; Member, American Institute of Electrical Engineers, etc.

CONTENTS

(Numbers refer to Paragraphs)

PRODUCTION OF LIGHT

CHARACTERISTICS OF ELECTRIC LAMPS

ACCESSORIES FOR ILLUMINANTS

ILLUMINATION CALCULATIONS

APPLIED ILLUMINATION

PHOTOMETRY

BIBLIOGRAPHY, 303

where

J = radiation intensity; C = constants;
θ = temperature in deg. abs. and e = logarithmic base

Curves of radiation from a black body, computed according to this law, appear in Fig. 2.

5. Perfect black-body or temperature radiation is not found in artificial illuminants. Among incandescent electric lamps it is approached—most closely by "untreated" carbon-filament lamps (10-watt, 110-volt and 50-watt, 220-volt types)—in lesser degrees by "treated"-carbon, "metallized"-carbon and tungsten-filament lamps. The carbon filaments depart from a black body less than does platinum, for which a displacement-law constant (Par. 4) of 2630 has been found.

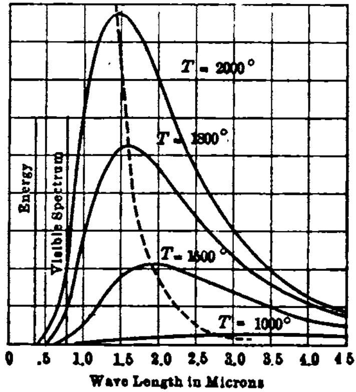

Fig. 2.—Black-body radiation at several temperatures.

6. Gray-body radiation is distributed throughout the spectrum in the same proportions as black-body radiation, but is everywhere less intense. It differs from black-body radiation in quantity, not in quality.

7. Selective radiation is distributed differently throughout the spectrum and does not obey the laws of black-body radiation. If it is relatively strong between the limiting wave lengths of visibility, particularly if near the middle of the visibility range, the body produces more light, and the selectivity is favorable. Curves of black-body, gray-body and of one kind of selective radiation are given in Fig. 3.

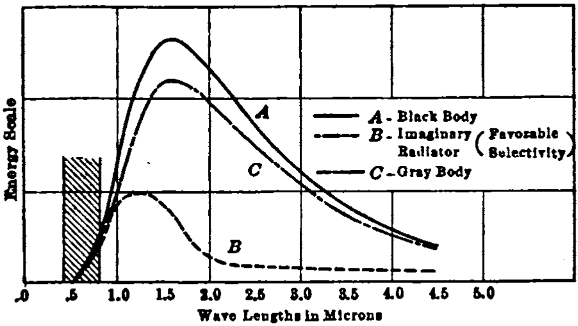

Fig. 3.—Three kinds of radiation.

8. Luminescence is that form of light production in which the radiating body (usually a gas or vapor) changes its nature in the process. Such radiation usually is characterised by a line spectrum. Luminescence embraces all forms of light production other than incandescence. In electric lighting it is the process by which light is obtained from gases or vapors. The mercury-vapor and the metallic-electrode (magnetite and

There can be no one value for the mechanical equivalent of light applicable to all illuminants, if all energy in the visible range is included, because of the variation of eye sensibility with wave length. If, however, a narrow band of spectral radiation be separated and studied, a definite and reproducible ratio between energy and light value may be obtained. And if this band be selected from the part of the spectrum where the light value is highest (say 0.55μ), the minimum possible mechanical equivalent of light will result. Ives,* having compared with his own the experimental data and calculations of other investigators, has assigned the value of 0.02 watt per mean spherical candle, or 0.0016 watt per lumen, as the most probable mechanical equivalent of yellow-green light, to which the eye is most sensitive.

With this criterion of light producing efficiency available for the highest point of the ocular-luminosity curve (Fig. 5), a scale of ordinates for that curve is established, and the curve yields the sensibility coefficient for each wave length. This applied to the radiation curve (Fig. 2), gives a curve of visibility, from which the total illuminating power may be integrated. The value so obtained should equal the candle-power or the lumens as measured by a photometer. The value of mean spherical candle-power per watt or of total lumens per watt, when stated in terms of the most efficient light per watt, yields the "reduced luminous efficiency." (Drysdale's terminology.) The table of Par. 13 shows data of this kind based upon Ives' compilation.

13. Efficiency of light production

(Electrical World—Vol. LVII, p. 1566)

	Watts per mean sph. c-p.	Per watt		Reduced luminous efficiencies (based on radiated energy)
		Mean sph. c-p.	Lumens	
				Per cent.
Yellow-green 0.55μ......	0.02	65	800	100
Firefly..................	....	....	....	96
Black-body, about 5,000 deg. abs.	....	10	125	15
Ditto, excluding energy outside limits 0.76μ to 0.38μ.	....	22	274	34
Ditto, excluding energy outside limits 0.70μ to 0.40μ.	....	26	330	41

14. In "reduced luminous efficiency" (see Par. 13) we have a very practical measure of efficiency of light production, because for any illuminant the ordinary commercial rating is directly comparable with the standards of highest possible efficiency. With this system of rating, everything depends upon the correctness of the standard of light production. But it may be noted that all artificial illuminants are so low in efficiency that a considerable error in fixing the standard would not alter materially the conclusions as to the inefficiency of illuminants. Standards for this purpose appear in Par. 16.

15. White-light efficiency. "Reduced luminous efficiency" (Par. 14) is the light flux per watt in per cent. of the yellow-green flux obtained from 1 watt radiated at 0.55μ. Such yellow-green light would be undesirable for most illuminating purposes. The generally accepted ideal is white light. Ives† has proposed the radiation between 0.70μ and 0.40μ from a black body at 5,000 deg. abs. as a standard of white light, and has assigned 330 lumens per watt as the most probable value of the most efficient white light obtainable. This is a satisfactory criterion for illuminating purposes. Ives‡ also has studied the spectrophotometric curves of some of the common incandescent sources to ascertain what proportion of their light is available to

* Luminous Efficiency, *Trans.* I. E. S., Vol. V, p. 113.
† *Electrical World*, Vol. LVII, 1909, p. 1566.
‡ Bulletin, Bureau of Standards, Vol. VI, p. 238.

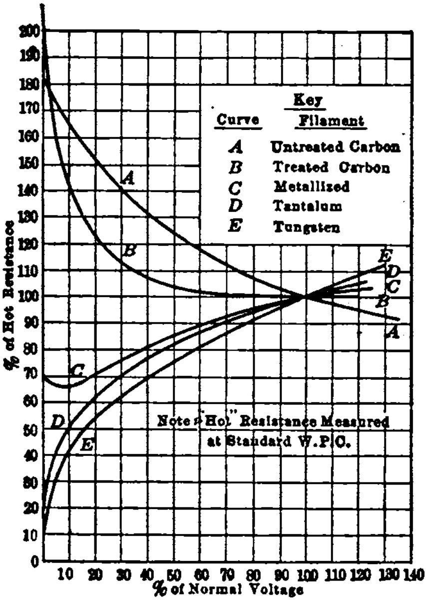

FIG. 6.—Resistance characteristics of incandescent lamps.

21. Resistance of filament lamps

Lamp	Cold resistance	Resistance at standard efficiency
20-watt untreated-filament	1062 ohms	582 ohms
60-watt treated-carbon	459 ohms	225 ohms
60-watt metallized-carbon	156 ohms	222 ohms
50-watt tantalum.................	44 ohms	262 ohms
60-watt tungsten.................	16.5 ohms	206 ohms

22. The physical characteristics of these lamps (Par. **20**) are shown in Fig. 7, 100 per cent. volts corresponding with rated efficiency. Throughout a range of a few volts above and below normal, these relations may be expressed as parabolic equations.

$$\frac{V_1}{V_2} = \left(\frac{e_1}{e_2}\right)^k \tag{4}$$

The exponents* are not determined beyond question, particularly for tungsten filament (Mazda) lamps, where improvements in manufacture are being made so rapidly that statistics for the final establishment of these values are not available for lamps of latest manufacture. Best known values for the exponents are given in Par. **23**, and are reasonably accurate throughout a working range of voltage variation. Par. **24** shows corresponding exponents for the variation in life with change in watts per candle.

* Edwards, E. J. *General Electric Review*, March, 1914.

25. Ives compilations of spectrophotometric and colorimetric values of illuminants

Source	Energy value by wave-lengths										Sensation values		
	0.41μ	0.43μ	0.47μ	0.49μ	0.53μ	0.55μ	0.57μ	0.59μ	0.65μ	0.69μ	Red	Green	Blue
1 Black body at 5,000 deg. abs.	72.0	79.0	91.0	92.5	98.0	99.0	100.0	100.0	97.1	93.5	33.3	33.3	33.3
S											26.8	27.2	46.0
2 Blue sky	177.0	185.0	180.0	162.0	132.0	120.0	108.0	100.0	82.0	72.5			
C											32.0	32.2	35.8
3 Overcast sky	...	...	...	...	...	...	...	...	...	...	34.6	33.9	31.5
4 Afternoon sun	...	...	...	...	...	...	...	...	...	...	37.7	37.3	25.0
5 Hefner	1.9	3.5	10.5	16.3	37.5	53.2	74.5	100.0	210.0	320.0	50.5	40.3	6.2
											55.0	38.8	6.2
6 3.1-w.p.c. carbon lamp	4.0	7.0	18.0	25.5	47.0	62.0	79.0	100.0	176.0	234.0	50.9	40.6	8.5
											51.3	40.4	8.3
7 Acetylene	5.5	9.6	21.9	30.3	52.0	66.5	82.0	100.0	160.0	205.0	48.1	41.0	10.9
											49.1	40.5	10.5
8 Tungsten 1.25 w.p.c	6.5	10.2	22.8	31.5	52.5	66.5	82.0	100.0	158.0	201.0	47.9	41.1	11.0
											48.7	40.5	10.9
9 Nernst	...	...	...	...	...	...	...	...	...	...	49.2	40.7	11.1
10 Welsbach, ¼ per cent. cerium	...	...	...	...	...	...	...	...	...	...	42.5	40.8	16.7
11 Welsbach, ¾ per cent. cerium	...	...	26.4	38.3	64.0	78.0	90.0	100.0	114.0	120.0	45.2	42.0	12.8
											45.5	42.0	12.5
12 Welsbach, 1¼ per cent. cerium	...	...	...	...	...	...	...	...	...	...	47.2	41.8	11.0
13 D. C. arc	...	21.8	37.0	45.5	65.5	76.0	88.0	100.0	142.0	170.0	41.0	36.3	22.7
14 Mercury arc	...	...	...	...	...	...	...	...	...	...	29.0	30.3	40.7
15 Yellow flame arc	...	...	...	...	...	...	...	...	...	...	52.0	37.5	10.5
16 Moore carbon dioxide tube	...	...	...	...	...	...	...	...	...	...	31.3	31.0	37.7

range of flicker as the frequency is increased; and the more marked flicker when the finer-filament lamps are operated at a given frequency. They indicate that the tungsten lamp is less adaptable for use upon low-frequency currents than the carbon lamp.

Experience indicates that while lighting from 25-cycle circuits is satisfactory for many purposes, yet is not entirely satisfactory for all classes of service with all sizes of lamps. This frequency appears to be just a little too low to be generally acceptable.

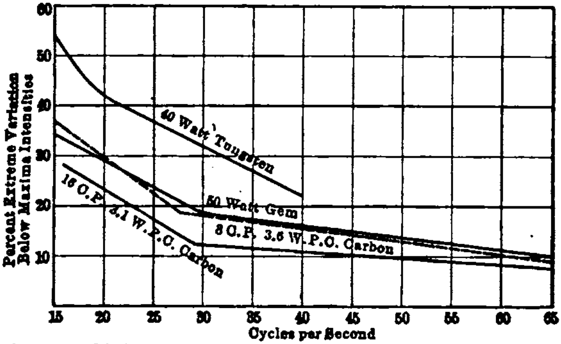

FIG. 8.—Flicker as indicated by cyclic candle-power variations.

29. Limits of acceptability for multiple incandescent lamps. The measure of rating uniformity of incandescent lamps in respect to light intensity, energy consumption and efficiency is indicated by the limits of acceptability prescribed in the standard specifications.

Type	Watts	Permissible variation from standard rated values		
		c-p.	watts	watts per candle
105 to 125 volts...	......	....	....	....
Tungsten (Masda).	40	....	± 15 per cent.	± 8 per cent.
Gem..............	50	±7.5 per cent.	± 7 per cent.	....
Carbon...........	50	± 15 per cent.	± 11 per cent.	....

30. Spherical reduction factor. It has been customary, when dealing with incandescent lamps, to measure and rate them in terms of mean horizontal candle-power. As for most purposes, the total light produced is the quantity to be considered, it is often desirable to reduce these values to mean spherical candle-power. The ratio of the mean spherical to the mean horizontal candle-power is the spherical reduction factor. For certain lamps this is shown as follows:

	Approximate spherical reduction factor
Treated carbon-oval filament..........................	0.82
Metallized carbon (Gem) oval filament..........	0.82
Tantalum..	0.77
Masda, 60 watts..	0.78

36. Untreated carbon filaments are now employed principally in sign lamps of the 10- and 20-watt sizes of the 110-volt range, and in lamps of the 220-volt range. As the filament has a higher resistance, it is shorter and may be disposed in a small bulb, where the longer treated filament cannot be utilized. As they are capable of only 30 to 40 per cent. of the useful life of treated-filament lamps, they are operated at a lower efficiency and are used only where necessary. Abroad, notably in England, they have been employed much more generally than in America, due to the prevalence of 220-volt circuits. See Fig. 9.*

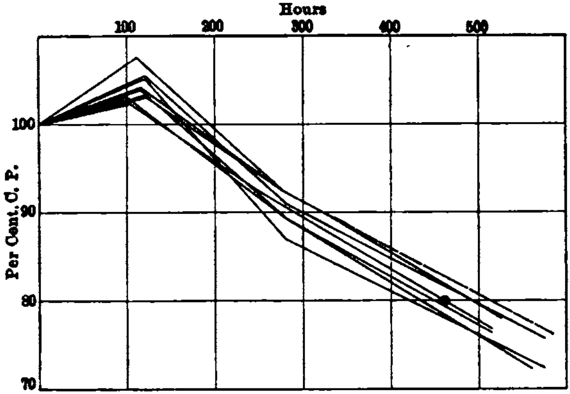

FIG. 9.—Typical candle-power performance of 16 c-p., 220-volt, "untreated" carbon-filament lamps at 3.8 watts per mean horizontal candle-power.

37. Untreated carbon-filament lamps

Rated and average watts	Mean horizontal c-p.	Total lumens	Commercial rating watts per mean horizontal c-p.	Specific consumption watts per mean spherical c-p.	Specific output lumens per watt	Average total life
105 to 125 volts						
10	2.0	21.2	5.0	5.88	2.12	2,000 hr.
20	4.8	51.2	4.15	4.88	2.56	1,000 hr.
200 to 260 volts						
35	7.95	84.0	4.40	5.24	2.40	1,000 hr.
60	16.26	170.4	3.69	4.40	2.84	750 hr.
120	32.52	340.8	3.69	4.40	2.84	750 hr.

38. Candle-power-performance curves of typical high-grade treated carbon filament lamps are given in Fig. 10, being a combination of curves published by several lamp manufacturers from independent tests of their products.

39. The candle-power deterioration throughout life is due in approximately equal parts to decrease in watts occasioned by increase in filament resistance, and to increase in absorption of light due to bulb blackening.

* Howell. *Transactions* American Institute of Electrical Engineers, June 19, 1905.

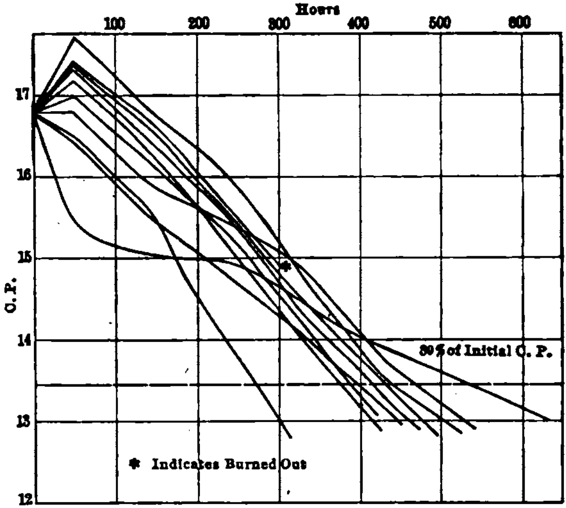

Fig. 10.—Typical candle-power performance of 50-watts, 110-volt "treated" carbon-filament lamps at 2.97 watts per candle.

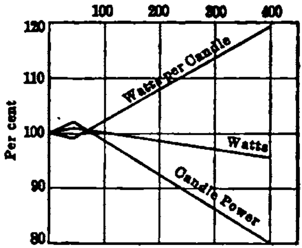

Fig. 11.—Change during "useful" life—"treated" carbon-filament lamp.

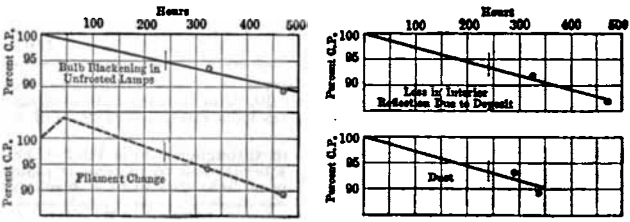

Fig. 12.—Analysis of candle-power decline in frosted carbon-filament lamps.

Fig. 11 shows change in candle-power, watts and watts per candle of an average high-grade treated carbon filament lamp throughout useful life.

40. Frosted carbon-filament lamps decline in candle-power at about twice the rate of clear lamps. An analysis of the cause of such decline appears in Fig. 12.*

41. Performance on direct current compared with alternating current. So far as is known there is no material difference between the performance of carbon lamps on direct-current and on 60-cycle sine-wave current.

42. The rating uniformity of treated carbon-filament lamps is suggested in Figs. 13 and 14, which exhibit extremes of good and bad practice.

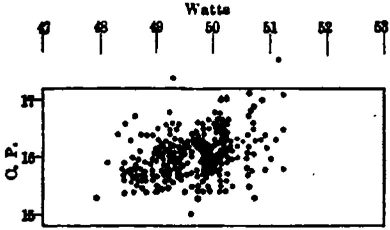

Fig. 13.—Rating of well-selected group of carbon-filament lamps.

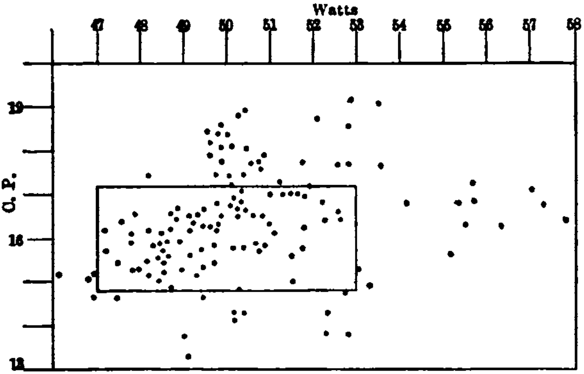

Fig. 14.—Rating of poorly selected group of carbon-filament lamps.

43. Passing of the treated carbon-filament lamp. At the present time (summer, 1914) the treated carbon-filament lamp is almost obsolete. The higher efficiency of tungsten (Mazda) lamps and of metallized (Gem) carbon lamps, has rendered the use of carbon-filament lamps very uneconomical, and the demand for them has almost ceased.

METALLIZED CARBON-FILAMENT LAMPS

44. In manufacture this filament is baked in an electric furnace before being treated or flashed. After treatment a second baking at high tempera-

* Millar. *Electrical World*, 1907, Vol. XLIX, p. 798.

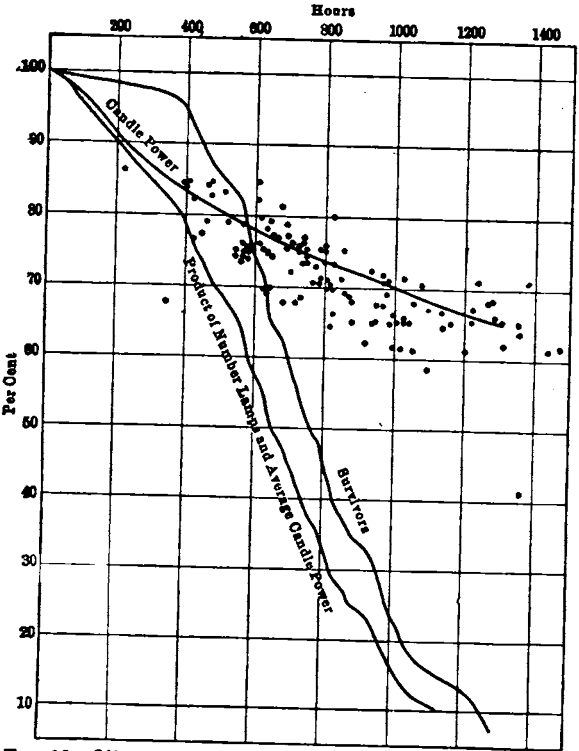

FIG. 16.—Life performance of 80-watt Gem lamps at 2.46 w.p.c.

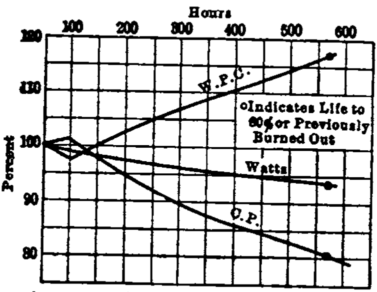

FIG. 17.—Life performance of a typical 50-watt Gem lamp at 2.5 w.p.c.

sales in 1912. Already this place has been surrendered to the tungsten-filament lamp. Probably the metallized carbon-filament lamp will become obsolete within the next few years.

TANTALUM FILAMENT LAMPS

52. Standard tantalum lamps

(Employed in very small quantities)

Rated and average watts	Mean horizontal c-p.	Total lumens	Commercial rating watts per mean horizontal c-p.	Specific consumption watts per mean spherical c-p.	Specific output lumens per watt	(On d.c.) average total life
25	12.7	126.0	1.97	2.56	5.04	800 hr.
40	22.35	221.6	1.79	2.32	5.54	600 hr.
50	27.93	277.0	1.79	2.32	5.54	600 hr.
80	44.69	443.2	1.79	2.32	5.54	500 hr.

53. Performance upon alternating current.* The tantalum lamp performs less acceptably upon alternating current than upon direct current. Fig. 19 shows the breaking up of the filament after burning upon an alternating current circuit. From this, the character of the effect which is responsible for the inferiority on alternating current is apparent.

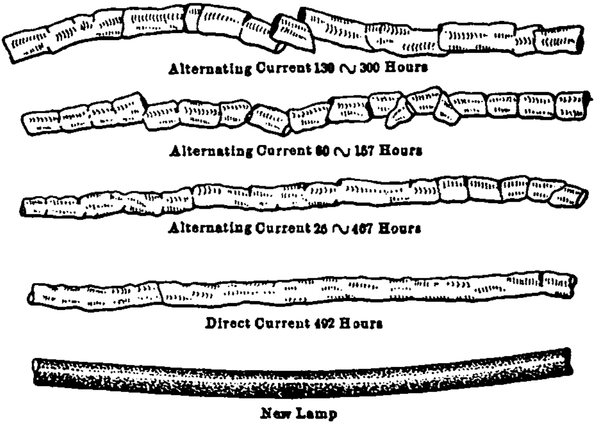

FIG. 19.—Appearance of tantalum filament after operation as stated.

54. Comparative performances on various frequencies*

Nature of supply	Hours "Useful Life"
Direct current..........................	606
25 cycles..............................	324
60 cycles..............................	151
130 cycles.............................	122

* *Transactions* American Institute Electrical Engineers, November 23, 1906.

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were attached to the lead wires in a special manner which contributed to the ruggedness of the lamp.*

61. Drawn wire. This was followed shortly by the announcement that tungsten wire had been drawn, and that drawn-wire tungsten lamps had been made successfully. Wire thus drawn was perfectly ductile, but, in the process of exhausting the bulbs and burning for a short time in the factory, much of the ductility was destroyed. Nevertheless, by employing a long filament of this wire, wound continuously as in the tantalum lamp, a much stronger tungsten lamp was achieved than previously had been available. Some idea of the increase in strength of the filament itself is given by the diagram in Fig. 20.†

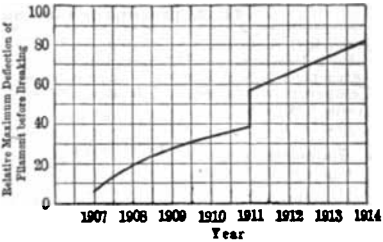

FIG. 20.—Increasing strength of tungsten filaments.

62. Modern manufacture of tungsten lamps. "The raw material used in the filament factory is a concentrated ore of tungsten, from which pure tungstic oxide, a fine-grained yellow powder, is obtained. This is 'doped' and reduced to tungsten metal by hydrogen in an electric furnace; the metal produced being in powder form, rather coarse grained, gray in color, and very heavy. This tungsten powder is formed into ingots about ¼ in. square and 6 in. long, by pressure alone, no binder being used. The pressure, which is very great, is applied transversely and compacts the tungsten so that the ingot can be handled. It is then placed in an electric furnace in an atmosphere of hydrogen and heated to a white heat, the effect of this heat being to compact and strengthen the ingot and make it a good conductor of electricity. The ingot is then placed in an atmosphere of hydrogen and heated to near the melting point, long enough to thoroughly sinter the ingot. The ingot now has a high luster, and the powder particles of which it is composed are welded together quite firmly. The square ingot now goes to a swaging machine. It is heated to white heat, taken out into the open air and swaged. During this operation a cloud of tungstic oxide rises from the ingot. The ingot is reheated and swaged several times before the square ingot becomes round. The heating and swaging are continued until the ingot is changed to a rod, 3/100 in. in diameter and 30 ft. long. Before this, when the rod is about 9/100 in. in diameter, it begins to have a fibrous structure. At 3/100 it has a well-developed fibrous structure, but can easily be broken by bending back and forth once or twice.

From thirty mils the rod or wire is reduced in size by hot drawing through diamond dies. The wire is heated to a bright red heat and is still red hot after passing through the die. This degree of heating is continued until the wire is only three mils in diameter, which is about the size of the filament in a 100-volt, 100-watt lamp. Below this, the temperature of drawing is reduced and the last drafts of any wire are made below red heat. The wire is now quite ductile and the last drafts may be made cold if desired. During this drawing the wire is lubricated with graphite, which forms a coating and prevents oxidation of the wire. It also lubricates the wire when it passes through the die. The last draft is made through a very perfect die which reduces the diameter of the wire very slightly, and in this way very long pieces are made which are the same size throughout."‡

Wire so produced is cut accurately to length and is wound upon the filament supports. A bulb-blackening preventive is introduced. After

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* Scott. "A New form of Tungsten Lamp," *Proceedings* National Electric Light Association, May, 1910."

† "Recent Progress in the Art of Lamp Making" by Randall and Edwards, National Electric Light Association, 1913.

‡ J. W. Howell. *General Electric Review*, March, 1914.

68. Classification of principal tungsten vacuum lamps, according to type and size

	Watts	Volts		Watts	Volts
Sign lamps......	2½	10-13	General lighting	150	100-130
	5	10-13		250	100-130
	5	50-65		400	100-130
	10	100-130		500	100-130
				25	200-260
General lighting.	15	100-130		40	200-260
	20	100-130		60	200-260
	25	100-130		100	200-260
	40	100-130		150	200-260
	60	100-130		250	200-260
	100	100-130			

69. Rating. Mazda lamps for multiple circuits are rated in watts. It is the present rating practice in this country to maintain the wattages of

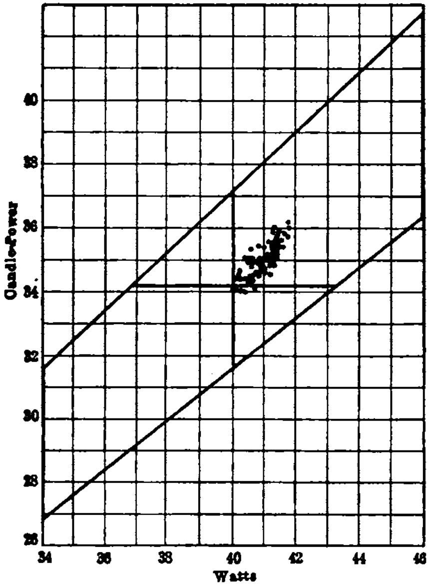


Fig. 22.—Rating of group of drawn-wire Mazda lamps.

lamps and to increase the candle-power whenever improvements in lamp manufacture warrant efficiency increase. Typical rating of carefully manufactured and assorted Mazda lamps is indicated in Fig. 22. The outline shown in the diagram represents the standard limits of acceptability for such lamps. See Par. 29.

75. Loss of light due to frosting of bulbs*

	Per cent. loss of light*	
	Bowl frosted	All frosted
Straight side bulbs, 25 to 250 watts.......	3	8
Round bulbs, 25 to 40 watts..............	5	8

76. Influence of external temperature upon the performance of lamps. But little information is available on this subject. Among carbon-filament lamps it has been found that relatively high external temperatures (200 deg. fahr.) result in a few poor-vacuum lamps, which "slump" in candle-power. This presumably is due to the water vapor expelled from the glass at the higher temperature. Among Mazda lamps more care is taken to eliminate water vapor, and this effect, not very serious among carbon lamps, should be less noticeable in the performance of Mazda lamps.

77. Influence of the character of the current supply upon the performance of Mazda lamps is not available as conclusive data. It has been asserted that differences in wave form of alternating current affect the performance materially. This is not accepted, however, and the weight of evidence appears to indicate the contrary. It is known, furthermore, that the performance on respectively sine-wave 60-cycle current and direct current does not differ enough to influence practice.

78. Concentrated filaments. An improvement effected in 1913 is the winding of the filament in a very fine helix which greatly reduces its length and makes possible modified forms of lamps. This concentrated filament† is employed in lamps designed for projection work in which it is important to reduce the over-all dimensions of the light source. It also has been used in tubular lamps for show-cases. The life of such lamps is shorter than that of lamps of the standard type.

79. Linolite lamps are a special form of tubular lamps particularly adapted for use in lighting show-cases, and other spaces for which their dimensions are favorably adapted. No data are available as to the relative life of such tubular lamps and ordinary bulb lamps at a given efficiency.

TUNGSTEN FILAMENT LAMPS FILLED WITH INERT GAS

80. General effects of the gas.‡ As a result of work of the Research Laboratory of the General Electric Company it has been found that inert gas within the bulb of a tungsten lamp operates to: (a) cool the filament; (b) reduce the rate of evaporation; (c) convey the evaporated material to the top of the bulb. The problem of increasing the efficiency of tungsten lamps—at least those having stouter filaments—is that of avoiding bulb blackening, which is the life-limiting feature.

The cooling effect of an inert gas decreases the candle-power of the filament, and in this respect the gas is detrimental. To obtain the same efficiency as in a vacuum it is necessary to increase the watts and operate the filament at a higher temperature. On the other hand the gas pressure reduces the

* Courtesy Edison Lamp Works.
Hyde. *Electrical Review*, April 6, 1907.
Millar. *Electrical World*, Vol. XLIX, p. 798.

† Randall and Edwards. "Recent Progress in Lamp Making." *Transactions* National Electric Light Association, 1913.
Harrison and Edwards. *Transactions* Illuminating Engineering Society, Vol. VIII, p. 533.

‡ Langmuir. *Transactions* American Institute Electrical Engineers, October, 1913.
Langmuir and Orange. *Transactions* American Institute Electrical Engineers, October, 1913.

Series lamps				
Amp.	Candle-power	Volts	Watts	Watts per horizontal c-p.
5.5	60	8.5	46.8	0.78
	80	10.8	59.2	0.74
	100	13.1	72.0	0.72
	250	30.9	170.0	0.68
	400	49.5	272.0	0.68
6.6	60	7.1	46.8	0.78
	80	9.0	59.2	0.74
	100	10.8	71.0	0.71
	250	24.6	162.5	0.65
	400	38.8	256.5	0.64
	600	56.7	384.0	0.64
7.5	60	6.2	46.8	0.78
	80	7.9	59.2	0.74
	100	9.5	71.0	0.71
	250	21.0	157.5	0.62
	400	33.1	248.0	0.62
	600	49.6	372.0	0.62
15.0	400	14.4	216.0	0.54
20.0	600	15.0	300.0	0.50
	1000	25.0	500.0	0.50

GENERAL CHARACTERISTICS OF ARC LAMPS

84. The electric arc is unstable on constant-voltage supply because of its volt-ampere characteristics whereby the voltage decreases as the current is increased. It is essentially a constant-current device. When used upon multiple circuits, ballast resistance, if direct-current, or reactance, if alternating-current, must be placed in series with the arc to limit the current. All arc lamps must be provided with automatic operating mechanisms to start the arc and to feed the electrodes as they are consumed. In addition, lamps for series service must be provided with shunt devices which protect the lamp and maintain the circuit in case the lamp fails to operate.

85. Operating mechanisms usually are actuated by electromagnets or solenoids, often in conjunction with weights and dashpots or other restraining device. "Series lamps," having series magnets only, regulate for constant current in the lamp. "Shunt lamps," employing shunt magnets only, regulate for constant voltage. The more usual "differential lamp" is equipped with both series and shunt magnets, and regulates for constant relation between current and voltage. Much ingenuity has been displayed in developing feeding mechanisms for arc lamps. Numerous methods have been employed, among which may be mentioned the gravity, clutch, rocker-arm, brakewheel, clockwork, motor and hot-wire feeding devices. These applications are described in publications of manufacturers and the principal methods are described in text-books.

86. Classification of arc lamps. Arc lamps may be classified in a number of ways according to the viewpoint. The classifications adopted in Par. 87 are comprehensive. In the following pages the several types of arc lamps are discussed in the order indicated. Vacuum tube lamps, which might be included in this class, are discussed later (Par. 116).

CARBON-ELECTRODE ARC LAMPS

88. The open arc is now regarded as obsolete. In its most common form it was of the direct-current 9.6-amp. type—the old "full arc" to which the rating of "2,000 c-p.," was applied in earlier years. The arc is about $\frac{3}{16}$ in. (0.48 cm.) long and of low luminosity. The end of the negative (lower) electrode, after a few hours of burning, assumes a conical shape and yields some little light by incandescence. The end of the positive (upper) electrode becomes concave, and the "crater" thus formed is the chief source of light produced by the lamp, the process being that of incandescence. Only the feeble light from the arc itself is produced by luminescence. The end of the positive electrode becomes intensely hot, attaining at the hottest part of the crater to from 3,900 to 4,000 deg. cent.*

89. Light distribution from the open arc. Fig. 24 shows the open carbon arc.† It will be apparent at once that the lower electrode obstructs a large portion of the light emanating from the crater. The curve in Fig. 25 shows actual distribution of light compared with probable distribution if the lower electrode were transparent,‡ the difference illustrating the loss of light due to obstruction by the lower electrode.

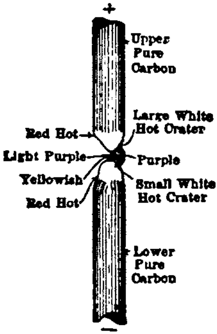


FIG. 24.—Open carbon arc.

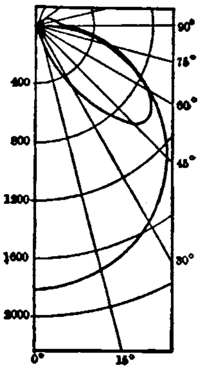


FIG. 25.—Distribution of light in vertical plane about 9.6-amp. direct-current open arc lamp. Also estimate of distribution if obstruction of lower electrode could be avoided.

90. Photometric and electrical data on direct-current open carbon arc lamps

	"Full arc"	"Half arc"
Amperes	9.6	6.6
Watts	450	325
Mean spherical candle-power	410	240
Maximum candle-power	900 to 1,200	....
Specific consumption—watts per candle	1.09	1.35
Nominal candle-power rating	2,000	1,200

91. Electrode life—open arc lamp. The open arc lamp suffered from short life of electrodes, unsteadiness of light, and poor light distribution. The electrode life was 7 or 8 hr. and it became common practice to

* Weidner & Burgess. Bulletin Bureau of Standards, Vol. I, No. 1, 19.
† Blake and Couchey. "Arcs and Electrodes," *Gen. Elec. Review*, 1913, p. 497.
‡ Trotter. "Illumination—Its Distribution and Measurement," p. 147.

trodes are raised to a high temperature, but neither attains the high temperature of the anode in the direct-current arc. The characteristics of light distribution from the two types of lamps appear in Fig. 27. It is general practice to equip the alternating-current lamps with a reflector which directs, below the horizontal, some of the light which would otherwise be distributed above the horizontal. The multiple lamps are less efficient than the series lamps. A certain amount of ballast is necessary, and this accounts for the difference between the line voltage (100 to 120 volts), and the arc voltage (70 to 75 volts). If the circuit is for alternating current, a reactance is employed, which does not occasion a large wattage loss but reduces the power-factor. If a direct-current circuit, a resistance is used, which occasions a direct loss in watts.

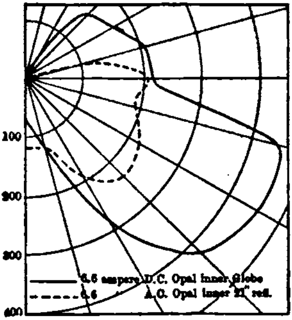


Fig. 27.—Light distribution in vertical plane about enclosed carbon arc lamps.

96. Intensified carbon arc lamps. The efficiency of a carbon arc lamp may be increased by diminishing the diameter of the electrodes with a given current or by increasing the current with given electrodes. In intensified carbon arc lamps the diameter of the carbons is reduced, producing a gain in efficiency and a light which is more nearly white and steadier than that of the ordinary enclosed arc lamp of which it is a refinement. Such lamps are used chiefly for lighting interiors where white light is desired, as in clothing stores. The intensified carbon arc was developed in Europe and exploited in small sizes operating at 2 and 3 amp., with an electrode life of 20 hr. or less. In this country the developments were along the lines of somewhat larger lamps operating at higher currents and longer electrode life. Typical lamps of this type are somewhat smaller than ordinary enclosed arc lamps, and are designed for either direct-current or alternating-current service. Small-diameter electrodes (about 7 mm.) are used, and life of about 70 hr. is realized. With opal globes an efficiency corresponding with approximately 2 watts per mean spherical candle-power is obtained in the direct-current lamp. The General Electric Company has developed a lamp of this type for direct-current service, in which two converging 6-mm. upper-positive carbons are used with a vertical lower carbon of 9.5 mm. diameter. This lamp is somewhat larger and more substantially built than other lamps of the class. The specific consumption when employed with an opal globe is slightly more than 2 watts per mean spherical candle-power.

THE FLAME ARC LAMP

97. Nature of flame arc. Impurities in the carbon are detrimental in the arc lamp of types in which the chief light production is accomplished through the incandescence of the electrode ends. As carbon is the most refractory material known, impurities are always more volatile, and their presence tends to reduce the temperature of the electrode ends. Hence, in the manufacture of carbons for such lamps, purity is considered of first importance. In the flame arc, the purpose is to secure light from the arc rather than from the electrode ends. The carbon is impregnated with chemicals which, when volatilized and driven into the arc, become highly luminous. The lower temperature of the carbon ends, due to these impurities, is immaterial, since little dependence is placed upon the ends for light production. The flame arc is simply a carbon arc into which mineralized salts are introduced. These may be of calcium, for yellow light; of barium and titanium, for white light; and of strontium, for reddish light. The carbon electrode serves as an electrical conductor and assures a hot and steady arc. The chemicals with which it is impregnated include those which are efficient light producers, and others whose functions are to promote high arc temperature and to steady the arc.

LONG-BURNING FLAME ARC LAMPS

102. General features. With the development of flame arc lamps which have an electrode life of 100 hr. or more, the flame arc has been placed in a position to compete with other illuminants for street-lighting service. In this type, electrodes of about ⅞ in. (2.22 cm.) diameter are employed within a globe which restricts the air supply. It is known as the "long-burning" or "enclosed" flame arc. Long electrode life is secured at the expense of some efficiency. For this type of lamp, solid impregnated carbons have been developed in place of the familiar cored carbons employed in the original flame arc lamps. These are available in both yellow and white light forms, the latter being slightly less efficient. See Fig. 30.*

103. Electrical characteristics of flame arc lamps of one manufacture appear in Par. 104. To adapt the alternating-current lamps for use upon various circuits, compensators are supplied, sometimes built in and sometimes external to the lamp proper.

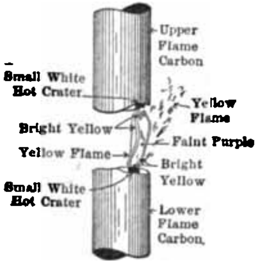


FIG. 30.—Long-burning flame arc.

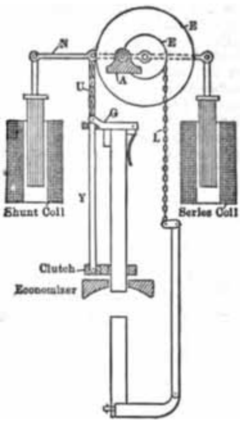


FIG. 31.—Mechanism of long-burning alternating-current flame arc lamp.

104. Approximate electrical data of long-burning flame arc lamps of one manufacture

	Amperes		Volts		Terminal watts	Power-factor, per cent
	Terminal	Arc	Terminal	Arc		
Alternating-current multiple 110-volt (compensator)	7.5	10.5	110	47	540	66
Alternating-current series.....	10.0	10.0	60	47	465	78
Alternating-current series (compensator)	7.5	10.0	86	47	500	78
Alternating-current series (compensator)	6.6	10.0	98	47	500	78
Direct-current multiple 110-volt.	6.5	6.5	110	67	715	....

105. Life of electrodes. Carbons for enclosed flame arc lamps are usually of ⅞ in. diameter and are 14 in. long. The unused portion of the upper is used for trimming the lower. A life somewhat in excess of 100 hr. is had. The mechanism of an alternating-current enclosed flame arc lamp of one make is illustrated in Fig. 31.

* Blake and Couchey. "Arcs and Electrodes," *Gen. Elec. Review*, 1913, p. 497.

111. Photometric data on magnetite arc lamps, standard electrode

	Volts	Watts	Mean spherical candle-power	Watts per mean spherical candle-power
4-amp.—clear globe	78	312	240	1.30
6.6-amp—opal globe, internal reflector	78	515	695	0.74
6.6-amp.—ornamental-alabaster globe	78	515	725	0.71

NOTE.—The new (Autumn, 1914) electrodes result in a gain of about 45 per cent. in efficiency, over that shown above for standard electrodes. A 5-amp. lamp has been added to the schedule, giving, with the new electrode, about the same light as the present 6.6-amp. lamp.

112. Light distribution characteristics. The distribution of light about three types of magnetite arc lamps is shown in Fig. 33, manufacturers' data being employed.

113. Regulating mechanism. In Fig. 34 are shown the essential regulating features of the magnetite lamp.* The electrodes are separated when no voltage is applied at the lamp terminals. When the circuit is energized, the electromagnet O raises its core D, bringing the lower or negative electrode A into contact with B, starting the arc. This closes the circuit through series coil S and short-circuits OR, releasing D and allowing the lower electrode A to drop into its position as fixed by the clutch Q. As A is consumed, the shunt magnet P is strengthened, withdrawing core F until finally the shunt circuit OR is closed at MN and the arc is restruck. This mechanism regulates for constant arc length.

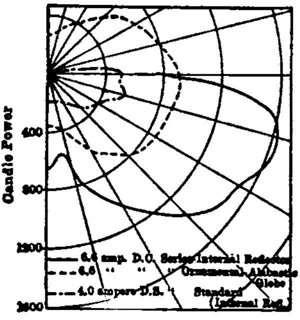


FIG. 33.—Distribution of light in vertical plane about magnetite arc lamps.

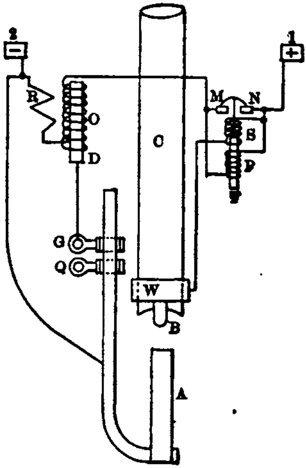


FIG. 34.—Regulating mechanism of magnetite arc lamp.

114. The ornamental magnetite lamp is a modification of the standard form, the regulating mechanism being placed below the arc. In efficiency and operating characteristics it is quite similar to the standard pendant lamp.

* Steinmetz. "Radiation, Light and Illumination," p. 158.

121. Data on low-pressure mercury arc lamps. Data upon commercial forms of Cooper Hewitt low-pressure lamps are given in Par. 120. The tubes employed are about 1 in. in diameter and are in length about 1 in. for one and one-third volts of the vapor column. A life of about 4,000 hr. is claimed for the tubes, with a candle-power decline of about 25 per cent. in the first 1,000 hr.

122. Color. The light given by the low-pressure mercury vapor lamp is greenish-blue, and is without red rays (Fig. 4, Par. 8). This bars the lamp from use for many purposes. It has been found to be well adapted for use, however, in installations where color values are of little importance, as in print shops, warehouses, some factories, drafting rooms, etc. It has been found to have peculiar value in work where fine detail discrimination is required.

123. Correcting the color. Attempts have been made to correct the color value of the mercury vapor lamp. Other materials, tungsten for example, have been employed with mercury. The mercury lamps have been used in combination with incandescent lamps.* Ives† reports that one candle-power mercury vapor light, mixed with 0.54-candle-power tungsten-lamp light, yields a good white light for general purposes. Hewitt has employed a fluorescent paint to transform some of the radiation in the green portion of the spectrum into radiation of longer wave length.

124. High-pressure mercury arc lamp. In order to benefit by the higher efficiency obtainable at high vapor pressure an evacuated tube of

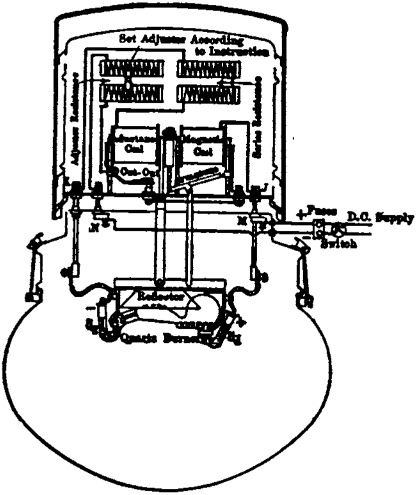


FIG. 36.—High-pressure, quartz-burner mercury arc lamp.

fused quartz is used, as glass softens at a lower temperature than that required. The lamp is operated upon the same basic principles as underlie the operation of the low-pressure lamp. The cathode is of mercury and the anode is of mercury or tungsten. The quartz tubes (burners) are 5 to 10 in. long. The operating mechanism, illustrated in Fig. 36, is equivalent to that of the low-pressure lamp.

* Marshall. *Trans.* Illg. Eng. Society, 1909, p. 240.
† Bulletin, Bureau of Standards, Vol. VI, p. 265.

In starting, the tube is tilted by an electromagnet, which is short-circuited as soon as the arc is struck by the breaking of the conducting stream of mercury. At first the current is high, about three times normal, and the arc voltage is very low, the excess voltage being taken up by the ballast resistance. The lamp gives relatively little light and that of an abnormally green color. The heavy current quickly vaporizes the mercury, increasing the vapor pressure and resistance of the arc. Gradually a condition of normal operation is approached, and, after about 15 min. current and voltage at the arc are of substantially correct values. It is understood that lamps are being developed, or have been developed, for alternating-current service and for series service.

125. Data on high-pressure mercury vapor lamps

Direct-current supply	Burner volts	Current	Terminal watts
110	85	3.8	418
220	165	3.3	725
550	345	2.0	1,100

126. Efficiency and life of quartz lamps. But little is published regarding the efficiency of the quartz lamp. Difficulty in photometry of its greenish light may account for this, at least in part. Experience in this country shows, however, that early reports of very high efficiency, which emanated from Europe, are not being realized in the forms of this lamp which have been developed. Six-tenths of a watt per mean spherical candle-power seems indicated as the initial specific consumption of a 220-volt direct-current multiple lamp. About three quarters of a watt per candle is required for the 110-volt multiple direct-current lamp. In a series type a somewhat higher efficiency should be realized. A burner life of 2,000 hr. is claimed by the manufacturers.

127. Moore tubes—nitrogen. The Moore tube for general lighting purposes is manufactured in lengths up to 200 ft. from glass tubes about 1.75 in. in diameter. This is filled with nitrogen which is replaced as required by an ingenious automatic valve which feeds the tubes at intervals of about 1 min. The tube ends are enclosed in a sheet-metal box containing the tube electrodes, the gas tank, the gas valve, step-up transformer, etc. The efficiency of the nitrogen tube is of the order of 100 lumens per ft. and the consumption is about 2.5 watts per c-p. The power-factor is about 75 per cent. The life of the tubes is very long.

128. Moore tubes—carbon dioxide. Tubes, which are usually shorter when employing carbon-dioxide gas, yield light which very closely approximates average daylight. As the efficiency is quite low, the use of these tubes is practically confined to color-matching purposes. Carbon-dioxide tubes have been manufactured in lengths of the order of 10 ft., devised to form a daylight window, and also in the smaller sizes.

129. Neon tubes. A six-meter tube operates at about 800 volts. The tubes are of about 1.75 in diameter. The electrodes are relatively large in order to reduce vaporization and avoid exhaustion of the gas. The tubes have a limited life, which, however, is said to be sufficient for commercial purposes. The life is longer for long tubes. The specific consumption is about 0.6 watt per candle. The light of the neon tube is distinctly lacking in blue radiations. In order to correct for this, a little mercury is employed in some of the tubes, with the neon. Such tubes are said to operate at about 1.0 watt per candle. When used in certain combination with tubes containing pure neon, a light which closely simulates daylight in appearance is obtained. A modified form of neon tube in which tubes of much smaller diameter are employed, is arranged to form script letters which serve for electric signs.

ACCESSORIES FOR ILLUMINANTS

GENERAL PRINCIPLES

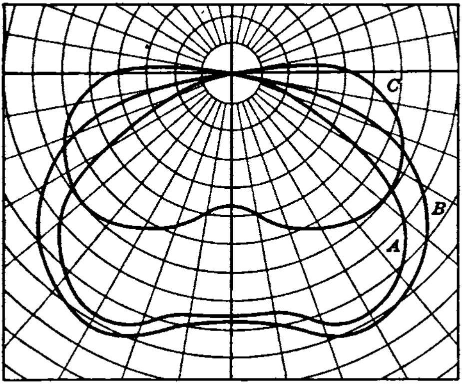
130. The purposes commonly served by lighting accessories are as follows: (a) redirection of light; (b) concealment (partial or complete) of light source; (c) decoration. Local conditions peculiar to the installation determine choice and the weight to be given of these factors.

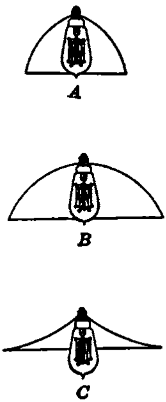
Class of service for which designed primarily	Reflector: Material	Reflector: Nature of reflecting surface	Reflector: Most usual shape	Influence upon light flux: Distribution characteristic	Light above horizontal: Transmitted light	Light above horizontal: From source	Per cent. reduction in total flux
Industrial..	Enameled iron	Glossy	Flat inverted bowl or dome	Broad		Much	7–45
				Medium	None		20–50
	Aluminum finished	Matt	Inverted bowl or dome	Medium and Narrow	None		20–60
				Broad			15–30
	Mirrored glass	Glossy	Inverted bowl or dome	Broad	None		12–18
				Medium	None		15–20
				Concentrated	None		25–35
Commercial.	Mirrored glass	Glossy	Bowl or dome	Broad	None		12–18
				Medium	None		20–35
				Concentrated	None		25–45
				Asymmetrical	None		25–45
	Prismatic glass	Glossy or matt	Bowl or dome	Broad	Much		7–12
				Medium	Much		9–15
				Concentrated	Much		12–29
	*White glass, light density	Glossy or matt	Bowl or dome	Broad	Much		6–12
				Medium	Much		7–18
	White glass, medium density	Glossy or matt	Bowl or dome	Broad	Some		8–15
				Medium	Some		10–18
	White glass, dense	Glossy or matt	Bowl or dome	Broad	Little		12–25
				Medium	Little		15–30
Decorative utility.	Prismatic glass, etched	Matt	Various	Various	Various		10–30
	White glass, etched	Matt	Various	Various	Various		10–30
	Tinted glass	Matt or glossy	Various	Various	Little		20–79
	Colored glass	Matt or glossy	Various	Various	Little		20–70
							30–80
		Shades					
Chiefly decorative.	Etched clear glass	Matt or glossy	Various	†			
	Fabrics	Matt	Various				
	"Art" glass	Matt or glossy	Various				
	Metal or pottery	Matt or glossy	Various				

† Influence upon light flux is usually not considered where shades are used primarily for ornamentation. Unless combined with a utility reflector the redirection of light is usually negligible and the reduction in light flux large. Etched glass or sandblasted shades should rarely be used. Most other shades as the term implies are more or less effective in shading the light source, and the opportunity which they offer for artistic treatment is often seized with pleasing results.

* Opal, phosphate, cased opal, milk, etc.

"The distribution shown in curve *A* may be classed as intensive. By placing the lamp somewhat lower in the reflector, a more extensive distribution of light may be secured which will be preferable for most locations requiring a general illumination. This form of curve, so far as distribution in the lower hemisphere is concerned, is practically ideal for industrial lighting purposes where the lamps are suspended at usual heights. The form of this curve is desirable both because it tends toward a uniform illumination on the work, and because the lamp filaments are well screened. On the other hand, it must be remembered that the wider reflector, *B*, will in practically all cases supply 10 or 15 per cent. more useful light than can be obtained from a bowl-shaped unit in either the intensive or extensive position. Furthermore, the shadows resulting from the use of a light source of large diameter, such as *B*, are less sharp than those from *A*."





Percentage Light Flux			
Unit	*A*	*B*	*C*
Total Light from Lamp	100.0	100.0	100.0
Light Absorbed by Reflector	37.0	18.6	14.8
Light in Upper Hemisphere	0.0	0.0	6.4
Light in Lower Hemisphere	63.0	81.4	78.8
Light in 60 Deg. Zone	53.4	59.2	41.3

Fig. 37.—Light redirection by reflectors of various shapes.

139. Data on reflectors. In Par. 140 are given statistics of reflectors used with 100-watt Mazda lamps, showing the light absorbed by the reflectors, some characteristics of the distribution obtained, and some physical data on the reflectors.

REFLECTORS FOR INDUSTRIAL LIGHTING

141. Porcelain-enameled reflectors.* "Any practical reflecting surface absorbs a considerable percentage of the light incident upon it. When incandescent lamps were first used in industrial lighting, the efficiency of porcelain as a reflecting surface was recognized, and various translucent reflectors of this material came into extensive use. However, they were not found entirely successful because they were lacking in mechanical strength; in many locations breakage resulted, causing the loss of the reflector and, which was more serious, often damaging material or injuring employees. It was largely for this reason that they were replaced by the

* Bulletin 20, National Electric Lamp Association.

familiar tin cone reflectors which, though less efficient, had the advantage of greater mechanical strength. The difficulties that were met in the first attempts to enamel a metal surface with porcelain which has a high reflecting power and adheres without cracking, have been overcome, and to-day the porcelain-enameled steel units are most frequently employed in industrial plants. They combine with the strength of a metal shell the high reflecting power of porcelain. Such a surface absorbs approximately 35 per cent. of the incident light."

142. Light absorption. The most effective porcelain-enameled reflectors intercept the light which is more than 60 deg. above the nadir and redirect it with a loss of about 30 per cent. of the total flux. The absorption, however, varies considerably with the quality of the enameling.

143. Enamel-paint reflectors. "Metal reflectors with a surface of white enamel paint are available at prices materially lower than those asked for the porcelain-enameled products. However, owing to the relatively rapid depreciation of this surface and to the fact that these reflectors are seldom designed with proper regard for the efficient distribution of light, their use is likely to result in the waste of a considerable portion of the money annually expended for lighting. A loss of even 10 to 20 per cent. of the light in this manner will each year amount to several times the added cost for the most efficient equipment.

144. Aluminumized reflectors. "Aluminumized reflectors have approximately the same initial efficiency as the porcelain enameled, and allow a better control of the direction of light rays. Moreover, their cost is lower than that of porcelain-enameled equipment. On the other hand, reflectors of this class have heretofore failed to maintain their high initial efficiency in service. Their use is, therefore, to be recommended only where a better control of the light flux—for example, a concentrated distribution—is desired. An aluminumized surface has recently been developed which is superior to the older forms in maintaining efficiency.

145. "Mirrored-glass reflectors form another class of opaque units which find some application in industrial lighting. These reflectors make possible a control of light rays even better than that secured with the aluminumized units. They excell in efficiency the other classes of equipment discussed, and the best mirrored reflectors appear to retain their efficiency with practically no loss throughout life. Their cost, however, is higher than for the other units, and, in common with all glass reflectors, they are limited to those locations where breakage is not a serious matter. They are especially valuable where a concentrated light is required."*

146. Prismatic-glass reflectors. Like other relatively fragile reflectors these may be used only where danger of breakage is small. They are not subject to the action of fumes or gases as some metal reflectors. They are extremely efficient, and where high concentration of light is desired, they are superior to white-glass reflectors.

147. Opaque reflectors. Certain further comments of an impartial nature are excerpted from a paper by Powell,† and an article by Stickney and Powell.‡ "The great majority of industrial reflectors are of the opaque diffusely reflecting types. The reflecting surfaces may be of enameled porcelain, white-enamel paint, or aluminum either painted or mat. The enameled porcelain reflectors are especially advantageous, if of a high quality, because of ease of cleaning, resistance to acid fume, resistance to heat, and ability to withstand weather in outdoor service. These reflectors are perhaps not quite so efficient when new as those finished in white paint and as usually designed do not yield so wide a range of distribution characteristics as do some other types of reflectors.

"Aluminum-finished reflectors offer a wide range of distribution characteristics, and are efficient and satisfactory when new. In most forms they are liable to serious depreciation due to the collection of dust, and as a result of cleaning. One manufacturer now markets an aluminum-finished reflector

* Bulletin 20, National Electric Lamp Association.

† An Investigation of Reflectors for Tungsten Lamps, General Electric Review, 1913, p. 717.

‡ Data Concerning Incandescent Lamp Reflectors, *Electrical World*, September 6, 1913, p. 477.

which has a coat of lacquer, which is said to facilitate cleaning and render the surface permanently efficient.

"Mirror reflectors are of high efficiency and offer opportunities for a wide range of design, as to light distribution. Compared with other industrial reflectors, they are however somewhat costly and fragile."

REFLECTORS FOR COMMERCIAL LIGHTING

148. Translucent reflectors. In commercial lighting opaque reflectors are rarely used except in show windows. It is a usual requirement that considerable light shall be thrown upon the ceiling and walls which dictates the employment of translucent reflectors. As commercial lighting offers, perhaps, the readiest field for the sale of new types of lighting auxiliaries, a wide variety of translucent-glass reflectors has been designed. This type includes prismatic glass and a great variety of white glass, as opal, phosphate glass, etc. In each type these reflectors are to be found in various sizes and shapes, differing in light-distribution characteristic. The several types and makes of reflectors differ among themselves in efficiency, light transmission, etc. Where high concentration of light is required, the prismatic-glass reflectors offer some advantage. Among many of the white-glass reflectors there is little choice, except in appearance. The differences are those largely of appearance of the glass itself, and of ornamentation. Neglecting these two features, the white-glass reflectors of various makes are to be grouped naturally in regard to the amount of light transmitted, it being the general order that those which transmit the most light reflect less light downward. ... reflectors, commercial reflectors may be procured with ... surfaces, the latter being preferable for almost ... standpoint, though they require some- ... surface reflectors.

... of the translucent reflectors are of ... that they are very pleasing in appear- ... of decorative glassware. Still, ... are designed predominantly ... value where the illumination is ... oration. Among the latter ... and of various fabrics. It ... shades. On all reflectors ... including many which are ... data are available. ... 150.

otherw... "art" glass and ... le to attempt to show ... industrial and commercial ligh... tive in appearance, definite engine... rmation of this kind appears in Par. 1...

...ribution of light in various zones about ... and inverted bowl reflectors*

Type of reflector	Typical zonal distribu... 0 to 60 deg., per cent.	0 to 90 deg., per cent.	0 to 180 deg., per cent.	...sor... per ce...
...ic—focusing	50	68	87	13
...ic—intensive	44	65	87	13
...tic—focusing (satin finish)	40	60	87	13
...ized steel—intensive	51	58	58	42
...ized steel—extensive	52	61	61	39
...atic—intensive (satin finish)	37	57	87	13
...m density—opal	40	54	82	18
...atic—extensive	40	62	86	14
...y density—opal (depolished)	41	59	72	28
... density—opal	34	57	91	9
...atic—extensive (satin finish)	33	55	88	12
... lamp (for comparison)	16	47	100	....

...weet. "The Choice of Reflector," Illg. Eng. Society, New York Section, ..., 1912.

... Mazda lamps

151. Depreciation due to dust. Certain information has been published showing the depreciation in reflecting efficiency due to collection of dust on lamps and reflectors in industrial service. Perhaps the most comprehensive data applicable to modern equipments of reflectors and Masda lamps is that shown in Bulletin 20 of the National Lamp Works of the General

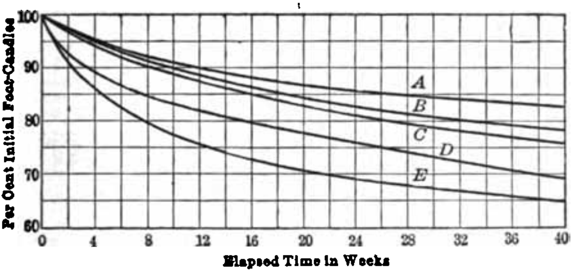


Fig. 38.—Reduction in light due to dust.

A. Dome enameled steel. *C*. Dense opal glass.
B. Bowl enameled steel. *D*. Prismatic glass.
E. Light density opal glass.

Electric Company published October, 1913. This is summarised in Fig. 38. The curves show decrease in illumination on the working plane.

152. Enclosing glassware. The sphere commends itself for many purposes of ornamentation and is therefore a popular form in design of lighting auxiliaries. It, with various modifications as to shape, forms an important class. Obviously, light absorptions run higher and light control is less definite than is the case with open-mouth reflectors. In the matter of redirection of light, much may be accomplished in an ordinary glass sphere by varying the location of the light source within the sphere, but the tendency with such glassware is always to yield distribution characteristics which approach a circle. There are some forms of enclosing glassware, however, in which special attention has been given to this phase of the subject with very notable success in the redirection of light. Par. 153 gives some data upon enclosing glassware of various types.

153. Photometric data upon enclosing glassware employed with 1,000 lumen Masda lamp*

Description	Lumens with glassware				Per cent. light absorbed by glassware
	0 to 60 deg.	0 to 90 deg.	90 to 180 deg.	Total	
10-in., 2-piece pressed-Alba ball ...	182	379	385	754	24
14-in., 2-piece pressed-Alba ball ...	190	384	335	719	28
12-in., 1-piece blown-Alba ball	223	469	395	864	14
12-in., blown-Alba acorn	243	476	347	822	18
12-in., cased Melilite ball	181	396	321	717	28
12-in., ground-glass ball	206	484	419	903	10
14-in., prismatic reflector bowl	412	589	180	769	23
12-in., prismatic reflector ball	455	618	103	721	28

* "Characteristics of Enclosing Glassware." Lansingh, *Transactions* Illuminating Engineering Society, 1913, p. 447.

BOWLS FOR INDIRECT LIGHTING

154. Cove lighting. Recognition some years ago of the need for concealing brilliant light sources from view led to systems of indirect lighting in which the light was thrown upon some reflecting surface which became a secondary source of illumination. One method consisted in locating the lamps within a cornice or cove concealed from view and illuminating the room via the ceiling. By this system, control of the light was largely lost, and efficiency of utilisation was very low. In one case reported, only 15 per cent. of the total light produced by the lamps was delivered upon a working plane.* While this low efficiency was perhaps an extreme and better values have been realised, yet the cove lighting system was so inherently low in efficiency as to be unsuccessful.

155. Indirect lighting fixtures. A more recent development of indirect lighting is one in which the lamp is located within bowls, usually hung centrally in a room or bay. By backing the lamps with efficient reflectors, and controlling the direction of light, a higher order of efficiency may be obtained and a more desirable direction of the light secured. Indirect lighting systems possess the advantage of high diffusion, and are therefore valued where freedom from shadow and glare is a consideration of primary importance. Some statistics showing the proportion of the total light produced which may be delivered upon a working plane by this system of lighting are given in Par. 156.

157. Luminous-bowl. A recent development is the luminous-bowl indirect-lighting unit. In this fixture the bowl is rendered luminous for purposes of decoration only, it usually being of the same order of brightness as the ceiling immediately above it, which is the principle secondary light source. In some fixtures in which as much as possible of the light is directed upon the ceiling, small auxiliary lamps are employed for the purpose of rendering the bowl luminous. These may be wired separately, providing, themselves, a feeble illumination which, as an alternative to the use of principal lamps, may be useful for special purposes in certain installations.

SEMI-INDIRECT LIGHTING UNITS

158. Translucent bowls. A development of the past few years consists in the use of glass bowls enclosing the light source and reflecting most of the light to the ceiling, as in the indirect lighting system, while transmitting in various proportions enough light to give an appreciable direct component. Some data upon bowls of this type, of one manufacture, are presented in Par. 160. Referring to the data in this table it will be seen that the authors have made a study of the influence of contour of bowl upon the distribution of light, and likewise of the influence of optical density of glassware. Their conclusions from these figures and others given in the paper, follow in Par. 159. Data on semi-indirect installations appear in Par. 163.

159. Effect of change of light source and bowl contour. "The distribution of light is materially affected by changes in the position of the lamps within the bowl; changing from a single lamp to a closely clustered group of two or three lamps does not introduce large variations in the distribution characteristics, although the single lamp results in a somewhat wider distribution above the horizontal. The ratio of light above the horizontal to that below the horizontal in the four types of glass of the contour 3, chosen for this purpose, vary from 1.26 for the least dense (etched glass) to 6.4 for the most dense (Calla); and the effect of change in the contour of the bowls is that with the shallower bowls the distribution both above and below the horizontal is not so wide, more light being centred near the bowls while with the deeper bowls there is, of course, a larger ratio horizontal."

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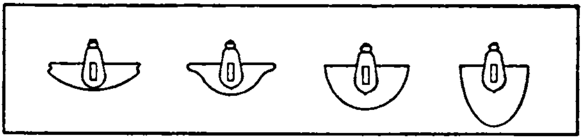
* "The Elements of Inefficiency in Diffused Lighting Systems." Millar. *Transactions* Illuminating Engineering Society, 1907, p. 583.

160. Photometric data of semi-indirect glass bowls employed with one Masda lamp*

Description of glassware	Contour, see Fig. 39	Per cent. of total light from lamp which is distributed within stated zones†			
		180 deg. to 120 deg.	180 deg. to 90 deg.	90 deg. to 0 deg.	Total
Etched crystal glass with new cut design....	3	22	47	37	84
Druid.................	3	27	54	30	84
Veluria...............	1	36	60	25	85
	2	36	58	24	82
	3	30	57	24	82
	4	28	60	24	84
Calla..................	1	44	68	11	79
	2	46	71	11	82
	3	41	68	11	79



1 2 3 4

Fig. 39.—Contours referred to in Par. 160.

161. Reflectors in railway coaches. Some information upon the distribution of light in a typical railway day coach has been made available by the Committee on Illumination of the Association of Railway Electrical Engineers.‡ While railway-car illumination is to some extent a special problem, yet the behavior of most reflectors in such service is an important indication of what may be expected in other lines. In the tests which are here recorded, the car was equipped with Mazda lamps located in the centre deck or monitor, and spaced at intervals of two and three seats respectively. Conditions in all respects were favorable to lighting efficiency because the equipment was new and clean and operated under correct conditions. As indirect and semi-indirect equipments were used, it is important to note that the coefficient of diffuse reflection of the car ceiling was 65 per cent.

162. Data on railway-coach lighting. Results are summarized in Par. 164 which shows a description of the auxiliaries, the total light produced by the lamps, the average intensity of illumination throughout a horizontal plane 33 in. above the floor, the per cent. of the total light produced which is delivered to such horizontal plane and the angle above the nadir at which the lamp filament is screened from view by the reflector. The total horizontal area lighted was 566 sq. ft.

In these railway-car tests open-mouth reflectors are shown to deliver upon the horizontal plane of reference, proportions of the total light which range from a maximum of 59 down to a minimum of 25 per cent. Indirect-lighting equipments with ceiling of the quality stated, deliver upon the plane of reference about 25 per cent. of the total light produced in the car. Slightly better values are shown for the enclosing and the semi-indirect equipments.

* "A Photometric Analysis of Diffusing Bowls with Varying Indirect Component." Rowe and Magdsick, *Trans.* Illg. Eng. Soc., 1914.

† 180 deg. is the Zenith; 0 deg. is the Nadir.

‡ *Railway Electrical Engineer*, October, 1913, and Report of 1914 Committee of Association of Railway Electrical Engineers.

163. Data on semi-indirect lighting installations

Source of data	Type of unit	Area illuminated	Ceiling	Walls	Per cent. total flux falling on working plane	In terms of comparable direct lighting system. Per cent.
Univ. of Mich., E. E. Dept., Elec. World, Mar. 28, 1914, p. 715.	Alba Hem. 3 60-watt lamps	Display room 60 by 37 ft.	White	White	30.8	....
Univ. of Mich., E. E. Dept., Elec. World, Mar. 28, 1914, p. 715	Alba Hem. 3 60-watt lamps	Office 60 by 48 ft.	White	White	31.2	....
Henninger, I. E. S. Trans., 1912, p. 248	Inverted prismatic	Room 18 ft. 10 in. by 23 ft.	Factory white	Natural pine	......	50.6
Cravath, I. E. S. Trans., 1912, p. 402	Bowl-shaped opal glass (inverted)	Small room 12 by 16 ft. 6 in.	Light cream	Light green	37.6	71.0
Sweet, I. E. S. Meeting, Feb. 8, 1912	....	....	Light	....	25.0	55.0
Sweet, I. E. S. Meeting, Feb. 8, 1912	....	....	Medium	....	18.0	42.0
Sweet, I. E. S. Meeting, Feb. 8, 1912	....	....	Dark	....	11.0	28.0
N. E. L. A. Handbook for Railway Elec. Engineers	....	....	Light	....	35.0	65.0
Aldrich and Malia, I. E. S. Trans., 1914, p. 111	Inverted opal reflector 100-watt lamps	Large room	Light cream	Light buff and green	50.7	92.2
Edwards and Harrison, I. E. S. Trans., 1914, p. 171	Inverted opal reflector and hemisphere	Small room 14 ft. 6 in. by 17 ft. 9 in.	Light	Green-gray	21.0	62.0

ACCESSORIES FOR SPECIAL PURPOSES

165. Show-window lighting. For show-window lighting and certain other purposes an asymmetrical distribution of light is usually required. Example of reflector designed for such a purpose is shown in Fig. 40.

166. Street lighting. Various auxiliaries for redirecting part of the light produced by street illuminants have been developed. Some of the most effective in this respect are to be found among the newer designs of auxiliaries for Mazda type *C* (gas-filled) series lamps. Illustration of this is given in Fig. 41. In some street illuminants, as the magnetite and metallic-flame arc lamps, a reflector is built in the lamp casing. In others, the diffusing globes with which the lamps are equipped are so shaped as to modify the distribution characteristic materially. These are inconspicuous methods of accomplishing a measure of light redirection which usually is less marked than that accomplished by the use of external reflectors.

167. Glass plates. Translucent glass plates consisting either of frosted glass, opal glass, so-called art glass, ribbed glass or prismatic glass are largely employed as skylights and as diffusing screens for artificial lighting. Some data upon the transmission coefficient of such glasses are given in Par. 169.

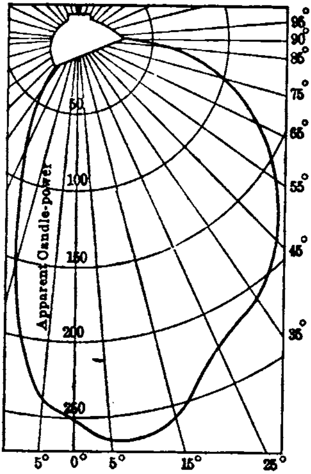


Fig. 40.—Asymmetrical distribution, adapted to show-window lighting.

168. Glass for redirecting daylight. Ribbed and prismatic glass is used to a large extent in industrial lighting for directing into large rooms a

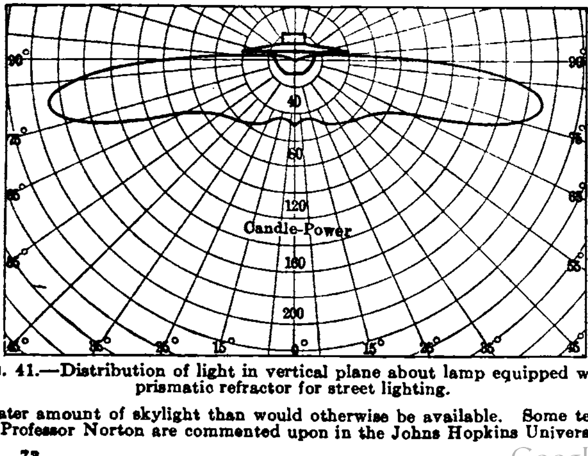


Fig. 41.—Distribution of light in vertical plane about lamp equipped with prismatic refractor for street lighting.

greater amount of skylight than would otherwise be available. Some tests by Professor Norton are commented upon in the Johns Hopkins University

170. Headlights may be considered in this connection but only in a general way because the design of headlights is a specialty in itself and has but little application in general illuminating practice. An excellent symposium on the subject is to be found in recent articles by Messrs. Sugg, Dennington and Porter.* Much attention has been given to the subject of locomotive headlights and an excellent résumé of state laws on this subject together with comments is to be found in the report of the Committee of Locomotive Headlights of the Association of Railway Electrical Engineers.†

ILLUMINATION CALCULATIONS

GENERAL CONSIDERATIONS

171. Light flux. According to approved concept, light is regarded as luminous flux.‡ The output of a lamp is its **total luminous flux.** The brightness of a diffusely reflecting or transmitting surface is proportional to its **specific luminous flux.** The intensity of illumination received on any surface is the **flux density.** Thus luminous flux is analogous to magnetic and electrostatic flux. Comprehension of light flux is facilitated by considering a point source to be located at the centre of an imaginary non-reflecting sphere. The total luminous flux produced by a source of 1 c-p. radiated uniformly, is divided by the number of unit solid angles or steradians in the sphere in order to arrive at the unit of luminous flux which is the lumen "equal to the flux emitted in a unit solid angle (steradian) by a point source of 1 c-p."

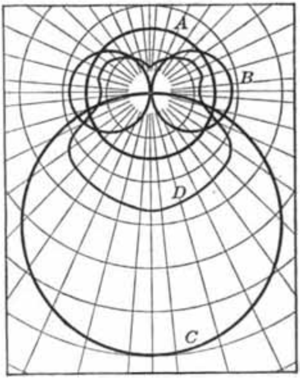


FIG. 42.—Four distributions of a given flux.

172. Distribution of light. In practice, light is rarely radiated uniformly, and it is therefore necessary to consider the flux to be distributed in a great variety of ways. The determination of light distribution characteristics of sources, is a regular part of illuminating engineering practice, and most calculations performed involve this distribution characteristic. In Fig. 42 are illustrated four different distributions of a given luminous flux. The curves show a section of revolution. The circle (curve *A*) indicates uniform distribution from a punctiform source; curve *B* shows distribution from a theoretical line source, distributing no light at the poles. Curve *C* shows the distribution from a uniformly radiating circular disc, and curve *D* shows a light-distribution characteristic typical of a certain class of reflectors.

COMPUTATION OF TOTAL FLUX, OR MEAN SPHERICAL CANDLE-POWER

173. Zonal areas. In Fig. 43, curve *D* from Fig. 42 is reproduced. The polar diagram at the left shows the flux density or intensity in any direction, in the vertical plane, considered. Referring to the representation of a sphere on the right, it will be noted that the total area of a zone of a given altitude at the equator is much greater than the total area of a similar zone near the pole. The flux density, or intensity, of the light distributed throughout each zone, is indicated in the distribution curve to the left. The area of each zone must be multiplied by the mean flux density, in order to obtain the total flux distributed throughout the zone.

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* *Electrical World*, October 11, 1913, pp. 741-745.

† *Railway Electrical Engineer*, October, 1913.

‡ Sharp. "The Concepts and Terminology of Illuminating Engineering," *Trans.* Illg. Eng. Society, 1907, p. 414.

177. Constants for computation of mean spherical candle-power or total flux from light-distribution data

10 deg. zones		15 deg. zones		30 deg. zones	
Angles from vertical axis	K	Angles from vertical axis	K	Angles from vertical axis	K
175 deg. 5 deg.	0.016	180 deg. 0 deg.	0.009	180 deg. 0 deg.	0.034
165 deg. 15 deg.	0.046	165 deg. 15 deg.	0.067	150 deg. 30 deg.	0.259
155 deg. 25 deg.	0.074	150 deg. 30 deg.	0.131	120 deg. 60 deg.	0.448
145 deg. 35 deg.	0.100	135 deg. 45 deg.	0.184	90 deg.	0.518
135 deg. 45 deg.	0.124	120 deg. 60 deg.	0.226	....	.....
125 deg. 55 deg.	0.142	105 deg. 75 deg.	0.253	....	.....
115 deg. 65 deg.	0.158	90 deg.	0.261	....	.....
105 deg. 75 deg.	0.168	....	.....	....	.....
95 deg. 85 deg.	0.174	....	.....	....	.....

178. Kennelly's method. Kennelly has devised a graphical method of rectilinear construction for determinations similar to those carried on by means of a Rousseau diagram.*

179. White-Wohlauer method. The "Fluxolite" diagram facilitates the same kind of computations, but yields total lumens instead of mean candle-power.†

COMPUTATION OF ZONAL FLUX

180. Zonal flux. This does not differ from calculation of total flux. In fact most determinations of total flux or of flux in one hemisphere are merely additions of zonal-flux values. The Rousseau, Kennelly and White Wohlauer methods yield zonal flux readily. Constants for use in determining mean zonal candle-power directly from angular candle-power values are given in Par. 181 for certain zones. Multiply the sum by 2π (6.28) times the difference between cosines of limiting angles to obtain corresponding lumens.

181. Constants for use with candle-power values to yield approximate mean zonal candle-power

Angle from vertical axis at which c-p. is known	Constants 75-deg. zone	Constants 60-deg. zone	Constants 45-deg. zone	Constants 30-deg. zone
10-deg. intervals				
70 deg.	0.221	....	....	....
60 deg.	0.204	0.147	....	....
50 deg.	0.180	0.267	....	....
40 deg.	0.151	0.224	0.383	....
30 deg.	0.117	0.174	0.297	0.301
20 deg.	0.080	0.119	0.203	0.445
10 deg.	0.041	0.060	0.104	0.226
0 deg.	0.005	0.008	0.013	0.029
15-deg. intervals.				
75 deg.	0.170	....	....	....
60 deg.	0.304	0.219	....	....
45 deg.	0.249	0.369	0.295	....
30 deg.	0.176	0.261	0.446	0.432
15 deg.	0.090	0.135	0.230	0.504
0 deg.	0.012	0.017	0.029	0.064

* Kennelly. *Electrical World,* March 28, 1908.
† Wohlauer. *Illuminating Engineer,* Vol. III, p. 655.

CALCULATIONS OF ILLUMINATION INTENSITY

185. Classification of methods. Assuming that light distribution data, such as those presented in Fig. 44 are available, it becomes possible to compute the illumination produced upon any given plane by the light source in any given location. For the sake of simplicity it will be considered that the light source, whose distribution is indicated in the diagram, is mounted over the centre of a horizontal plane which is to be illuminated. For such computations there are three customary methods. The flux of light delivered upon the horizontal plane will be the sum of that directed toward the plane from the source and that reflected to the plane from ceiling walls, etc.

186. Flux method (direct light). For many purposes an approximate calculation of the flux delivered upon the plane of reference is adequate. In such cases it may serve to determine the approximate square feet of the plane to be illuminated and to estimate the total flux which will reach such plane. For example, assume that a certain room has a floor area 12 ft. 7 in. by 12 ft. 2 in., and that it is desired to estimate the light flux delivered upon a horizontal plane 36 in. above the floor from a light source located over the centre of the area, and 6 ft. 4 in. above the plane of reference.* Roughly, the flux delivered within an angle of 45 deg. above the horizontal will fall upon this plane. Applying zonal constants (Par. 181) to the candle-power values in Fig. 44, we have either or both of the following:

Angle	Constant c-p.	Angle	Constant c-p.
40	$0.383\times100=38.3$	45	$0.295\times 99=29.2$
30	$0.297\times102=30.3$	30	$0.446\times102=45.4$
20	$0.203\times105=21.3$	15	$0.230\times107=24.6$
10	$0.104\times110=11.4$	0	$0.029\times113=3.3$
0	$0.013\times113=1.51$	....	....
Mean zonal c-p.......102.81		Mean zonal c-p.......102.5	

With a mean candle-power of 103 distributed throughout a zone extending from the nadir to 45 deg., the flux in lumens is found by multiplying 103 by the number of unit solid angles in the 45. deg. zone or $103\times2\pi(\cos\theta_0-\cos\theta_{45})=190$ lumens.

187. Flux method (indirect light). Referring to report of test* of the installation described it will be seen that the lumens directed to the plane of reference by the lighting unit are 191 in number, with which value the above determination is in accord. The light source produces 779 lumens. As 191 lumens reach the plane of reference $(779-191=)$ 588 are incident upon ceiling and walls, where they are partly absorbed and partly reflected either toward the plane of reference or elsewhere. The greatest uncertainty in estimating total flux on a plane is arriving at the amount of such indirect light. The test* shows that 189 lumens or $(189/588=)$ 32 per cent. of this flux, which the lighting unit directed elsewhere, ultimately reached the plane of reference, thus equalling the light directed toward the plane by the lighting unit. In this case the room was small and the reflection from ceiling and walls was more effective than usual. If instead of a room the area is a bay in a larger room, the light, which here falls upon the walls, will add to the illumination of adjoining bays, and the bay under consideration will profit likewise from adjoining bays. In any installation this indirect light must be estimated taking into consideration the flux directed elsewhere than upon the plane of reference and the reflecting qualities and location of the reflecting surfaces. Some data on this subject are given in Par. 196.

EFFICIENCY OF UTILIZATION

188. Definition. Where the illumination of such a plane is the principal purpose of the lighting installation, the ratio of flux delivered upon the plane to total flux produced by the illuminant is sometimes called the "efficiency of

* Actual conditions described by Sharp and Millar, "Illumination Tests," *Trans.* Illg. Eng. Soc., 1910, p. 391.

reflector, 42 per cent. of the total light produced is delivered upon the plane of reference if the walls have reflection coefficients of 30 per cent., while 45 per cent. is delivered upon the plane if the reflection coefficients of the walls amount to 60 per cent. These very complete data should be helpful in forming a correct estimate of the net ratios of light utilization in small and medium sized rooms with central-ceiling equipments.

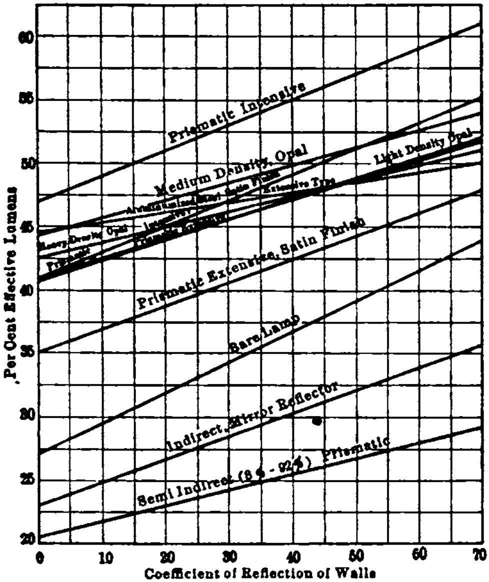

FIG. 45.—Per cent. flux delivered upon working plane when reflection coefficient of ceiling is 0.60.

192. Influence of wall reflection on efficiency of utilization. A study of these data of Sweet (Par. 191), indicates that with 60 per cent. ceilings the loss in flux on the plane of reference involved in changing from 40 per cent. to 10 per cent. reflection walls, ranges, for the several equipments, from 5 per cent., in the case of opaque reflectors where very little light is incident upon the walls, to a maximum of 20 per cent. in the case of a bare lamp. The details of these losses are given in Par. 194.

193. Comment on flux method. From the foregoing (Par. 189 to 192) a reasonably accurate estimate of the influence of ceiling and walls may be formed. As the flux directed toward the plane of reference by the lighting unit may be computed quite accurately where a light distribution curve is available, and as this direct lighting is usually the greatest proportion of the total which reaches such plane, it will be seen that estimates of the illumination produced may be made very quickly by this method, and will be usually as precise as conditions require. The computation of the angle below which all of the flux is directed toward the plane, is a simple matter of triangulation. Most recent light-distribution data are accompanied by zonal-flux data (Fig. 44) which makes the approximation of the total flux within the directly applied zone a mere matter of addition. Where zonal values are not available computation of the flux from the light distribution curve is reasonably simple (Par. 186).

accomplished by using a reflector which, while directing most of the light toward the plane, will still transmit sufficient to light the ceiling and walls acceptably. With such equipments it is reasonable to expect that 50 per cent. of the light may be delivered upon the plane of reference. At once it is established that 764 lumens should be generated within the room. This will be produced by a 100-watt Mazda lamp, which produces about 1,000 lumens, leaving a margin of 25 per cent. for absorption by reflector, depreciation due to dust, etc.

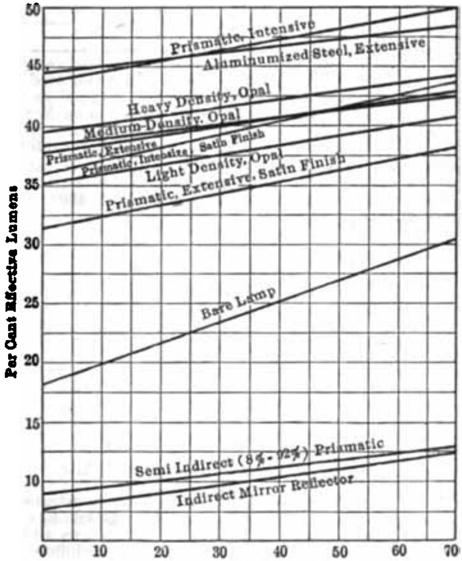

FIG. 47.—Per cent. flux delivered upon working plane when reflection coefficient of ceiling is 0.20.

196. Absorption-of-light method. An alternative method of computing light flux for an illumination installation is the "Absorption-of-light" method.* This is based upon the fundamental consideration that all of the light within a room being absorbed, the illuminants must produce the sum of the light flux absorbed by the various surfaces. That is to say, the average incident flux upon each surface multiplied by the coefficient of light absorption characteristic of that surface and by the area of the surface will yield the total flux absorbed by that surface, and the sum of the flux absorbed by all exposed surfaces within a room must aggregate the total flux to be produced by the lighting unit. (In such case, of course, the absorption of light involved in the use of an auxiliary must be added to this aggregate to ascertain the total amount of light to be produced by the illuminant proper.) Referring to the room already mentioned,† we find the data necessary to verify this method. These are summarized in Par. 197.

* McAllister. "The Absorption-of-light Method of Calculating Illumination," *Electrical World*, November 21, 1908.

† Actual condition described by Sharp and Millar "Illumination Tests," Trans. Illg. Eng. Soc., 1910.

202. Table of squared and cubed cosines (Par. 203)

Angle (deg.)	Cosine		Angle (deg.)	Cosine	
	Squared	Cubed		Squared	Cubed
1	1.000	1.000	21	0.871	0.813
2	0.999	0.998	22	0.859	0.797
3	0.997	0.996	23	0.847	0.780
4	0.995	0.993	24	0.834	0.762
5	0.992	0.988	25	0.821	0.744
6	0.989	0.983	26	0.808	0.726
7	0.985	0.978	27	0.794	0.707
8	0.980	0.971	28	0.780	0.688
9	0.975	0.963	29	0.764	0.668
10	0.970	0.955	30	0.750	0.649
11	0.963	0.945	31	0.735	0.630
12	0.956	0.935	32	0.719	0.610
13	0.949	0.925	33	0.703	0.590
14	0.941	0.913	34	0.687	0.570
15	0.933	0.901	35	0.671	0.550
16	0.924	0.888	36	0.654	0.529
17	0.914	0.874	37	0.638	0.509
18	0.904	0.860	38	0.621	0.489
19	0.894	0.845	39	0.604	0.469
20	0.883	0.829	40	0.587	0.449
41	0.569	0.429	66	0.165	0.0673
42	0.552	0.410	67	0.153	0.0596
43	0.535	0.391	68	0.140	0.0526
44	0.516	0.372	69	0.128	0.0460
45	0.500	0.353	70	0.117	0.0400
46	0.483	0.335	71	0.106	0.0345
47	0.465	0.317	72	0.0955	0.0295
48	0.448	0.300	73	0.0855	0.0250
49	0.430	0.282	74	0.0759	0.0209
50	0.413	0.265	75	0.0669	0.0173
51	0.396	0.249	76	0.0585	0.0142
52	0.379	0.233	77	0.0506	0.0114
53	0.362	0.218	78	0.0432	0.00900
54	0.345	0.203	79	0.0363	0.00695
55	0.329	0.189	80	0.0300	0.00523
56	0.312	0.175	81	0.0244	0.00383
57	0.297	0.161	82	0.0194	0.00270
58	0.281	0.149	83	0.0149	0.00181
59	0.265	0.137	84	0.0109	0.00114
60	0.250	0.125			
61	0.235	0.114			
62	0.221	0.103			
63	0.206	0.0936			
64	0.192	0.0842			
65	0.179	0.0754			

of a surface which is not a perfect diffuser may vary with angle of view, but if it is large enough to cover the field of view, its apparent brightness will not vary with distance.

206. Relation of brightness to incident light. This may be stated only for a projected area of a perfectly diffusing plane surface for which $b = mE$ where b is the brightness; m is the coefficient of diffuse reflection; and E is the incident flux. Brightness is expressed in candle-power per sq. cm. or in candle-power per sq. in. Interiors as illuminated at night have brightness values of the order of 0.0005 candle-power per sq. cm.

APPLIED ILLUMINATION

THE FUNDAMENTALS OF VISION

207. Contrast vision. We see things by reason of contour, relief and color, *i.e.*, shade perception and color perception. According to Fechner's law of sensations we perceive a fixed fractional difference of the total, irrespective, within limits, of the amount of the total sensation, and the sensation is proportional to the logarithm of the stimulus. This minimum perceptible contrast is usually of the order of 1 per cent., and, with increasing brightness within wide working limits, the visual power increases but slowly.

208. Color sensations. Ocular discernment as presented in the Young-Helmholtz theory is based upon three primary sensations: red, green and blue-

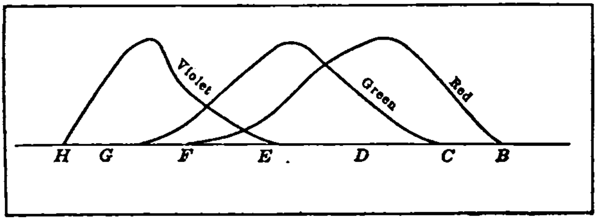

FIG. 51.—Primary color sensations.

violet, respectively. These overlap much as shown in Fig. 51, the curves of which show what color sensations will be stimulated by radiation of any given wave lengths within the visible spectrum. The seat of color sensation is said to lie in the cones of the retina which are found almost exclusively in the fovea, the rods being limited largely to employment in twilight vision.

209. Protective equipment of eye. The protective apparatus of the eye against excessive radiation, consists, first, of the **pupil**, whose automatic response to changes in intensity of light under certain conditions are shown* in Fig. 52. It will be seen that the area of the pupil aperture does not alter sufficiently to protect the eye against effects of the large changes in illumination which it must encounter; the second protective element is to be found in retinal adaptation.

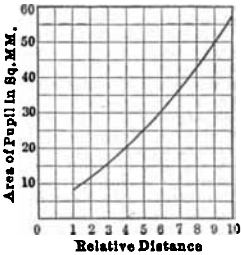

FIG. 52.—Reaction of pupil to variations in light.

210. Other ocular characteristics. Some of the physiological characteristics of the eye which are of importance in illumination work are as follows: (a) **adaptation**, the slow retinal change which supplements the rapid pupillary change both tending to adjust the eye

*Lambert's Experiments as reproduced in the "Art of Illumination" by Bell.

accomplish this it may be necessary to provide an illumination of uniform intensity, or the flux may have to be distributed dissymmetrically. Shadows are important, contrasts must be correct and a careful study of the intensities necessary to produce brightness of the right order is essential to success in lighting installations.

215. Intensities for various classes of service. For the more usual classes of work, intensities of illumination range from 1 to 7 foot-candles. In some classes, as in draughting rooms, 10 to 20 foot-candles are required. In other classes of lighting, very much higher values must be provided, notably in show-window lighting where the demand for great brilliancy fixes a standard of 25 or 30 foot-candles for general purposes and in industrial work, as in sewing upon dark garments where the work is done over limited areas, values as high as 100 foot-candles may be desirable. The standard to be set in any given installation must be reached after careful study of the local conditions and of the requirements peculiar to that installation. Pronouncements of various writers on this subject are of value in serving as a general guide, but they should not be regarded as final for any particular installation. A compilation of published data on intensities is presented in Par. **219**.

216. Direction. The best direction for the strongest component in any illumination system is peculiarly a matter for determination after study of local conditions. In natural lighting there is usually a strongly directed component, the only exception being a condition of diffused light such as that produced by mists, rain, etc. A great variety of directions for this principal component is experienced, ranging from one almost directly downward at mid-day in the summer to one which is almost horizontal just after sunrise or just before sunset. It is probable that the most pleasing direction for daylight conditions lies well between these two extremes.* The direction of light in interiors illuminated from side windows is unnatural and in many instances is neither pleasing nor comfortable. This is especially true of offices in high buildings where nothing but the sky is visible through the window from a point well in the interior of the room.

217. Direction of light affects appearance. A suitable direction for light is very important in industrial work where the avoidance of shadows and the avoidance of glare are of paramount importance. The appearance of a room is very largely dependent upon the direction of the light.† In ornamentation, relief designs are absolutely dependent upon the relation of light and shade.‡ Usually they require not only a noticeable directed component but also they require that the direction of that component shall be correct. So also, in the general appearance of a room and of the objects contained in it, shadows are important and their proper direction is a prominent factor in determining the final appearance of the room. The direction of incident light is, to some extent, a determining factor in the extent and characteristic of the reflection from surfaces.‖

218. Diffusion. See Par. **220**. If light from a point source passes through crystal glass or is reflected by a mirror, the rays are uniformly divergent, that is characteristically radiating. If the crystal glass or the mirror be replaced by an etched glass and a mat reflecting surface respectively, the uniform radiating characteristic is lost, the rays are scattered, and further propagation takes place in a multiplicity of directions. Such light is called diffused light. If the surface which occasions the diffusion is of large area and the illuminated object is relatively close to the diffusing surface, it is illuminated by diffused light. If, however, the object is relatively far removed from the diffusing surface, it is illuminated by light from essentially one direction, the rays are nearly parallel, and the light is but little diffused. Hence, diffusion is a relative term, and the subject is difficult to treat in a definite way.

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* "Distribution of Luminosity in Nature." Ives and Luckiesh, *Trans.* Illg. Eng. Soc., 1911.

† Ives. "Some Home Experiments in Illumination," *Trans.* Illg. Eng. Soc., 1913, p. 238.

‡ Luckiesh. "Importance of Direction, Quality and Distribution of Light," *Proceedings* American Gas Institute, 1913.

‖ "The Effect of Variation of the Incident Angle on the Coefficient of Diffuse Reflection." Gilpin, *Trans.* Illg. Eng. Soc., 1910.

220. Various degrees of diffusion. See Par. **218.** Perfect diffusion of light is obtained within a hollow sphere whose inner reflecting surface is mat. Some plane-reflecting surfaces are nearly, if not quite, perfect diffusers of light. Perfect diffusion may be represented graphically by a circle, tangent upon the diffusing surface. Imperfectly diffused transmission or reflection may be represented by various curves having radials elongated in the direction of regular transmission and reflection, indicating correspondingly lesser distribution in other directions than is provided by perfect diffusion.* A variety of reflection characteristics is illustrated in Fig. 53, ranging from perfect diffusion to a combination of regular and diffuse reflection characteristic of glossy paper.

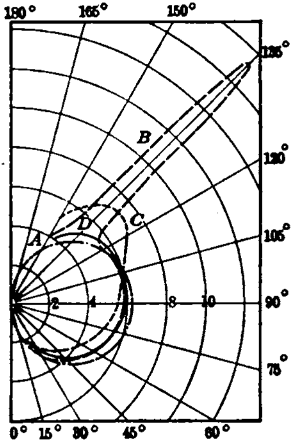

Fig. 53.—Various degrees of diffuse reflection. Light incident 45 deg. below horizontal, surface being vertical. A, perfect diffusion; B, reflection from glossy paper; C, reflection from semi-glossy paper; D, reflection from mat paper.

221. Need for diffusion. Diffusion tends to avoid glare and to soften shadows. Its accomplishment involves the substitution of secondary light sources which are relatively large and therefore of low brightness when compared with the source of light. Artificial lighting is usually inferior to natural light in respect to diffusion.† In practically every installation there is a real necessity for introducing artificial means of diffusing the light.

222. Color in its physical aspects has been treated in the discussion of the production of light (Par. **27**). The spectrophotometric values of light from the several common illuminants have been supplemented by color-sensation values as determined with color-mixing instruments. Referring further to the subject in its physiological relations, it may be noted that there are three primary colors, namely: red, green, and blue-violet, using pure spectral light. With these three colors, light of any desired color value may be produced. In his ability to modify the color of light, the illuminating engineer has at his disposal a means of enhancing the attractiveness of an interior as will be brought out more in detail under discussion of congruity in illumination, Par. **232**. It also is a field in which there is an opportunity for profiting by certain peculiarities of vision (Par. **206**).

PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF ILLUMINATION

223. Contrast. Once the correct general intensity of light (Par. **216**) is secured, all other aspects involved in direction (Par. **217**), diffusion (Par. **218**) and color (Par. **222**) as well as in the distribution of the light to produce various intensities, must be so manipulated as to secure the proper degrees of contrast. The more the subject of good illumination is considered, the more prominently does contrast force itself upon attention as a fundamental which must be served if an installation is to be successful. This applies both to contrast of light and shade and to contrast of color. Contrast of light and shade resolves itself into a question of varying brightness, embracing the range of brightness values from a brilliant incandescent-lamp filament or an arc, down to the deepest shades within view. The unshaded

* Nutting. "The Diffuse Reflection and Transmission of Light," *Transactions* Illg. Eng. Soc., 1912.

† Luckiesh. "Investigation of Diffusing Glassware," *Electrical World*, Nov. 16, 1912 and April 26, 1913.

incandescent lamp glowing outdoors in the daytime does not appear very bright against a background of sky, and may be viewed directly without discomfort. The same unshaded lamp burned at night in a room which is decorated in light colors, will prove annoying, while if burned in a room of which the decorations are of low reflecting quality, as dark woodwork, the lamp will prove positively intolerable. In the three cases the brightness of the lamp remains the same, and it is the varying contrast with its surroundings which explains in the one case, absence of discomfort and in the other extreme case, the most serious kind of ocular discomfort.

224. Need for concealing light sources. In Par. 81 brightness values for various unshaded light sources are given. It will be observed, for example, that these range from less than one candle-power per sq. in. for the Moore tube to 4,000 candle-power per sq. in. for the magnetite arc. This is, indeed, a wide range in brightness. When, however, it is remembered that the brightness of a very well-lighted wall, decorated in some light tone is of the order of 0.003 candle-power per sq. in., it will be seen that the variations in brightness of commercial light sources are small in comparison with the contrasts between any of them and the surfaces with which they are likely to be surrounded in practice. Herein lies the necessity for shading light sources in order to protect the eye against excessive contrasts. Entirely capable of protecting itself against excessive brightness, the eye is not able to see the objects of relatively low brightness and at the same time guard itself against the very high brilliancy of an exposed light source. There still remains the necessity for avoiding the intrusion of reflected images of the light sources in the ordinary field of view. A well-shielded light source may be exposed in the direction of a polished table top, the surface of which may reflect an image of the light source, subjecting the eye to almost as great strain as though the actual source were exposed. Glossy paper, shiny materials to be worked upon, polished woodwork, etc., are likely to introduce this sort of difficulty. Nature's surfaces as a rule are not shiny; artificial surfaces are likely to be shiny. In abolishing glossy paper, polished woodwork, etc., a long step is taken toward the elimination of excessive contrasts in artificial lighting. It is not possible, however, to abolish all such surfaces, and in other cases it is not done. It is, therefore, desirable to conceal the light source further. Accordingly, the improvement of a few years since in providing translucent reflectors which largely cover incandescent lamps and shield them from direct view, has been supplemented more recently by frosting the lower part of the bulbs of the lamps and the interior surfaces of the reflectors in order to soften and diffuse the light. Consequently, when reflected images are encountered, their brightness is rendered of as low an order as practicable. More recently still, bowls have been employed, either opaque or translucent, which intervene between any point of observation and the light source proper, softening and diffusing the light and directing a part or all of it toward the ceiling, whence it is further diffused and reflected downward.

225. Glare due to light source. Excessive brightness of surfaces or objects within the field of view gives rise to glare. Where the light source itself is within view, or a more or less imperfect image is viewed upon some shiny surface, the effect is much the same and is a manifestation of the same difficulty, namely excess of contrast (Par. 223). Glare or excess of contrast may actually reduce one's visual power temporarily; it may occasion discomfort and eye-strain; or, if continued long enough, may seriously impair visual organs. In the way of reduction in visual power, observations have been made of the extent of the effect.* Such studies are so complicated and difficult that definite results can be obtained only under very extreme conditions. In Fig. 54 is shown the reduction in visual power due to the presence of an exposed lamp in a dark room. The observers viewed a dimly illuminated test object. The presence of a 16-candle-power bare lamp 2 deg. from the test object, reduced the observers' ability to discern the test object to about the same extent as would follow a reduction in the illumination to 20 per cent. of that which was provided. As the light source was placed more and more distant from the observed object, its influence became less marked, falling off rapidly until the angle of separation was 4 deg. and thereafter at a slower rate until, at about 15 deg., the

* Sweet. "An Analysis of Illumination Requirements in Street Lighting," Journal of the Franklin Institute, May, 1910.

effect disappeared. Because of the very exaggerated conditions of dark surroundings and dimly illuminated test object, the results here obtained show diminished visual power far beyond that which would likely be experienced in practice. They illustrate the effect, however, and are suggestive of the need for concealing the light source. It is to be noted that, though no reduction in visual ability could be measured when the source was removed 15 deg. from the centre of the field of view, yet the discomfort and annoyance due to its presence were very severe.

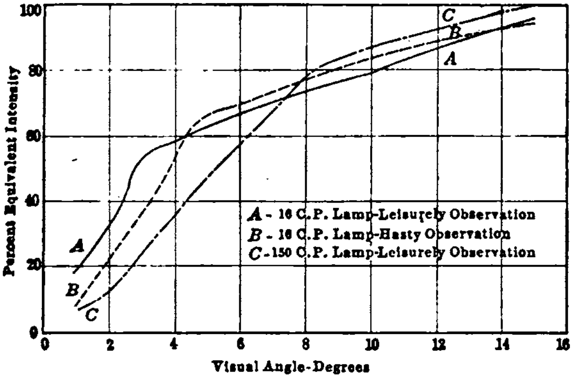

FIG. 54.—Influence of glaring light source in decreasing visual power.

226. Glare due to reflected image of light source. Glare due to images of light sources reflected from shiny surfaces is probably more productive of harm in the present stage of practice than is glare directly due to exposed light sources. While the imperfect rendering of the image by the usual polished surfaces decreases the brightness materially, yet the location of the reflected image is often so near the centre of the field of vision as to be much more serious than an exposed light source further removed. Viewing a glossy paper at the critical angle in which the image of the light source is reflected to the eye, it may be impossible to read print. This effect is diminished by altering the position of the object or of the observer, but, due to minute irregularities of the surface of the paper, there is still likely to be an appreciable regular reflection toward the eye. Likewise, paper which is only slightly glossy may reflect regularly toward the eye an appreciable section of the image of the light source without introducing so serious an effect as to prompt the observer to change position. Such conditions are the source of much discomfort and dissatisfaction experienced in artificial lighting. If they are to be avoided, light sources must be shielded both from immediate observation and from possibilities of reflection from glossy surfaces.

227. Coefficients of reflection. If it be assumed that softly diffused light is distributed generally throughout an interior producing uniform illumination, contrasts are dependent wholly upon the reflecting qualities of the illuminated surfaces. As these are usually less readily changed than the distribution and quality of the light, it is desirable to consider them before determining upon the degree of uniformity which should be achieved in light distribution. Uniform illumination with uniform decorations in an interior would be undesirable from every standpoint. Uniform illumination with heavily contrasted decorations and fittings may be acceptable. It is therefore of interest and value to obtain information on the coefficients of reflections of various surfaces, such are contained in Par. **228**.

231. Permissible contrasts. In general, authorities state that bright objects to which the eye is subjected should not exceed 4 or 5 c-p. per sq. in. (0.62 to 0.78 c-p. per sq. cm.) if physiological requirements are to be met. This applies to interiors at night. The limitation is relative rather than absolute. One authority,* while asserting the impracticability of fixing any standard, suggests that if the brightness of the object upon which the eyes are employed is of the order of 10 times that of surrounding objects, physiological requirements will be met satisfactorily.

232. Congruity. The requirements of esthetics are for illumination and an illuminating equipment which shall be pleasing to the senses and in harmony with the character of the premises illuminated. In buildings of notable architectural design the equipment should not only be suitable for its surroundings but the illumination should produce such combinations of light and shade, such contrasts, such color effects as will bring out in true proportions the important architectural features of the building, and will render its ornamentation in the manner conceived by the architect. In churches the illuminating equipment and the illumination must be of a character which is in keeping with the religious purposes for which the building is designed. In manufacturing establishments, effective illumination should be provided from simple, practical equipments. Incongruity of fixture, auxiliary, or illuminant; or unsuitability of light in quality, intensity, direction, etc., may mar an otherwise efficient illuminating system.

233. Pigmentary colors. Color of light, like color in decoration, is an aspect which affords many opportunities for skillful use by the illuminating engineer. In pigments, red, yellow, and blue of certain kinds and in certain proportions will produce white or any other desired color. They are sometimes referred to, therefore, as the primary colors, though, in a scientific sense, pure prismatic colors, respectively, red, green, and blue-violet, are the primary colors. The colors used for decoration are, however, dependent for their appearance upon the quality of the light by which they are illuminated.

It will be obvious, of course, that pigments which appear to the eye similar as regards color may be quite different physically, and that therefore their rendering under light of various colors may be markedly different from that here indicated. This is a field of application in which nothing may be taken for granted; only by trial can the appearance of a given pigment under a given light be determined. In decoration, therefore, a knowledge of the quality of the light employed is of first importance. It is essential that light be provided of such color value as will produce the effect desired in decoration.

234. Ultra-violet light. Some alarm has been felt by physiologists lest ultra-violet light from our ordinary illuminants should prove harmful to the visual organs. It appears to be quite clear, however, that nothing of this kind is to be feared. Recent investigations† show that little is to be apprehended on this score. The ultra-violet radiation from commercial illuminants is shown in Par. 235.

The data in this table arrange illuminants according to their ultra-violet, radiation. Luckiesh, studying the same subject at about the same time, arrived at the following conclusion:

"It appears that when glass is used over any commercial light source there can be very little harmful effect when moderate intensities are used. Considering the greater intensities of daylight, protection, if necessary in any case, is really needed against it rather than against artificial illuminants except in the case of special use of the latter light sources."

METHODS OF ILLUMINATION

236. Direct lighting. The fact that light sources are usually placed higher than the surfaces to be illuminated and that a downward direction of the light is rather generally desirable under such conditions, has led to the

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* Cobb. "Physiological Points Bearing on Glare," *Trans.* Illg. Eng. Soc., 1911.

† Bell. *Electrical World*, April 13, 1912.
Luckiesh. *Electrical World*, June 15, 1912.

room. Enclosing globes also are likely to produce results of much the same order. When the translucency of the semi-indirect bowl is so low that its brightness of transmitted light is not greater than that of the ceiling, the lighting effects are likely to be quite similar to those which obtain when indirect-lighting fixtures are employed.

239. Intermediate types of lighting equipment. In brief, opaque reflectors which allow little light to be distributed elsewhere than upon the working plane are distinctively direct-lighting equipments and form one extreme of a range upon the other extreme of which indirect-lighting equipments may be placed. Between these two extremes are a great variety of equipments, all of which distribute part of the light upon the ceiling and part of it downward. It is difficult to differentiate among these intermediate equipments from the standpoint of illuminating results. Most such equipments, however, may be located in one of three classes, namely: (a) inverted bowls or cones; (b) totally enclosing glassware; (c) translucent bowls.

240. Local illumination. The tendency in recent years has been to depend upon general lighting as far as possible and to supplement it by local illumination only where unavoidable. It is well to do so because with local illumination it is difficult to avoid glare either from the source directly or from the illuminated surface. When, however, it is necessary to illuminate locally some surface, which must be very brightly lighted, every precaution should be taken to avoid the evils just named. The application of diffusing media and care in locating the light source will go far toward accomplishing this; and satisfaction is doubly assured if, in addition, there is an ample general illumination supplementing the local illumination.

ILLUMINATION DESIGN

241. The purpose to be served. In laying out an installation a first step—so simple and obvious that its mention might appear unnecessary—is to determine the purposes to be served by the lighting installation. Usually one does not simply "light a room." He provides lighting in order to make a store attractive to the prospective customer and to promote the sale of goods; to illuminate the work on the machine and promote its prompt, accurate and safe accomplishment; to facilitate clerical work, promoting speed and accuracy without fatigue to the clerks; or to enhance the beauty and charm of a room in a residence. As a rule there are two or more principal objects to be attained in every installation. And the practitioner who familiarizes himself thoroughly with the conditions underlying the requirements established by these objects takes the first essential step in successful lighting design.

242. Choice of illuminant. Usually general conditions narrow the choice to two or three illuminants. In a residence any other illuminant than incandescent lamps would be unsuitable. In a steel mill the choice would probably be narrowed to Type C Mazda lamps and flame arc lamps. In a store either Mazda lamps or intensified carbon arc lamps would be employed, etc. In a street either magnetite or Type C Mazda lamps would probably be considered. Reliability, simplicity, efficiency, color of light, steadiness, cost (first, operating and maintenance) and size usually determine this choice.

243. Choice of auxiliary. Cost, ease of cleaning, ruggedness, efficiency new and maintained, light-directing qualities, diffusion, color, size and appearance have to be considered. Obviously, the importance of each qualification depends upon the nature of the installation.

244. Spacing and height. In industrial and commercial lighting it is generally considered that the spacing should be something like 50 per cent. greater than the vertical distance from the plane of illumination to the light source. This is a sufficiently good relation to form a point of departure in planning an installation. In large rooms it is useful to divide the floor area into squares or approximate squares. Desirable sizes of these squares are given in Par. **245**.* One light source may be placed over the middle of each such square. Often, however, the squares or rectangles which form the unit of space to be lighted are established by the confines of the room or by the pillars or beams which make the division of the room into bays. In such cases it may be practicable to treat the space as a unit or it may be necessary

* "Handbook on Incandescent Lamp Illumination," General Elec. Co., 1913.

mination to be obtained apply methods of point to point calculation as described in Par. 198 and add a uniform increase of, say, 10 per cent. of the average, to represent the light reflected from ceiling and walls.

247. Illumination of several classes of installations. No attempt can be made here to discuss the special design features of the several classes of lighting installation. Those interested in the subject are referred to the Transactions of the Illuminating Engineering Society and to the technical press for descriptive articles. An index to some of the more important articles which may be consulted in this connection, is given in Par. 250.

COSTS

248. Calculation of total operating cost.* "In determining the total operating cost of any system of lighting, three items should be considered: (a) fixed charges, which include interest on the investment, insurance and taxes, depreciation of permanent parts, regular attendance, and other expenses which are independent of the number of hours of use; (b) maintenance charges, which include renewal of parts, labor, and all costs, except the cost of energy, which depend upon the hours of burning; (c) the cost of energy, which depends upon the hours of burning and the rate charged.

"If data are compiled under these heads in convenient units, such as in (a) an annual charge, in (b) a charge per 1,000 hr. operation, and in (c) a charge per 1,000 hr. operation at unit cost of energy, the several items may easily be calculated for any given set of conditions, and the total annual operating cost of any lighting system obtained as their sum.

"Under fixed charges, the items of depreciation and attendance may be mentioned particularly. Depreciation should be charged on permanent parts only, and not upon parts the renewal of which is provided for in the maintenance cost. The rate for depreciation should, in many cases, be higher than the current practice, for obsolescence, rather than the wearing out of parts, determines the life of a lighting system. There are many installations in use to-day which are in good order and giving a fair measure of satisfaction, but which could be replaced at a large saving.

"Too much emphasis cannot be given to the desirability of regular attendance for those illuminants which do not require trimming from time to time. It is essential for satisfactory operation that such lamps and reflectors be cleaned at regular intervals, hence a fixed charge should always be included for this service. Lamps which require frequent trimming are cleaned at the same time, and the cost is included under the maintenance charge.

"The energy cost can usually be readily computed, but will, in the case of some electric illuminants, depend upon the voltage of the circuit, since this determines either the wattage or the power-factor. The effect of power-factor is seldom considered, although it governs the investment in generators, transformers, and wiring, and, in a small degree, energy required. To the central station or isolated plant, the volt-amperes required by a given lamp are perhaps as close a measure of the cost of service as the actual wattage consumed. When the consumer is purchasing energy on a kilowatt-hour basis this factor, of course, is eliminated so far as he is concerned."

Principles of cost accounting in illumination may be laid down and with discriminating application may serve to yield correct cost values. So largely, however, are costs in lighting dependent upon local conditions, and so greatly do these conditions vary, that it is unsafe to apply in one installation cost data obtained somewhere else, unless the differences in condition are first considered and allowance is made in the data for differences in such conditions. But little in the way of reliable impartial cost data has been published.

249. Cost of light in relation to other expenses. The total cost of artificial light as a part of the cost of living or as a part of the total cost of operation of a business enterprise is very small. In 1912 the Department of Commerce and Labor in a bulletin entitled "Retail Prices 1890 to 1911" shows that as an average of 2,567 workingmen's families in 1901, the average cost of lighting per annum was $8.15 out of a total cost of $768.54, or 1.06 per cent. expended in lighting. The report of the Commission of Labor for 1903, as presented at the 58th Congress, offers statistics compiled from the expenditures of 11,156 workingmen's families; these show that the cost of

*Harrison and Magdsick. "The Analysis of Performance and Cost Data in Illuminating Engineering," Trans. Illg. Soc., 1911.

250. Selected list of reference pertaining to illumination designs.—*Continued*

Author	Where published	Title
Law and Powell	Trans. I. E. S., 1913, p. 515.	Distinctive Store Lighting.
Edison Lamp Works, G. E. Co.	Bulletin No. 43403, 1914.	Store Lighting with Mazda Lamps.
Edison Lamp Works, G. E. Co.	Bulletin No. 43500, 1914.	Lighting of Large Stores.
Shalling	Trans. I. E. S., 1913, p. 17.	Department Store Lighting.
Cravath	Electrical World, 1909, p. 53.	The Illumination Design of a Clothing Store.
Residence Lighting		
Vaughn	Elec. Review and Western Elec., 1912, p. 1061.	The Illumination of the Home.
Powell	Trans. I. E. S., 1914, p. 45.	Lighting a Simple Home.
Office Lighting		
Aldrich and Malia	Trans. I. E. S., 1914, p. 103.	Indirect Illumination of the Offices of a Large Company.
Ryan	Trans. I. E. S., 1912, p. 597.	The Lighting of the Buffalo General Electric Company's Building.
Street Lighting		
Way	Elec. Review and Western Elec., 1914, p. 371.	Elements of a Street Lighting Contract.
Ford	Univ. of Iowa, Bulletin 1, 1914.	Street Lighting.
Street Lighting Committee	Trans. N. E. L. A., 1912.	Report.
Street Lighting Committee	Trans. N. E. L. A., 1913.	Report.
Street Lighting Committee	Trans. N. E. L. A., 1914.	Report.
Millar	Trans. I. E. S., 1910, p. 653.	Some Neglected Considerations Pertaining to Street Illumination.
Bell	Trans. I. E. S., 1908, p. 400.	Street Lighting.
Miscellaneous		
Jones	Trans. A. I. E. E., 1912, p. 1127.	The Problems of Interior Illumination.
Higbie	Michigan Technic, 1911, p. 64.	Design of Illumination with Particular Reference to Interiors.
Powell	General Elec. Review, March, 1914, p. 318.	Interior Illumination.
Marks	Trans. I. E. S., 1908, p. 538.	Illumination of N. Y. City Carnegie Library.
Parsons and Smith	U. S. Naval Medical Bulletin, Vol. IV, No. 3.	The Illumination of Study Rooms.
Knight and Marshall	Trans. I. E. S., 1910, p. 553.	Public School-room Lighting.
Marks	The Brickbuilder, 1913.	Lighting Public and Semi-public Buildings.

and that the illumination of a plane surface varies as the cosine of the angle of inclination to the incident ray (Par. 201). These laws must be applied with discrimination and with strict regard for their practical limitations. The inverse-square law holds good only when the light source is relatively small with reference to the distance from the source to the illuminated surface. If the distance is less than five times the maximum dimension of the source, material divergence from the inverse-square law will result. The law may not hold good for relatively short distances when reflecting or refracting devices are employed to concentrate the light in a particular direction, as, for example, when a parabolic reflector is employed with an incandescent lamp or, as a more extreme example, a search-light. The cosine law applies to any plane surface insofar as the incident light is concerned. In many cases, however, the incident light is judged by the reflected or the refracted light. In such applications, the cosine law holds good only if the surface is a true diffusing surface, altogether free from regular reflection characteristics.

254. Ocular characteristics affecting photometry. In the comparison of lights of similar color, the process is not unlike other physical measurements since visual peculiarities do not affect the result. In heterochromatic photometry, in which lights of different colors are compared, ocular characteristics must be borne in mind, and the measurements must be carried out with due regard to the requirements which they impose. The three characteristics of greatest importance are as follows: (a) the Purkinje effect (Par. 255); (b) yellow-spot vision (Par. 256); (c) partial color blindness (Par. 257).

255. The Purkinje effect is the name applied to the greater sensibility of the human eye to blue and green light at very low intensities than to red or yellow light. In accordance with this characteristic, if a mercury-vapor lamp is adjudged equal in illuminating power to a tungsten-filament lamp when the two are compared at a distance of 10 ft., the mercury-vapor lamp would be adjudged of higher illuminating power than the tungsten lamp if the comparison were to be made at a great distance.

256. Yellow-spot vision. The central portion of the retina of the eye, the yellow spot, comprehends a visual angle of 6 to 8 deg., throughout which the eye is less sensitive to green and blue light than is the surrounding portion of the retina. If a comparison of a mercury-vapor lamp and a tungsten lamp of equal power were to be made upon a surface so small as to fall within a visual angle of 6 deg., the mercury-vapor lamp would be adjudged of lower illuminating power than the tungsten. While a relatively higher evaluation would be accorded the mercury-vapor lamp if the illuminated surface were to be enlarged so as to comprehend a visual angle of say 24 deg.

257. Partial color blindness is often encountered. Eyes of certain individuals are found to be less sensitive to light of a given color than are normal eyes. The characteristic sensibility of the eye to light of different colors and of a given intensity when plotted diagrammatically is known as the luminosity curve* (Par. 10). If an observer's sensibility to red is low, as shown by the luminosity curve for his eye, he would, of course, adjudge the illuminating power of a mercury-vapor lamp to be relatively high as compared with that of a tungsten lamp.

258. Psychology in photometry. In all photometry and especially in heterochromatic photometry, observers whose eyes may have quite similar characteristics sometimes secure markedly different results, due to the fact that they form different concepts of the appearance which two illuminated surfaces must assume when they are balanced. Usually, an observer forms a concept and adheres to such concept until persuaded that it is improper. This is a matter of memory, tradition, and, sometimes, of external influence. It is common experience that observers who work together in photometry tend to form similar concepts and to agree in their observations under all conditions. Sometimes the concept agreed upon by such observers is the probable correct concept reached as a consensus of opinion. On the other hand it may be the concept of one observer which another observer has been influenced, unconsciously, to accept.

* Ives. *Philosophical Magazine*, December, 1912.

comparison purposes must be verified occasionally and the repeated use of the working standards employed in such verifications in turn limits their period of constancy. A complete range of reference standards and working standards is important if comparison standards are to be relied upon for accuracy.

PHOTOMETERS AND PHOTOMETRIC APPARATUS

265. Physical or non-ocular photometers. In the measurement of radiant energy there are employed, at various times, the thermopile, the radiometer, and the bolometer. These are affected by radiation of various wave lengths in several characteristic ways, and, for some classes of physical investigation, have very important uses. The photo-electric cell, the selenium cell, and the photographic plate also have been investigated with a view to employment as substitutes for the eye in conjunction with a photometric device. In addition to characteristics which impose serious limitations to their use for practical work, these devices are open to the further objection that radiation within the visible spectrum does not affect them in the same proportions as it does the human eye. Their sensibility characteristics do not conform to the luminosity curve of the human eye. The photoelectric cell, for example, is most sensitive in the region of 0.44μ in the violet end of the spectrum; the selenium cell, on the other hand, is most sensitive to radiation in the region of 0.7μ, which is in the orange-red region of the spectrum. It is possible to correct these devices by employing color screens of such characteristics as to alter the sensibility curve to the desired extent. It is understood that those who are engaged in the study of these devices feel encouraged to hope that they may yet prove their value in some classes of photometric work. Up to the present time, however, they have been of scientific interest rather than of utility, in so far as ordinary photometry is concerned.

266. Photometric devices—ocular. It is a characteristic of the human eye, termed "**induction**" that a uniform dark surface placed next a lighter surface appears darker in the region immediately adjacent to the lighter surface than it does in the region farther removed. It follows that in bringing two surfaces to equivalent brightness, the contrast will appear more marked if the surfaces can be brought into close juxtaposition, and, if the contrast is more marked, equivalency can be established with greater

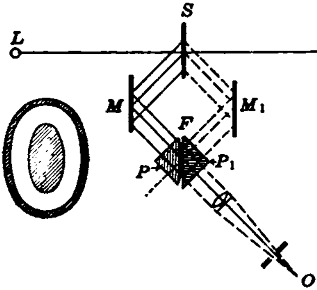

FIG. 55.—Lummer-Brodhun photometer, comparison type.

accuracy. Utmost precision in such adjustments is attained if the surfaces are made continguous and without distinguishable separation. A photometric device (sometimes called a sight box) is an appliance for promoting the brightness equivalency adjustment which is the essence of photometry. The more usual types may be classified as comparison devices, contrast devices, and flicker devices.

267. Comparison devices. For a description of many simple photometric devices which are of historic interest, see text-books.* The comparison

* Especially "Illumination—Its Distribution and Measurement," Trotter.

disc are essential to precision of operation. As in the Lummer-Brodhun contrast photometer, the Bunsen photometer presents to view two contrast fields. If properly constructed with mirrors of equal absorbing power, a condition of balance should bring equality of brightness and equality of contrast.

The Bunsen photometer is preferred by some for routine lamp testing where highest precision in individual measurements is not so important as good maintenance of accuracy throughout the day's work. It is inferior to the Lummer-Brodhun photometer in sensitiveness at low intensities. It is somewhat easier to make settings with the Bunsen photometer than with the Lummer-Brodhun photometer in comparison of lights of markedly different colors for the reason that the illumination of each surface of the disc is due in part to transmitted light from the other surface. Where colors differ, there is a tendency to blend and decrease the color contrast below the actual contrast encountered with a photometer like the Lummer-Brodhun, where the lights are not mixed.

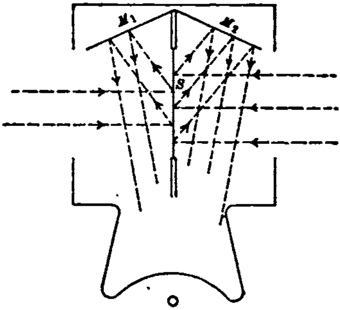

Fig. 57.—Bunsen photometer.

270. Flicker photometer. In flicker photometry the criterion of adjustment is the disappearance of the flicker effect, or rarely, the equality of two flicker effects. The flicker photometer is used as a rule only where lights of markedly different colors are to be compared. Due to persistence of vision, the colors, though markedly different, tend to blend when presented to the eye in rapid alternation, and the color differences cease to be perceptible, while differences in brightness of the two surfaces are still visible. It is thus possible to make comparisons of markedly different lights with much less difficulty than when the equality-of-brightness method is employed, and different observers are much more likely to secure similar results, because the criterion rests upon a physiological effect and leaves room for less difference of opinion or less variation of concept than does the equality-of-brightness method. Ives, who has made the most recent and extensive investigations of the subject,* has found that with the flicker photometer, blue and green light is adjudged of lower illuminating power when compared at low intensities with red and yellow light. This is a reversal of the Purkinje effect (Par. 255) which obtains in equality-of-brightness measurements at very low intensities. He concludes, as the result of his investigations, that the flicker photometer offers the best means of dealing with heterochromatic photometry, but its use should be limited by specifying a standard intensity at which comparison shall be made, a standard visual angle for the photometric field, and observers who are free from peculiarities of color vision. Incidentally, a similar prescription applied to any kind of photometry would do much toward standardization. Ultimately, heterochromatic photometry must be based upon the illuminating power as judged by some such criterion as equality of brightness or power to reveal detail. The disappearance of flicker cannot be considered as an ultimate criterion. However, a flicker photometer once verified and accepted in a given form as a reliable device for heterochromatic photometry, should prove very useful in that class of work because of the readiness with which settings can be made.

271. Forms of flicker photometer. Rood† devised the first flicker photometer, which consisted of a wedge, the two faces of which formed the photometric surfaces, which were viewed alternately through a revolving lens. The Whitman photometer is provided with a wheel, portions of whose rim are inclined in opposite directions. As the wheel revolves, it

* *Philosophical Magazine*, November, 1912.
† Science, Vol. VII, p. 757.

applications, any of the methods of varying the intensity which have been described, may be employed. The principles are the same and the applications differ only in accordance with the dictates of convenience and practicability.

277. Photometer bars. In the measurement of horizontal candle-power and in the measurement of distribution of light about a source, it is customary to employ a track upon which carriages supporting lamps or photometric devices, may travel smoothly and easily. The **Reichsanstalt bar** is an approved type which, with various modifications, may be procured from any manufacturer of photometric appliances.

278. Light-distribution apparatus. A considerable variety of appliances for facilitating the determination of radial distribution of light, is available. These appliances include the Dibdin photometer; devices employing respectively one mirror, two mirrors and three mirrors; the Matthews photometer, employing a ring of mirrors and apparatus in which the test plate is revolved about the source. For detailed description see text-books on photometry and manufacturers' catalogues. All such appliances are designed to facilitate the determination of the intensity of light at various angles in the vertical plane. Since the inverse-square law does not always apply strictly to light from reflectors at the short distances at which the light is utilised, it is good practice to maintain a fixed distance between the surfaces of the photometric device and the centre of the light source.

INTEGRATING PHOTOMETERS

279. General description. An integrating photometer yields in a single measurement the value of the total flux of light or the mean spherical candle-power of a light source. In general, most such devices, by optical or mechanical means, reduce the intensity of the light, at various angles to the vertical of the light source, in proportion to the area of the zone which the angle bisects, and provide a summation of such reduced intensities for the several angles throughout the vertical plane of the source. The **integrating sphere** intercepts and provides an indication of the total light produced by the source. Perhaps the earliest integrating photometer was **Blondel's lumeter.*** Kennelly† also devised an apparatus for mechanical integration. The instruments of Matthews and Ulbricht, and especially the latter, which are used at the present time are described in text-books.

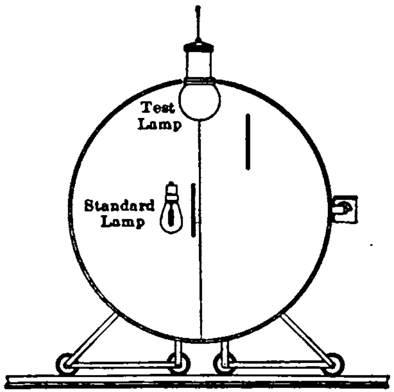

Fig. 59.—Integrating sphere for measuring total lumens or mean spherical candle-power.

280. Ulbricht integrating sphere. The integrating sphere devised by Ulbricht has been found to be the most accurate and practical form of integrating photometer It has been shown that if a light source be located within a hollow sphere having a diffusing inner surface and be screened from a given element of that surface, the illumination of such element, being due entirely to diffuse reflection, will be independent of the location

* Blondel. "La Determination de l'intensite moyenne spherique des sources de lumiere," *Comptes rendus*, March and April, 1895 and *L'Eclairage Electrique*.

† Houston and Kennelly. "Electric Incandescent Lighting," p. 461.

Surfaces which conform most closely to this requirement are, however, not permanent in character. Also, any opaque surface is undesirable for some classes of work because it must be viewed from above, under which conditions it is almost impossible to avoid some obstruction of light by the photometer and the observer. The most satisfactory simple test plate for measurement of illumination under most conditions, consists of a thin milk glass which is free from selective absorption and provided with fine diffusing surfaces, and viewed from below, its brightness being judged by transmitted light. Such plates do not conform exactly to the cosine law of perfect diffusion, but the variation of the best plates from that law is immaterial in most classes of work. The broken line curve in Fig. 60 illustrates the variation of a typical translucent-glass test plate of a simple type.

283. Weber portable photometer. The Weber photometer, Fig. 61, was perhaps the first portable photometer embodying most of the features which have been found to be essential to this class of apparatus. In its latest form it consists of a rotating tube containing, at one end, the ocular aperture, *O*, at the centre a Lummer-Brodhun cube, *P*, and at the other end either an attached test plate or a diaphragm for use with a detached test plate, *T*. This tube revolves upon the end of a fixed horizontal tube containing at the other end the comparison lamp, *C*. A translucent glass, *G*, is moved along the axis of this tube, its brightness varying inversely as the square of its distance from the comparison lamp. Looking through the ocular aperture, one sees, as the centre of the photometric field, a portion of either the attached or the detached test plate, and surrounding it a portion of the comparison-lamp glass, the brightness of both being, of course, independent of their distance from the eye. The value corresponding to the location of the comparison-lamp glass, is indicated upon an external scale. This photometer is provided with some absorbing glasses to increase the range, and, in addition, has green and red glasses for insertion in the ocular tube in order to assist in heterochromatic photometry in accordance with a two-color method. This method of color photometry has very limited application.

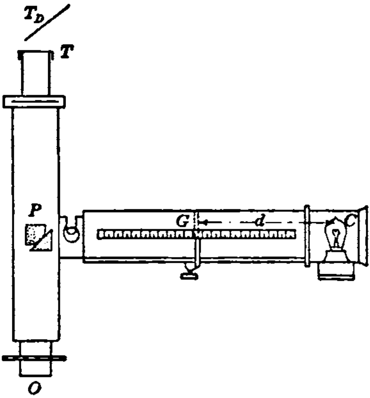

FIG. 61.—Weber portable photometer

284. Beckstein photometer. This instrument is semi-portable. It employs a Lummer-Brodhun cube, an incandescent comparison lamp, a variable sector disc, about which a beam of light is rotated (Par. **274**), the prisms being driven by a small attached motor. It is provided with a multiplicity of attachments and adjustments which render it perhaps more suitable for academic purposes than for practical photometry.

285. Sharp-Millar photometer. This is the form of portable photometer which is most generally used in this country. It is available in three sizes, respectively 12, 24, and 39 in. long. Fig. 62 shows the essential features as embodied in the smallest size. The photometric device, *P*, consists of a Lummer-Brodhun cube or a microscope glass, mirrored except for a central aperture. Looking through this aperture from ocular aperture *O*, the observer sees either the attached test plate, *T*, which is upon the end of a rotating tube, or the detached test plate, T_d. The photometric surface, as seen through this tube, is surrounded in the photometric field by a portion of translucent glass comparison window, *W*. The illumination of window *W* varies inversely as the square of the distance to moving comparison lamp *C*. The values of a setting is indicated upon a direct-reading translucent scale, illuminated from spectrophotometry is liable to systematic and accidental errors, effects of stray light being notable among the errors of the former class. Results of spectrophotometric tests show relative intensities of light in the several wave lengths throughout the visible spectrum (Par. 27). These are difficult to comprehend and interpret unless one is well versed in such work. Usually it is necessary to refer spectrophotometric differences to differences in color with which one is well acquainted (as that between the Mazda and carbon lamps) in order to form a fairly good concept of magnitude.

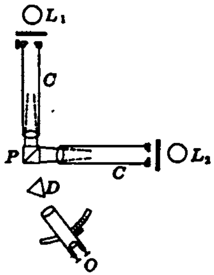

Fig. 63.—Scheme of spectro-photometer.

287. Colorimeter. It is generally considered that there are three primary color sensations (Par. 208). In colorimetry, three glasses corresponding to these sensations, respectively red, green and blue, are interposed between the light source to be studied, and a device which mixes the transmitted lights and brings the resultant combined light into juxtaposition with some comparison light for color match. Diaphragms, or variable-width slits, are employed to secure the proper relative proportions of red, green and blue light. In the Ives colorimeter* variable width slits are employed with the colored glasses. The adjustment scale for each slit is calibrated from 0 to 100. With each slit opened to the maximum, the resultant mixture appears white when average daylight is received upon the colored glasses. Color

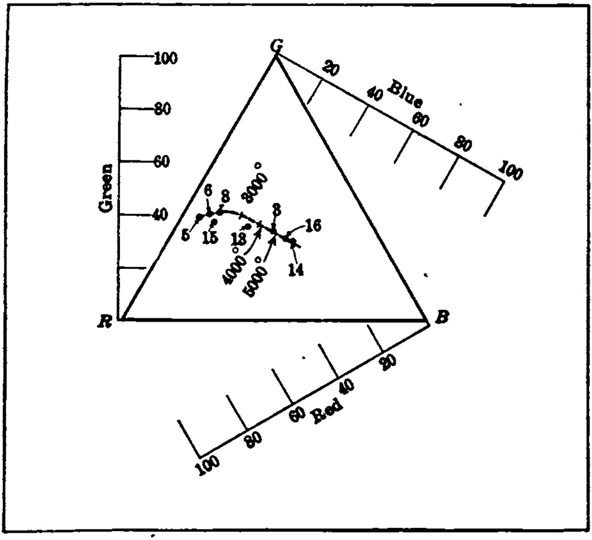

Fig. 64.—Color triangle. For key to numbers see Par. 27.

sensation values are expressed in terms of such maxima. The colorimeter may be employed in the study of light from line spectrum sources, whereas

* Ives. *Journal Franklin Institute*, 1907, p. 164.

293. Absorbing screens form a valuable adjunct to photometric equipment. Their transmission coefficient, however, is not accurately controllable, and a simple decimal value is therefore rarely obtained. Absorbing screens should transmit without diffusion, and should be free from serious selective absorption. Unfortunately, the usual absorbing screens having low coefficients of transmission, have considerable selective absorption.

294. Baffle screens. In practically all photometry it is essential to guard the photometric device against stray light. Opaque screens having suitably proportioned apertures are largely employed for this purpose. A series of these screens, painted black (for most precise work they may be covered with black velvet), is used, for example, on a photometer bar. Where the photometric device or the comparison lamp travels along a track, these screens must be re-located as occasion requires. A most satisfactory method is to so install them that they will be adjusted automatically to the movement of the lamp or photometer carriage. This may be accomplished by mounting them upon lazy tongs, as in several types of commercial lamp-testing photometers, or allowing them to slide upon the track, being pushed in front of the lamp as it approaches the photometric device, and drawn after the lamp by cords or otherwise as it recedes, as in the Sharp-Millar photometer. An alternative to the use of baffle screens is the employment of black velvet to cover all surfaces which may possibly reflect stray light to the photometric device.

295. Rheostats. The easy fine adjustment of the current or voltage of a lamp is important to precise work in photometry. Too much care cannot be expended in providing thoroughly satisfactory rheostats for this purpose. Step rheostats are unsatisfactory unless the steps are of such low resistance, in relation to the magnitude of the current, that the change per step is extremely small. A helix of resistance wire, with the coils well insulated, wound upon an insulated tube and mounting a sliding collar having a multiplicity of contact points, is the most generally acceptable form of rheostat for photometric work.

296. Lamp rotators. It is usually desired to obtain mean angular intensity of light rather than the light in some particular direction at a given angle. Wherever the nature of the illuminant permits, it is desirable, therefore, to rotate the light source during test, allowing the eye to integrate the intensities to obtain a mean. Most forms of illuminants can be rotated. The speed of rotation of course depends upon the extent to which the light distribution is asymmetrical. If the distribution is approximately symmetrical, a low speed of rotation will suffice. This being the case, it has been found practicable to rotate almost all types of illuminants, including most arc lamps and some forms of gas lamps. The lamp rotator therefore becomes a valuable adjunct in a photometric laboratory. It must be good both mechanically and electrically. As the moving electrical contact required for the supply of the lamp may involve some potential drop, it is customary in the best construction to provide auxiliary moving contacts either of the brush type or of the mercury-cup type, in order to allow the measurement of voltage immediately at the lamp terminals.

PHOTOMETRIC TESTING

297. The substitution method of photometry consists in calibrating a photometer by means of a standard lamp of as nearly as possible the same characteristics as the lamps to be tested, and substituting the lamp to be tested for the standard lamp. A skilled photometrist employing a photometer of exact construction which is perfectly screened and is used with correct electrical instruments for determining the electrical conditions of circuits which are free from potential drop, may obtain correct results in the practical comparison of a test lamp against a standard lamp. Whatever the methods employed, every care should be exercised to secure these favorable conditions for photometry, but if, in spite of care, some conditions exist which are not exactly as they should be, it is quite possible that the substitution method may result in cancelling the effect of such conditions and avoiding erroneous results. By using standard lamps of the same size and type as the lamp to be tested, the substitution method results in correcting both errors of illumination and errors of electrical measurement. If stray light from a 100-candle-power lamp adds 5 per cent. to the illumination of a photometric surface when a moving photometric device is set at 100 on a scale, it will have the same effect when a standard lamp of the same size is used. If then a comparison lamp be calibrated for temporary use by means of the 100-candle-power standard lamp, it will be adjusted 5 per cent. too high. When the 100-candle-power test lamp is measured, the light of the comparison lamp against which it is balanced and the light from the test lamp will both be 5 per cent. too high. The result will be a correct setting. If a voltmeter be employed which has an error of 1 per cent., the effect of the error will be cancelled in the same way if the substitution method is followed. Where considerable photometric work is to be done, the provision of an ample range of reference standard lamps, in order to permit the extensive application of the substitution method, is true economy.

298. Good practice in measuring illumination. It is well to be provided with reference standard lamps and a box equipped with baffle screens or black velvet to prevent stray light, in order to produce illumination of known intensities from the standard lamp upon the photometer test plate. It is well to have sufficient standardising equipment of this kind to permit of the verification of the photometer scale at a few points throughout its range and also the verification of photometer absorbing screens. The same equipment may be used in verifying the brightness calibration of the photometer, provided a standard surface of known qualities is obtained with the standard lamps. In such calibration, light of a known intensity is thrown upon the standard surface and the corresponding brightness of the surface is computed (Par. **205**), employing its coefficient of diffuse reflection.

In some illumination work it is sufficient to measure the intensity of illumination at certain points in a room, and it is usually sufficient to measure the brightness of certain objects in the room, as far as data on brightness are concerned. More frequently, however, it is desired to know the average maximum and minimum illumination intensities on certain planes, and to derive the coefficient of utilization (Par. **188**). In such instances it is customary to divide the plane of reference into rectangles, usually providing 20 to 30 such rectangles for the room, or for each bay in the room. A determination of the illumination intensity is then made at the centre of each such rectangle. The mean of such values is usually a fair approximation of the average intensity for the entire plane. Where a detached test plate is employed in the measurement of illumination on a horizontal plane or at any given angle of inclination to the horizontal, it is often desirable to employ an automatic-leveling test plate. In the measurement of horizontal illumination in interiors, a plane 30 or 36 in. above the floor is usually selected. A complete study of a room used, for example, for office purposes, should include the average horizontal illumination on such a plane; the uniformity of such illumination intensities; the brightness of the walls, light sources and other especially prominent objects within view; and measurements of either illumination intensities or brightness on desks to show depth and nature of shadows encountered.

299. Precautions for avoidance of error. The following suggestions are commended by experience, and, if followed, are likely to result in the avoidance of some of the most common errors.

Reduce color differences by the use of authoritatively calibrated color filters (Par. **290**).

Follow the substitution method (Par. **297**) as closely as practicable. Provide reference or working-standard lamps of the same size and type as the lamps to be tested.

Consult the characteristics of the light source under test and adapt practice accordingly. For example, allow an arc lamp or a large series incandescent lamp to burn for a short period in order to attain working temperature before making measurements. In testing arc lamps whose values vary through a cycle corresponding with the feeding period, make certain that results are average for such period.

Verify photometer-scale calibration by tests of standard lamps.

Repeat verification at reasonable intervals even though photometer has not been used in interim.

Verify indications of electrical instruments used.

Observe strict cleanliness of apparatus. Dust on transmitting glasses increases coefficient of absorption. Dust on black velvet reflects light.

Verify a few test results by tests upon other apparatus. It is relatively simple for an observer to repeat settings with a given photometer. Make certain that such settings are in accord with results determined by others employing different equipment.

In tests of reflectors make certain that the light source is strictly in accord with the manufacturer's standard of construction, both as to type and dimensions.

Assure correct location of the reflector with reference to the light source. Slight variation in any of these conditions may affect the result materially.

In tests for candle-power and in light-distribution tests, look along the photometric axis from the position of the photometric device to the test lamp and to the comparison lamp. Make certain that all of the light emanating from the light sources in the direction of the photometric device, reaches the photometric surface. Make certain that no other light reaches the surface, that is, avoid stray light.

300. Sampling. In sampling for test purposes, whether the samples be lamps, lighting auxiliaries, or illumination installations, it is important that the samples be unquestionably representative of the product which is to be judged by the results of the test. It is also essential that the samples be sufficient in number to guard against the exertion of undue influence upon the final result due to the presence of an eccentric individual among the samples. It is hardly possible to judge intelligently in these matters unless one is thoroughly acquainted with the characteristics of the product which is being sampled. No small part of expertness in testing lies in the successful sampling of the product to be tested. Lamps, reflectors, etc., are not uniform, and very misleading results may follow upon injudicious sampling.

301. Principles of comparison. In comparing illuminants it is important to bear in mind first, that some illuminants require more adaptation and suffer in efficiency more in adaptation for a given service than do other illuminants; and, second, that some illuminants deteriorate more largely in efficiency during life than do others. For example, a magnetite arc lamp as equipped is well adapted to street-lighting service, and its efficiency in the condition delivered by the manufacturer is substantially its service efficiency. On the other hand, incandescent lamps may have to be equipped with globe or reflectors or both before application to street-lighting service, and their efficiency as shipped by the manufacturer is materially higher than is their service efficiency. As another example, the candle-power depreciation of a 25-watt Mazda lamp is less during its life than is the candle-power depreciation of a 100-watt Mazda lamp. Conclusions based upon initial laboratory values should be modified where necessary before determining upon relative merit of two different kinds or sizes of illuminants for a given class of service. Likewise, lighting auxiliaries are not always directly comparable on the basis of their initial laboratory values. The deterioration of reflecting surfaces may be rapid. Some surfaces collect and retain dust more largely than do others, and, in consequence, their deterioration of light is greater in a given period.

302. Discussion of results. In discussion of test results it is rarely possible to draw unqualified conclusions as to relative merit between appliances or installations which are of more or less the same order of merit. In any test all that is demonstrated is that a sample or a set of samples or an installation has been found, in a given instance, to be superior in certain respects. It is dangerous to draw sweeping conclusions from tests. To do so may mislead when test data are applied to appliances or installations which have not actually been tested. In discussing results of tests and drawing conclusions from tests it is well to be cautious in accepting the basis of measurement as a final indication of value. The candle-power of an incandescent lamp is one direction or in one plane is not necessarily an indication of the illuminating power of the lamp. In the long run, the total light flux or the mean spherical candle-power is most nearly a correct indication, but even this measurement may fail to indicate the real value of an illuminant for a certain class of service. It may be shown that the minimum normal illumination intensities provided by two installations of illuminants for street-lighting service are equal, but this does not demonstrate that the two systems are of equal value. One may deliver twice as much light as the other upon the street. The mean horizontal illumination may be in the long run a reasonably good measure of street-lighting effectiveness, but even this measure may fail to indicate the facts for certain classes of service. In short, tests of illumination should be conducted and conclusions should be drawn from such tests in accordance with the dictates of common sense and good engineering practice.

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SECTION 15

INDUSTRIAL MOTOR APPLICATIONS

CONTENTS

(Numbers refer to Paragraphs)

SECTION 15

INDUSTRIAL MOTOR APPLICATIONS
MACHINE TOOLS

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1. Definition. The term "machine tools" cannot be accurately defined. Broadly they are machines used to work and shape metals. A legal definition, taken from the Underwood tariff law, Par. 167, reads as follows: "Machine tool as used in this paragraph shall be held to mean any machine operated by other than hand power which employs a tool working on metal."

2. The two principal classes into which they divide are distinguished by the kind of motion of the work or cutting tools. This motion may be either rotating or reciprocating. In the former instance the speed is usually constant throughout each operation, and the energy absorbed is used in overcoming the friction of the machine and in doing useful work in cutting or forming metals. The exceptions are machines that accelerate during the cutting operations, such as squaring-up lathes and lathe-type cutting-off machines. In the second class the power is subject to great fluctuations during a working cycle. For, in addition to the friction losses and useful work done there are large, regular demands for energy with which to retard and accelerate heavy parts of the machine, or the pieces which are being shaped.

3. The friction losses in rotating machines, such as lathes, boring mills, drilling machines, milling machines, grinders, and the like vary almost directly as the speed, the gear ratio remaining constant. The loss in the gearing and feeding mechanism comprises the larger part of the friction losses.

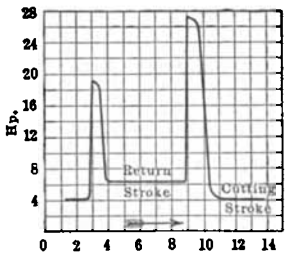

FIG. 1.—Power curve of a 60 by 60-in. planer.

4. The friction losses in reciprocating machines, such as planers, shapers, slotters, and the like, are very small in comparison with the losses due to inertia. In fact the inertia losses often exceed the useful work to such an extent as to determine the size of motor (this is especially the case with short-stroke machines). Fig. 1 shows a power curve taken by G. M. Campbell for a 60 × 60 in. × 20 ft. Pond planer. It shows the power input when running light plotted with time. The cutting-stroke speed was 25 ft. per min. (7.6 m. per min.) and the return-stroke speed 60 ft. per min. (18.3 m. per min.).

5. Group drive and individual drive. Motor applications to machine tools divide into two classes, group drives and individual drives. It is impossible to lay down a general principle to be followed in the selection of drive for a given case, for there are many modifying factors. Very large machines (those located under a crane) and all machines requiring variable-speed drive are commonly provided with individual motors. Small and medium-sized machines are usually arranged in groups and driven from a line shaft which in turn is driven by a constant-speed motor. If there are a number of reciprocating machines in the group, it is not uncommon to add a fly-wheel to the motor.

6. A comparison of lineshaft and individual-motor drives,* for machine tools is given in the following table:

Item	Lineshaft drive	Individual motor drive	Advantage of individual motor
1. Power consumption.	Constant friction loss in shaft, belts and motor, power for cutting.	Friction loss (motor and tool only) useful power only while working.	Less power required.
2. Speed control.	No. speeds = No. cone pulleys × No. gear ratios.	No. speeds = No. controller points × No. gear ratios.	More speeds possible; time saved in speed adjustments.
3. Reversing.	Clutch and crossed belt.	Reversible controller.	Time saved in reversing.
4. Adjusting tool and work.	Stopping at any definite point very difficult.	Can be started in either direction and stopped at any point.	Time saved in setting up and lining up.
5. Speed adjustment.	Large speed increments between pulley steps.	Small speed increments between controller steps.	Time saved by obtaining proper cutting speed.
6. Size of cut.	Limited by slipping belt; large belts hard to shift.	Limited by strength of tool and size of motor.	Time saved by taking heavier cuts.
7. Time to complete a job.	....	....	Much less time required as indicated for previous items.
8. Liability to accidents.	Slipping or breaking belt; injury to machine tools, cutting tool or prime mover.	Injury to machine tool, cutting tool or motor.	Much less liability to accident.
9. Checking economy of operations.	Close supervision required, very difficult to locate causes of delay.	Accurate tests possible by means of graphic meter which records automatically all delays and rate of cutting.	Causes of delay and remedies easily located without personal supervision.
10. Flexibility of location.	Location determined by shafting, and changes difficult.	Location determined by sequence of operation changes readily made.	Greater convenience in handling and increased economy of operation; more compact arrangement possible.

7. Motors for individual drives have been tentatively standardised by a committee of the National Machine Tool Builder's Association conferring with a committee of the American Association of Electric Motor Manufacturers. Although the design data were agreed upon in substance early in 1910, the motor manufacturers have failed to use it in the manufacture of their product. An abstract of the report of these committees appears in Par. 8.

* Robbins, Charles. *Trans.* A. S. M. E., Vol. XXXII, page 182.

(e) **Axle lathes, wheel lathes and driving-wheel lathes** should be driven by direct-current motors.

(f) **Chucking lathes** usually are not motor-driven. If motors are used they should be of variable speed.

(g) **Automatic screw machines** in small sizes should be group-driven; in the larger sizes they should preferably be driven by variable-speed motors.

(h) **Sensitive drilling machines** in general should not be motor-driven. However, if machine is placed in an isolated location, a motor may be directly applied to the machine itself or the machine may be driven through a countershaft, from a motor on the floor.

(i) **Vertical and radial drilling machines** are usually group-driven unless they are isolated. If such machines are motor-driven, the variable-speed type should be selected. The motor may be direct connected to the machine itself or set up to drive the machine countershaft.

(j) **Boring machines,** if used for specialized work, are preferably belt-driven. If used for a variety of operations, a variable-speed motor is desirable.

(k) **Grinders** should be driven by constant-speed motors belted to the grinder countershafts.

(l) **Planers,** particularly those of small size, if located under a crane, should be driven by variable-speed motors. A recent development is the reversing-motor planer drive which is now being extensively tested, and promises to prove successful.

(m) **Shapers, slotters, etc.,** should usually be group-driven.

(n) **Knee and column-type milling machines** in the large sizes should be driven by variable-speed motors, especially if used in "gang" operations.

(o) **Planer-type milling machines** should be motor driven. Either the constant-speed or the variable-speed types will prove satisfactory.

10. Values of horse power required to cut metal*

Lathe-type tools

Material	Horse power required to remove 1 cu. in. per min.
Brass and similar alloys	0.2 to 0.3
Cast iron	0.3 to 0.5
Wrought iron Mild steel (0.30–0.40 per cent. carbon)	0.6
Hard steel (0.50 per cent. carbon)	1.00 to 1.25
Very hard tire steel	1.5

Drills

Material	Horse power required to remove 1 cu. in. per min.
Brass and similar alloys	0.4 to 0.6
Cast iron	0.6 to 1.0
Wrought iron Mild steel (0.30–0.40 per cent. carbon)	1.2
Hard steel (0.50 per cent. carbon)	2.0 to 2.5
Very hard tire steel	3.0

11. Determination of horse power required for machines under group drive. A table of power values for machine tools is given in Par. 12. These values are the result of tests made by the author under actual shop conditions, and apply to small and medium-sized machines only. The output of the factory where the investigation was made was light automatic machines. The parts operated on during the tests were iron and steel castings, drop forgings and bar stock. Manufacturing conditions were highly developed, and the degree of finish allowed was small. Because of these conditions the power values are still useful although they were obtained before the common use of high-speed steel in cutting tools. The values

* Robbins, Charles. *Trans.* A. S. M. E., Vol. XXXII, pp. 199 to 209

have been checked by their application to a number of factories whose total power load was known. This showed that, for a group of machines, the sum of the power values given in the table is about 20 per cent. higher than the average working load. This is because of the intermittent service of tools for various reasons, or the departmental slip.

12. Power machine tools in groups (see Par. 11)

Kind	Size	Observed horse power; maximum	Observed horse power; average
Boring Machines:			
Bullard, single head	36 in.	0.78	0.52
Bullard, double head	42 in.	1.72	1.08
Cam Cutters:			
Brainard	No. 2	....	0.67
Brainard	No. 4	0.48	0.32
Brainard	No. 5	0.48	0.32
Lathe type, single head	....	....	0.82
Lathe type, double head	....	....	0.50
Cutting-off Machines.			
Hurlbut-Rogers	$1\frac{1}{8}$ in.	....	0.12
Hurlbut-Rogers	2 in.	0.28	0.14 to 0.18
Hurlbut-Rogers	3 in.	0.34	0.20 to 0.22
Drilling Machines:			
Prentice Bros. radial	No. 0	....	0.72
Prentice Bros. radial	No. 1	3.18	1.12
Woodward & Rogers	Sensitive single-spindle	....	0.31
Dwight-Slate	2-spindle	....	0.32
Woodward & Rogers	Sensitive 3-spindle	....	0.35
Woodward & Rogers	4-spindle	....	0.48
Woodward & Rogers	6-spindle	....	0.71
Prentice upright	16 in.	....	0.25
Prentice upright	18 in.	....	0.35
Prentice upright	20 in.	....	0.42
Prentice upright	22 in.	....	0.59
Blaisdell upright	24 in.	....	0.47
Blaisdell upright	26 in.	....	0.22
Blaisdell upright	28 in.	....	0.25
Blaisdell upright	30 in.	....	0.30
Blaisdell upright	34 in.	....	0.45
Blaisdell upright	36 in.	....	0.53
Blaisdell upright	46 in.	....	0.63
Blaisdell upright	50 in.	....	0.83
Gear Cutters:			
Brainard	No. $4\frac{1}{2}$	....	0.15 to 0.32
Gould & Eberhardt	No. 3	....	0.20
Brown & Sharpe	No. 3	....	0.20
Grinders:			
Brown & Sharpe cutter and reamer grinder	No. 3	....	0.32
C. H. Besly & Co. Gardner grinder	No. 4	1.42	0.53
Brown & Sharpe plain	No. 11	....	0.80
Brown & Sharpe surface	No. 2	....	0.40
Brown & Sharpe surface	No. 3	....	0.50
Brown & Sharpe universal	No. 1	....	0.60
Brown & Sharpe universal	No. 2	....	0.76
Diamond wet tool grinder	....	3.29	0.97*
Leland & Faulconer wet grinder	....	....	0.41 to 0.82 †

* Carrying 1 20-in. wheel. † Carrying 2 24-in. wheels.

15. Bolt and nut machinery

(a) Bolt cutters—motor A, B or C (Par. 12)		
Style	Size (in.)	Horse power
	1, 1¼, 1½	1 to 2
Single	1¾, 2	2 to 3
	2½, 3½	3 to 5
	4, 6	5 to 7½
Double	1, 1½	2 to 3
	2, 2½	3 to 5
Triple	1, 1½, 2	3 to 7½
(b) Bolt pointers—motor B or C		
	1½, 2½	1 to 2
(c) Nut tappers—motor A, B or C		
Four-spindle..............	1, 2	3
Six-spindle...............	2	3
Ten-spindle..............	2	5
(d) Nut facer—motor B or C		
	1, 2	2 to 3

16. Bolt heading, upsetting and forging machines

Motor A,* B† or C‡ (Par. 12)	
Size (in.)	Horse power
¾ to 1½	5 to 7½
1¾ to 2	10 to 15
2¼ to 3	20 to 25
4 to 6	30 to 40

17. Boring and turning mills

Motor A, B or C (Par. 12)		
Size (in.)	Horse power	
	Average work	Heavy work
37 to 42	5 to 7½	7½ to 10
50	7½	7½ to 10
60 to 84	7½ to 10	10 to 15
Size (ft.)		
7 to 9	10 to 15	
10 to 12	10 to 15	30 to 40
14 to 16	15 to 20	
16 to 25	20 to 25	

* Speed variation is sometimes desired when different sizes of bolts are headed on the same machine.

† Compound-wound, direct-current motor.

‡ Wound secondary or squirrel-cage motor with approximately 10 per cent. slip.

21. Drilling machines—multiple spindle

Motor A, B or C (Par. 12)		
Size of drills (in.)	No. of spindles	Horse power
$\frac{1}{16}$ to $\frac{1}{4}$	6 to 10	3
$\frac{1}{16}$ to $\frac{3}{8}$	10	5
$\frac{1}{16}$ to $\frac{1}{2}$	10	$7\frac{1}{2}$
$\frac{1}{4}$ to $\frac{3}{4}$	10	10
$\frac{1}{2}$ to 1	10	10 to 15
2	4	$7\frac{1}{2}$
2	6	10
2	8	15

22. Gear cutters

Motor A, B or C (Par. 12)	
Size (in.)	Horse power
36 × 9	2 to 3
48 × 10	3 to 5
30 × 12	5 to $7\frac{1}{2}$
60 × 12	5 to $7\frac{1}{2}$
72 × 14	$7\frac{1}{2}$ to 10
64 × 20	10 to 15

23. Grinders

(a) Tool, snagging, etc.—motor B or C (Par. 12)		
Wheels		
No.	Diameter wheel (in.)	Horse power
2	6	$\frac{1}{2}$ to 1
2	10	2
2	12	3
2	18	5 to $7\frac{1}{2}$
2	24	$7\frac{1}{2}$ to 10
2	26	$7\frac{1}{2}$ to 10

(b) Cylindrical—motor A, B or C (Par. 12)

Dia. wheel (in.)	Length work (in.)	Horse power	
		Average work	Heavy work
10	50	5	$7\frac{1}{2}$
10	72	5	$7\frac{1}{2}$
10	96	5	$7\frac{1}{2}$
10	120	5	$7\frac{1}{2}$
14	72	10	15
18	120	10	15
18	144	10	15
18	168	10	15

26. Milling machines

Motor A, B or C (Par. 13)

Vertical slab milling machines	
Width of work (in.)	**Horse power**
24	7½
32 to 36	10
42	15

Vertical milling machines

Height under work (in.)	Horse power
12	5
14	7½
18	10
20	15
24	20

Plain milling machines

Table feed (in.)	Cross feed (in.)	Vertical feed (in.)	Horse power
34	10	20	7½
42	12	20	10
50	12	21	15

Universal milling machines

Machine no.	Horse power
1	1 to 2
1½	1 to 2
2	3 to 5
3	5 to 7½
4	7½ to 10
5	10 to 15

Horizontal slab milling machines

Width between housings	Horse power	
(In.)	Average	Heavy
24	7½ to 10	10 to 15
30	7½ to 10	10 to 15
36	10 to 15	20 to 25
60	25	50 to 60
72	25	75

31. Presses, hydrostatic wheel

Motor B or C (Par. 13)	
Size (tons)	Horse power
100	5
200	7½
300	7½
400	10
600	15

Presses for notching sheet iron or steel, motor A, B or C, ½ to 3 horse power.

32. Punching machines

Motor B* or C† (Par. 13)		
Dia. (in.)	Thickness (in.)	Horse power
[illegible]	[illegible]	1
[illegible]	[illegible]	2 to 3
[illegible]	[illegible]	2 to 3
[illegible]	[illegible]	3 to 5
[illegible]	[illegible]	5
1	[illegible]	5
1	1	7½
1[illegible]	1	7½ to 10
1[illegible]	1	10 to 15
2	1	10 to 15
2[illegible]	1[illegible]	15 to 25

33. Rolls—bending and straightening

Motor B‡ or C§ (Par. 13)		
Width (ft.)	Thickness (in.)	Horse power
4	[illegible]	5
6	[illegible]/16	5
6	7/16	7½
6	[illegible]	15
8	[illegible]	25
10	1[illegible]	35
10	1[illegible]	50
24	1	50

34. Saws, cold and cut-off

Motor A, B or C (Par. 13)	
Size of saw (in.)	Horse power
20	3
26	5
32	7½
36	10 to 15
42	20
48	25

* Compound-wound motor.

† Wound secondary or squirrel-cage motor with approximately 10 per cent. slip on the larger sizes.

‡ Standard bending roll motor.

§ Wound secondary induction motor.

39. The direct-connected adjustable-speed reversing motor is the most recent development in motors for machine tools. It has been applied to planers, slotters, key-seaters, wire and tube drawing machines and large boring mills. Its advantages lie in increased production and saving of power. Figs. 2 to 6, inclusive show five planer drives.* These curves are drawn to the same scale and show the power required to drive "light" and with normal cuts, see Par. **38**.

40. Power required by portable armature drills
(Andrew Stewart, before Glasgow Techn. College Sc. Soc.)

Size of tool	Spindle rev. per min.	Wt. of tool, lb.	Diam. hole, in.	Depth hole, in.	Time sec.	Metal	Watts	Watts per lb. metal per min.†
Breast	800	13	[illegible]	1.5	65	Cast iron	305	7,200
1 M 1	450	17	[illegible]	1.0	120	Cast iron	330	4,230
1 M 2	250	30	[illegible]	0.5	40	Steel	495	8,448
1 M 2	250	30	[illegible]	1.5	70	Cast iron	660	3,300
1 M 3	150	32	1	1.5	120	Cast iron	550	3,666
1 M 3	150	32	1	0.5	80	Steel	495	6,447
1 M 3	150	32	1[illegible]	1.5	180	Cast iron	440	4,125
1 M 4	100	52	2	1.5	180	Cast iron	990	2,564
3 M 3	150	48	1[illegible]	1.5	120	Cast iron	770	3,200
3 M 4	100	58	1[illegible]	2.75	105	Cast iron	1,320	2,620
3 M 4	100	58	1[illegible]	3.0	240	Cast iron	1,540	3,286
3 M 4	100	58	2	2.0	150	Cast iron	1,880	2,940
3 M 4	100	58	2[illegible]	2.75	240	Cast iron	2,200	3,040
3 M 4	100	58	2	1.3	150	Mild steel	1,860	4,650

WOOD-WORKING MACHINERY

BY CHESTER W. DRAKE

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SAWING

41. Band saws are replacing circular saws in most saw mills, since the saving they effect in the kerf much more than offsets their higher first cost, labor and maintenance charges. Band saws having wheels 8 ft., 9 ft. and 10 ft. diameter are in principal use and their power requirements vary widely with the kind and size of logs and the cutting speed.

42. Type of motor suitable for band saws. Induction motors, either of the squirrel-cage or wound-rotor type may be used for driving band mills, but special attention to the motor and control characteristics are necessary. The band wheels have a total weight of several tons, and when running at a saw speed of 10,000 ft. per min. have a very large fly-wheel effect. Consequently, a motor is required which has a high starting torque and is able to bring the mill to speed in about a minute. A squirrel-cage motor with a high slip (7 or 8 per cent.) will develop a high torque at starting, and besides this has the additional advantage due to its slip of allowing the band saw to slow down at times of heavy load, and give up some of its stored energy. In this way the load fluctuation on the motor and the system may be considerably reduced. A slip-ring motor gives a high starting torque, but with the secondary short-circuited has a low slip, and consequently the motor is subjected to all the instantaneous peaks of load. A permanent resistance may, however, be connected in the secondary circuit to give any desired slip. An advantage of this method is that the heat thus generated is external to

* Fair, Charles. *American Machinist*, Vol. XXXVIII, page 103.

† These figures include losses in the motor. Careful tests in which the motor losses were separated showed that the power utilised at the drill point varied from 3.13 to 4.1 kw. per lb. of mild steel per min. and from 1.57 to 2.69 kw. per lb. of cast iron per min., the low figures referring to 2-in. holes and the high ones to small holes.

Motor		Saws	Drive	Remarks
Horse power	Rev. per min.			
200	850	6-32 in.	Belted	
150	850	8-32 in.	Coupled	
75	1,700	8-24 in.	Coupled	Larger motor required for stock over 2-in. thick.
50	1,700	4-18 in. 4-24 in.	Coupled	See test below
50	850	6-24 in.	Belted	Saws run 1,590 rev. per min.
30	3,480	2-6 in.	Coupled	Lath edger

Test on the above 50-h.p. coupled motor showed a friction load of 6 kw. With a feed of from 180 to 190 ft. per min., on hemlock stock, the following results were obtained:

4 cuts in 3-in. stock................ 68 kw., peaks reaching 75 and 80 kw.
2 cuts in 6-in. stock................ 68 kw., peaks reaching 75 and 80 kw.

47. Trimmers. The driving shafts of trimmers can be readily driven by coupled squirrel-cage motors and speeds of 680 to 850 rev. per min. are customary. The following are instances of successful applications.

Motor		Saws	Drive	Remarks
Horse power	Rev. per min.			
50	680	20-30 in.	Coupled	
50	850	21-32 in.	Coupled	Also drives transfer chains.
30	850	12-24 in.	Coupled	
5	1,120	2-18 in.	Coupled	Lath bundle trimmer

48. Slashers are best driven by standard squirrel-cage motors coupled to the saw shafts. The speed is determined by the saw diameter since it is not desirable to use a cutting speed much higher than 10,000 ft. per min. The following are typical installations.

Motor		Saws	Drive
Horse power	Rev. per min.		
50	850	14-40 in.	Coupled
40	580	6-36 in.	Belted
30	850	5-46 in.	Coupled
25	1,120	6-38 in.	Coupled
20	850	4-36 in.	Belted

49. Hogs. The rotating element of a hog is very heavy and the discussion of squirrel-cage versus slip-ring motors (Par. 42) applies here also.

Diamond Iron Works' hogs

No.	Style	Rotor		Capacity	Horse power
		Diam. (in.)	Rev. per min.	Cords per hr.	
1	B	60	650	16	65
1½	B	48	825	12	50
2	B	34	1,000	10	40
3	S	48	825	16	75

44-in. band rip and resaw. Berlin No. 282 44-in. ×4-in. wheel, 680 rev. per min., geared to a 15 h.p. 1,120 rev. per min. squirrel-cage motor. Friction load 4 kw. Resawing 6-in. to 8-in. poplar, 24 ft. per min.; average load, 12 kw.

54-in. band resaw. Mershon saw, 540 rev. per min., belted to a 20-h.p 1,120 rev. per min. squirrel-cage motor; friction, 5.5 kw. Resawing oak 4 in. to 6 in. wide, 70 ft. per min.; average load, 18 kw.; peaks, 21 kw.

Horizontal band resaw. Berlin No. 287 hopper feed, width of hopper 26 in.; belted to a 40 h.p., 850-rev. per min. squirrel-cage motor; friction load, 9 kw.; tests, sawing oak.

Width (in.)	Feed (ft. per min.)	Load (kw.)	
		Average	Peaks
13½	30	32	50
24	22	44	50

53. Circular saws

Cut-off saws		Combination benches, dado, etc.	
Diam. (in.)	Aver. h.p.	Diam. (in.)	Aver. h.p.
10–14	3	12–16	5
16	5	20	7½
*16	7½	....	....
24	7½	....	....
30	10	....	....
†32	25	....	....
36	15	....	....

Rip saws

Diam. (in.)	No. of saws	Feed (ft. per min.)	Aver. h.p.
12–14	1	Hand	5
16–20	1	Hand	7½
14–16	1	65–200	10–15
16	2	50–160	20
36	1	Hand	20
36	1	50–160	30

Self-feed rip saw. 13-in. saw, 2,250-rev. per min., belted to a 10 h.p., 1,700-rev. per min. squirrel-cage motor; friction load, 2.5 kw.

Stock	Feed (ft. per min.)	Aver. load (kw.)
1 in. oak	73	5
1 in. oak	116	7.5
1 in. oak	150	9.2
2 in. hemlock	150	12.5

Resaws

Diam. (in.)	Feed (ft. per min.)	Aver. h.p.
24–30	30–80	15
36–42	30–80	20
48	30–80	30

* Double cut-off or trimmer.
† Double automatic cut-off.

54. Jointers

Width (in.)	Aver. h.p.
8–12	2
16–24	3
30–36	5
Glue jointers	3–5

55. Surfacers

Capacity (in.) width and height	No. of feed rolls	No. of heads	Feed (ft. per min.)	Aver. h.p.
18×6	2	1	22–32	5
24×7	4	1	18–32	7.5
24×8	4	2	20–35	10
24×6	6	2	30–45	15
24×8	6	2	40–80	30
24×8	4	2	40–80	20
30×6	4	2	30–50	20
30×8	6	2	40–100	30
30×7	4	2	16–50	15

56. Planers, matchers and flooring machines

Capacity (in.)	No. of rolls	No. of heads	Feed (ft. per min.)	Aver. h.p.
9×6	6	4	40–80	30
15×6	6	4	40–102	40
15×8	4	4	30–45	30
24×6	6	4	59–104	40
24×8	6	5	40–80	40
30×8	6	4	40–80	40

Planers and matchers. Berlin No. 94 15-in. P. & M. with a 30-h.p., 1,120-rev. per min. squirrel-cage motor coupled to countershaft; friction load, 2 heads, 8 kw. Double-surfacing 12-in. wet oak at 60 ft. per min., reducing from $1\frac{1}{4}$-in. to $\frac{7}{8}$-in., required average of 30 kw., peaks 40 kw.

Hoyt No. 33 19-in.×8-in. P. & M. belted to a 30-h.p., 1,120-rev. per min. squirrel-cage motor; friction load, 2 heads, 8 kw.; 4 heads, 12 kw. Double-surfacing cypress 12 in. wide, reducing from 1-in. or $1\frac{1}{4}$-in. thick to $\frac{7}{8}$ in. thick, feed 50 ft. per min.; average load, 18 kw.; oak, same cut as above, 22 kw., peaks 32 kw.

57. Timber sizers

Cap. (in.)	No. of rolls	No. of heads	Feed (ft. per min.)	Aver. h.p.
20×12	8	4	25–85	50
20×16	6	4	25–85	40
30×20	8	4	25–85	50

For extra-heavy service, 75 h.p. is sometimes required.

58. Tenoning machines

	Aver. h.p.
Single end, hand feed, average duty..................	5
Double end, hand feed, average duty..................	10
Double end, power feed, average duty.................	15
Automatic blind slat tenoner.........................	3

59. Outside moulders or stickers

Cap. (in.)	No. of heads	Feed (ft. per min.)	Aver. h.p.
4×4	1 and 2	12–68	5
Sash	2 and 3	20–35	5 to 7.5
4×4	3 and 4	12–68	7.5
6×4	4	15–66	10
10×4	4	10–60	15
10×8	4	14–80	20
12×5	4	10–60	20
14×5	4	10–60	20

60. Mortising machines

Size of chisel or bit (in.)	Description	Aver. h.p.
¼ to 1	Hollow chisel sash	3
¼ to 1	Chisel mortiser with borer	3
¼ to 1½	Horizontal automatic hollow chisel	5
Up to 2½	Vertical automatic hollow chisel	7.5
	Chain mortisers	3

61. Sanding machines

Drum sanders		
Face of drum. (in.)	**No. of drums**	**Aver. h.p.**
30	3	7.5
36·42	3	10
48–54	3	15
60–66	3	20
72	3	25
84	3	30
30–36	2	7.5
42–48	2	10
30–36	1	5
42	1	7.5

Sanders. Berlin 42-in. 3-roll Invincible belted to a 15-h.p., 1,120-rev. per min. squirrel-cage motor; friction, 3.2 kw.; sanding oak 6 in. wide, average load, 4 kw.; sanding oak 27 in. wide, average load, 8 kw., peaks, 9 kw.

Belt sanders

No. and width of belts	Aver. h.p.
2– 6 in.	3
1– 6 in.	2
1–14 in.	3
1–18 in.	5

Combination sanders

Drum and spindle	13 in.×16 in. drum 1½ to 4 in.×7½ in. spindle	Aver. 3 h.p.
Column, post or arm sanders		
8 in. diam. disc..............................		Average 3 h.p.
Disc sanders		
Two discs, 36 in. to 48 in. diam..................		Average 3 h.p.

74. Jib cranes comprise suitable jibs or booms, provided with motor-driven hoisting tackle. In some cases, also, a motor with suitable gearing is provided for swinging the jib into different positions.

75. Electric locomotive cranes comprise a jib or boom, usually carried by a turn-table which is mounted upon trucks. Frequently individual motors are provided for raising and lowering the boom, for rotating the boom, for hoisting the load, and for propelling the machine along the tracks. In other cases only a single motor is used, the different functions being set into operation through mechanical clutches.

76. Miscellaneous. Under this head may be mentioned charging cranes for open-hearth steel furnaces, skip hoists for elevating and dumping ore, coke, etc., into blast furnaces, also special cranes and unloaders for unloading bulk cargoes, such as ore or coal, from vessels.

77. Types of motors. The type of motor most commonly used for operating the various motions of cranes is the series-wound, direct-current motor. The series-wound motor is admirably adapted to the purpose because under heavy load it has the tendency to slow down, thus relieving the power station of a heavy load fluctuation; on the other hand, in the case of light loads, the motor speed increases, thus producing what is generally known as a "lively" crane. Compound-wound direct-current motors are used only in special cases. Where alternating current is available, and its conversion into direct current would entail a very considerable expense, alternating-current motors may be used. The preferable type of alternating-current motor for this service is the slip-ring type, in which resistance is introduced in the rotor circuit in order to obtain variation in speed. This type of motor affords much better results, as far as torque and speed variations are concerned, than the squirrel-cage motor, the torque of which decreases very rapidly as the voltage applied to the terminals of the primary winding is reduced. The speed range of both of these types of alternating-current motors is limited and hence they do not produce nearly so active a crane as one equipped with direct-current series-wound motors. In many large industrial plants, covering considerable areas, energy is generated and distributed in the form of alternating current. The motors which require but slight speed variation are operated directly from the alternating-current mains, while synchronous converters or motor-generator sets are installed to produce direct current for the operation of cranes, hoists, and other machines which must operate through a wide range of speed and under greatly varying load.

78. The selection of the proper normal rating of hoist motors* to be used is in general a difficult problem on account of wide variations in service requirements, particularly as to the matter of frequency of operation. As an illustration, two extreme cases may be taken: 1st, that of a crane installed in an engine room or pump house, the crane having been installed originally to assist in erecting the heavy machinery, being subsequently used only at varying and infrequent intervals for lifting parts of machinery when it becomes necessary to make adjustments or repairs; 2nd, the case of a traveling crane provided with a lifting magnet for handling pig-iron or other magnetic material in bulk, or equipped with a grab bucket for handling coal, sand, slag, etc. There are instances of the operation of cranes of this type four times per min., practically 24 hr. per day for indefinite periods, the lifted load being practically constant in value and almost equal to the rated capacity of the crane. It is obvious that in the first case cited, the heating of the motor windings presents a small problem, while in the latter case this item is of paramount importance. Of course the torque exerted by the hoist motor in lifting the maximum load which will be encountered, must be taken into consideration in both cases. If possible the cycle of operations should be considered as follows: 1st, the time required to hoist with maximum load; 2nd, the period of rest at the upper limit of travel; 3rd, the time of lowering; 4th, the period of rest at the lower limit of travel before the next cycle is started. The current required in lowering with a mechanical brake, or the current required in dynamic braking (Par. **83** and **464**) must also be taken into consideration. These figures known, they may be plotted in terms of time and current, so that the square-root of the mean-square current may be

* See "Horse Power of Crane Motors," *Machinery*, Dec., 1913, page 286.

armature and the field are connected in separate circuits. On the first point of the controller, in lowering, the field is excited through a resistance which allows practically full-load current to pass through the field winding; also a considerable amount of resistance is included in the armature circuit. It will be seen that on the first lowering point the armature is shunted by the field winding and the brake winding. This naturally produces an extremely low speed. As the controller lever is moved from step to step, the resistance in the field circuit is increased, while the resistance in the armature circuit is decreased. Increase in resistance in the field circuit naturally reduces the field excitation and counter e.m.f., thus allowing the speed to increase. The resistance in the field circuit is ordinarily so proportioned that the speed can increase as much as 100 per cent. to 150 per

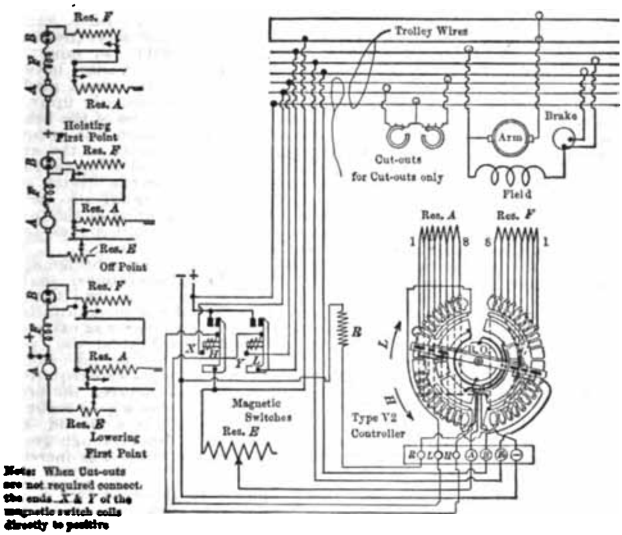

FIG. 7.—Face-plate type controller arranged for dynamic braking.

cent. above normal full-load speed. It will be seen that at all times the field is supplied with current from the mains, and at full speed this may amount to only half of the full-load current. On the other hand, the armature is also connected to the supply mains, and as soon as the counter e.m.f. reaches a value sufficient to overcome line voltage, current is actually returned to the line, so that the net current required in lowering the load is the difference between the current supplied to the field from the line and the current returned to the line by the armature. In lowering heavy loads the current returned to the line is greater than the current drawn from the line by the field, so that the lowering load is made to do useful work.

85. Slow-hoisting motor control. This type of control differs from the one illustrated in Fig. 7 only in the respect that a shunt is placed around the armature in order to reduce the speed, thus producing an extremely slow hoisting speed. This type of controller is frequently used in foundries where extremely slow speeds are required in lifting patterns from flasks, etc.

86. Limit stops are now customarily provided in connection with the hoisting motion of cranes and hoists. In the absence of a limit stop, the hoisting block, perhaps carrying a load, might be carried upward into

If, however, the overload relays continue to act when energy is applied, the operator must necessarily look for trouble in the mechanism of the crane.

90. Energy supply. In a plant in which a large number of cranes are employed, it is by no means necessary to provide generator capacity equal to the total rated horse power of all of the motors used. In a large industrial plant in which 127 cranes were installed, generator capacity corresponding to 25 per cent. of the total rated horse power of motors used on the cranes was found ample to care for the load. Where only a single crane is installed it is wise to provide generator capacity sufficient to take care of full-load on the hoist and bridge motions, leaving it to the overload capacity of the generator to take care of the current required by the trolley, in case all three motions of the crane should be operated at the same time. Naturally, the larger the number of cranes installed in a given plant where a definite cycle of operations is not carried out, the smaller may be the proportion of generator capacity to the total horse power of the crane motors.

ELECTRIC HOISTS

BY WILFRED SYKES

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91. Drums. Hoists are generally classified according to the shape of the drum. In general use are the cylindrical, the conical and the cylindro-conical drums, the last mentioned being a combination of the first two, part of the drum being cylindrical and part conical (Fig. 9). The object of the conical drum is to reduce the starting torque, as the load is exerted on the drum at a smaller radius when the cage is at the bottom of the shaft. The cylindro-conical drum is used with the same object. All other things being equal, the rope wear is less with the cylindrical drums than with other types of drums.

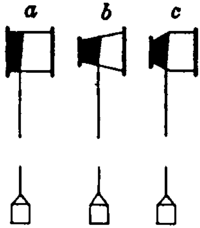

FIG. 8.—Unbalanced hoists.

92. Flat ropes. The above types (Par. 91) use round ropes. Flat ropes, generally about 0.5 in. thick, are sometimes used, the rope being wound upon itself on a reel, so that the radius at which the load is suspended gradually increases, the effect being similar to that of the conical drum. Flat ropes on reels are used only to a very small extent, on account of the excessive maintenance charges.

93. Balanced and unbalanced hoists. When running balanced the empty cage descends as the loaded cage ascends, the cages and cars balancing each other. When working unbalanced only one cage is used, and the load,

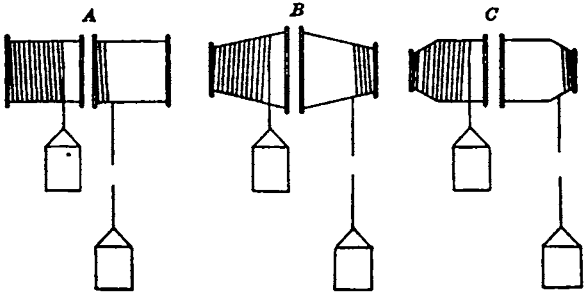

FIG. 9.—Balanced hoists.

100. Ilgner balancing system. The arrangement now most widely used, was devised by Mr. Karl Ilgner. As arranged for alternating-current supply, it consists of an induction motor with a wound rotor, coupled mechanically to a direct-current generator, which in turn supplies energy to a direct-current separately excited hoist motor. The motor-generator set is supplied with a fly-wheel of sufficient capacity to care for the peak loads. The field of the direct-current generator is separately excited, and a controller is provided so that the excitation and the polarity of the generator can be varied as desired. The field polarity of the hoist motor remains constant, so that by reversing the armature current the direction of rotation can be changed. By varying the excitation of the generator, the voltage applied to the armature of the hoist motor can be varied, and in turn the speed of the hoist.

101. Action of the automatic regulator. A regulator is provided for automatically inserting resistance in the rotor circuit of the induction motor, thereby reducing the speed of the motor-generator set, which causes the fly-wheel to give up part of the energy stored in it. The rate at which the speed is changed depends upon the difference between the input that is to be maintained on the induction motor and the power required to drive the generator. When the load on the generator is reduced below the value for which the automatic regulator is set, the fly-wheel speed is increased by automatically removing resistance from the rotor circuit, energy being stored in the fly-wheel in order to enable it to carry the peak load, due to the succeeding cycle.

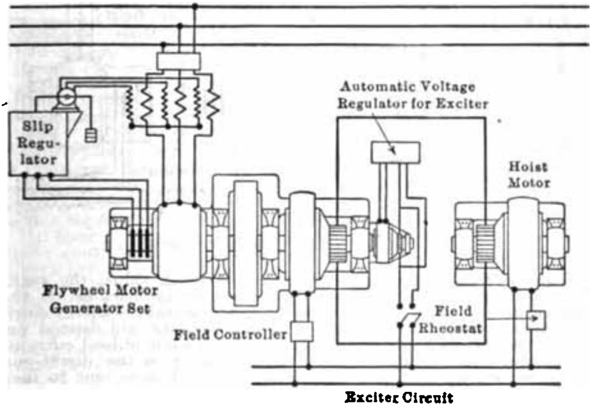

Fig. 10.—Ilgner balancing system.

102. Details of Ilgner balancing system. This system provides not only for power equalization, but also for the control of the hoist motor by the manipulation of the generator excitation, thereby eliminating rheostatic losses, and the difficulty of controlling large machines. The general arrangement of this scheme is shown by Fig. 10. In practice the speed of the fly-wheel set is varied from 15 to 20 per cent. during a hoisting cycle. High-speed fly-wheels with peripheral speeds reaching 25,000 ft. per min. are used in order to minimise the weight.

103. The losses with the Ilgner system are comparatively high, and it is seldom that an over-all efficiency of more than 50 per cent. is realised from the combined electrical and mechanical equipment. This efficiency decreases when the hoist is operated below its normal capacity, due to the constant no-load loss of the fly-wheel motor-generator set. However, for important hoists, the advantage of equalising the input, and

and consequently the fly-wheels can be comparatively light. The machines of the converter equalising equipment need be only large enough to deal with the load variations from the mean value, and under ordinary circumstances, the capacity need not be more than about one-half that of the motor-generator set for the same duty. The equalising equipment is quite independent of the hoisting motor, so that it may be out of service without cessation of hoisting. However, in this event the peak loads will be felt on the line. With the Ilgner system the hoist is directly dependent upon the motor-generator set.

107. Significance of the starting method. The main difference between the two systems is that the Ilgner method provides for starting the hoist motor by voltage control without any rheostatic losses while the converter system makes no provision for doing so. When considering the economy of both systems, this difference must be taken into account as starting losses are often a large proportion of the total input. The question of starting is very important with large hoists, and on this account the Ilgner system is preferred for heavy work.

108. Control for alternating-current motors. Magnetic-switch controllers are used to a considerable extent. Liquid controllers for the rotor circuit are also used, and these have the advantage of providing smoother acceleration and of being simpler in construction.

109. Types of switches in use. For the control of the primary, both oil and air-break magnetic switches are in use. For circuits of 550 volts and under ordinary magnetic switches are quite satisfactory. For 2,200-volt motors, special air-break switches are in use, and when properly designed are preferable to other types on account of the accessibility of the contacts and their ability to withstand hard service. Oil switches are used to a considerable extent but for very severe service they must be very liberally rated, otherwise there is danger of explosion, due to the heat generated in the oil. Drum controllers can be used only for small hoists requiring motors not larger than 75 h.p., and are not at all suitable for severe operating conditions. Magnetic-switch controllers can be used for all sizes, but liquid controllers are used only for motors of about 300 h.p. and above.

110. Control for direct-current hoist motors. Drum controllers are satisfactory for direct-current motors under 100 h.p., providing the service is not too severe. Magnetic switches should be used for motors above this capacity. Liquid controllers are not satisfactory for direct current. In cases of very large hoists with peak loads of 1,000 h.p. and above, rheostatic control, for either direct-current or alternating-current motors is not very practicable. When power equalisation is not required, a motor-generator set is used without a fly-wheel. In every respect the operation is the same as with the Ilgner system, except that the speed of the set is not varied. The efficiency of such an arrangement is often greater than that of the hoist with rheostatic control, and the maintenance is usually less than that of a large rheostatic controller, although the amount of apparatus involved is greater.

ELEVATORS

BY DAVID L. LINDQUIST

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111. Classification of electric elevators. There are two general classes of electric elevators, namely, those with winding drums, and those with traction sheaves. The drums of the former type are spirally grooved, the cables winding or unwinding as the elevator is raised and lowered. With elevators having winding drums it is advisable to restrict service to car speeds under 200 ft. per min. and for travels less than 100 ft. For elevators of the latter class, the sheaves are straight grooved for receiving the cables, the car being raised or lowered because of friction existing between sheave and cables. Elevators of this class, are especially adapted to service requiring car speeds of from 200 ft. per min. to 700 ft. per min. inclusive, regardless of length of travel.

112. Roping and counterbalancing of elevators with winding drums. Necessary connections are usually made between drum and car and counter-proportioned to approximately 70 per cent. of the actual weight of the car, the weight of the back drum counterbalance being equal to the difference between the total weight and that of the car counterbalance. Either method of counterbalancing imposes on the motor a net maximum load of approximately two-thirds the rated capacity of the elevator.

For car travels in excess of 100 ft. it is advisable to compensate variation of load on motor, produced by change in position of cables during run, by means of a compensating chain attached from the car to the middle point of the hatchway, as shown in Fig. 12, or attached from car to counter-balance as indicated in Fig. 13. The following formulas derive total compensating weight required, where h = weight of hoist ropes per ft.; dw = weight of drum counterbalance ropes per ft.; cw = weight of car counterbalance ropes per ft.; c = weight of compensating chain (or ropes) per ft. With compensating chain attached to car and middle point of hatch: $c = 2(h + dw + cw)$. With compensating chain attached to car and counterbalance: $c = (h + dw + 2cw)/2$. For installations employing the single counterbalance only; $cw = 0$.

113. Roping and counterbalancing of elevators with traction sheave From Fig. 14, which clearly indicates roping required by what is known as the 1 : 1 traction-sheave type, it will be noted that the single length of ropes used are directly connected to car and counterbalance at either end. By the use of a secondary or idler sheave these ropes are passed over the traction sheave a second time as a means for increasing rope contact, which, under the influence of the combined weight of car and counterbalance, provides the adhesion requisite to elevator service.

The foregoing arrangement corresponds to that used for the 2 : 1 traction-sheave type with the exception that the ropes, instead of being directly connected to car and counterbalance, are passed under traveling sheaves located at the upper end of both car and counterbalance; from this point they are extended vertically to the top of the hatchway and there securely and permanently anchored. This latter roping produces a decrease in car speed with a consequent increase in the lifting capacity. Fig. 15 represents the 2 : 1 roping arrangement.

One of the striking advantages resulting from this arrangement of ropes and method of driving them, is the total loss of traction obtained if either car or counterbalance is obstructed in its descent, or bottoms on its respective oil buffer, causing complete cessation of all car motion even though the driving member may continue to revolve. This property of the traction-sheave elevator constitutes an extremely important and effective safeguard by enabling the absolute fixing of the car travel between two given limits, inasmuch as with proper roping the car will be brought to rest on its oil buffer before the counterbalance comes into contact with the overhead work and *vice versa*. A further advantage of the traction-sheave elevator lies in the fact that the faces of the sheaves are entirely independent of the height of the building.

Counterbalancing must in all cases be proportioned for an equal margin of safety to counteract the tendency to slip on both up and down direction of travel under maximum load conditions. Where there is a considerable surplus of traction, however, the weight of the counterbalance should be made dependent upon the average loads in the car, which, for this type of elevator, usually range from approximately 33 to 45 per cent. of the maximum. Ordinarily, the total weight of the counterbalance should equal that of the car plus from 33 to 45 per cent. of the maximum load in the car.

Elevators with traction sheaves should in all cases be provided with rope compensation and with connections arranged in accordance with Fig. 14; the weight per hatchway ft. of the compensating ropes should equal approximately the weight of the hoist ropes per hatchway ft. minus one-fourth the weight per ft. of the electric control and lighting cables.

114. Electric elevator machines. The machines used for driving the two types of electric elevators mentioned are distinguished by their methods of power transmission between motor and winding drum or traction sheave, namely, (a) worm gear; (b) worm and spur gear; (c) helical or herring-bone gear; (d) 1 : 1 gearless traction; (e) 2 : 1 gearless-traction machines. All of these machines are preferably arranged for location over the hatchway in each and every case, although, under certain conditions, they can be arranged for location at the base of the hatchway.

115. Worm-gear machines. These machines are used for both passenger and freight service and may be arranged with either winding drum or traction sheave. For the smaller sizes, known as dumbwaiter machines, duties ranging from 500 lb. at 100 ft. per min. to 100 lb. at 500 ft. per min. are possible, while in the larger sizes duties rarely exceed from 10,000 lb. at 100 ft. per min. to 4,000 lb. at 400 ft. per min.

In order to preserve alignment, all parts should be assembled on a ribbed bedplate extending underneath the entire machine. The armature shaft

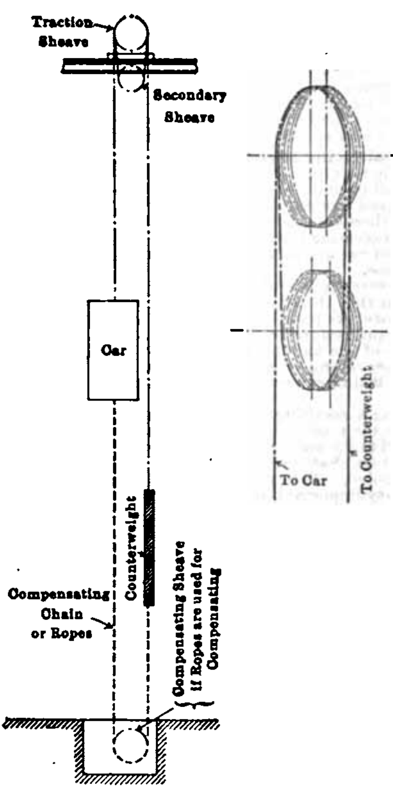

Fig. 14.—Roping arrangement for use with traction sheave.

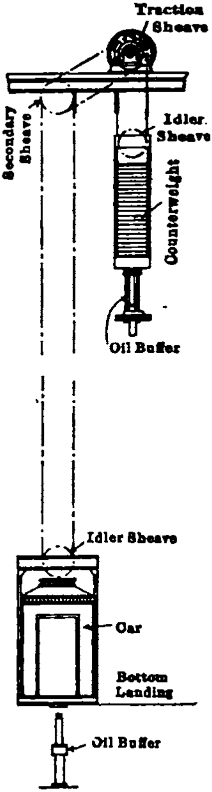

Fig. 15.—Two to one roping arrangement.

of the motor is usually coupled direct to the worm shaft, the face of this coupling being utilized as the brake pulley. The worm and shaft should be solid and integral and of high-grade steel, the worm meshing with a bronze-rim worm wheel attached to a cast-iron spider. This spider, being directly and mechanically connected to the winding drum or traction sheave, renders power transmission at this point entirely independent of keys. Self-aligning ball thrust bearings are provided on the worm shaft.

116. Worm and spur-gear machines. The two types may be classified as safe lift machines and geared freight machines, the former being a special adaptation of the worm-gear machine when it is desired occasionally to lift loads greater than the normal and at considerably reduced speeds. This type is generally installed in office buildings, where, with the special arrangement applied to one or more of the ordinary passenger elevator machines, the handling of safes averaging from 4,000 lb. to 9,000 lb. in weight at a slow rate of speed, is greatly facilitated. To accomplish the increase in lifting capacity, a special provision is made for placing necessary gears in mesh between the armature and worm shaft, thereby reducing the car speed and increasing the lifting capacity in direct proportion to the ratio of the gearing inserted. By this method, therefore, and usually with a slight addition in counterbalance, the safe-lift loads are carried without requiring more current from the line than during normal operation. Geared freight machines differ from the worm-gear type by the addition of a single spur-gear reduction between the worm gear and the winding drum, thereby constituting them essentially slow-speed machines with relatively large lifting capacities.

117. Helical gear or herringbone gear machines. These machines, which can be arranged for use with either winding drums or traction sheaves, are provided with a single gear reduction to the motor by means of the helical or herringbone type of gear, usually made in accordance with the Wuest method. Such gears permit a larger ratio of reduction with greater efficiency than can be obtained with ordinary spur gears. The motor speeds usually range from 300 to 600 r.p.m.

118. Gearless traction machines, 1 : 1 ratio. This machine represents a combination of extreme simplicity, maximum economy and highest efficiency. Briefly, it is a two-bearing electric machine, the armature, traction sheave and brake pulley being contained on the same shaft, all parts being compactly grouped on a cast-iron bed. The motor is of the plain shunt-field, slow-speed type of about 60 r.p.m. transmitting energy direct to the traction sheave. Contrary to general belief, these motors have the remarkably high efficiency and a distinctive procedure has been to arrange design with a view to realising the highest efficiency (about 90 per cent.) at half rated capacity. This figure corresponds with the average loads for this class of service, the full-load efficiency being approximately 87 per cent. Frequently these machines are provided with ball bearings as a means for further increasing the efficiency and decreasing the space required.

Machines of this type should be located over the hatchway whenever it is at all possible. They are used for car speeds of from 500 to 750 ft. per min. with loads ranging from 2,000 to 3,500 lb. inclusive. To date only machines employing direct-current motors have been produced.

By means of a special arrangement, the regular machines can be converted so as to enable the lifting of safes weighing from 5,000 to 8,000 lb. This arrangement includes the placing of a second magnet brake in operation and also the adding of extra weight to the regular counterbalance. When lifting safes, maximum field strength of motor is utilized, producing a proportionately slow car speed.

119. Gearless traction machines, 2 : 1 ratio. All mechanical features of these machines correspond to those of the 1 : 1 gearless-traction type. They have been designed for traction sheave elevators requiring lower car speeds than obtained with the 1 : 1 machine without the necessity of gear reductions the car speed reduction being produced by the 2–1 roping arrangement previously described. The machines have been designed for direct-current service only, using shunt-field motors of from 80 to 140 rev. per min., with resultant car speeds of from 250 to 450 ft. per min., and they have been installed for capacities up to 11,000 lb. passenger load. By an arrangement similar to that with which the 1 : 1 gearless-traction machines are equipped, these machines can also be used for safe lifting.

120. A common characteristic of all elevator motors is that they must be specially constructed to withstand repeated stresses produced by frequent starting and stopping. In general, however, the performance of alternating-current and direct-current motors differ to such an extent as to necessitate their separate consideration.

121. Direct-current motors. This class of motors must be designed for sparkless commutation at starting, stopping and reversal of rotation under all fluctuations of load within their rated capacity, and be capable of exerting a heavy starting torque with minimum requirements as to starting current, especially where frequent starts and stops are made, in order to reduce the energy consumption and the reaction on the generating plant. Because of these requisite features, commercial motors are rendered generally unsuitable. As a means for reducing starting currents, those motors used for driving geared elevator machines, and usually operating at from 300 to 900 rev. per min., are arranged to start as compound-wound motors having a heavy series field which should be cut out, usually by a short-circuiting process, as the motor speed increases. At full speed, therefore, the motor operates as a plain shunt-field type.

Because of the high self-induction of the field winding required by motors used for driving the 1 : 1 and 2 : 1 gearless-traction machines, which generally operate at from 60 to 140 rev. per min., when at full speed, the fields are connected permanently across the supply lines, with reduced current when machine is at rest; this procedure shortens the length of time required to bring the field to full strength on starting. Such a method of field connection materially reduces motor starting current. For direct-current types of motors, starting torque and starting current are usually twice the rated torque, and not in excess of 125 per cent. of the current at rated capacity.

122. Polyphase slip-ring induction motors. This type represents beyond question the most satisfactory alternating-current motor for elevator service. The rotor, which is polar wound, is connected to a series of slip-rings, thereby permitting the insertion of an external resistance in the rotor circuit, resulting in large starting torque with reasonably low starting current. Since the resistance of a slip-ring motor is external, it may be adjusted for several values of starting torque, and good elevator practice, therefore, is to provide a larger external-rotor resistance than is required for necessary starting torque at full-load, thus limiting first inrush of current to a predetermined amount, with connections so arranged that if motor fails to start the imposed load, rotor resistance will be gradually short-circuited until required starting torque is obtained. As elevator loads are frequently considerably under full-load values, the maximum starting resistance allows the elevator to start with a current much lower than that required with full-load in the car. With the external rotor resistance it is possible to use a rotor winding of extremely low internal resistance, and since the external resistance is completely short-circuited when motor attains full speed, resultant slip and temperature rise are reduced to a minimum, and high running efficiency is obtained. The speed variation of this type of motor is very small, and it fulfills the best obtainable balance between the three values of starting current, slip and running efficiency, which are of extreme importance when applied to elevator motors.

123. Two-speed polyphase slip-ring induction motors. For car speeds in excess of 200 ft. per min., and where conditions demand accurate floor stops, it is advisable to use two-speed motors. These motors, which have been used successfully, contain double windings on both the stator and rotor. The switches governing them are mounted on the controller panel, being electrically and mechanically interlocked in order to prevent confiction. Starts are always made with the high-speed winding, and connections to the slow-speed winding, which is used for stopping purposes only, are so arranged that the motor is electrically retarded to a predetermined slow speed of usually ¼ to ⅓ of full speed.

124. Polyphase squirrel-cage induction motors. Squirrel-cage motors are generally undesirable for elevator service except in the smaller sizes. With motors of this type, the rotor winding is permanently short-circuited, thus preventing the employment of external resistance at starting. In order to prevent the possibility of starting currents becoming excessively high, it is therefore necessary to wind the rotor with self-contained resistance, this method resulting in high slip, comparatively low efficiency and a high temperature rise, especially when the motor is operating frequently. Since rotor resistance is permanently fixed, the motor starting current rises to a maximum, with each start, irrespective of load. Motors of this class should only be used on a power line, where the high starting current required is not objectionable and where the service is sufficiently light to eliminate the possibility of danger from overheating.

125. Single-phase motors. Up to the present a type known as the repulsion-induction motor alone has proven successful and in sizes up to and including 15 h.p. These motors, which start as one of the repulsion type, are provided with a centrifugal governor, usually located within the armature core, so designed and adjusted that at about 80 per cent. of full speed the rotor winding is automatically short-circuited, and the motor operates as if it were of the simple induction type. These motors cannot be reversed while operating, as induction motors. Devices are required to prevent change of connections until speed has dropped below that point at which the repulsion connections are re-established in order that reversal of rotation may become effective. Although starting currents are comparatively high, this condition is not objectionable in the smaller sizes, and in the larger sizes the starting current may be appreciably reduced by an external resistance in the stator circuit so connected that it is effective at the moment of starting and during the first period of acceleration.

126. Brakes. All elevator machines are equipped with brakes for the purpose of assisting in stopping and holding the car securely at a landing, under any and all conditions of loads up to and including the maximum specified. The brakes, which must be so designed as to be equally effective for either direction of rotation, generally consist of two separate and independent shoes, lined with leather or asbestos preparations, and actuated by heavy helical steel springs. Brake release should be obtained by means of an electromagnet, as this method enables the making of such connections that the brake will be instantly and positively applied on failure or interruption of current supply. See Par. **459** to **463**.

127. Methods of control. The controlling apparatus of an elevator constitutes one of its most important features, including devices for establishing direction, for producing proper acceleration, retardation, and speed regulation, and also including the necessary safety appliances. Usually slate panels bolted to floor standards are provided, the switches being mounted on its face with connections to these switches, and all resistances located on the rear. All contacts of the various safety devices are usually connected in circuit with the holding coil of what is known as a potential switch, and, since all current to the controller and machine is carried through the contacts of this switch, the operation of any one safety feature immediately interrupts all current to the equipment. This switch also constitutes a no-voltage circuit breaker and an excessive drop in voltage will cause the switch contacts to open. The motor circuits are completed by the reversing switches, two in number, one for the "up" and one for the "down" direction, respectively. The brake circuits are made simultaneously with the closing of either direction switch. In order to prevent conflict, reversing switches are generally electrically or mechanically interlocked.

128. Automatic starting. It is advisable, with direct-current elevators, to arrange the stepping-out of the armature starting resistance entirely independent of the operator, and by this process eliminate the damage which would result from a reduction of this resistance at too high a rate. As a means for reducing energy consumption, however, starting resistance should be stepped-out as rapidly as the load on the motor permits; this is accomplished by means of either series relay magnets or magnets dependent on the counter-electromotive force of the motor for operation. See article on "Motor Control" elsewhere in this section.

129. Dynamic braking. Except with the small-capacity machines, the wiring of direct-current controllers invariably includes a dynamic-brake circuit which is obtained by introducing a resistance across the armature terminals on stopping. The stopping field in some cases is obtained by having the shunt field (permanently in series with a limiting resistance) connected directly across the supply line. In other cases it is obtained by providing an extra low-resistance shunt field; in the smaller machines the residual magnetism of the field poles is sufficient. Although connecting the field permanently across the supply line slightly increases energy loss, an important safety feature is gained, for with such connections it becomes impossible to attain excessive car speeds either up or down should, for any reason, the machine brake fail to apply. By various methods stopping resistance is automatically stepped-out as the load on the motor permits, thereby strengthening the dynamic-braking effect. As explained, single-counter-weight immediately causes sufficient loss of traction to prevent further motion of the car and counterbalance.

136. Final hatchway-limit switches. To guard against the possibility of damage through disarrangement of the automatic terminal-stopping device, final limit switches are located, one each, beyond the terminal landings, and are operated by a cam on the car, in case the car overtravels to a point at which these switches become operative. The contacts of these switches are also placed in series with the holding coil of the circuit-breaker, causing immediate interruption of current to the machine when opened.

137. Governor switches. With high-speed elevators, regulating devices are usually provided, these being operated by a speed governor. These devices control car speed by means of field regulation of the motor, and are usually applied when the car speed exceeds normal by certain predetermined amounts. One or more speed-regulating switches are used, the number depending upon the average speed of the car, and, by their use, maximum speed variation is retained within certain predetermined limits. Governors should preferably be provided with a breaking contact adjusted to open at a car speed slightly lower than that at which the car safeties are set to operate. Therefore, connecting this contact in series with the holding coil of the potential switch or circuit-breaker, usually stops the elevator by interrupting all current to the motor, without the necessity of applying the car safeties.

138. Car safety switch. All electric elevators should be provided with a small enclosed switch, located within the car and so connected in the controlling circuits that current to the machine will be interrupted when it is opened. This switch is furnished for emergency purposes only.

139. Car-safety devices. The expression "car safety" is usually applied to that form of safety which is designed to bring the car to rest by locking it to the guide rails, in case excessive speed has been attained, irrespective of the cause. All elevators should be equipped with a device of this nature. The application of car safeties should be made dependent upon on a centrifugal or inertia governor, adjusted with a definite and fixed relation to the speed of the car and arranged to operate at approximately from 30 to 50 per cent. above normal car speed. The general practice is to support the safety device within the lower member of the car frame, with the governor substantially supported at the top of the hatchway, although, in some cases, specially designed governors are mounted on the car. With the governor located over the hatchway, it is driven by an endless rope attached to the car and safety mechanism in such a manner that, in case of excessive speed, the governor holds or grips this rope and the safety is applied, usually by means of a drum, sheave or lever arrangement.

Under certain building conditions, namely: where a room or vault is located directly underneath the hatchway, it is advisable to furnish a guide grip safety for the counterbalance as well as for the car, in order to prevent damage such as might otherwise occur through the breaking of the ropes. On all of the recent higher class installations counterbalance safeties have been furnished even where the foregoing condition has not existed.

140. The number of elevators required in a building depends on several conditions, namely: height of building, relation of area of building to its height, net rentable area in sq. ft. per floor, character of elevator service required by prospective tenants and relative location of building. In average office buildings it is not considered good practice to attempt to serve more than from 18,000 to 24,000 sq. ft. of rentable floor area per elevator. The mileage of each elevator in a modern office building ranges from 15 to 40 miles per day, depending on the character of service and type of elevators used.

141. General consideration of energy consumption. Usually, it is safe to assume that the loads distributed by an elevator to the different floors of a building are the same, approximately, as those loads returned to the starting point, and with such load conditions the work done consists merely of overcoming the friction. Of greater importance, therefore, in the energy consumption, is the power expended in imparting the kinetic energy required to bring the masses up to speed, and the machine which will register the lowest power consumption must have a low moment of inertia together with a low value of friction.

145. The average performance of some existing installations in actual service

Machine type	Specification		Rise	Class of service and building	Energy cons. kw-hr. per car mile
	Control	Maximum lifting capacity			
Worm-gear and drum...	Magnet, direct current	2,000 lb. at 300 ft. per min.	140 ft.	Hotel, passenger service	3.3
Worm-gear and drum...	Magnet, direct current	1,500 lb. at 275 ft. per min.	113 ft.	Small building, passenger service	2.35
Worm-gear and traction-sheave	Magnet, direct current	3,000 lb. at 300 ft. per min.	165 ft.	Large department store passenger service, stop at each floor	8.71
Worm-gear and traction-sheave	Magnet, direct current	3,000 lb. at 300 ft. per min.	170 ft.	Small office building passenger service	5.1
1:1 traction.........	Magnet, direct current	2,500 lb. at 550 ft. per min.		Large office building passenger service. Local service from 1 to 14 only.	4.0
				Express service from 1 to 25—no stops below 15.	2.85
2:1 traction..........	Magnet, direct current	3,000 lb. at 450 ft. per min.		Small office building passenger service	3.91

All of these readings are for direct-current elevators only. From 20 to 30 per cent. more power consumption will be required by alternating-current elevators under the same conditions.

POWER PUMPS

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GENERAL

148. Classification of power pumps. Power pumps for all practical purposes can be divided into two general classes—displacement pumps and centrifugal pumps. Displacement pumps may be further divided into reciprocating pumps and rotary pumps, while centrifugal pumps may be divided into turbine and volute pumps. As will be shown later, the two classes of displacement pumps differ radically in design and are really distinct classes, while the difference between turbine and volute pumps is a difference of detail of construction, rather than a difference of type.

149. Calculation of the horse power required, is based upon a consideration of the opposed head (expressed in ft. or lb. per sq. in.) the pump delivery (expressed in gal. per min. or cu. ft. per sec.); and the efficiency of pump and mechanical transmission. Pump efficiencies vary with the different types, sizes, and working conditions. See Par. **154**, **157**, and **165**.

The head will include the static head pumped against and also the head of pipe friction. A calculation of required horse power should always consider the latter component of total head if the pipe is of considerable length. **Friction head** may be calculated with reasonable accuracy by means of Eq. 3. Accuracy within 6 per cent. may be expected for new, smooth pipes, while accuracies within 20 per cent. may be secured by its use on practically all pipes met in common practice. This expression is a modification of the well-known "Exponential" formula for straight smooth pipe.*

$$h_f = 1.6\,\frac{G^{1.87}}{d^5}\left(\frac{L}{1{,}000}\right) \tag{3}$$

where G is the delivery in gal. per min.; L is the total length of the pipe in ft.; d is the inside diameter of the pipe in in.; and h_f is the friction head, expressed in ft., for the *whole* pipe length. The horse power required to pump a certain quantity of water through a given length of pipe of known diameter against a given head is expressed as follows:

$$\text{h.p.} = \frac{G \times H}{3{,}950 \times \text{Efficiency}} \tag{4}$$

where G is the delivery in gal. per min., and H is the sum of the static head and the friction head, both expressed in ft.

For use in these formulas it is well to note that 1 cu. ft. per sec. corresponds to 448.8 gal. per min.; also a pressure of 1 lb. per sq. in. corresponds to a head of 2.304 ft., for water weighing 62.5 lb. per cu. ft.

DISPLACEMENT PUMPS

150. Slip. In all displacement pumps, the volume of liquid pumped is always less than the piston displacement, or, in the case of the rotary pump (Par. **156**) the displacement of the rotating element. This difference is due, partly, to leakage past the piston (in the case of the reciprocating pump), or the rotating element (in the case of the rotary pump), and partly due to leakage through the valves. The difference between the displacement of the moving part (piston or rotating element) and the volume of water discharged, is called the slip, and is usually expressed in per cent. of the total displacement. This slip may vary from 2 per cent. in a new pump to 50 per cent. in a badly worn pump. Generally speaking, anything under 5 per cent. may be considered fairly good performance for pumps that have been in service any length of time.

151. Effect of speed on capacity of displacement pumps. Neglecting slip, the capacity of all types of displacement pumps varies directly with the speed, regardless of the head pumped against. For constant head, the horse power required varies almost directly as the speed and, therefore, as the capacity. This, of course, is not strictly true, for the pump efficiency

* Moritz, E. A. *Eng. Record*, Dec. 13, 1913.

fficiency increases with the capacity of the pump, for the same reason that he efficiency of similar pieces of apparatus increases with the size.

155. Reciprocating-pump types. Most displacement pumps are of he reciprocating type. In very small sizes, they are generally single-cylinder umps, while in the larger sizes they are more frequently triplex pumps. Vhile most manufacturers of this type of pump build duplex pumps, the atter have not found favor to the same extent that the other two types have. ll simplex, duplex and triplex pumps are built in both the single-acting and ouble-acting pattern, *i.e.*, built to discharge only during one stroke of each evolution or during both strokes. It should be noted that in the case of he **single-acting pump,** the simplex pump gives one impulse, the duplex wo and the triplex three impulses per revolution, while in the case of the louble-acting type, the simplex gives two, the duplex four and the triplex ix impulses per revolution. Where uniformity of discharge and absence f pulsations is of primary importance, this feature will have a very direct earing on the type of pump selected.

156. Rotary pumps in their essential parts consist of two rotating lements, sometimes called impellers or cams, enclosed in a casing. These wo elements "mesh" in much the same manner as a pair of gears, bearing n each other in line contacts. Consequently, any wear that occurs cannot e compensated for by packing or by adjustment of the moving parts. The lip in this type of pump is caused by the leakage through the line contact f the impellers and through the clearance space between the ends of the mpellers and the pump casing. While these pumps do not require priming, they frequently have a small connection from the discharge pipe back into the pump casing to "seal" the joints between the impellers, as well as the small clearance space between the impellers and the casing.

These pumps are primarily designed for low-head work and show their greatest efficiency at low heads. When used for high-head work, it is generally for intermittent service, such as fire-pump service. They probably find their greatest field, however, in pumping heavy oils, liquid tar, syrup and liquid food products of various kinds. The speeds are usually so low that motors of ordinary speed must be geared or belted to the pump shaft.

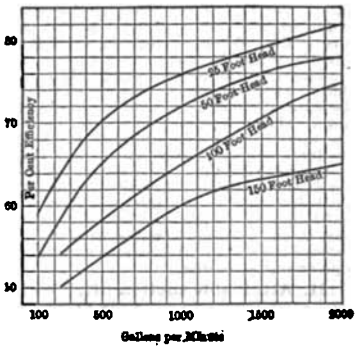

FIG. 21.—Efficiency curves of rotary pumps under various heads.

157. Efficiency of rotary pumps. Typical efficiency curves of this type of pump are shown in Fig. 21. These curves, like the curves in Fig. 20, do not represent the performance of a single pump, but rather the efficiencies of a series of pumps, designed for definite conditions of capacity and load, plotted in a single curve.

CENTRIFUGAL PUMPS

158. Mechanical construction. Centrifugal pumps for low heads are almost always of volute type, but manufacturers and designing engineers apparently differ as to the best practice to be followed for pumps discharging against higher heads. The turbine and the volute types of pump use substantially the same type of impeller. The difference between the two types lies in the design of the water passages of the casing. The volute pump, as its name implies, has these water passages built in the form of a volute, increasing in size toward the discharge opening. For the lower heads, the velocity of the water is comparatively slow and there is little or no "churning" and "eddying." Moreover, as this type of pump is cheaper to build than a turthe peripheral speed of the impeller increases, either on account of larger diameter or of higher rotative speed, the allowable head per stage increases correspondingly. When several centrifugal pumps are installed in the same station, they may be so connected that by the operation of a few valves, the pumps can be operated in series against a head aggregating the combined working heads of all the pumps, the capacity remaining the same as for one pump; or they may be operated in parallel, giving the total combined capacity, the limiting head in this case being the same as for a single pump.

163. The up-keep expense of centrifugal pumps is usually small for the reason that the only moving parts in contact are the shaft and bearings. The clearance between the impeller and casing is almost always greater than the permissible wear of the bearings, so that there is little likelihood of the two coming into contact. Even if they did, this would probably be detected and the pump shut down before any damage was done.

High-head conditions require high impeller velocity, which gives high velocity to the water leaving the impeller. In order to obtain good efficiency these conditions demand high velocities in the diffusion chamber (if there be one) and in the volute. High velocity of water results in rapid corrosion of cast iron, the usual material used for volute pumps. This corrosion occurs wherever the water at high velocity comes in contact with the iron, and particularly so wherever a sudden change in direction of flow occurs which will cause shock and the formation of eddies. However, it is often found that the efficiency of centrifugal pumps increases slightly after they have been in service for a time and this is due to the scouring action of the water on the surface of the water chambers.

164. Piping connections. From the principle of operation of centrifugal pumps and especially of turbine pumps, the velocity in the pump casing is very likely to be higher than good practice would permit for velocity of water in pipes, consequently the size of the pipe connection should be calculated on the basis of allowable velocity in the pipe rather than simply to make the connection of the size of the suction and discharge openings of the pump. To avoid shock, due to sudden change of section of the pipe, this change in size of pipe should be made by means of a standard "increaser" or "reducer," and this fitting should be installed at the pump opening. As already pointed out, the suction connections must be absolutely air tight if satisfactory operation is to be obtained. Incidentally, also, the packing glands must be drawn up tight, but only tight enough to prevent leakage, care being taken to avoid excessive friction on the shaft at this point. Some pumps have a connection from the discharge chamber to the glands in order to keep them under a "**water seal**" at all times. When this connection is provided, the glands should be loose enough to permit constantly a slight leakage.

165. Characteristics of centrifugal pumps. Fig. 22 shows typical curves of efficiency of standard centrifugal pumps designed for various heads and capacities. These curves may be compared with the curves of Fig. 20 of reciprocating pumps. Figs. 23 and 24 show the characteristic curves of typical centrifugal pumps. Attention is called to the slope of the so-called "capacity-head" curve in the two cases. In Fig. 23, the highest head is the "shut-off pressure" and the curve falls from this point on. In Fig. 24, the pressure rises at first above the "shut-off pressure" and then falls as the capacity is increased. While the shape of the curve depends primarily on the shape of the impeller vanes, it will be found in general, although by no means in every case, that volute pumps will show a curve similar to Fig. 23 and turbine pumps a curve similar to Fig. 24. With a head-characteristic curve similar to that in Fig. 23, the horse-power curve usually reaches a maximum slightly above normal capacity and then drops off. This feature is very important in the selection of a pump for service where the head is likely to be materially reduced at times, as it will prevent the motor from being overloaded. A pump with the characteristics shown in Fig. 24 should be used only where there is no likelihood of its being operated at heads greater than, equal to, or approaching the "shut-off pressure," or where the head is likely to be reduced to a value considerably below the normal working head. At heads equal to, or greater than the "shut-off pressure," there are two capacities corresponding to each condition of head. At these points, the operation becomes unstable with a probability that the pump will discharge intermittently, the water surging up and down in the discharge pipe. With

AIR COMPRESSORS

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167. Rating. The rating of air compressors is made on the basis of the piston displacement of free air per min., and in designing a motor drive, the first problem which arises is the determination of the power output required of the motor for the compressor operating under the desired conditions.

168. Measurement of discharge. The relation between the piston displacement and the amount of air actually delivered, has been taken, in the past, from indicator cards, but this method is extremely inaccurate, since slippage due to leakage past the piston rings and leakage back into the cylinder through discharge valves, cannot be detected. As a matter of fact, these leakages tend to make an apparently better card and to increase the apparent volumetric efficiency. Recent tests have been made by discharging the compressed air through orifices and calculating the quantity of free air delivered per min. by Fliegner's formula (Par. **169**).

169. Fliegner's formula may be stated as follows: $G = (0.53AP)/(\sqrt{T})$, where G = flow in lb. per sec., A = area of orifice in sq. in., P = absolute pressure (in lb. per sq. in.) of air behind the orifice, and T = absolute temperature (deg. Fahr.) of the air behind the orifice.

The weight of 1 cu. ft. of air is found by the following formula: $W = 1.325B/T$, where W = weight of 1 cu. ft. of air, B = barometer reading in in. of mercury, and T = absolute temperature (deg. Fahr.) at the compressor intake.

The delivery of cu. ft. of free air per min. then equals $G \times (60/W)$.

170. Efficiency. In practice it is found that compressors with mechanically operated rotary inlet valves show volumetric efficiency, varying from 91 per cent. at 100 rev. per min. to 88 per cent. at 188 rev. per min. Piston inlet machines at 100 rev. per min. give 88 per cent. efficiency, and at 188 rev. per min., 79 per cent.

The above figures may be used in determining the actual amount of air delivered by the compressor. The power required per cu. ft. of air depends upon the type of compressor, whether single-stage or multi-stage, and upon the method of driving, whether direct-connected, belted or geared (Par. **173** and **174**).

171. Two-stage compression should be used for capacities over 200 or 300 cu. ft. per min., where the pressure is between 40 and 200 lb. per sq. in. Not only is there a saving in power of approximately 10 to 20 per cent., but the reduced terminal temperature permits better lubrication.

172. Theoretical power required to compress air. For the ordinary working pressure of 100 lb., the theoretical power required for isothermal compression of 1 cu. ft. of free air per min. is 0.131 h.p. To this must be added the power lost in friction and that given off as heat, during compression (Par. **175**).

173. Test of a direct-connected compressor. In a test made in New York City in January, 1912, the power input to the motor was 23.26 h.p. per 100 cu. ft. of free air per min. compressed to 100 lb. per sq. in. gage pressure and actually delivered through orifices. The compressor tested was direct-connected to a 400-h.p., 188-rev. per min., self-starting synchronous motor with belted exciter. The low-pressure cylinder was 26 in. in diameter, the high-pressure cylinder 15.5 in. in diameter, stroke 18 in., and the displacement capacity 2,070 cu. ft. at 188 rev. per min. The volumetric efficiency at this speed as shown by the orifice test was 88 per cent. The horse-power input at full-load was 425, and the indicated horse power of the air cylinders was 350. The overall mechanical efficiency including motor, exciter and compressor was 82.3 per cent.

174. Comparison of direct-connected compressor with belted compressor. For the purpose of comparison with a belted compressor where the power is usually specified as that delivered at the compressor pulley, the efficiency shown in Par. **173** may be divided into 91.5 per cent. for motor and exciter and 90 per cent. for the compressor. This gives a motor output of 389 h.p., or 21.4 h.p. per 100 cu. ft. of air delivered. Compared of control is inefficient because a considerable amount of power is wasted in heat which cannot be regained, and there is also some leakage.

182. Regulation by use of an unloading valve. The most satisfactory and economical method of regulation is the combination of an unloading valve on the intake cylinder and an **atmospheric relief valve** on the discharge, or high-pressure cylinder. The unloading valve on the intake is connected to the air receiver, and a rise in pressure causes it to close. All air is then cut off, and as soon as the system is pumped out, the low-pressure piston operates in a vacuum. But there will be a slight leakage past the valve and around the piston-rod stuffing box, and provision must be made for allowing this air to escape. If this is not done, a small amount of air will be carried over into the high-pressure cylinder and compressed over and over again, resulting in dangerously high temperatures and waste of power. An atmospheric relief valve is therefore provided which is operated automatically after the unloading valve is closed. This relief valve shuts off communication between the pressure line and the high-pressure cylinder, and at the same time opens a free exhaust from the high-pressure cylinder to the atmosphere.

When the pressure in the receiver falls slightly, the intake unloader opens, then the relief valve closes, and the work of compression is again taken up. This cycle is secured without shock, as the operation is comparatively gradual and as an appreciable space of time is taken to fully load or unload. With this method of control the machine is either operating at its most efficient point (full-load) or else no work is being done except that necessary to overcome the friction of the moving parts.

183. A load factor of 60 per cent. may be taken as an average figure for compressor operation. In the test referred to above (Par. 173), the compressor was equipped with combination unloading valves and the power required at 60 per cent. load factor was 3.1 kw-hr. per 1,000 cu. ft. of free air actually delivered at 100 lb. pressure. A compressor of the same capacity and type, but fitted with clearance control, was also tested at the same time, and at 60 per cent. load factor the power required was 3.5 kw-hr. per 1,000 cu. ft., or 12.9 per cent. greater.

184. Starting. No special difficulties are encountered in starting, since the compressor is started without load and the load is not thrown on until the machine is up to normal speed.

185. Automatic starting and stopping. In cases where the demand for air is very intermittent and no air is required for long intervals, the compressor may be automatically stopped and started. The main switch is controlled by the air pressure and is thrown out when the pressure rises, and thrown in when the pressure falls. The unloading valve is controlled by a solenoid which holds the valve open when the compressor is running, but allows it to drop and close when the main circuit is opened. The compressor always starts unloaded since the solenoid is not energized until the motor is up to speed and the last contact has been made in the starter. On account of the effect of repeated starting on the electrical supply line, automatic starting is not recommended for large units, or for installations where the starting and stopping is at all frequent.

FANS AND BLOWERS

BY MERTON S. LEONARD

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186. Definitions. Fans will here include only **centrifugal fans** having inlet at centre and discharging at the periphery, either directly or through a casing which directs the air to the outlet; and **propeller fans** which move the air in an axial direction by propulsive force, similar to the propeller of a ship. **Blowers** will here include only **positive rotary blowers**, which, by the action of a rotating impeller or impellers in a very closely fitting casing, create pressure by direct compression.

187. Characteristics of fans and blowers. Fans and blowers, like pumps and unlike most other machines, may operate with equal efficiency since it is very likely to give trouble on account of its complexity and refinement.

195. Method of control (alternating-current). Any method of control which is adaptable to alternating-current motors in general is suitable for alternating-current fan motors. However, such motors are usually arranged to operate at only one speed, and are provided only with a starting device. If it is necessary to vary the volume or pressure of the fan or blower, it may be accomplished by throttling the air with a damper.

196. Methods of direct connection. Whenever feasible it is best to mount the fan wheel directly upon the motor shaft. This can usually be done with small centrifugal fans and with propeller fans up to about 60 in. diameter; however, the deflection and the critical speed of the shaft should be investigated to determine whether or not this is safe.

When it is not feasible to mount the fan wheel upon the motor shaft, it is best to provide the fan with two bearings and connect the motor by means of a flexible coupling. It is more common, however, on account of low cost and space economy to provide the fan with one bearing and connect the motor by means of a solid-flange coupling. If this is done, care must be taken properly to align the bearings, and to maintain the alignment.

197. If a fan handles hot gases, means must be provided for the protection of the motor from the heat. This is accomplished by cooling the shaft or the bearings with water, or by separating the motor and the fan with a long shaft extension, or by driving the fan with a belt or chain.

198. Suppression of noise. If there is danger of noise being transmitted through the air ducts, as in auditoriums, theatres, schools, churches and hospitals, it is often better to drive the fan by belt from the motor. This is particularly true of alternating-current motors.

199. Belt drive for fans. It is often possible to use a smaller and less costly motor by use of belt-drive, when the fan speed is lower than necessary for a motor of the same horse power. It is generally preferable to belt alternating-current motors, because the most desirable speed of a standard fan for a given duty is seldom the same as the available motor speed, making it necessary to build a special fan, and thus increasing the cost, if direct-connected.

It is desirable to drive by belt, when the required fan speed or the fan horse power is in doubt, as an inexpensive change in size of pulley will correct the error, if one is made.

200. Method of motor application to blowers. Blowers are essentially slow-speed machines. It is, therefore, almost always desirable to belt or gear the motor. If geared, the motor and the blower should be mounted on the same base to assist in maintaining alignment.

201. Approximate horse power of centrifugal fans. The horse power required to drive any centrifugal fan may be represented by the following formula:

$$\text{h.p.} = K\left(\frac{T}{1000}\right)^3 DW\left(\frac{w}{0.075}\right) \tag{5}$$

Where K (Par. 203) is a constant depending upon the design and upon other conditions, T is the peripheral velocity or the tip speed of the blast wheel in ft. per min.; D is the mean diameter of the blast wheel in feet; W is the mean width of the blast wheel in feet; w is the absolute density of the gas handled, in lb. per cu. ft.; 0.075 is the weight of standard air at 65 deg. fahr. in lb. per cu. ft.

202. Approximate horse power of propeller fans. The horse power required to drive any propeller fan may be represented by an expression of the form,

$$\text{h.p.} = K_1\left(\frac{T}{1000}\right)^3 A\left(\frac{w}{0.075}\right) \tag{6}$$

Where K_1 (Par. 204) is a constant depending upon the design and upon other conditions, T is the peripheral velocity or the tip speed of the wheel in ft. per min.; A is the gross area of the wheel in sq. ft.; w is the absolute density of the gas handled in lb. per cu. ft.; 0.075 is the weight of standard air at 65 deg. fahr. in lb. per cu. ft.

the main of unloaders, bucket-handling gantry cranes, car dumpers, self-propelled transfer cars and belt conveyors. Fig. 26 represents a stiff-leg unloader, with a gantry crane for stocking such ore as is not to be immediately loaded into cars. Fig. 27 shows a gravity-type unloader and a gantry crane.

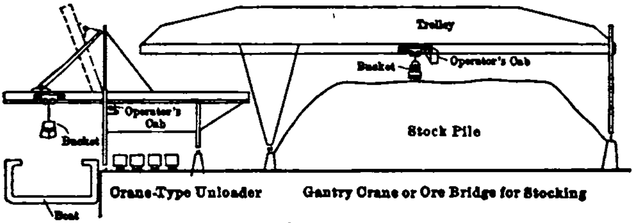

FIG. 27.

207. Motors for severe service are usually of the mill type with large shafts, fire-proof insulation, heavy frames, small moment of inertia of armature and great commutating capacity. Shafts are generally tapered at the pinion end to allow for easy removal of the pinion, and axle bearings are often used where a gear ratio of about five-to-one is desired. The frames are generally entirely enclosed, although many of the larger sizes are constructed with part of the upper frame cut away in order to facilitate the dissipation of heat. It is probable that in the future, forced ventilation will become common practice, as is already the case in electric locomotives.

208. Motors for light service where direct current is available, and of 25 h.p. or under, are usually of the crane type. This construction is much cheaper than the mill-type construction, yet is quite satisfactory for intermittent service where no severe overloads occur. The frames are entirely enclosed, as heating is not a consideration.

209. Motors for car dumpers, where there is usually abundant space available, and where the electrical apparatus is well protected from the weather, are often of the open type with commutating poles. The speed of rotation is preferably lower than for the mill motor, owing to the greater radius of gyration of the armature.

210. Motors for transfer cars are commonly either of the railway or mine type, the latter often being preferable on account of their low speed, high torque and large gear reduction. Standard drum-type controllers are ordinarily furnished with these motors.

211. Mill motors, where alternating current only is available, may be obtained for 3-phase, 25-cycle, 220-volt or 440-volt circuits. For a frequency of 60 cycles it is necessary to use an open type of frame, an outboard bearing being desirable for sizes above 25 h.p. Alternating-current motors should be of the slip-ring type, except for belt conveyors with light starting requirements, where squirrel-cage motors may be used. They should be of sturdy mechanical construction, and should be wound for high torque. Low rotor speeds are desirable as tending to keep the acceleration load at a minimum.

212. Controllers for heavy duty are always of the contactor or magnetic-switch type with overload and automatic acceleration relays. Dynamic braking for lowering buckets, etc., is now almost universal; not only is the energy of the lowered mass dissipated in resistors instead of brake friction, but the operator is given a very delicate control by means of his master controller instead of having to manipulate an air or hand brake. Where direct current is not available, dynamic braking is obtained by means of a small low-voltage generator set, which provides direct current for exciting the stator winding of the motor lowering the load, thus allowing it to become an alternating-current generator. Since only part of the winding can be used for this purpose, and since an induction motor possesses inherently a limited torque, this system of dynamic braking is not as reliable as where

218. Power required by transfer cars. In the case of transfer cars and the trolleys of unloaders and bridges, acceleration is the predominant factor. For loads of this kind, two motors are used as a rule, in order to obtain good traction; in such cases, series-parallel control is generally preferable. If the motors are permanently connected in parallel, it is safer to provide a separate set of reversing contacts for each armature. Armature-shunting points are occasionally employed to obtain very low speeds, and dynamic braking is sometimes provided in the case of a gantry crane or unloader trolley. To obtain dynamic braking for a series-wound trolley motor, it is necessary to connect the field in series with a resistance across the line, so that the characteristics of a shunt generator may be obtained. An air brake is generally preferable for trolley service, except when the operator is located at some distance from the mechanism, in which case the motor should be provided with a magnetic brake, preferably of the disc type, and the controller should give dynamic braking on or near its central position.

219. The frictional resistance of the ordinary trolley may be taken at 25 lb. per ton; for a transfer car with standard trucks, 15 lb. per ton is ample. The horse power for the final assumed speed should first be figured as follows: h.p. = friction force at rim of wheel multiplied by the speed in ft. per min. and divided by the efficiency (expressed as a decimal) and by 33,000. About twice the result should be taken as the nominal horse power required, this value being based on a rise of 75 deg. cent. in 1 hr. The performance of the trolley or car can then be easily worked out by means of the motor curves, the step-by-step method being used as explained in Par. **226**. It will sometimes be found that the motor chosen is too small; where there is any doubt, the moment of inertia of the armature should be obtained and should be translated into its equivalent weight at the trolley speed. The calculations should then be gone over more carefully; for slow trolley speeds, the inertia of the armature becomes a very considerable part of the whole.

220. The longitudinal drive of an unloader or bucket-handling gantry partakes of the nature of a trolley drive, but owing to the much lower speed and higher friction, inertia plays a smaller part, and dynamic braking is unnecessary. Friction may be taken at about 40 lb. per ton, although this figure is quite uncertain. The heating is not a factor in this class of service, but sufficient commutating capacity should be allowed to take care of a wind-pressure equivalent to one and one-half times the friction; this is merely a general rule, but is one which works well in practice. In some cases long gantry cranes are driven by independent motors at each end; this scheme is quite successful, even with series motors, although an automatic device should be provided to prevent one end from leading the other. With this type of drive, the motors should be provided with magnetic brakes, the disc type being preferable because the shock when stopping is less than with the post brake. For the ordinary gantry or unloader, one motor is generally connected by bevel gears to both trucks; a mechanical foot brake which is held in the released position by the weight of the operator is preferable to a magnetic brake in this case, since it can be applied more gently.

221. The gear efficiency of one reduction of cut spur gears in this class of work may be generally taken as 95 per cent.; for cut bevel gears, 90 per cent. For important motions, the cut herringbone gear is becoming popular; it should have an efficiency of at least 97 per cent. if properly erected. The **coefficient of friction** for the ordinary bearing will average about 0.05, while for sheaves it is better to allow a value of 0.07. These figures may be safely followed except in special cases, such as in gearing for longitudinal drives where there is decided likelihood of poor alignment of shafts and gears.

222. The calculation of power house or substation capacity for a dock is a long and tedious process, since it is a matter of some conjecture as to just how the peak loads, which are usually violent, will coincide. A 10-ton stiff-leg ore-unloader having a total capacity of 400 h.p. in five motors will show a momentary peak load of 1,200 amp. and an average load of 400 amp. Two such machines working together will occasionally take 1,800 amp. for 1 or 2 sec. One 15-ton stiff-leg ore-unloader with seven motors totalling 700 h.p. and requiring an average load of about 500 amp. will draw a peak of 1,800 amp. The maximum current for four such machines, however, will not exceed 4,000 amp. Gravity-type unloaders are likely to show a higher proportional peak load because practically all the work is done by a motor speed of 820 rev. per min.; then ft. per min. = (900/820) × rev. per min. = 1.1× rev. per min.; also the force at the rim of the wheel will have the same ratio to the motor torque as the friction force has to the friction torque; or, force = (1,060/205) × torque = 5.17 × torque. Assume effect of armature weight equal to 1,500 lb. at 0.7 ft. radius; equivalent weight of one armature at trolley speed = [1,500 × 0.9 × (2π × 0.7 × rev. per min.)^2]/(ft. per min.)^2 = ([1,500 × 0.9 × (2π × 0.7 × rev. per min.)^2]/(1.1 × rev. per min.)^2 = 2,160 lb.; or say 5,000 lb. including gearing. Total weight per motor for acceleration = 85,000 + 5,000 = 90,000 lb. Assume that acceleration while short-circuiting the resistance is 2.5 ft. per sec. per sec., which is as high a value as the operator can endure with comfort; this initial rate of acceleration is determined by the rapidity with which the starting resistance is cut out. Since the force of acceleration = F_a = (wt. in lb./g) × acceleration in ft. per sec. per sec., then F_a = (90,000/32.2) × 2.5 = 7,000 lb. Since the friction force is 1,060 lb., the total force = 7,000 + 1,060 = 8,060 lb. Motor torque = T = 8,060/5.17 = 1,560 ft-lb. From the characteristic curve, when T = 1,560, h.p. = 119; rev. per min. = 402. Therefore ft. per min. = 402 × 1.1 = 442, and ft. per sec. = 7.4. This is the speed which is attained at the instant the last section of resistance is cut out. The time = t_1 = speed/acceleration = 7.4/2.5 = 3.0 sec. The distance = d_1 = average speed × time = (1/2) × 7.4 × 3.0 = 11 ft. After the starting resistance is cut out, the trolley will continue to accelerate at a diminishing rate, as long as the force supplied by the motors exceeds the friction force. Assume that the horse power has decreased to 60; then from the motor curve, rev. per min. = 560. Since ft. per min. = 1.1 × rev. per min., the ft. per min. = 616, or ft. per sec. = 10.3, and the increase = 2.9 ft. per sec. The average speed = (10.3 + 7.4)/2 = 8.85 ft. per sec. Referring again to the curve, T = 560, therefore F = 2,900 lb.; $F_a = F - F_f$ = 2,900 − 1,060 = 1,840 lb., acceleration = $A = g \times F_a$/90,000 = 0.66, average A = (2.5 + 0.66)/2 = 1.58, t_2 = (increase in speed)/(average acceleration) = 2.9/1.58 = 1.8 sec., d_2 = 8.85 × 1.8 = 16 ft., total time up to this point = t = 3 + 1.8 = 4.8 sec.; total distance up to this point = d = 11 + 16 = 27 ft. Assume the horse power has dropped to 35; then rev. per min. = 760, ft. per min. = 836, ft. per sec. = 13.9, increase = 3.6, average speed = 12.1 ft. per sec.; T = 240, F = 1,240, F_a = 180, A = 0.06, average A = 0.36, t_3 = 10.0 sec., d_3 = 121 ft., t = 14.8 sec., d = 148 ft. Assume trolley coasts for 1 sec. at 13.9 ft. per sec.; t_4 = 1, d_4 = 14 ft., t = 15.8 sec., d = 162 ft. Assume retardation = 2.5 ft. per sec. per sec.; t_5 = 13.9/2.5 = 5.6 sec., d_5 = 39 ft., t = 21.4 sec., d = 201 ft. The time originally allowed for a trip one way was 20 sec., but since the trolley will return light at a somewhat higher speed, the gear ratio originally assumed is close enough. If the heating is figured for the loaded trip and for one-half the cycle, the results will be on the safe side. Mean effective h.p. = $\{[(119^2 \times 3) + (119^2 \times 1/2 \times 1.8) + (60^2 \times 1/2 \times 1.8) + (60^2 \times 1/2 \times 10) + (35^2 \times 1/2 \times 10)]/[60 \times \tfrac{1}{2}]\}^{\frac{1}{2}}$ = 52. A fully enclosed mill motor can keep up this cycle for about 3 hr., but not indefinitely. If the crane will not operate for over 8 hr. at any one time, 80-h.p. mill-rated entirely enclosed motors should be used. For continuous operation use the same motors with the semi-enclosed frames, which will have a mill rating of about 90 h.p. and root-mean-square rating of about 70 h.p.; or if convenient, forced ventilation may be used with the totally enclosed motors. In any case, the armature, fields, etc., will be the same, the difference in rating being due to the different methods of cooling. The maximum loads to be commutated should not exceed those shown on the motor curve.

226. Calculations for bridge drive (Par. 223). Assume that the total crane weighs 1,200 tons, and that a 2-motor longitudinal travel drive is desired. Friction force per motor at 40 lb. per ton = 40 × 1,200 × ½ = 24,000 lb. Assume that a speed of 75 ft. per min. is desired, and that each motor has one spur-gear and two bevel-gear reductions. The efficiency would be approximately 77 per cent. The friction load per motor = 71 h.p. If 80-h.p. mill-rated motors were used, the friction torque read from the curve would be about 720 lb. at 1 ft. radius. Assuming the wind load = 36,000 lb. and acceleration at 0.25 ft. per sec. per sec. = 9,300 lb., the total maximum load = 69,300 lb. and approximate maximum torque = (69,300/24,000) × 720 = 2,080 ft-lb., which is well within the commutating limit of an 80-h.p. mill motor.

230. Energy supply, in the form of either direct or alternating current is communicated to the motors by conductors which lie parallel to the track, the contact being made by shoes or wheels. Sometimes storage batteries, suspended from the telpher or the carriage, are employed. On steep grades the telpherage traction, in some installations, has been assisted by supplementary cables, either fixed or movable.

231. Motors. The sizes of motors for telphers and hoists will depend upon the class of work to be done; the motors for telpher-tractors vary from 5 to 15 h.p., and for the hoists from 3 to 75 h.p., the loads being from 500 lb. to 30,000 lb. The load factor for the tractor motor is 0.25 and for the hoisting motor 0.16. The driving wheels and the motors may be connected by gears or by chain drive. The maximum service efficiency of the motors is that corresponding to the efficiency obtained between one-half and three-quarters full-load. The motors are of slow or medium speed.

Direct-current, 250-volt or 500-volt, series-wound motors are preferable for tractors and hoists although alternating-current motors afford satisfactory results. The motors should be dust and weather proof, and should have a 50 per cent. reserve in their rating. The average combined efficiency of the motors and gearing, for the tractor and hoist, is from 65 per cent. to 75 per cent.

232. Brakes. The telpher brake is of the mechanical type, and the hoist brake is of either the electro-mechanical or electro-dynamic types. Spur gears and chain drive on the tractor transmit the power from motor to track wheels, and either spur or worm gear is used to transmit power to the hoisting drum.

233. Trackage. Telphers either run in one direction on a closed track circuit (Fig. 30), or to and fro over a single line. On the single line the automatic telphers reverse themselves on completing their trips. The spacing between the cars is automatically regulated by a block system, and the cars are also automatically controlled at switches and crossings. The track consists of either a cable, or a T-rail supported on a wooden stringer, or upon the top or lower flange of an I-beam. There are also track rails of special section. The radii of the curves are from 8 ft. to 20 ft.

234. Track supports. The track is supported on brackets attached to buildings, or is supported on "A" bents. Supports under straight track are spaced 20 ft. apart, and on curves the spacing is 8 ft. For long spans cables or trusses are used.

235. Tracks may be fixed or movable. In Fig. 30 the side tracks $B.B'$. are fixed, but C is movable, being attached to a travelling bridge. The speed of this bridge is from 300 ft. to 900 ft. per min. The motor driving this bridge would have a load factor of 0.16.

The telpher train passes from these side tracks B', by means of a gliding switch, upon the movable track C. This track therefore may be placed anywhere over the area between the fixed side-tracks. The telpher returns by means of the track B', to its starting-point. By the operation of this movable track, all the space can be served; this operation is called **transferage.** The minimum allowable radius of curves is 8 ft.

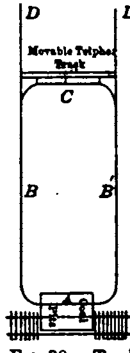

FIG. 30.—Typical arrangement of telpherage tracks.

236. Performance. The loads hoisted and conveyed on telpher hoists have been as high as fifteen tons. The maximum speed of conveying on a straight level track is about 1,000 ft. per min. The running speed is reduced at curves, according to their radii.

237. For terminal work, the capacity of each hoist is 2 tons at 60 ft. per min. (18.288 m. per min.). Two hoists can be combined so as to raise 4 tons. The motors being series-wound, the speed of hoisting will increase as the load is diminished.

238. For freight handling, from two to four carriage hoists constitute a train which has a total maximum carrying capacity of 8 tons. Such trains are used for assorting as well as for distributing, according to consignments. Many telphers can be operated in one installation, the number being limited only by the design of the track layout. As the speed of man-telphers is greater than that of automatic telphers and the loads heavier, the capacity is greater for a given length of track.

239. Installation costs. The overhead trackage, made part of and attached to the building structure, costs the same in proportion as other structural steel. The weight, including the brackets, averages about 50 lb. per lineal foot. The steel is fabricated at the mill.

STEEL MILLS

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240. Classification. Rolling mills are usually named after the material produced by them, although they are sometimes classified according to the layout of the mills. The principal types of mills are as follows:

(a) **Blooming mills,** rolling ingots, as cast, to blooms or billets. All material rolled in a steel mill must pass through the blooming mill or its equivalent, to be reduced to proper dimensions for handling in the finishing mills. The mills are built either two-high reversing, or three-high running continuously in one direction.

(b) **Slabbing mills** (modification of the two-high blooming mill) produce slabs with finished edges, which are afterward rolled into plates. Vertical rolls are provided for finishing the edges.

(c) **Billet mills** are usually of the continuous type, with rolls in tandem, and roll material from the blooming mill to a suitable size of billet for the finishing mills. Material passes directly from one stand to the other, the speed of the rolls being arranged to correspond to the reduction in area after each pass.

(d) **Plate mills** may be either two-high reversing, or three-high running continuously in one direction, and roll slabs to plates of various thicknesses. They are sometimes provided with vertical rolls for finishing the edges of the plates and are then known as universal mills.

(e) **Structural mills** are usually three-high and are used for rolling girders, heavy angles, channels, etc. In small plants such material may be rolled by the reversing-blooming mill.

(f) **Merchant mills** are used for rolling small angles, channels and all types of profiles. They are usually three-high, with the finishing stand sometimes two-high.

(g) **Bar mills** are usually three-high, and generally consist of roughing stand and a separate finishing stand. These are used for rolling bars of all sections and sizes.

(h) **Rod mills** are special types of bar mills, and are used for rolling small sections at high speeds.

(i) **Rail mills** generally roll blooms or heavy billets to rails of various sections, and are made two-high or three-high, according to the layout.

(j) **Sheet mills** roll 0.5-in. to 1-in. bars to sheets of all gages; they are always two-high, and generally have separate roughing and finishing stands.

In addition to the foregoing types, there are several other forms of construction, used for rolling certain sections of material, but their use is generally confined to one particular installation.

241. Arrangement of mills. The simplest type of mill, having more than one stand, is arranged on one axis, all stands being driven by one set of pinions in the middle or at one end of the mill (Fig. 31). This type of mill is generally used for rolling small sections only, but is occasionally used for heavy sections when transfer tables are provided to move the metal from one stand to the other.

The usual arrangement for rolling light sections is shown by Fig. 32, the roughing stand runs at a slower speed than the finishing stand, and usually has larger rolls to obtain greater strength, in order that large reductions can be made. The metal is roughed down to such size that it can be readily handled by the higher-speed finishing stands. The motor is generally direct-connected to the finishing stands, the roughing stands being rope driven. A better arrangement is to drive the roughing and finishing stands separately, so that the speed of each can be adjusted for different products to give the maximum output.

Occasionally the various stands are arranged on one axis, the finishing stands being separately driven to give the proper speed adjustment. The object of driving the finishing stands at different speeds than the roughing stands is to increase the capacity of the mill, and to finish the material at such a rate that it does not become too cool; this difference in speeds also makes it possible to work without an exceedingly large loop from one pass to the other.

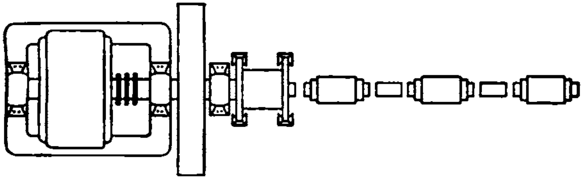

Fig. 31.—Simple mill for rolling light sections.

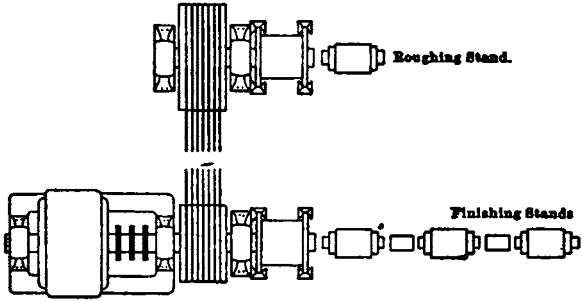

Fig. 32.—Mill with separate roughing stand.

242. Direct-connected drive. The best arrangement is to connect the motor direct to the mill, if the mill speed is such that this is feasible. In general, the lowest speeds possible for direct-connection at 25 cycles are as follows: 250 to 500 h.p., 125 rev. per min.; 500 to 1,000 h.p., 100 rev. per min.; 1,000 to 2,000 h.p., 85 rev. per min.; 2,000 h.p. and upward, 70 rev. per min.

243. Geared drive. The first cost of slow-speed motors is high, and if very large motors are not required, some speed-reducing arrangement is generally used for slow-speed mills. The low power-factor of the slow-speed motor is a serious objection. Gearing has been used extensively for connecting motors to mills, and the use of cut double-helical gears makes possible pitch-line speeds previously impracticable. Although the maintenance is increased, gears permit the installation of high-speed motor of good performance at low cost. The use of gears introduces losses and offsets the increased efficiency of high-speed motors, but the advantage of high power-factor is important. An important advantage of gear drive is that in the case of very slow-speed mills, the fly-wheel (Par. 247) can be located on the pinion shaft and run at such a speed that comparatively small weight is required. This is of particular importance in sheet mills, which run at approximately 30 rev. per min., as sufficient fly-wheel effect cannot be obtained to equalize the input properly if the fly-wheel is located on the mill shaft.

When connecting the motor to the mill, the fly-wheel (Par. 247) should be so placed that the shocks from the rolls are not transmitted to the motor.

as a general practice, the limit of peripheral speed in such cases is 6,000 ft. per min., because higher speeds are not considered safe, owing to the uncertainty of the shrinkage stresses. By special construction to avoid such stresses, cast-iron wheels for a peripheral speed of 10,000 ft. per min. have been built with success. For moderately high speeds, cast-steel wheels are commonly used, the usual limit of peripheral speed being 12,000 ft. per min.; but in special cases cast-steel wheels run at speeds up to 22,000 ft. per min. Such speeds are dangerous if the material is not homogenous and free from initial stresses, but with proper design and annealing, they have proved successful. For speeds up to 30,000 ft. per min. fly-wheels have been built from discs cut from single plates, the plates being riveted together to form a solid wheel.

248. Factors affecting power requirements. The power required by rolling mills depends upon the following factors: (a) volume of metal displaced in a given time; (b) manner in which the section is changed; (c) temperature of metal during rolling; (d) class of material; (e) size of rolls. The determination of the best arrangement of motor and fly-wheel for any particular mill necessitates the analysis of the power required for each pass. The

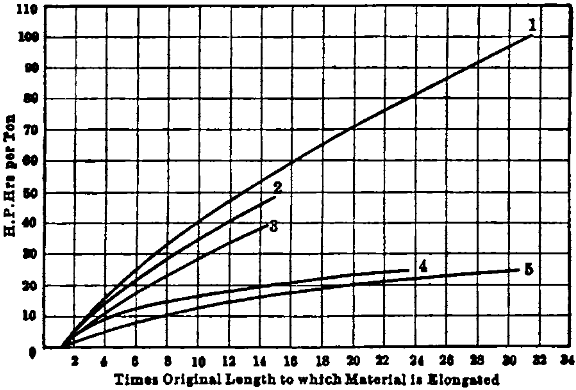

FIG. 34.—Curves showing average energy consumption of different types of mills.

Curve No. 1, rolling small billets of high-carbon steel to rods.
Curve No. 2, rolling billets to light rails.
Curve No. 3, rolling billets to flats and squares.
Curve No. 4, rolling ingots to billets.
Curve No. 5, rolling slabs to plates.

average output required can be obtained from Fig. 34, which shows **average energy consumption for different classes of materials.** The figures given are h.p. hr. per ton of metal rolled, plotted against elongation. To these figures should be added the friction of the mill, in order to obtain the motor load. The size of the motor may be determined from these curves, provided that the tonnage taken corresponds to the maximum that the mill will roll if working continuously, and that there is sufficient fly-wheel effect available to equalize the peak loads.

249. Motor rating and temperature rise. Rolling-mill motors are usually rated on a temperature rise of 35 deg. Cent. and they have a continuous overload capacity of 25 per cent. with 50 deg. Cent. rise and a 1-hr. overload capacity of 50 per cent. with 60 deg. Cent. rise. With the knowledge now available of the power requirements, a standard temperature rise of 40 deg. Cent. with a 25 per cent. overload capacity for 2 hr. is satisfactory, if the conditions are properly analyzed.

251. Energy consumption per ton of material

Type of mill	Original cross-section (in.)	Finished product (in.)	Tons per hr.	H.p. hr. per ton
Reversing blooming mill......	20×20	8×8	95	21
Reversing blooming mill......	16×16	3×3	40	42
Plate mill..............	6×30	½×30	50	28
Plate mill..............	7×24	⅜×24	70	16.5
Sheet mill..............	7×30×½	0.025	8	165
Sheet mill..............	7×30×½	0.04	10	128
Rail mill..............	4×4	40 Rail	75	20
Billet mill..............	4×4	1½×1½	50	20
Rod mill..............	1½×1½	¼ Round	20	60
Bar mill..............	4×4	1×1	15	48

252. Types of motors adaptable to rolling-mill practice. Alternating-current motors are used almost exclusively for driving rolling mills, direct-current machines being adopted only in a few installations of comparatively small capacity, or where there are special speed requirements.

Special types of direct-current and alternating-current auxiliary motors for steel-mill service have been developed, the principal characteristics of these machines being high overload capacity without injury, and great mechanical strength. Accessibility is also an important factor in order to facilitate rapid repairs. Mill motors are built from 5 to 150 h.p., being usually rated on a temperature rise of 75 deg. Cent. after 1 hr. operation. They are equipped with heat-resisting insulation, because they are often located near furnaces where the temperature of the motor even without load may be very high. The maintenance cost of such motors is approximately one-fourth that of the modified railway motors previously used. Full particulars of these motors can be obtained from the publications of the manufacturers.

253. Control. It is becoming general practice to use hand-operated controllers only for auxiliary motors up to about 30 h.p., larger machines being provided with magnetic-switch controllers. The principal characteristics of steel-mill controllers are simplicity, reliability in operation and ability to stand abuse. The special construction necessary to meet these conditions increases appreciably the cost of steel-mill controllers as compared with controllers for ordinary industrial service.

For motors driving main rolls, magnetic-switch controllers are generally used, the resistance being so arranged that various running points up to 15 per cent. slip may be obtained, in order that the motor will slow down on heavy loads and allow the fly-wheel to give out a part of the energy stored in it. Automatic slip regulators are now being adopted, in order to regulate the rate at which energy is delivered by the fly-wheel, thereby obtaining better equalization of the load on the motor. Liquid regulators are used on account of their simplicity and small maintenance, as well as quickness in action and sensitivity.

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portions of the plant, and is often from 80 to 85 per cent., based upon the ratio of average to maximum demand.

258. Motor characteristics. Induction motors only should be considered; already over 90 per cent. of the motors installed are of the alternating-current type, and the percentage is steadily increasing. The simplicity and ruggedness of the squirrel-cage motor make it admirably adapted for the severe and dusty service of cement mills. The bearings should be made dust proof. Ball and tube mills and others of similar type are very difficult to start, and motors which drive these machines should have a starting torque of not less than twice the value of full-load torque; friction clutches are unnecessary if proper motors are used. Slip-ring motors are often used for large gyratory crushers, which may become choked with rock and impose very severe starting conditions. Speed variation is sometimes desired on the kilns and dryers, but this requirement can be met easily by the use of slip-ring motors with resistance which will reduce the speed to one-half of normal.

259. Type of drive. For satisfactory service and long life, a motor should not be subjected to severe vibration. Either belts or flexible couplings are able to absorb the vibration of the grinding machinery, but the dust causes rapid deterioration of belts and, therefore, the best practice is direct-connection wherever possible. The countershafts of ball and tube mills rotate at about 160 rev. per min. and, on 25-cycle circuits, motors at this speed are connected through flexible couplings. Motors may often be placed in a separate room, the shafting extending through into the mill proper. For Fuller mills, or for other vertical-shaft mills, special belted vertical motors can be obtained which are more satisfactory than horizontal motors with quarter-turn belts.

260. Jaw crushers are often used for secondary crushing, or upon clinker, and the following are typical ratings.

Superior Jaw Crushers—Blake Type
(Power and Mining Machinery Co.)

Size of jaw opening (in.)	Weight of crusher (lb.)	Capacity per hr. according to size				Driving pulley			Horse power (aver.)
		Tons	In.	Tons	In.	Diam. (in.)	Face (in.)	Rev. per min.	
10×7	7,550	6	2	2½	1	24	7½	250	7½
15×9	12,000	16	3	8	1½	30	8½	250	10
20×10	21,500	38	4	19	2	36	13	250	20
24×15	38,000	60	5	25	2½	42	16½	250	25
36×24	68,000	130	6	70	3	Pulleys to suit conditions		250	75
42×40	130,000	225	8	130	4½			250	100
60×48	205,000	290	9	180	5			200	150
84×60	400,000	450	11	280	7			100	200

Champion Crushers (American Road Machinery Co.)

Size no.	Size of jaw opening (in.)	Weight of crusher (lb.)	Tons per hr. according to material and feed	Driving pulley			Horse power
				Diam. (in.)	Face (in.)	Rev. per min.	
3	7½×13	5,500	8 to 12	38	8	170	12
4	9×15	8,800	12 to 18	48	9	155	15
4½	10×20	12,500	16 to 24	50	10	150	18
15	11×22	12,000	18 to 26	48	9	150	20
5	11×26	20,000	24 to 35	60	9½	140	25
20	18×50	60,900	70 to 100	72	12½	105	50 to 60

265. Kent mills. This mill (made by the Kent Mill Co.) is in very extensive use both as an intermediate and a fine grinder. Being of the roll and ring type it can be started with comparative ease, and a 40-h.p. motor is usually supplied to drive the mill with its elevator and screen. The pulleys on the mill are 36 in. × 8 in., and 64 in. between centres, running at about 200 rev. per min. Motors with double-extended shafts make a simple and satisfactory drive.

266. Tube mills of 5, 5.5 and 6 ft. diam. by 22 ft. long are now in common use in cement mills. The required power varies with the charge of pebbles and the feed, but averages 100, 150 and 200 h.p., respectively, for the above mills. For belt drive, motors from 480 to 690 rev. per min. are used, while for coupled drive 160 rev. per min. is customary. The F. L. Smidth No. 16 and 18 tube mills are usually driven by 100-h.p. and 150-h.p. motors, respectively. When "cylpebs" (short cylindrical pieces of steel) are added to a tube mill the power required is increased 20 to 30 per cent.

267. Fuller mills. The Lehigh Car Wheel & Axle Works have on the market three sizes of Fuller mills, known as the 33 in., 42 in. and 54 in. The smaller mill is used principally for coal, while the two larger sizes are adapted to pulverizing either raw material or clinker. The power requirements are given in the following table.

Size of mill (in.)	Pulley			Horse power
	Diam. (in.)	Face (in.)	Rev. per min.	
33	33	10	210	25-40
42	54	18	160	75-90
54	75	21	125	150-200

Vertical belted motors make the best drive for these mills.

268. Griffin mills. These mills, also of the vertical type, are manufactured by the Bradley Pulverizer Co. Since the driven pulley is above the mill, they are seldom individually driven, but such drive is made feasible by proper mounting of the motor.

Size	Pulley		Horse power
	Diam. (in).	Rev. per min.	
30 in.	30	190-200	30
36 in.	40	135-150	40
Giant	42	160-170	60-75

269. Bonnot pulverizer. Although this is a vertical mill, it has a horizontal pulley running at about 215 rev. per min. Only one size of mill is manufactured; this requires from 75 to 85 h.p. Either a belted or a coupled motor may be used.

270. Aero pulverizers. These reduce crushed coal to an impalpable powder, and blow it into the kiln, mixed with the correct amount of air for combustion.

Aero pulverizers						
Size no.	Weight (lb.)	Height (in.)	Floor space (in.)	*Normal capacity of soft coal (lb. per hr.)	Rev. per min.	Horse power
A	1,800	28[illegible]	61[illegible] × 27[illegible]	600	2,000	10
B	3,500	38[illegible]	77[illegible] × 29	1,000	1,600	15
C	4,200	51[illegible]	78[illegible] × 29	1,500	1,500	20
D	4,400	44[illegible]	78[illegible] × 29	2,000	1,400	30
E	5,600	46[illegible]	97 × 33	2,800	1,400	40

* The capacity may be increased 25 per cent. or decreased 50 per cent. without material loss of economy.

voltage of 500 has an advantage over 250 volts in that very much less copper is needed and greater distance can be covered. The danger is, however, considerably greater, and many states are legislating against the use of over 300 volts underground. Compounding is necessary due to the long lines that are required in reaching the workings. The type of load is such that heavy short-time peaks frequently occur.

279. Predetermination of generator capacity. When a mine is small and electric power is used for only one or two locomotives, the capacity of the generator will be determined entirely by the peak loads. For instance, if the load were to consist of two 10-ton locomotives each having two 50-h.p. motors, the conditions will be as follows: 1-hr. rating of motors, 200 h.p.; continuous rating of motors about 80 h.p.; maximum load with both locomotives starting 300 h.p. To compensate for the line drop and efficiency, 1 kw. should be allowed at the switchboard for every horse-power at the machine.

It will be seen from the above that on a heating basis, an 80-kw. generator can be used. This machine, however, could not take care of a load of 300 kw. The generator should have a capacity of not less than 150 kw. If old second-hand generators and engines are installed, it will be necessary to provide for a capacity of from 200 to 250 kw., as there would be a lack of overload capacity. The efficiency of power generation will not be very high, since the unit will be carrying a small load a considerable portion of the time. Excellent examples of load diagrams showing the low average and the high peak loads obtained at a coal mine power plant are shown in a paper presented before the A. I. E. E., April, 1913, by Wilfred Sykes and Graham Bright.

If we were to add to the above a third locomotive, a pump load of 50 h.p., a fan load of 50 h.p., and a cutting load of four 25-h.p. cutters, we would have the following conditions:

One-hour rating of motors............	300 + 50 + 50 + 100 = 500
Continuous rating of motors............	120 + 50 + 50 + 40 = 260
Maximum load of......................	400 + 50 + 50 + 100 = 600

For the maximum locomotive load, two locomotives can be considered as starting, each developing 150 h.p., and one running taking 100 h.p. There will, no doubt, be a diversity among the machines, so that the actual peaks will not be over 550 h.p. The generator capacity should be 300 kw., preferably divided between two units of 150 kw. each. From these figures it will be seen that, for the larger plants, the generators can be operated more nearly at their continuous capacity.

At larger mines, or where one company operates a group of mines, a central alternating-current generating system is frequently installed. Energy is generated at 2,200 volts, 3 phase, 60 cycles, and is either transmitted to substations at 2,200 volts, or stepped up to 6,600 volts or 11,000 volts. Motor-generator sets or rotaries are used at the substation to transform the alternating current to direct current. Motor generator sets are generally to be preferred to rotaries, as compounding is more easily obtained. In determining the capacity of the central plant, the machine and line losses must be taken into account in determining the size of the main generating units. These losses will average from 15 to 20 per cent. The capacity of the central plant will not be the sum of the individual substations, as there will be considerable diversity. The diversity factor will range from 1.2 to 1.5 to 1.

280. Design and advantages of mines using purchased energy. When central-station power is used, the power application is very much simplified. For haulage, cutting and inside pumping, a motor-generator set or synchronous converter is used. The motor-generator sets are generally of the synchronous type, owing to the high power-factor which can be obtained with the synchronous motor. This high power-factor will compensate for the lower power-factor obtained on the induction motors used for driving fans, pumps, and tipple or breaker machinery. The substation can be a very simple structure and, in a great many cases, the old generating room can be used. The care of a substation is an extremely simple matter when compared with an isolated plant. For fans, compressors, outside pumps, tipple and breaker machinery and machine or blacksmith shop drive, the squirrel-cage motor is best adapted, as regards first cost and upkeep. This apparatus can be operated at all times independent of the motor-generator set which, in many cases, operates only 8 or 10 hr. per day.

power is purchased, all outside motors can be of the alternating-current type, so that the motor-generator sets, or synchronous converters, need only supply the haulage, cutting, inside lighting and pumping. Where very heavy starting loads obtain, the wound-rotor induction motor with drum type controller should be used. Where only moderately heavy starting torques are required, the squirrel-cage motor is best adapted. The rotor characteristics of this motor will depend upon the character of the load. This is by far the simplest and most rugged motor built, the control also being very simple. Where starting requires a low torque, a low resistance end-ring can be used; where high starting torques are required, a fairly high-resistance end-ring should be used. The cast end-ring has solved all end-ring troubles which were once so prevalent.

288. Pumping. For inside pumping the reciprocating duplex or triplex pump is most used for the smaller sizes. The centrifugal pump will probably average a higher efficiency, but is not so well adapted for moving about and for use under various heads. The capacity of the motor can be readily determined by the amount of work to be done. See Par. **148** to **166**.

289. Ventilation. Mine fans are inherently low-speed machines and are very well adapted for direct connection to a steam engine. For economy in first cost and operating cost an electric motor is inherently a high-speed machine, usually requiring some speed-reducing device in such an application. Belting seems to be the most popular method, although gearing, chain drive, and even rope drive, are used occasionally. See Par. **186** to **206**.

290. Machine mining. Pick mining is a rather slow and laborious process of mining coal, although a large portion of the coal is still mined by this method. Machine mining has become a necessity owing to the increasing demand for coal and the limited supply of labor. Punchers and chain machines are the two types generally used. **Punching machines** were first driven by compressed air, and most of the machines of this type are still operated in this manner. The electric puncher is coming in rapidly; this machine consisting of a motor-driven compressor attached to the cutting mechanism, so that compressed air really is used to operate the puncher. This machine has the advantage of electric transmission, but is heavier and more expensive than the straight-air puncher.

The **chain machine** is the most rapid of all mechanical cutters. The chain cutter will require a motor having an intermittent rating of from 20 to 30 h.p., while the pneumo-electric machine will require a motor rated from 10 to 15 h.p. As a rule direct-current compound-wound motors are used to operate coal-cutting apparatus. Alternating-current motors are being introduced for both punching and cutting machines and have been very successful. They, however, require a separate power circuit consisting of two feed wires with track return. They possess the advantages of simplicity of construction and less danger of the workmen coming in contact with live parts.

LOCOMOTIVES

291. Locomotives for main haulage and gathering are of the direct-current type, designed to operate on 250- or 500-volt circuits. The series type of motor is invariably used as it has the best speed-torque characteristics for the service. The service is somewhat similar to street-railway conditions and the same general methods are used to determine the weight and capacity of the equipment.

Mine locomotives are built in weights ranging from 3 tons to 30 tons and gages ranging from 18 in. to the standard of 4 ft. 8.5 in. The wheels may be cast iron with chilled tread, steel tired, or rolled steel. Gathering locomotives are built to replace mules; these weigh from 3 to 8 tons with equipment varying from two 10-h.p. motors to two 40-h.p. motors.

292. Locomotive-adhesion and weight calculations. The cast-iron wheel will afford a running coefficient of adhesion of 20 per cent., and a starting coefficient of 25 to 30 per cent. when sand is used. The steel-tired or rolled-steel wheel will have a running coefficient of 25 per cent. and a starting coefficient of 30 to 33.33 per cent. with sand. The above figures are conservative and can be easily obtained with fair rail conditions. The weight of locomotive is determined by the following formula:

$$T(30+20G)+20GW = 400W. \text{ for cast-iron wheels,}$$
$$= 500W. \text{ for steel wheels.}$$

exceeded for satisfactory operation. The following table has been prepared by the Baldwin Locomotive Works and represents the best modern practice.

If a heavier locomotive is desired than is shown in this table, tandem units are often applied.

297. Rating of locomotive motors. Although the motors of a mine locomotive are given a 1-hr. rating, it is the average heating that determines the capacity for all-day service. This heating is proportional to the square of the current. The average of the square of the current will give a squared value, the square-root of which is really the capacity of the motor for all-day service. This value is known as the square-root of the mean-squared current. It is obtained by finding the different values of the current for one motor throughout a round trip. These current values can be obtained from the characteristic motor curve of the particular motor used. After the weight of the locomotive has been determined, one of the standard motors for this weight is selected and calculations made to determine if it is of the proper capacity. The total tractive effort per motor is determined for each grade, allowing 20 lb. per ton for the friction of the locomotive. For each total tractive effort the current and speed are obtained from the curve, and the time is calculated. By squaring each current value and multiplying by the time, we have the sum of the products of various squared values of the current, multiplied by the time. This summation should be increased by from 5 to 10 per cent. to make allowance for acceleration and switching movements at each end. The final value is then divided by the total time, and the square-root extracted. The characteristic curve gives the continuous current capacity, which can be compared with the final result obtained.* The capacity of the equipment should not be based on h.p. per ton weight of locomotive, since the 1-hr. rating of the motor is no indication of what its performance will be under certain given conditions.

298. An electric reel is sometimes applied to a gathering locomotive so that it can be taken into rooms where no trolley wire is erected. This reel may be chain driven from one of the axles or motor driven from a small independent special motor which maintains a constant pull on the cable. This cable may be single-conductor or double-conductor, depending upon the track conditions. A No. 4 A.W.G. cable is generally used.

299. A traction reel can also be supplied on a gathering locomotive. It consists of a small motor-driven crab with from 300 to 400 ft. of steel cable. This type of reel is used where the room grades are very steep, and are driven to the dip.†

300. The storage-battery locomotive is rapidly coming to the front for gathering purposes. Until recently the storage battery was not rugged enough to stand the rough service that exists in mining conditions. Two types of battery are now available for this work, the lead-cell and the Edison. The iron-clad Exide is the most satisfactory type of the lead cells. The efficiency between battery and locomotive wheels will range from 60 to 66 per cent. In order to calculate the proper battery to use, the entire trip should be divided into as many sections as there are different characteristics. The car friction should be taken at 30 lb. per ton, and the tractive effort 20 lb. per ton for each per cent. of grade. The total tractive effort multiplied by *three* will give the watt-hours per train mile. The total watt-hours per round trip can thus be obtained. The total watt-hours divided by the voltage of the battery will give the ampere-hours of the battery. For a lead cell the voltage per cell will be 2, and to calculate the number of positive plates per cell, the ampere-hours should be divided by 31.5. The proper size of Edison cell can be selected from the ampere-hours required. Batteries for this kind of service are rated on a 4.5-hr. basis. The size of either type

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* For a more detailed explanation of the determination of weight and equipment of a mine locomotive see article, *Electric Journal* of March, 1912, entitled "The Determination of Weight and Equipment of a Mine Locomotive," by Graham Bright. (This article gives an example with complete set of calculations.) Also see *Coal Age*, issues of March 6 and March 20, 1915.

† Additional information regarding gathering locomotives can be obtained from articles printed in the *Electric Journal*, Vols. VIII and IX, by G. W. Hamilton.

of battery can be reduced considerably if noon-hour charging, or other short-time boosting charging can be effected.

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REFRIGERATING PLANTS

BY AUGUSTUS C. SMITH

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302. Motors adaptable to refrigerating service. Ammonia compressors and auxiliary apparatus in refrigeration plants may be driven either by direct-current motors or by induction motors. The flexibility of speed control of the direct-current motor offers an advantage, but the possibilities of speed control of the induction motor together with the characteristic advantages of this type are sufficient reasons to justify its selection where alternating current is available.

303. Motor speeds and speed control. Motors for the operation of ammonia compressors should be of the variable-speed type, so that where the operating conditions require it, suitable speed control can be secured. Compressors of 50 tons capacity, and over, are operated usually at about 70 rev. per min., so that a motor speed of 500 rev. per min. or less, is desirable.

304. Multispeed motors. With the two-speed motor, the compressor can be operated at full speed and at half speed; while with the three-speed motor, it can be operated at full speed, two-thirds speed and one-third speed. This method of speed control, however, provides for changes in the compressor at fixed and predetermined steps only, and does not, therefore, provide for the flexibility in speed control necessary to meet the usual requirements in the operation of refrigeration machines.

305. With the slip-ring type of motor and resistance speed control flexibility of operation equivalent to that of the steam compressor is attainable. The power-factor of this motor remains practically constant at all speeds, but the efficiency falls off with the reduction in speed; operating the compressor continuously, at reduced output, with this type of motor, is therefore uneconomical from a power-consuming standpoint.

306. Plant duplication. In plants where it is necessary materially to reduce the output, during certain periods of the year, it is desirable to employ more than one compressor unit. This is especially true in large refrigeration plants, where the total compressor capacity should be divided among individual units, properly proportioned according to the required operating conditions.

307. The standard rating for ammonia compressors is based on 15 lb. suction pressure, 185 lb. condensing pressure, and condensing water at 70 deg. Fahr. (21 deg. Cent.). The power necessary to drive a compressor varies directly with the operating pressure, the horse-power being determined by indicator card.

308. Power requirements per ton. Ammonia compressors operated at 15 lb. suction pressure and 185 lb. condensing pressure, having a rated capacity over 5 tons of refrigeration per 24 hr., require about 1.5 h.p. per ton of refrigeration; compressors having from 5-ton to 1-ton capacity, operated under like conditions, require from 1.5 h.p. to 2 h.p. per ton. Increasing the above pressures to 25 lb. suction, and 200 lb. condensing pressure, would increase the power necessary to operate the compressor about 16 per cent.

309. Varying pressures and output requirements. In the daily operations of a refrigerating plant, it is frequently necessary to operate a compressor at increased pressures. In some localities during warm weather the temperature of the condensing water will exceed 70 deg. Fahr. (21 deg. Cent.), and during extremely warm weather it may be necessary to force the compressor beyond its rated capacity in order to meet unusual requirements, all of which require increased power. For compressors of 50-ton rated capacity and smaller, about 25 per cent. additional motor capacity should be provided for these possible excessive operating conditions; for larger compressors,. from 15 to 25 per cent. additional motor capacity should be provided, depending upon the local and probable operating conditions of the plant.

310. Classification of ice-making plants. Ice-making plants may be divided into two classes: those making ice from **distilled water**, and those making ice from **raw, or natural water**. The former method uses the **can system**, while the latter may use either the can system, or the **plate system**. The compressor-room equipment for an ice plant of equivalent capacity is the same for all of these methods, except for the plate system, where about 15 to 20 per cent. more compressor capacity is required.

311. Operating data on 90-ton can-system ice plant using distilled water

Month	Maximum input (kw.)	Input (kw-hr.)	Tons of ice made
January	115	92,530	2,033
February	102	65,080	1,493
March	97	71,870	1,737
April	192	133,550	3,055
May	209	139,550	3,742
June	230	145,686	3,291
July	218	157,640	3,657
August	230	156,700	3,579
September	219	160,250	3,408
October	205	154,090	2,989
November	112	76,460	1,792
December	122	91,210	2,226
Total	....	1,444,616	33,002

312. Equipment of plant using can system. The compressor-room equipment in this plant (Par. **311**) consisted of two vertical 16-in.×24-in. double-cylinder single-acting ammonia compressors of 70 rev. per min., at full-speed. Each of these compressors had a rated capacity of 45 tons of ice per 24 hr., when operated at 15 lb. suction pressure and 185 lb. condensing pressure, with condensing water at 70 deg. Fahr. (21 deg. Cent.). Each was belt-driven by a 175-h.p., 500-rev. per min., 3-phase, 25-cycle, 2,200-volt, variable-speed, slip-ring induction motor. The speed control consisted of a 13-step drum controller, and iron-grid resistance of sufficient capacity to permit the continuous operation of the motor at any speed from full speed to one-half speed continuously.

the ice from the cans; 1 7.5-h.p. motor direct-connected to brine agitator. The distilled water used is furnished from a 10-h.p. boiler operated at from 10 to 15 lb. steam pressure.

318. Operating data on plant using centre-freeze system. The first complete month's operation of the above plant showed a total maximum demand of 125.8 kw., with an energy consumption of 91,056 kw-hr., and a production of 1,599 tons of ice. This is equivalent to a resultant maximum demand of 2.42 kw., or 3.24 h.p. per ton of ice, and 57 kw-hr. per ton of ice.

319. The Audiffren-Singrun refrigerating machine in its completed form, as placed on the market, is in reality a self-contained refrigerating plant, and is especially adapted for use in restaurants, butcher shops, clubs, apartment houses, and large residences, or where the average requirements may run from 10 to 100 lb. of ice per hr., or the refrigeration effect equivalent to the melting of from 15 to 100 lb. of ice per hr. The ideal method of drive is the electric motor, which can be of any type.

This machine operates on the compression system, using sulphur dioxide which condenses at a very low pressure, as the refrigerating medium. The principal element of this machine consists of a shaft on which two drums are mounted, and the driving pulley. One of these drums, located at about the mid-point of the shaft, contains the condenser, and revolves in a tank of running water which serves to carry off the heat absorbed. The other drum, in which expansion of the sulphur dioxide takes place, is connected to the condenser drum by a bronze pipe (which forms part of the shaft), and revolves in a tank containing either the brine or the water to be cooled.

The air is entirely exhausted from these drums, and, after having received the proper charge of sulphur dioxide and necessary lubricating oil, they are hermetically sealed, thus absolutely protecting all of the vital working parts from any outside element which might cause their wear or depreciation, and further making it impossible for any unskilled operator to tamper with the mechanism of the machine.

320. Rating and operating characteristics of the Audiffren-Singrun refrigerating machine, when operated under average conditions of brine at 27 deg. Fahr. (−2.8 deg. Cent.) and condensing water (at outlet) at 77 deg. Fahr. (25 deg. Cent.).

	Machine number			
	2	3	4	6
Capacity in B.t.u. absorbed per hr....	2,260	5,640	11,280	22,560
Capacity in pounds of ice per hr......	10.5	26.0	52.0	105.0
Hours necessary to produce refrigeration equivalent to melting 100 lb. of ice.	6.38	2.55	1.28	0.64
Horse power required...............	0.55	1.26	2.15	4.3
Horse power of motor recommended..	0.75	1.50	3.0	5.0
Kw-hr. required to produce refrigeration equivalent to melting 100 lb. of ice.	2.63	2.39	2.09	1.57
Kw-hr. required to produce 100 lb. of ice.	3.92	3.62	3.15	2.34
Water at 68 deg. Fahr. (20 deg. Cent.) required, in gal. per hr.	40.0	100.0	200.0	400.0

To obtain actual power and energy consumption of motor, divide the above power values by the efficiency of the motor.

TEXTILE MILLS

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321. Mechanical drive from steam plant. If the power plant can be centrally located, the mechanical drive with a belt or rope tower, is most efficient. By this arrangement energy is imparted to the shafting on each floor directly. The steam plant usually proves the most flexible of the stopped individually, doffing and empty bobbin replacing may be accomplished without stopping more than one frame at a time. Ring spinning and twisting may well be treated similarly to fly frames, although here again individual motors may be used.

330. Looms are perhaps the most susceptible to power variations of any textile machinery. The power to drive a loom varies with the speed of the loom, usually expressed as so many picks per min., a pick being one strand of filling left in the warp by a traverse of the shuttle. While there are so-called positive shuttle looms, most shuttles are thrown across the lay of the loom by a blow of the picking stick. As the shuttle enters the box at the end of its traverse, it pushes out one side of the box, called the swell, which operates a stop motion; when the shuttle does not properly enter the box, the swell is not displaced and this is called "banging off." The speed of the shuttle must therefore be sufficient to accomplish this, yet not so much as to cause rebound. The adjustments vary with the speed. The power to drive a loom also varies with the weight of goods, the beat-up, the number of harnesses and boxes in use.

331. Advantage of motor drive for looms. Overhead shafting and belts are objectionable on account of the damage likely to occur from flying slugs, oil, etc. As looms must be stopped and started continually, and as they start under full-load immediately, belts in weaving rooms require much attention if high efficiency is to be maintained. The shafting can be put below the floor, and long lines reduced by group drives, but the belt from shaft to loom remains. The individual motor obviates practically all of these troubles. It may be arranged to drive through a clutch or be geared directly to the loom. In the first case the motor is kept running all the time, while in the second case it is started and stopped with the loom. The shipper handle of the loom is connected with the control switch of the motor, so that the operative has nothing new to learn. A direct-connected motor must start instantly with full-load torque. The induction motor with small slip has, then, an advantage over belted drives in cleanliness and in constant speed. **Variations in angular velocity** are undoubtedly less in the case of direct electric drives than with belted drives, as shown by tachometer readings.

332. Power requirements for cotton-mill machinery.

Gins saw	10 saws per 1 h.p.
Gins roller 40 in.	1.25 to 3 h.p.
Bale opener	2.0 to 3 h.p.
Hopper feeder	1.50 to 3 h.p.
Thread extractor	2.0 to 4 h.p.
Single cylinder beater	3.0 to 4 h.p.
Two cylinder beater	6.0 to 8 h.p.
Top flat card	0.20 to 0.33 h.p.
Revolving flat card, 40 in. Production per hr.	
7 lb.	0.75 h.p.
9 lb.	1.0 h.p.
12 lb.	1.25 h.p.
Sliver lapper	1.0 h.p.
Ribbon lapper	1.0 h.p.
Comber, 6 heads	0.50 h.p.
Comber, 8 heads	0.75 h.p.
Railway head	0.33 h.p.
Drawing frame, 1 head	0.25 h.p.
Drawing frame, 5-head metal rolls	1.0 h.p.
Drawing frame, 6-head plain rolls	1.0 h.p.

Speeders,	Spindles per h.p.
Coarse	30
Intermediate	42
Fine	48
Slubber fly-frame; spindles per h.p.	50
Intermediate	60
Fine (roving)	90
Jack (fine)	110
Spinning-frame warp, 16's and coarser spindles per h.p.	70
22	75
40	80
60	90
80	100
Filling	
Spindles 8,500 rev. per min.	85
Spindles 9,700 rev. per min.	80
Twister sp. per h.p. 6,500 r.p.m.	80
Filling winder sp. h.p.	300
Spooler	200 to 300
Mule	100 to 120
Warper h.p.	0.25
Denn warper	1.00
Baller h.p.	0.50
Slasher (drum) h.p.	1.50
Plain loom narrow light	0.33
Fancy loom wide heavy	1.0
Reel 50 sp.	1.0
Brush and shear	3.0
Folder	0.25

PAPER AND PULP MILLS

BY JOSEPH H. WALLACE

Industrial Engineer, Member, American Society of Mechanical Engineers

338. General application. Motors are generally well adapted for driving pulp- and paper-making machinery where the source of power is steady and reliable and will insure continuous operation of the plant. The choice of the grouping method (group drive), or the assembling of several machines to be driven by one motor through shafting and belting, and the unit method (individual drive), or the driving of each machine by its individual motor, will be determined by local conditions of layout and the probability of one or more machines in a group requiring operation while others in that group are shut down. Where machines can be assembled in groups that are easily served by short lines of shafting, the grouping method is more often to be preferred. The motor units then become larger, and being fewer in number, installation and maintenance costs are reduced, and speed reductions are more easily secured without the use of countershafts or gears. The unit method is preferable in case of large machines or where direct-connected apparatus can be used, and in places where points of power demand are scattered and would involve long lines of shaft to group the machines together. It affords convenience in locating machines in places desirable from the operator's standpoint, and is preferable where individual control of machines is frequently required.

339. Equipment adaptable to motor drive. In the equipment of paper and pulp mills specially suited to motor-drive can be included the following: flat and centrifugal screens, stuff pumps, suction-box pumps, white-water and effluent pumps, water-supply pumps, winders, rewinders, cutters, refining engines, elevators, exhaust fans, kollergangs, agitators, mixers, slushers, concentrators, savealls, wet machines, rotary digesters, rotary boilers, conveyors, shredders, chippers, supercalenders and beaters.

340. Jordan engines. The application of motors for driving Jordan engines is very successfully accomplished by direct connection. The motor is mounted on an extension of the Jordan base, and mechanical arrangements provided for the movement of the Jordan plug either by a coincident movement of the motor, or by a special form of coupling connecting the motor with the Jordan shaft. In the refinement of paper stock much depends upon the pressure put upon the Jordan plug as it rotates within its shell or casing. The power required is influenced by the pressure applied, and a good indication of what the refiner is doing is presented by the readings of a wattmeter placed in the feeder circuit to the motor. When power-factor correction is necessary or desirable, the direct-connected Jordan engine presents an excellent opportunity for attaching a synchronous motor large enough to provide for the required condensing effect. Jordan engines are started without the working load applied, and the friction load is usually within the capacity of self-starting synchronous motors.

341. Beaters. The question of driving beaters and other large units electrically will be largely affected by the elements entering into the generation of energy. Beaters are usually grouped, and driving can be economically accomplished through main line shafting. Considerable quantities of power are required within comparatively narrow limits, and conditions are often in favor of steam engine drive instead of motor drive, where the power can be developed in efficient slow-speed compound condensing steam engines located in close proximity to the beater room. This method is especially favorable where electric power is generated with steam-driven equipment. Mills deriving electric power from hydroelectric plants can usually adopt the motor drive for beaters with success.

342. Fourdrinier and cylinder paper machines that require variable speed, and steam for drying purposes, are driven best by variable-speed steam engines, using the exhaust steam for drying the paper. Pulp grinders are seldom driven by electric motors; the power requirements are so great that the method almost invariably accepted as the best is to attach the grinders direct to a water-wheel shaft.

343. Types of motor suitable. In general polyphase alternating-current (induction) motors give the best satisfaction in pulp and paper mill service where constant speed is desired. In cases where variable speeds are true in the case of beaters and Jordans, when a variety of product is made in the same mill. Loads will frequently vary 100 per cent. in the treatment of different stocks, and the most careful judgment is required in the selection of motors that will meet the maximum demand, as this condition may exist for much longer periods than the overload capacity of a motor for the average load would allow.

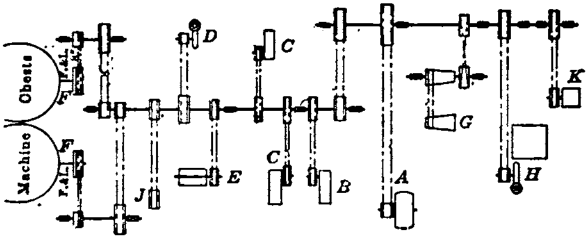

FIG. 36.

A—100-h.p. three-phase induction motor, 330 rev. per min.
B—16-in. by 18-in. vacuum (suction box) pump.
C—14-in. by 12-in. vacuum (suction box) pump.
D—8-in. fan pump (stock to screen).
E—10-in. by 10-in. triplex stuff pump.
F—Agitators in machine stuff chests.
G—Fourdrinier shake.
H—6-in. centrifugal for back water.
J—Three 12-plate screens.
K—Rotary vacuum pump for suction couch roll.

349. Power required by the constant line, operating in connection with a 104-in. Fourdrinier machine (Fig. 36). Power input was derived from wattmeter in feeder line to motor.

Kw. input	Amp. per phase	Volts	Power-factor	B.h.p. (motor efficiency, 90 per cent.)
65	99	440	0.87	78.4 h.p.

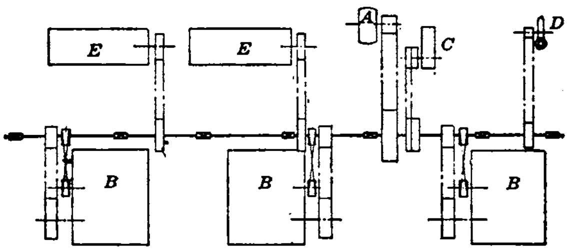

FIG. 37.

A—50-h.p. three-phase induction motor 570 rev. per min.
B—Three 72-in. wet machines.
C—14-in. by 12-in. vacuum pump.
D—Centrifugal pump.
E—Two 10-plate screens.

350. Test on group of wet machines (Fig. 37). Machines in operation—one wet machine, two screens, vacuum and centrifugal pumps and shafting. Power input derived from wattmeter readings in feeder line to motor.

355. Summary of approximate power required by paper-making machinery

Constant speed line or pump line on paper machine	40–125 h.p.	Stuff pumps	5– 10 h.p.
Fourdrinier paper machines (variable speed parts)	50–400 h.p.	Chippers	75–100 h.p.
Beaters	30– 75 h.p.	Crushers	25 h.p.
Jordan engines	50–300 h.p.	Barkers	10– 12 h.p.
Screens, flat platescreens	4– 6 h.p.	Grinders	250–350 h.p.
Wet machines	8– 12 h.p.	Centrifugal screens	10– 15 h.p.
		Supercalenders	50–100 h.p.

PRINTING, BINDING AND LINOTYPE MACHINERY

BY CHARLES E. CARPENTER

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356. Control. There is a rapidly growing tendency among the manufacturers of printing machinery to equip their motor-driven machinery with self-starters and self-starting, predetermined-speed-adjusting controllers, operated either directly from the line (service) switch or by the operation of one or more push-button or hand-control stations.

357. Job or platen presses, from the smallest to the largest size, on account of their large inertia, require a motor much larger to start than to operate them. In the following table the motor sizes are ample, although under normal printing conditions the machines require about half the rated motor horse power, or even less. The best practice is to obtain about 40 per cent. speed reduction below normal by armature resistance and about 25 per cent. increase above normal by field control. This is accomplished by the use of a predetermined-speed-adjusting self-starting controller, usually supplied with a self-contained line switch for starting and stopping (Fig. 38).

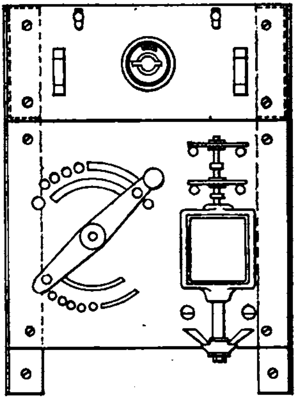

Fig. 38.—Starter-controller with self-contained line switch.

358. Power required by job or platen presses

Size: inside chase	Maximum impressions per hr.	H.p.
8 in. × 12 in.	2,800	0.25
10 in. × 15 in.	2,500	0.25
12 in. × 18 in.	2,250	0.33
13 in. × 19 in.	2,100	0.33
14 in. × 20 in.	2,000	0.50
14½ in. × 22 in.	2,000	0.75
17 in. × 22 in.	1,700	1.00
Automatic feed, high speed		
13 in. × 19 in.	3,500	1.5

press near the floor, convenient for operation from a point beneath the press. Where automatic feeders are used, a "Feeder clutch switch" should be attached to the clutch rod for automatically slowing down the press when the feeder clutch trips, and for automatically accelerating the press back to its predetermined speed when the feeder clutch rod is again thrown in, thus eliminating the necessity for operating push buttons or other starting devices. Reversal is only an occasional performance, and a double-pole two-way knife-blade switch for reversing the armature connections can be placed under the running board.

362. Power required by rotary lithographic presses

Size of sheet	Normal impressions per hr.	H.p.
Zinc or aluminum		
32 in.×45 in.	2,000	4
42 in.×53 in.	1,800	5
45 in.×65 in.	1,500	5
50 in.×65 in.	1,400	5
Offset		
22 in.×28 in.	4,000	2
26 in.×34 in.	3,000	3
30 in.×42 in.	2,800	4
34 in.×46 in.	2,500	5
38 in.×52 in.	2,400	6
44 in.×64 in.	2,000	10

363. Rotary typographical presses (not newspaper presses) are divided into two classes, sheet-feed rotaries and magazine rotaries. The sheet-feed rotaries range in power requirements from 5 h.p. to 10 h.p., and require non-reversing self-starting, predetermined-speed-adjusting push-button controllers, similar to those for rotary lithograph presses. On account of the high speed at which these presses are operated, it is essential that they be equipped with a very efficient quick-acting dynamic brake to prevent damage to the plates, etc., in case the feeder trips out for any cause. Magazine rotaries require from 7.5 h.p. to 25 h.p. motors, used in conjunction with push-button controllers. The smaller size may be used with a predetermined-speed-adjusting controller, Fig. 39, but a better equipment, especially for larger presses, would be a controller where the press may be accelerated or retarded from several interlocking (safety) push-button stations.

364. Embossing presses of various sizes require moderate-speed compound-wound motors from 1 h.p. to 15 h.p., arranged with from 25 to 50 per cent. field (speed) control, and should be used in connection with a self-starting predetermined-speed-adjusting controller without dynamic brake, controlled from one or two push-button stations for "run, stop and inch."

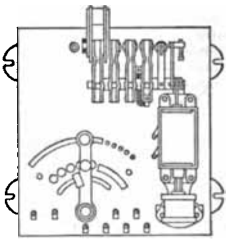

Fig. 40.—Controller for large folders.

365. Folders of the type generally used in printing offices require moderate-speed shunt-wound motors from 0.5 h.p. to 3 h.p., with combined armature and field control; 20 per cent. field (speed) control and 50 per cent. armature control may be considered good practice for ordinary requirements, without dynamic brake. For 0.5 h.p., 0.75 h.p. and 1 h.p. sizes the controller shown in Fig. 38 should be used; this may be controlled from the line switch. For larger sizes the controller shown in

372. Power requirements of individual machines

Mill proper		
	H.p. each	H.p. total
19 10×42 Style AA roller mills Corr.	17	324
20 10×36 Style AA roller mills smooth	20	400
12 80 in.×77 in. vibromotor universal bolters	3	36
20 8-ft.×32-in. centrifugal reels	4	80
4 8-ft.×32-in. round reels	3	12
22 7-ft.×30-in. purifiers	2.5	55
10 7-ft.×32-in. purifiers	2	20
5 aspirators for 7×40 purifiers	0.5	2.5
4 8-ft.×32-in. flour dressers	3	12
6 No. 7 bran and shorts dusters	8	48
2 70-in. double steel plate fan	27	54
2 55-in. steel plate fan	15	30
1 40-in. single steel plate fan	8.5	8.5
53 elevators	1	53
25 dust collectors	0.33	9
Total		1144

Wheat-cleaning department		
	H.p. each	H.p. total
1 No. 4 comp shake Dbl receiving separator.	8	8
2 No. 5 comp shake Dbl receiving separator.	10	20
8 No. 90 milling separator	10	80
1 No. 7 automatic magnetic separator	0.125	0.125
1 No. 8 standard aut magnetic separator	0.125	0.125
2 No. 10 standard aut magnetic separator	0.375	0.75
1 No. 8 2 high scourers	40	40
2 No. 9 2 high scourers	50	100
1 No. 31 dust collec. for grinder	0.33	0.33
3 No. 32 dust collec. for grinder	0.33	1
4 No. 33 dust collec. for grinder	0.33	1.33
1 No. 36 dust collec. for grinder	0.33	0.33
4 No. 46 dust collec. for grinder	0.50	2
2 32-in.×8-ft. round reels with drums	3	6
1 30-in. attrition mill	60	60
1 45-in. double steel plate fan	14	14
16 conveyors	....	6
Total		340

BEET-SUGAR MILLS

BY WIRT S. SCOTT, M.E. IN E.E.,

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373. Power requirements. With electric motors properly applied, the total power consumption should not be over one-half of that required for steam-engine-driven factories. The machines of the types mentioned in Par. 374 to 392 inclusive, vary in size according to the individual requirements, but the examples cited will serve as a guide as to the average practice.

374. Beet lift. Sixteen feet diameter by 2 ft. wide, with 33 buckets 12 in. deep, making 4 rev. per min., driven by pinion meshing with 8 ft. gear on lift; 10 h.p. required, at constant speed, with high starting torque.

375. Beet washer. Six feet diameter by 18 ft. long, with thirty-two 24-in. arms or paddles. Shaft makes 14 rev. per min.; 7.5 h.p. required, at constant-speed and with a moderate starting torque.

376. Beet elevator. Thirty-four buckets, 22 in. wide by 17 in. deep, V-shaped; 70 to 120 ft. per min.; 10 to 20 h.p. required, at constant speed, with moderate starting torque.

377. Beet slicer. Capacity 50 tons per hr., 55 rev. per min.; 25 h.p. required, at constant speed, with high starting torque.

378. Cossette conveyor. Capacity 60 tons per hr., belt 12 in. wide by 125 ft. long; belt speed, 250 ft. per min.; 5 h.p. required, at constant speed, with light starting torque.

379. Sugar mixers. Shaft 50 ft. long, 12-in. paddles, speed 1.5 rev. per min.; 10 h.p. required, at constant speed, with moderate starting torque.

380. Tube mill or granulator; 6 ft. diameter by 30 ft. long, 10 rev. per min.; 10 h.p. required, at constant speed, with high starting torque.

381. Bagging machinery. Bag-sewing machine, requires 2 h.p.; bag stacker, requires 3 h.p.

382. Pumps. Hydraulic gasket pump, for operating doors on bottom of diffusion batteries, requires 5 h.p. Carbonation pump, 450 gal. per min., 50 lb. pressure, requires 25 h.p. Thick juice pumps, 450 gal. per min., 30 lb. pressure, requires 10 h.p.

383. Crystallizers. Ten feet diameter by 16 ft. long; paddles 4.5 ft. long secured to driving shaft which makes one revolution in 5 min. The power required varies considerably during the cycle of operation, the amount required at the completion of the operation being almost double that required at the start. For this reason the machines are best driven in groups of from four to eight, by one motor. For driving an individual machine, from 2.5 to 3 h.p. is required at the beginning of the cycle, and 5 h.p. at the end. Since the complete operation may require 60 hr., a motor must have sufficient capacity to operate at maximum capacity continuously, with individual drive. Where crystallizers are driven in groupe of from four to eight machines, 3 h.p. per crystallizer will be sufficient.

384. Centrifugals. The sugar centrifugal is one of the most important machines in sugar making, the operating conditions of which are very severe due to the inertia of the load and the cycle of operation. The time required for the complete spinning process varies with the grade of sugar. Ordinarily one man can operate two centrifugals on granulated sugar and up to four centrifugals on white sugar. When these machines are to be individually driven the cycle of operation must be known, as the rating of the motors will depend upon the root-mean-square value of the power requirements, and the torque required for accelerating in a given time.

385. Average cycle of operation of group-driven centrifugals with fine granulated sugar. The average time required is as follows: filling, one-fourth speed, 30 sec.; accelerating, one-fourth to full speed, 10 sec.; full speed, 120 sec.; power off, retarding by braking, 20 sec.; revolving at about 25 rev. per min., 30 sec.; total time, 3 min., 30 sec.

386. Average cycle of operations of individually driven centrifugals with fine granulated sugar. Filling basket, revolving by hand, 10 sec.; accelerating, 100 sec.; full speed, 30 sec.; power off, retarding by braking, 20 sec.; stop, unloading by hand, 60 sec.; total time, 3 min. 40 sec.

387. Average cycle of operations of individually driven centrifugals with coarse granulated sugar. Filling basket, revolving by hand, 10 sec.; accelerating, 60 sec.; power off, retarding by braking, 20 sec.; stop, unloading by hand, 60 sec.; total time, 2 min. 30 sec.

388. Average cycle of operations of individually driven centrifugals with coarse white sugar. Filling basket, 25 sec.; accelerating, 100 sec.; full speed, 15 min.; power off, braking, 30 sec.; stop, unloading by hand, 145 sec.; total time, 20 min.

389. Group-driven centrifugal machines furnish a very satisfactory arrangement, whereas individual drive, although successful, has been used to a much lesser extent. The character of the load is very similar to that of a fly-wheel, so that with these machines arranged in a group and driven by one motor, the centrifugals in operation will help to bring the idle machines up to speed and maintain a uniform load on the motor. This can best be shown by the following data. A group of ten 40-in. centrifugal machines, driven by a 100-h.p. motor, with 1 machine starting, requires 20.5 h.p.; with 2 machines starting, and 1 at full speed, 40 h.p.; with 3 machines starting, and 3 at full speed, 52.5 h.p.; with 4 machines starting, and 4 at full speed, 60 h.p.; with 1 machine at full speed 5.5 h.p.

390. When centrifugals are individually driven, the peak load is about eight times the normal running load; for a 40-in. machine the peak is approximately 40 kw. input, corresponding to about 40 h.p. output. Since at the very start the speed is zero, the horse power is zero, therefore the power required at start should be stated in terms of pounds torque at 1 ft. radius. The starting torque, together with the root-mean-square horse power for the cycle, furnishes sufficient data for determining the motor required.

391. The speed of a direct-connected centrifugal machine increases very rapidly at the start and at a much lower rate as the motor approaches synchronous speed. The motors are usually of the squirrel-cage type with high-resistance end rings designed to give approximately 15 per cent. slip at full-load; but, since full-load is never attained except at starting, the maximum speed which can be attained by the centrifugal is almost synchronous speed, and in nearly every case the operation is completed before the machine has attained its highest possible speed.

392. The torque necessary for starting a loaded centrifugal machine, and accelerating it to a given speed in a certain length of time can be determined by the following formula:

$$T = 2\frac{Wr^2}{g} \times \frac{2\pi N}{60 \times S} \qquad \text{(ft-lb.)} \qquad (8)$$

T = pounds torque at 1 ft. radius, W = weight in lb. to be accelerated, R = radius of gyration of entire mass in ft., N = rev. per min. machine will attain in S seconds, S = seconds required for accelerating.

The above expression does not take into consideration friction and windage, and it will be necessary to increase the result thus obtained by 10 per cent. in order to obtain the required starting torque.

LAUNDRY MACHINERY

BY FRITZ BALZER

Mechanical Engineer, Troy Laundry Mach'y Co. Ltd.; Member, American Society of Mechanical Engineers; Member, Verein Deutscher Ingenieure

393. Advantage of electric drive. The power laundry with its large number of different machines can employ electric drive to great advantage. The elimination of belts reduces the friction load of the plant, permits the convenient location of the different machines to reduce handling expenses, assures cleanliness and light, reduces danger of accidents and finally decreases the operating cost. From a number of tests all over the country this saving in operating cost appears to be from 25 to 30 per cent. Alternating-current polyphase induction motors are recommended wherever possible.

394. Use of steam in processes. When introducing electric drive in any laundry it must be kept in mind that a laundry requires a large amount of steam for drying and for the heating and boiling of water. This question is important in the controversy regarding the generation of electrical energy versus its purchase from a central station. In the latter event, steam must be produced independently of the source of power. A careful study of conditions must be made in order to determine which method is the more economical.

395. Classification. Laundries may be divided into three groups: (a) those doing family work only; (b) institution laundries (hotels and hospitals); (c) laundries doing railroad or steamship work only. Each of these groups has a different requirement for steam in amounts which can be expressed in terms of the horse-power requirements. Thus, for group (a) the number of pounds of steam used per hr. could be expressed as 1.2 times the horse power for that group; for group (b) 1.4 times the horse power; and for group (c) 1.8 times the horse power.

suitable double-throw switch, which makes and breaks connections with two relays of a contactor panel. The switch is so arranged, as to disconnect the relay between reversals, in order to allow the contactors to open the main circuit and permit the motor to slow down. The load factor of this group varies between 55 and 60 per cent.

402. Mechanical reversing devices for washers are best suited for group drive from one shaft by gear or chain. The reversals are obtained by clutches attached to two bevel gears which are driven by a third gear. The washer is so arranged that connection is shifted from one clutch to the other clutch. Three 36-in.×70-in. washers require one 7.5-h.p. motor of 900 rev. per min. Other sizes may be calculated from the data given above. The load factor is 75 per cent.

403. Extractors are machines employed to remove the water from the goods after washing. This is done by placing the pieces in a perforated basket and revolving the basket at a very high speed, whereupon the water is thrown out by centrifugal force.

404. Extractor speeds (Troy Laundry Machinery Co. Ltd.)

Basket diameter (in.)	Speed (rev. per min.)		
	Copper	Steel	Monel metal
20	1,400	1,600	1,800
24	1,200	1,400	1,600
26	1,100	1,350	1,500
28	1,000	1,250	1,300
30	900	1,150	1,200
32	800	1,000	1,100
40	700	900	1,000
48	600	800	900

405. The power required to start an extractor is from two to three times the normal motor rating, but after the basket reaches its proper speed the power consumption drops very rapidly to only a fraction of the motor rating. The table below gives the necessary data for Troy machines with copper baskets, if run at the above speeds (Par. **404**). The power required to start the machine varies exactly as the square of the rated full speed.

Basket diameter (in.)	Rating of motor (h.p. intermittent)	Horse power at starting	Horse power running	Acceleration period (min.)
20	1.0	2.5	0.33	0.75
24	2.0	4.2	0.5	0.85
26	2.0	4.7	0.65	1.0
28	3.0	5.5	0.85	1.1
30	3.0	6.0	1.0	1.2
32	5.0	8.0	1.5	1.5
40	5.0	9.0	2.0	1.5
48	7.5	10.0	3.0	1.5

The above data were compiled from the results of a large number of tests; different loading, maintenance and speed conditions will, however, change these figures. The average load factor is 35 per cent.

406. Starchers are built for both collar and cuff work as well as shirt work. A great many types are on the market, the commonest machines being enumerated below. All direct-current motors should be enclosed on the pulley end to prevent the entrance of spray starch. For direct-current as well as for alternating-current they should be of the constant-speed, non-reversing type. The load factor is about 50 per cent.

driven, while the small finishing machines are belted from a line shaft attached to the finishing table.

Collar and cuff ironers, for the most part, require no special motors. However, in the case of steam-heated ironers, it may be sometimes desirable to use variable-speed motors, in order to choose the speed best adapted to the steam pressure, should the latter be changeable. The load factor is 55 per cent.

412. Power requirements of collar and cuff finishing machines

Troy No. 5....................	Gas-heated, 3 rolls, 24 in.	1.0 h.p.
Troy No. 5....................	Gas-heated, 3 rolls, 40 in.	1.5 h.p.
Troy No. 5....................	Gas-heated, 5 rolls, 24 in.	1.75 h.p.
Troy No. 5....................	Gas-heated, 5 rolls, 40 in.	2.0 h.p.
Troy No. 14..................	Gas-heated..............	1.0 h.p.
Troy..........................	Steam-heated, all sizes....	0.75 h.p.
B. & E. No. 22...............	Steam-heated............	0.75 h.p.

Finishing table. The motor, which is of 0.5 h.p. capacity, is of the non-reversing constant-speed type, and geared directly to the line shaft, from which the small finishing machines are belted. The load factor does not exceed 45 per cent.

413. Shirt finishing machines. These machines are used to iron or press the neckband, bosom, sleeves and bodies of shirts. For each of these operations a special machine is used, in some cases there are several types of machine for each operation. See Par. **414** and **415**.

414. Bosom ironers. Three distinct types of bosom ironers are in use; first, the reciprocating type, where the bosom passes back and forth under a revolving drum; second, the one-way type, where the bosom travels in one direction only under one or more heated rolls; and third, the presses.

Reciprocating ironers require a motor of 0.5 h.p. Reversals may be obtained by means of reversing switches, in which case direct-current motors must be compound-wound and alternating-current motors must have high-resistance rotors. Reversals may also be accomplished by means of mechanical-reverse devices, in which case non-reversing, constant-speed motors should be used. The reverse switch, as well as the mechanical device, is actuated by a foot treadle and lever connections. The load factor for reversing motors is 75 per cent., and for the mechanical reversing type 55 per cent.

One-way machines require motors of 1 h.p. capacity, without any special features. The load factor is 55 per cent.

Presses are built in two types. In one case a reversing motor operates a screw, and through it a toggle. This motor has a capacity of 0.5 h.p. Should it be a direct-current motor, it ought to be compound-wound; should it be an alternating-current motor, it ought to be equipped with a high-resistance rotor. Single-phase motors cannot be used unless some kind of mechanical reversing device is employed. The load factor is 75 per cent.

The other type of press is operated by a fluid (usually oil) under pressure. A constant-speed, non-reversing motor of 0.5 h.p. capacity operates the pump. The load factor is 55 per cent.

415. Neckband ironers. For this service, small motors of from 0.125 to 0.25 h.p. capacity are required. There are no special features, and the load factor is 55 per cent.

Sleeve and body ironers. These machines are almost identical, their only difference being in respective size. All modern machines are reversing and, like bosom ironers, are reversed either electrically or mechanically. The sleeve ironers require a motor of 0.25 h.p. capacity; the body ironers, 0.5 h.p. If the reverse switch is used the motors must be built for reversing duty (compound-wound if for direct current, or having high-resistance rotors if for alternating current). Single-phase motors cannot be used for this service. If the mechanical reversing device is employed, standard motors without special features should be used. The load factor of reversing motors is 75 per cent., of the others 55 per cent.

416. Flatwork ironers or mangles are used to dry and iron flatwork by passing the goods under pressure over heated rolls or chests. With rolls, one or more aprons may be used to insure perfect contact of the goods over the resistance, or with one or both of these features. Such motors are necessarily series wound and possess a speed torque characteristic in general similar to a series-wound direct-current motor. Consequently, their application is limited to disc types of fans, blowers, electric tools, etc.

420. Service rating of motors. Obviously a motor which is required to operate under load for short intervals will not attain the temperature reached when operating at a similar load continuously. Consequently, for intermittent service, smaller motors may be employed than for continuous service. However, where the motor is frequently started and stopped, though the aggregate running time is small compared to the idle time, the heating may become excessive due to the frequent inrush of current incident to starting. The simplest method of arriving at the proper motor capacity is by actual trial of a sample motor, subjecting it to a cycle of operations which will be equivalent to the most severe service conditions.

421. Split-phase motor characteristics. In analysing the speed-torque* characteristics and other features of split-phase motors for purposes of application, Fig. 41, will prove of use in the calculation of approximate value.

422. Calculation of full-load torque, knowing the horse power and the speed, may be illustrated by the following example: find the full-load torque of a 0.75 h.p. motor running at 1,700 rev. per min. at full-load (1,800 rev. per min. synchronous speed). Find in Fig. 41 the intersection of the vertical line through 1,700 rev. per min. with the curve marked 0.75 h.p. (560 watts), and horizontally opposite this intersection at the left is the torque 36.5 ounce-feet.

423. Starting torque. Since the starting torque and the pull-out or maximum torque of a small split-phase induction motor are limiting features, care should be taken that the motor selected will start the driven machine under the severest conditions of torque. The starting torque varies approximately as the square of the applied voltage, and any reduction in voltage caused by the inrush of current incident to starting, and possibly emphasized by insufficient wiring or transformer capacity in commercial circuits, reduces very materially the starting torque delivered by the motor. It is customary to select a motor which will start the driven machine at a voltage of approximately 80 per cent. of the normal circuit voltage.

The starting torque and the maximum running torque can be found by multiplying the full-load torque by the proper constants. For example, if the starting torque of the particular motor considered in Par. **422** is 1.5 times the full-load torque, its value will be $1.5 \times 36.5 = 55$ oz-ft. Likewise if the maximum running torque of the motor is 2.5 times the full-load torque, its value will be $2.5 \times 36.5 = 91$ oz-ft. These constants must be determined from the characteristic curves of the individual motor, Fig. 41.

424. The horse power at maximum torque can also be determined from the curve if the speed is known. For approximate results the slip of small split-phase induction motors at maximum torque can be assumed to be 25 per cent. In the case of the motor discussed in Par. **423**, the speed at maximum torque will therefore be approximately 1,350 rev. per min. Find in Fig. 41 the intersection of the vertical line through 1,350 rev. per min. with the horizontal line through 91 oz-ft. torque; this is near the line representing 1.5 h.p., which is the approximate power developed by the motor just before pulling out, or stalling.

425. Input. The problem is to find input in watts, when given the horse power and the efficiency. Assume for example that the efficiency of a 0.75-h.p. motor is 75 per cent. Find in Fig. 41 the intersection of the vertical line through 75 with the 0.75 h.p. curve, and horizontally across from this intersection is the value 746 watts.

426. Current per phase. Knowing the watts input, the power-factor and the voltage, the problem is to find the current per phase (or per terminal); for example, assume that the power-factor of the foregoing motor is 70 per cent. and the voltage is 220 volts. Locate in Fig. 41 the intersection of the 70 per cent. vertical power-factor line with the diagonal representing 746 watts. The horizontal line passing approximately through this point, repre-

* Torque measured with brake-arm and scales at 1 ft. radius.

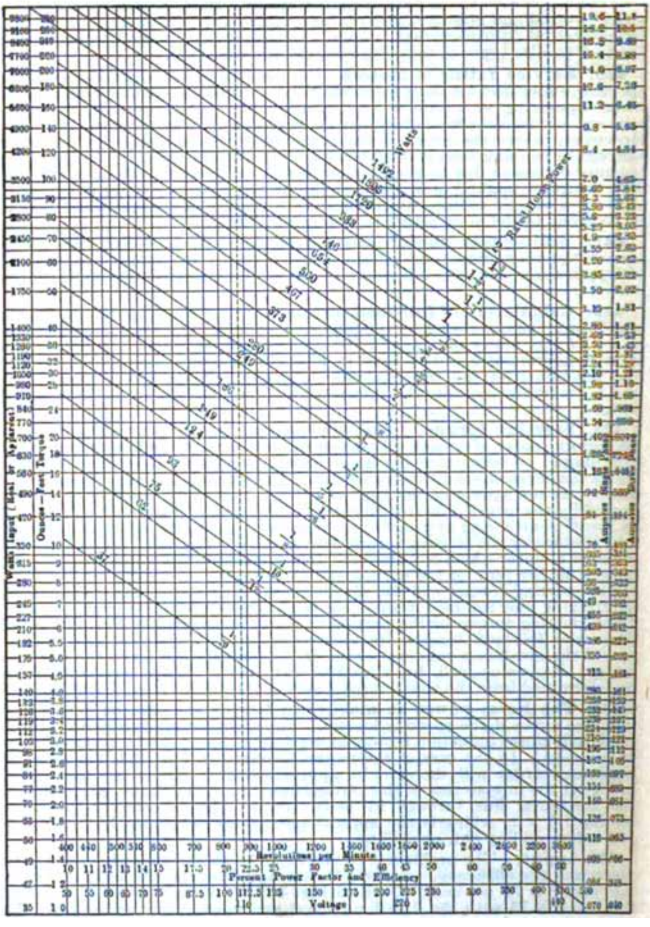

FIG. 41.—Characteristics of split-phase motors.

sents 1,050 apparent watts. Then from the intersection of the vertical line representing 220 volts with the diagonal representing 1,050 watts, the horizontal line representing amperes may be determined, namely, 4.8 amp. single-phase, or 2.8 amp. three-phase. The current per terminal in a two-phase motor is one-half that for a single-phase motor, and in this case would be 2.4 amp.

427. Approximate power requirements of small motor device machines used in the home, office and shop

Device		Motor			
Name	Capacity	Horse power	Starting condition	Rev. per min.	Belt
Air pumps	1 cu. ft. per min. air	1/4	Heavy duty	1,700	1 1/4 in. wide
Air pumps, 130 lb. pressure	2 1/2 cu. ft. per min.	1/2	Heavy duty	1,700	1 1/2 in. wide
Air pumps, 130 lb. pressure	4 1/2 cu. ft. per min. air	3/4	Heavy duty	1,700	2 in. wide
Air pumps, 135 lb. pressure	6 cu. ft. per min. air	1	Heavy duty	1,700	2 1/4 in. wide
Bread mixers	Household size	1/4	Stand. duty	1,700	5/16 in. dia.
Candy mixers	Small sizes	1/3	Heavy duty	1,700	1 1/2 in. wide
Centrifuges	Small sizes	1/10	Light load	1,700	1/4 in. dia.
Coffee grinders	2 lb. per min.	1/4	Heavy duty	1,700	1 1/2 in. wide
Coffee grinders	Household size	1/8–1/4	Stand. duty	1,700	1/4 in. dia.
Coffee roasters	25 lb. per min.	1/6	Light load	1,700	5/16 in. dia.
Duplicating machines	Average size for office	1/4	Stand. duty	1,700	3/8 in. dia.
Egg beaters	Household size	1/8–1/4	Stand. duty	1,700	1/4 in. dia.
Envelope sealers	Average size for office	1/20	Light load	1,700	1/4 in. dia.
*Ice cream freezers	2 quarts	1/4	Stand. duty	1,700	5/16 in. dia.
Ironing machines	Rolls 7×26 in. long	1/4	Heavy duty	1,700	5/16 in. dia.
Ironing machines	Rolls 7×42 in. long	1/3	Heavy duty	1,700	3/8 in. dia.
Mailing machines	Average size for office	1/20	Light load	1,700	1/4 in. dia.
Meat grinders	Household size	1/8–1/4	Stand. duty	1,700	1/4 in. dia.
Revolving window table	Depends on display	1/12–1/4	Stand. duty	1,700	1/4 in. dia.
Sign flashers	Small size	1/20	Light load	1,700	1/4 in. dia.
Sign flashers	Medium size	1/12	Light load	1,700	1/4 in. dia.
Sign flashers	Large size	1/4 and up	Light load	1,700	5/16 in. dia.
Small water pumps	120 gal. per hour	1/4	Heavy duty	1,700	3/8 in. dia.
Vacuum cleaners	Average portable	1/8	Stand. duty	1,700	5/16 in. dia.
Vacuum cleaners	Small stationary 600 r.p.m.	1/4	Heavy duty	1,700	1 in. wide
Vacuum cleaners	Aver. stationary 600 r.p.m.	1/2 and up	Heavy duty	1,700	1 1/4 in. wide
†Washing machines	9 sheets	1/3	Heavy duty	1,700	3/8 in. dia.
†Washing machines	6 sheets	1/4	Heavy duty	1,700	5/16 in. dia.
Water pumps	60 gal. per hour	1/2	Heavy duty	1,700	1 1/2 in. wide
Water pumps	720 gal. per hour	1	Heavy duty	1,700	2 1/2 in. wide

* Speed of freezer about 175 rev. per min.
† Includes wringer.

resistance. A typical starter* of this class is illustrated diagrammatically in Fig. 42.

The **no-voltage release** which is usually a part of the direct-current starter consists of the resistance-controlling lever (Fig. 42) normally held at the extreme left or in the open-circuit position by means of a spring, and an electromagnet in series with the shunt field of the motor, adapted to hold

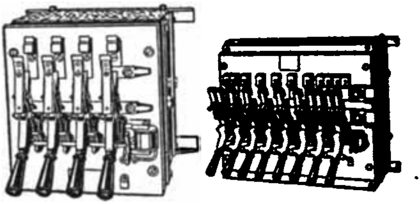

Fig. 43.—Direct-current starter for large motors.

the starting lever in the full-speed position as long as there is voltage on the line. In case of voltage failure this magnet will be de-energized, and the starting lever will return to its open-circuit position. This no-voltage release magnet is sometimes placed in the shunt-field circuit, and is sometimes connected across the line. The former arrangement is preferable because the motor circuit will be opened in case of failure of the shunt-field circuit.

In large capacities the use of a series of successively closed manually operated switches seems to be preferred by most controller manufacturers. Interlocks are usually provided which prevent the closure of such starting switches in any other than their regular order. Fig. 43 shows typical starters of this class.

431. Apportionment of resistance in direct-current starters. Fig. 44 shows the starting current required by a direct-current motor, it being assumed that a step of resistance is cut out each time the current falls to a predetermined value. For equal starting peaks the resistance must be divided unequally, the proper ratio between successive steps being a geometrical progression. The resistances of the steps, as well as the current peaks which will obtain, may be determined graphically from Fig. 44, where I_1 = initial inrush; I_2 = current at which a step of starting resistance is removed; I_3 = running current; r_0 = resistance of motor and its connections; R = external starting resistance. The ratios of progression with various numbers of starting steps, n, and for various values of α (which equals r_0/R) are given in the following tabulation:

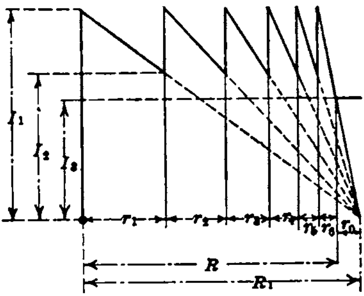

Fig. 44.—Direct-current motor starting current.

I_1 = Current peak.
I_2 = Current just before a step of resistance is cut out.
I_3 = Running current.
R_1 = Total resistance.
R = External or starting resistance.
r_0 = Resistance of motor and its connections.
$r_1, r_2, \ldots, r_n$ = Resistance of starting steps.

* No. 27. Par. 468.

connecting the stator winding, first across reduced potential obtained from the starting transformer, then directly to the line. In large capacities these induction starters are often arranged to operate in three or more steps, thus reducing the current surges. For moderate-capacity machines they are generally designed to connect the stator first across transformer taps which deliver from 40 per cent. to 75 per cent. of line potential, and then to the line. Induction starters are almost invariably arranged to disconnect the starting-transformer windings from the line in all positions except the starting position.

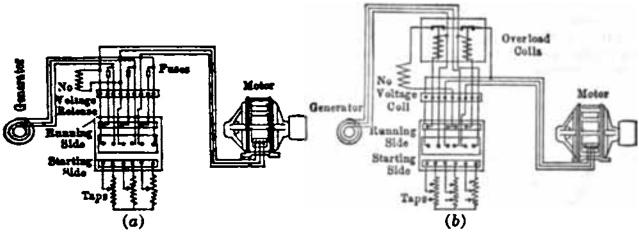

FIG. 47.—Induction starters for alternating-current motors.

Induction starters are also arranged to short-circuit the individual running fuses during starting. Sometimes the starting current is taken through auxiliary starting fuses of heavy capacity, but in most instances the motors are unprotected during starting. This class of starter is now almost invariably equipped with no-voltage release, and often with overload release which replaces the fuses. The overload release generally takes the form of overload relays which are adapted to open the circuit containing the no-voltage release magnet; this allows the switching mechanism to open the motor circuit. Where overload release is employed, the overload relays are individually short-circuited during starting. Fig. 47a is a connection diagram for a typical induction starter with no-voltage release and protected with fuses, while Fig. 47b shows the same device supplied with overload release.

In large plants one bank of starting transformers is sometimes employed for starting all motors, and a five-wire system is installed. Where this arrangement is employed the motors are first connected to a common line and two starting lines, and then directly to the distributing mains. Fig. 48 shows the arrangement described.

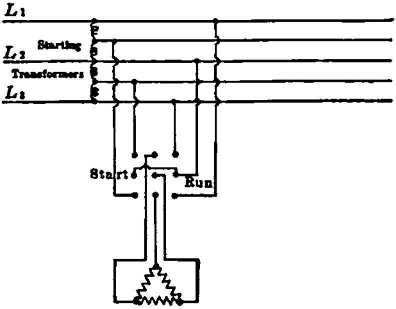

FIG. 48.—Five-wire system of starting alternating-current motors.

435. Secondary-resistance starters for alternating-current motors are used in connection with alternating-current slip-ring motors for the purpose of increasing the secondary impedance during starting, and are of the same general type as primary-resistance starters. Since slip-ring motors almost invariably have their secondaries wound polyphase, it is quite important that the starters used with such motors be designed to keep the secondary circuit as nearly in electrical balance as possible, for any unbalancing of this circuit reduces the starting torque which it is possible to obtain with a given line current. Generally speaking, unbalancing the secondary circuit 10 per cent. will reduce the possible torque by approximately 15 per cent.

In order to be quick acting and positive in operation, direct-current contactors should have coils which are capable of closing the switch with potential equal to 75 per cent. of normal impressed at the coil terminals, when the coils are at the operating temperature.

438. Alternating-current contactors are almost invariably called upon to handle two circuits simultaneously and are, therefore, almost invariably of the double-pole type. They are generally of the clapper form, but the magnetic circuit is necessarily laminated. Particular care should be taken to insure the holding of the laminations with sufficient rigidity to secure a permanent structure. The pull exerted by an alternating-current magnet is proportional to the square of the voltage impressed at its terminals, consequently it is not practicable to make alternating-current contactors which have the same operating range as direct-current contactors.

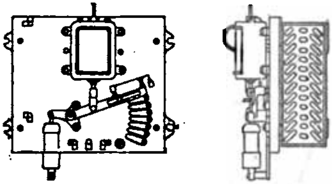

FIG. 50.—Direct-current time-acceleration starter.

It is practically impossible to obtain sufficient sealing pressure with alternating-current magnets to allow the use of laminated contacts, and, as a result, most alternating-current contactors depend upon butt contacts of copper for opening the circuit and for carrying the current when closed. Alternating-current contactors designed for voltages up to 550, are almost invariably equipped with magnetic blow-outs, and those built for higher potentials are generally arranged to open the circuit under oil. Air-break contactors have been made, however, for potentials up to 2,200 volts. These high-potential contactors are equipped with horn-type arc gaps, which permit the arc to increase in length until it reaches the point of disruption.

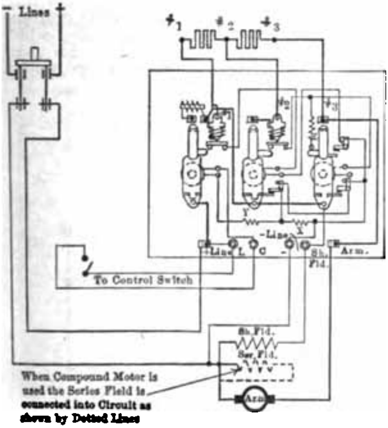

FIG. 51.—Series-relay current-limit self starter.

439. Time-acceleration self-starters are designed to accomplish the necessary starting operations in a predetermined and adjustable period. The timing may be accomplished in many ways, but a solenoid whose action is retarded by an adjustable dash-pot, is perhaps the most widely used device. A typical direct-current time-acceleration starter is shown diagrammatically in Fig. 50.

440. Current-limit self-starters are devised to halt the starting operation whenever the required starting current exceeds an adjustable predetermined value, the starting operation being resumed when the current falls below this limit. There are several forms of current-limit acceleration self-starters, and only those which are most widely used will be described.

441. A series-relay current-limit self-starter is shown in Fig. 51. It will be noted that the starting resistance is removed from the motor circuit by a series of successively energized magnetic switches or contactors. The motor circuit is initially closed by operating a control switch, thus from the positive line through the shunt-field windings, "f," to the negative line; also from the positive line through the armature, "A," the series field, "F," the resistance sections, "V_3" "V_2" "V_1," and the operating coil, "C_1" of the first series accelerating switch, to the negative line. If the initial current inrush is in excess of the value at which "C_1" locks open, no resistance will be cut out until the accelerating current has fallen to the point which will permit "C_1" to lift its plunger. When "C_1" lifts its plunger, switch "S_1" is closed, thereby short-circuiting resistance section "V_1" and including the winding "C_2." The operation of these series switches is progressive. When "C_3," the last of the accelerating windings, closes its switch "S_3," windings, "C_1," "C_2" and "C_3," are short-circuited and the shunt winding, "H_3," is connected in circuit directly across the lines. Winding "H_3" serves to hold "S_3" closed during running, thus guarding against the dropping out of the accelerating switches should the motor operate under light load.

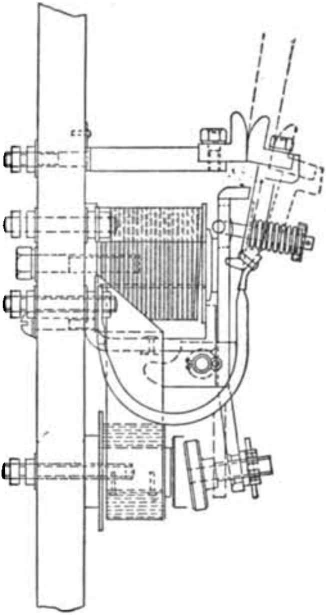

Fig. 54.—Magnetic lock-out switch.

443. The magnetic lock-out switch, illustrated in Fig. 54. is applicable to direct-current motors. It is a clapper-type switch of conventional form, operated by a series winding instead of shunt, and having a second series winding, separately mounted, adapted to act on a downwardly projecting extension of the switch clapper, and to hold the switch open as long as the force exerted by this secondary winding exceeds that of the closing coil. An adjustment is provided by which the air gap between the secondary or locking-out coil and its armature can be varied; thus the current above which the switch will be locked in an open position can be adjusted through a wide range.

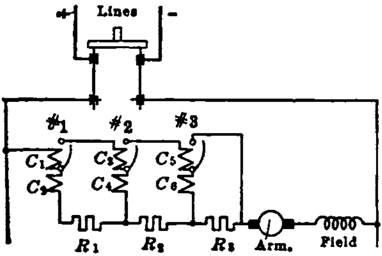

Fig. 55.—Starter comprising three magnetic lock-out switches.

Referring to the diagram, Fig. 55, which covers a simple starter consisting of three magnetic lock-out switches, it will be noted that when the line circuit is closed, the motor current passes from the positive line through the two windings of the first magnetic lock-out switch, thence through three sections of starting resistance to the armature of the motor to be started. As long as the current passing through these windings is in excess of a predetermined and adjustable value, the restraining force exerted by the lower or locking-out magnet will exceed the attractive force exerted by the upper or closing magnet, and the switch will maintain an open-circuit position. When the current has fallen below this predetermined value, the upper or closing magnet will develop sufficient pull to overcome the lock-out winding. As soon as the contacts of the switch engage, one section of the starting resistance is removed, and, with this section, the lock-out coil, so that any tendency which this coil might have to hold the switch in an open-circuit position is entirely removed. No. 1 accelerating switch, in closing, not only short-circuits a section of the resistance and its lock-out coil, but also automatically includes both windings of the second accelerating switch, which in turn locks open until the starting current has

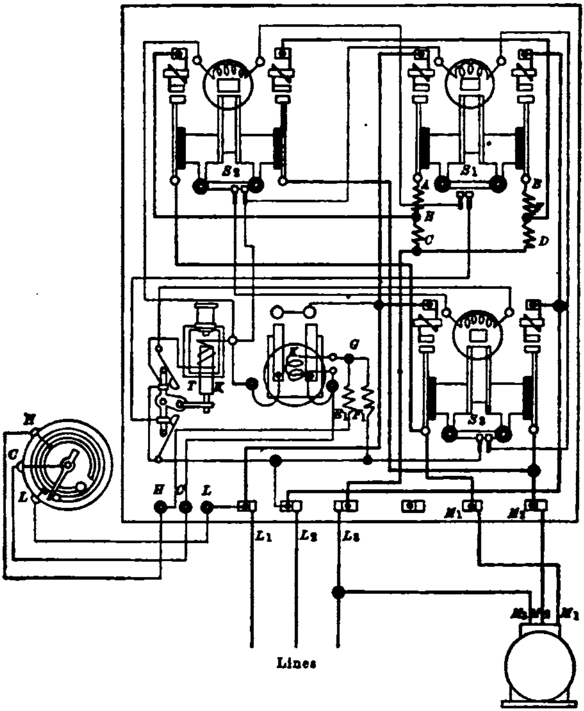

Fig. 56.—Alternating-current time-limit self starter.

fallen below the value at which it is adjusted to operate. These switches will remain closed with 5 per cent. of their normal current; consequently no shunt winding is ordinarily required for the last switch.

444. The counter-e.m.f. starter for direct-current motors is in reality a current-limit starter. In this device the starting resistance is removed by a series of magnetic switches whose operating windings are connected across the motor armature; these switches close successively as the counter e.m.f. of the motor increases with the speed.

445. Alternating-current induction self starters may also be of either the time-limit or current-limit type. In the former the primary windings are connected to the starting transformer for a predetermined length of time, and are then thrown directly on the line. Fig. 56 shows a typical starter of this class. A very similar starter is employed for the control of secondary starting resistance, the removal of the starting resistance being accomplished after a predetermined time interval. Both induction and primary-resistance self starters of the current-limit type are manufactured, but have not proven as satisfactory as the time-acceleration type on account of the low starting torque of squirrel-cage motors, and the possibility of their being so loaded that they will not accelerate sufficiently to enable a current-limit type of starter to change from starting to running position. Fig. 57 shows a current-limit acceleration controller for use in connection with an alternating-current slip-ring motor. This controller consists of a primary contactor and two

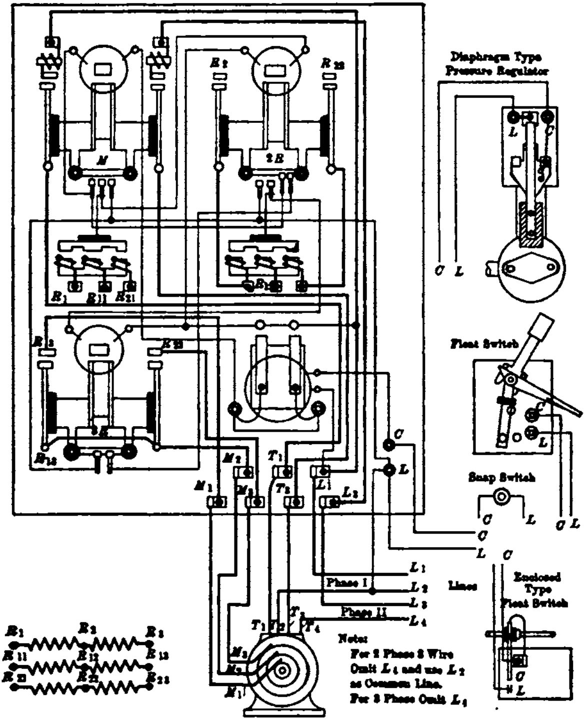

FIG. 57.—Alternating-current current-limit self starter.

secondary resistance contactors, all of which are double-pole type. The operation of the primary contactor may be controlled by a pressure regulator, a float switch, or a simple snap switch. The secondary resistance switches are arranged for successive operation, and are governed by two 3-phase, secondary series relays, which are arranged to halt acceleration whenever the motor current exceeds the value for which they are adjusted.

SPEED REGULATORS

446. Direct-current speed regulators. The speed of direct-current motors may be varied in two ways: first, by varying the potential impressed at the armature terminals, the field strength remaining constant (the speed

110 and 220, or 125 and 250 volts at the motor armature. To obtain reasonably small speed increments throughout the entire speed range, these three-wire systems require a motor whose speed may be varied by field control through a wider range than is required where a motor is operated on the four-wire system.

449. The field strength of a motor may be varied by electrical or mechanical means. When this is accomplished electrically, the field strength is generally varied by a field-regulating rheostat. Field regulation is effected mechanically by changing the air gap and consequently the reluctance of the field circuit. Either method produces the same results, the former having the advantage that the regulating rheostat can be conveniently located at some distance from a motor, also that the field strength can easily be increased to normal during starting.

The extent to which the speed of a motor can be varied by field control depends upon its design. Generally speaking, a standard machine will seldom commutate well if its speed is increased in this manner more than 20 per cent., while specially designed inter-pole motors have been built for speed ranges as great as 10 to 1. On account of their good inherent regulation and their high efficiency at all speeds, field-control motors are almost universally employed where speed control of direct-current motors is required.

450. A combination of armature-resistance and field control may be used to advantage where reduced speeds are required for comparatively short periods, and the expense of installation can be materially reduced by such procedure. It will also be found where a wide range of speed is required in connection with the Ward-Leonard system (Par. **468**, No. 18), Fig. 56, that it will be advisable to regulate the field strength of the motor as well as that of the generator.

451. Self-starting speed regulators. In machine-tool practice, self-starters are used to start and stop machines whose speeds are adjustable by a regulator controlling the motor fields. Such self starters may be equipped with a vibratory field-regulating relay, the winding of which is connected in series with the motor armature. When the armature current reaches a predetermined value this relay will short-circuit the field rheostat, thus increasing the motor field strength to normal. The field strength is continued at normal until the armature current decreases sufficiently to allow the relay to drop, thus inserting the field resistance and increasing the armature current because of the reduced counter e.m.f. Increase in armature current causes the relay again to short-circuit the field rheostat, and the relay continues to vibrate, alternately short-circuiting and cutting in the field resistance, until the motor has accelerated to such an extent that the field resistance may be left in circuit without causing the armature to take a current in excess of the relay setting.

452. Series-parallel control of two motors is a convenient and efficient means of obtaining two speeds, one speed being one-half the other. Such a control system has the added advantage of reducing the current required to produce a given starting torque. This system of control is most widely used in railway work (also see Par. **468**, No. 10).

453. Speed control of squirrel-cage motors may be accomplished in two ways: first, by changing number of poles; second, by varying the combined voltage and frequency impressed on the primary. The number of poles may be changed by the use of separate windings and selective energisation, or by regrouping the windings to change the number of poles. The former method is employed where more than two speeds are required. To obtain a 1 to 2 ratio the windings are generally connected as shown in Fig. 60. It should be particularly noted that in changing from the star, or half-speed connection, to the double star, or full-speed connection, it is necessary to reverse two of the incoming lines in order to prevent the motor from running in a reverse direction.

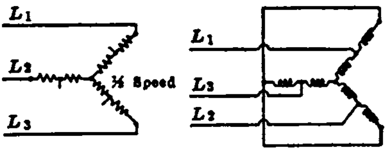

Fig. 60.—Two-speed squirrel-cage motor.

tends to oppose the first ("A"). See also Par. 468, No. 6. The synchronous speed for each of the concatenated connections can be determined as follows:

$$S = \frac{\text{cycles} \times 120}{P_1 \pm P_2} \quad \text{(rev. per min.)} \qquad (9)$$

where S is the synchronous speed in rev. per min.; P_1 is the number of poles of motor "A"; P_2 is the number of poles of motor "B." The plus sign should be used when the motors are in direct concatenation, and the minus sign when in differential concatenation. The diagram in Fig. 61 shows the connections for a cascade system.

There are so many methods by which the speed of one or more slip-ring motors can be varied (see Par. 468, No. 6, 7, 15 and 26), that it is impossible to cover them all in the limited space available.

457. Single-phase motors of the repulsion type may have their speed varied either by the use of primary resistance, or by shifting the brushes. The results obtained by various motor manufacturers are so widely diverse as to make it almost impossible even to outline the limitations of such systems.

458. Synchronous motors are not susceptible of speed control; see Par. 468, No. 22.

ELECTRICALLY OPERATED BRAKES

459. Classification. In the control of electric motors it often becomes desirable to provide a brake which is electrically released and applied by a spring or weight. Such brakes are made in three types—the multiple-disc, the band and the shoe type.

460. Band brake. In one type of band brake, a wheel is attached to the shaft to be braked, and this wheel is encircled by a band lined with a suitable friction material. Normally the band is brought into frictional engagement with the wheel by means of a spring; a solenoid is provided for the purpose of compressing these springs and relieving the brake band. The band brakes are manufactured for either alternating-current or direct-current service.

461. A multiple-disc brake is illustrated in Fig. 62. This typical form of brake is manufactured only for direct-current service. It consists of

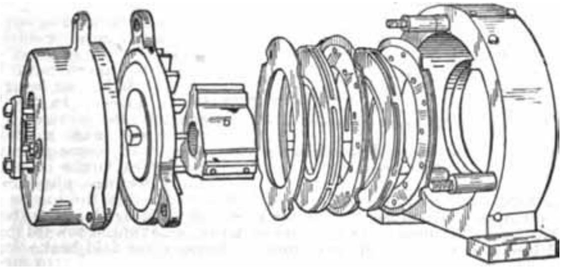

Fig. 62.—Exploded view of multiple-disc brake.

a hub which is mounted on the shaft to be braked, to which hub are keyed one or more discs and a stationary frame, in which are carried, by means of keys, two or more stationary discs. Normally the rotating discs are clamped between the stationary discs by the action of a spring, and by means of an electromagnet this spring can be compressed and the pressure on the friction discs relieved.

462. Shoe brake. A typical shoe brake differs from the band brake only in that the movable friction face is in the form of a shoe rather than in the form of a band. These shoe brakes are also made for alternating-current or direct-current service.

463. Advantages of the various types. The disc brake has the advantage, over either other type, of imposing no side strains on the shaft to which connecting a fixed step of resistance across the terminals of the motor armature after the line circuit is interrupted. As a result of this procedure the motor acts as a generator and serves to retard and stop the machine which it drives. While it is possible to effect a quicker stop by this method than if it were not employed, it does not provide for the quickest stopping that can be obtained; it is obvious at once that as the motor speed decreases, the potential generated by its armature correspondingly decreases, and the reduction in current which the armature will send through the fixed step of resistance results in a gradual diminution of the braking force, until it reaches zero when the armature stops.

Inductive resistance is often employed in the braking circuit for the purpose of prolonging the period during which the braking current remains at high value, and quicker stoppage can be effected by its use. Where the quickest possible stop is desired, a variable resistance should be connected across the motor armature; this resistance should be reduced by a series of magnetic switches, the successive closure of which will be halted whenever the braking current exceeds a predetermined value. With such an equipment, the braking current can be maintained at a high value throughout the entire stopping period, and much faster results obtained than are possible by any other method. In the interest of economy the starting resistance and the accelerating switches are generally employed for graduated dynamic braking. Thus the same apparatus which is used to limit the current of acceleration, serves also to limit the current of retardation.

467. Alternating-current motors can be used for dynamic braking only when direct-current is available for their excitation; the method is seldom used, for this reason. For quick stopping, the reversal of the primary and the inclusion of a high resistance in the secondary is equally effective and does not require direct current. For the retardation of descending loads it has not been very popular, largely on account of the general unpopularity of alternating-current motors for this class of service, direct-current machines being better adapted on account of their inherent characteristics (Par. 468, No. 11).

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SECTION 16

ELECTRIC RAILWAYS

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CONTENTS

(*Numbers refer to Paragraphs*)

TRAIN RESISTANCE

4. Tests. Careful experimental tests, carried out during the past few years with electric locomotives and motor-cars, have thrown new light on the much discussed question of train resistance at the higher speeds. Without, in any way, disparaging the care taken in tests made with steam locomotives, it was not until electrical methods of measuring power introduced greater accuracy than was possible by use of the steam indicator, that consistent results became obtainable with light trains operating at very high speeds.

The electric motor was the means of introducing the single-car train operating at speeds up to 70 miles per hr. At that time no data were extant concerning the operation of single-car trains. It was soon found that such a car operating alone required an input out of all proportion to the power required to propel a train composed of several such cars operating at the same speed, consequently new adjustments had to be made in train-resistance formulas then existing.

During the spring of 1900, a series of tests were made by Mr. W. J. Davis, Jr., on the Buffalo & Lockport Railway, which consisted in running a 40-ton electric locomotive alone and with trailers at speeds approaching 60 miles per hr., as a maximum. These tests probably constitute the first consistent attempt to utilize the benefits of greater accuracy which electrical methods of recording afford. Since then other tests, taken under better conditions and with various classes of equipment, afford data from which it is possible to predict, with a considerable degree of accuracy, the total resistance (wind, bearing and rolling) opposing the movement of cars or light trains up to speeds of 100 miles per hr.

5. Train resistance may be expressed in pounds tractive effort exerted at the rim of the driving wheels of the prime mover of a train. It includes all losses in bearings, losses due to rolling friction, bending rails, flange friction, etc., and the wind-resistance loss. The last item is made up of head-on resistance, skin or side resistance and eddy currents caused by the suction at the rear of the car or train. All these variables depend upon the condition of bearings, design of trucks, condition of the road-bed, shape and cross-section of cars, direction of wind, etc., so that any tests, to furnish authoritative data, must be sufficiently comprehensive to eliminate the errors of purely local conditions. As no such elaborate series of tests have yet been made, any formulas predicated on the data available must at best be approximate.

Data are available on the performance of locomotives and cars of modern construction as follows: Buffalo and Lockport experiments in 1900; Zossen high-speed tests in 1902-3; tests on New York Central type locomotive at Schenectady, 1905-6; tests on car No. 5 at Schenectady, 1906; tests made by the Electric Railway Test Commission, on the test car "Louisiana," 1904-5; New York Subway tests, 1905; Dynamometer car tests by Prof. Edward C. Schmidt, University of Illinois, 1910.

Many isolated tests have been made from time to time other than those mentioned above, but either the data was not sufficiently complete or the conditions were too unfavorable to justify using the results obtained as applying to other than local conditions. The data comprised in the tests given above are sufficiently general, as they include the operation of trains varying from a single 35-ton car, to a train of 532 tons, and at speeds up to 130 miles per hr. in the Zossen tests.

6. Frictional resistance. The laws governing the **friction of journal bearings** are fairly well understood, and such bearing friction opposing the motion of a train, need introduce no undetermined factors in a calculation of train resistance. Such friction losses decrease with the pressure on the bearings and are a function of the speed. Hence, the expression, $f' = A' + B'S$, where f' is bearing friction expressed as lb. per ton, A' and B' are constants determined by experiment (see Par. 8) and S is the speed expressed conveniently in miles per hr. **Rolling friction** (see Par. 22) is due to the friction of metal rolling on metal where the surfaces are not perfect; the bending of rails due to insufficient support, or meager cross-section of rail; and flange friction between rail and wheel flange. All these factors are proportional to speed, and hence may be represented by a straight line function of speed. As bearing and rolling friction are both approximately proportional to the speed they may constitute the first two terms of a train resistance formula,

$$f_1 = A + BS \qquad \text{(lb. per ton)} \qquad (1)$$

tory experiment and previous experimental train tests by Davis in 1900. Hence, that portion of train resistance which results from the effect of wind may be given by the relation

$$f_3 = \frac{CaS^2}{w} \qquad \text{(lb. per ton)} \qquad (3)$$

where f_3 is the wind resistance in lb. per ton, C is a constant, a is the projected area, and W is the train weight in tons. This equation leads to the third term of Eq. 4.

Values of C (*Kernot*, 1894)

$C = 0.004$ for flat surfaces, $C = 0.0020$ for cylinder,
$C = 0.0024$ for octagonal prism, $C = 0.0014$ for sphere.

11. Method of making wind resistance experiments. The simplest and most accurate is the coasting method, where a moving train is allowed to drift until it reaches standstill, the rate of speed decrease and elapsed time being accurately noted. The efforts of most experimenters have been directed toward securing such data during periods of no wind in order to eliminate this troublesome feature. However, a series of runs taken with and against a wind of known velocity offers much data not otherwise available, and affords a ready means of solving directly for the coefficient of the second and third term of the train resistance formula (Eq. 4).

For example, given a wind of 20 miles per hr. velocity, a series of runs made with and against such a wind will, at say 50 miles per hr. train speed, correspond to a wind pressure at 30 miles per hr. with the wind and 70 miles per hr. against the wind, the rolling friction being constant at the value obtaining at the train speed of 50 miles per hr. As the wind pressure varies as the square of the speed, such a series of tests affords a means of determining the coefficient of S^2 for the particular type of equipment used.

12. The shape of the car end has a large influence upon the coefficient of S^2, such a result being reasonably expected from the results of experiments by Goss, Kernot and others: in fact, Davis checked up the values of 0.004 found by Kernot for flat surfaces. As a matter of fact, no cars or locomotives used for high-speed service have perfectly flat ends, and hence, all experimental values of C have been found to be less than 0.004.

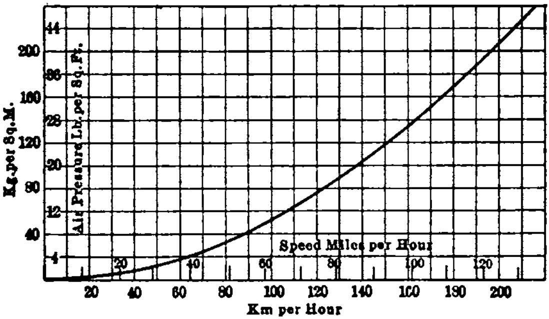


FIG. 1.—Wind-resistance test (Berlin-Zossen).

Little attempt has been made to construct cars for least wind effect, owing largely to a lack of full understanding of the benefits to be secured thereby. The cars used for high-speed suburban service and all electric locomotives, with few exceptions, are provided with partially rounded ends, with the result that the effective wind pressure is considerably reduced. A notable example of the extreme type of pointed nose design is the steel gasolene motor-car No. 7, of the Union Pacific Company, and such construction is a step in the right direction.

Values of C vary from 0.004 with perfectly flat ends to 0.0015 with noses

It is very possible that the higher values obtained at the maximum speeds were influenced by reason of the track being not rigid enough for speeds of 120 miles per hr., and hence increasing the value of B.

15. A consideration of trains of several cars makes it necessary toi ntroduce an additionalfactor in the third term of the proposed train-resistance formula that shall express the effect of the wind resistance upon the sides of the succeeding cars. The head-on wind resistance is borne by the leading car, and hence additional cars only introduce the additional skin friction offered by a train of greater length.

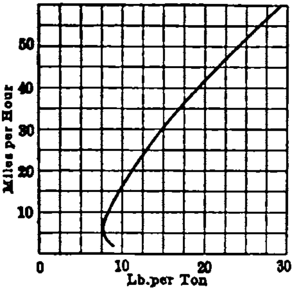


FIG. 4.—Train resistance (General Electric tests); weight 63,000 lb.

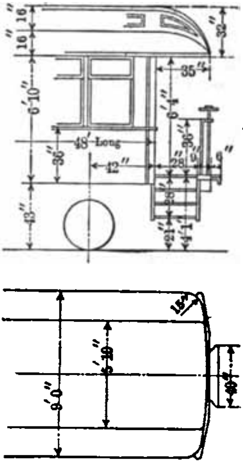


FIG. 5.—Elevation and plan, car No. 5 (General Electric tests).

16. The most reliable and exhaustive series of tests made with trains composed of a different number of cars is offered in the experimental runs of the New York Central locomotive No. 6,000, during its 50,000-mile endurance run, hauling trailers up to a nine-car train. Over 140 runs under different climatic conditions are condensed in the series of curves shown in Fig. 6, where the train resistance is expressed in pounds per ton weight of total train including locomotive. This set of curves indicates very plainly the reduction in train resistance per ton of train with the increase of train weight, such a reduction being largely due to the fact that the head-on wind resistance remains constant for any composition of train, being influenced only by the shape and cross-section of the locomotive.

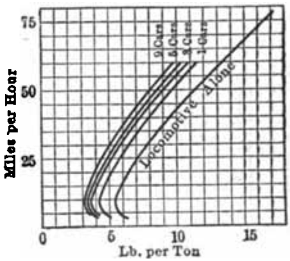


FIG. 6.—Train-resistance runs (N. Y. C. locomotive and train).

17. The increase in skin friction along the surface of succeeding cars corresponds closely to 10 per cent. of the value of wind resistance as expressed by Eq. 3, and for a train of several cars the expression for wind resistance becomes,

$$f_3 = \frac{CS^2a}{W}\left(1+\frac{n-1}{10}\right) \qquad \text{(lb. per ton)} \qquad (5)$$

where n represents the number of cars in the train. This may be substituted for the third term of Eq. 4.

The results of a series of dynamometer car tests conducted by the Engineering Experiment Station of the University of Illinois, are given by Prof. Edward C. Schmidt in a paper read before the A. S. M. E., May 14, 1910. These tests covered a wide range of car weights and train speeds; Fig. 14 gives the results thereof.

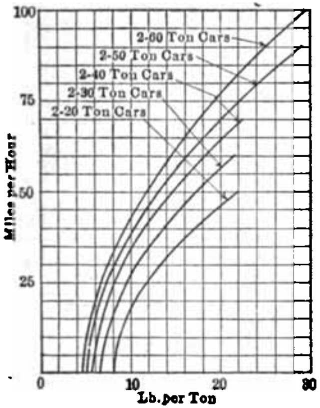


FIG. 10.—Train resistance, two-car train.

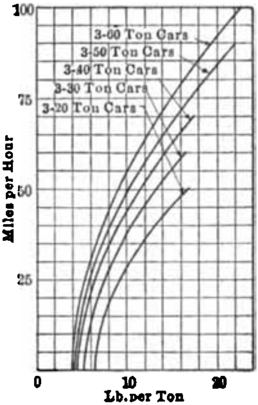


FIG. 11.—Train resistance, three-car train.

20. Track curves are usually expressed in degrees; a 1-deg. curve is taken arbitrarily as one in which a 100-ft. chord will subtend an arc of 1 deg. or, which is the same thing, will subtend a 1-deg. angle at the centre. Hence the radius of a 1-deg. curve is approximately $(100 \times 360)/(2\pi) = 5{,}730$ ft. Similarly the radius of any curve in feet is approximately 5,730/No. of deg.

21. Curve location. This custom of rating curves by degrees instead of by radius has undoubtedly arisen from the facility offered for laying out a curve in the field with a transit. For instance, a transit is set up at the point of curve, *PC* (Fig. 15), and several angles, *BAB*, *BAC*, etc., each equal to one-half the degree of the curve are laid off. In the first of these directions 100 ft. is measured off and a stake driven. From this stake another 100 ft. is measured off and lined in by the transit in its second position. One-hundred-foot chords are thus laid off until point of tangent *PT* is reached. As indicated in Fig. 15, this point is seldom at an even station, but is always indicated by a stake marked as shown, *PT*. Sta. 102+80. Likewise with the point of curve, *PC*. In case the *PC* is not at an even station, the first stake of the curve is driven at an even station so that the remaining stakes of the curve will come at

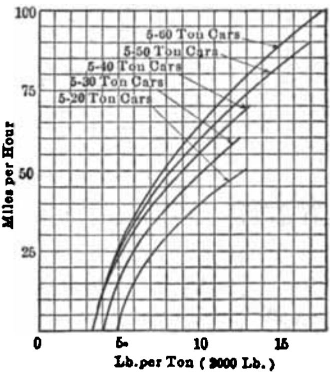


FIG. 12.—Train resistance, 5-car train.

resistance calculations except in the calculation of locomotive constants assigned to mountain grade service, where both sharp curves and heavy grades occur.

23. Grades are expressed in percentages, being the ratio of the distance the train is raised to the distance travelled, in other words, the ratio of the ordinate of a right-angled triangle to the hypothenuse. A grade of plus 1 per cent. is one where the train is raised vertically 1 ft. for each 100 ft. travelled; a minus 1 per cent. grade is one where the train falls 1 ft. for every 100 ft. of distance travelled. It follows that a plus 1 per cent. grade calls for a tractive effort of 20 lb. per ton, while a minus 1 per cent. grade is equivalent to delivering a tractive effort of 20 lb. per ton to the train.

Where gradients are small it is not necessary to consider the reduction in train weight due to the angle of direction of travel to the true horizontal in calculations of friction (Par. 6) and adhesion (Par. 28). However, with the excessive grades, it is necessary to correct for effective train weight.

Grades are divided in railway parlance into virtual grades and ruling grades.

24. Virtual grades are of limited length and are so called as they express the equivalent grade, a value always something less than the true grade. A train running at constant speed can surmount a certain grade as determined by the maximum tractive effort available. The moving train however may be compared to a fly-wheel, and has stored in the moving mass a large amount of energy, which is usually expended in heating the brake shoes during the period of stopping. This stored energy may be used to furnish the extra tractive effort required to ascend a heavier grade than the available locomotive tractive effort alone would permit, but in such a case the grade must be of short length. Hence, the actual grade may be considerably in excess of the virtual grade, provided it is so short that the inertia of the moving train can supply the additional energy required to ascend it.

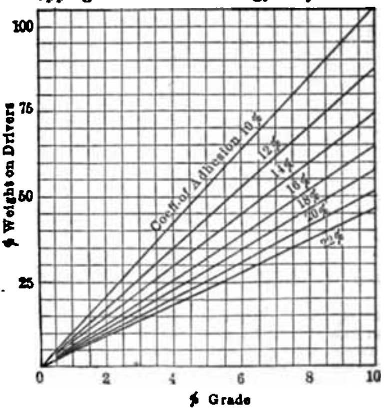


FIG. 16.—Relation between per cent. weight on drivers and per cent. grade.

25. The ruling grade means the maximum grade encountered on a given section of track and may be the actual grade, where such is of long extent, or the virtual grade, where the inertia of the train may be used to advantage in overcoming a heavier short grade. The ruling grade of freight hauling roads should be limited to 2 per cent. or less when the topography of the country will permit, in fact, on a modern freight road any grade exceeding 1 per cent. maximum would be considered excessive, and would demand the use of helper locomotives. While low grades are not so important on electric suburban railways where the income is largely derived from passenger receipts, the future possibilities of freight traffic over these lines makes a low gradient desirable whenever possible.

26. Coefficient of adhesion expresses the ratio between total tractive effort and weight on drivers. Coefficient $= F_s/W$ where F_s is the maximum possible tractive effort in lb., and W is the weight on the drivers in lb.

This is expressed in per cent. and is a variable depending upon the condition of track and composition of wheel. See Par. 27.

It is good practice to design the motive power of a car or locomotive so that it can slip the wheels on a dry rail, this practice not being strictly foltotal tractive effort on grade is expressed by the sum $4+10+(20 \times \text{per cent. grade})$, in lb. per ton.

Based upon above formula, Fig. 17 is made up, giving the **weight of locomotive required** to operate trains from 500 to 3,000 tons gross weight on any grade. It is assumed that all the locomotive weight is on the drivers, an assumption that may hold true in slow-speed freight service if the alignment is good. Where pony or bogie guiding trucks are necessary for safety in rounding curves or to prevent "nosing," divide the values of locomotive weight as obtained from Fig. 17, by the percentage of weight on drivers to total locomotive weight obtaining in the design of locomotive required.

SPEED-TIME CURVES AND MOTOR CHARACTERISTICS

31. Acceleration. The many problems connected with train acceleration can be treated either analytically or graphically. As will be shown later, there are so many variables entering into the consideration of train movements at variable speeds that the analytical method becomes somewhat complicated and difficult to follow. The graphical method is equally as accurate, much easier to work with, and the final results are given in such form that they are of general application without calling for the familiarity of terms and symbols made necessary by the analytical treatment.

There are several terms used in connection with train acceleration phenomena which are defined in Par. 32 to 38.

32. Tractive effort is the torque in pounds developed at the rim of the wheels, divided by total train weight in tons. This term is usually expressed in pounds per ton of train weight and includes train resistance losses.

33. Braking effort, also expressed in pounds per ton is the opposite of tractive effort, expresses the force tending to retard the motion of the train and bring it to rest.

34. Rate of acceleration is the increment expressing the rate of increase in speed of train, and may be expressed in feet per sec. per sec., or miles per hr. per sec.—usually the latter.

35. Rate of braking is the increment expressing the rate of decrease in speed of train. Both rate of acceleration and rate of braking may vary considerably during successive periods of time, depending upon type of motive power and brake rigging used.

36. Train resistance a variable, expressed in pounds per ton and tending to retard the motion of the train (Par. 4 to 30).

37. Speed-time curves express the relation of the above variables in curve form, generally with speed in miles per hr. as ordinates, and elapsed time in seconds as abscissas.

38. Energy curves show the energy consumption, generally expressed as watt-hours per ton mile, for different rates of acceleration, braking and train resistance, for various elapsed times over a given distance run.

39. Curves of free acceleration. A better understanding of the possible movements of a car or train operating at different speeds over different distances, is obtained by eliminating the type of motive power and brake rigging used, and assuming straight-line acceleration, coasting and braking curves. The results so obtained are fundamental, and may be applied to examples, considering any type of motive power using a correction factor, which will be treated later, known as the efficiency of acceleration.

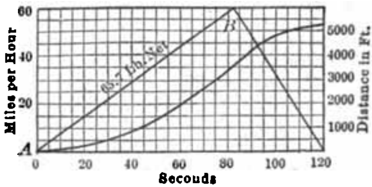


FIG. 18.—Typical speed-time-distance curve (no coasting).

40. The problem of train acceleration deals with the movement of a given weight over a given distance within a specified time. As it is impracticable to start and stop the train instantaneously, it is necessary to deal with some finite rate of acceleration and braking, thus giving rise to the simple form of speed-time curves shown in Fig. 18. The speed-time curve is here duction of friction occasions a falling off of speed during the coasting period proportional to the friction value taken, which for the sake of simplicity is here assumed to be constant at all speeds.

The speed-time curves shown in Fig. 18 and 19 both indicate the completion of the run of 5,280 ft. in 120 sec., although in one case the rate of acceleration was that produced by 65.7 lb. per ton, and in the other case by 100 lb. per ton. These curves are of equal area, as the distance in each case is 5,280 ft. Thus, it becomes possible to produce any number of speed-time curves, for a given distance and elapsed time, by varying the rate of acceleration with consequent variation in time of coasting.

A more extended set of curves is given in Fig. 20, for the same distance of 1 mile covered in 120 sec., the rate of acceleration varying from 0.713 miles per hr. per sec. as a minimum to an infinite number of miles per hr. per sec. as a maximum.

A train resistance value of 15 lb. per ton is assumed constant at all speeds and the dotted curve, *A*, *B*, is described by the loci of the maximum speeds reached with the different rates of acceleration. The highest maximum speed required is obtained with no coasting, and the minimum speed is obtained with an infinite rate of acceleration. The pounds per ton corresponding to the different accelerating rates are given as including 15 lb. per ton train resistance, hence the net tractive effort values corresponding to the rates of acceleration indicated are 15 lb. per ton less than the figures given.

43. Application of unit-distance speed-time curves. Instead of plotting similar curves for distances other than 5,280 ft., advantage may be taken of the fact that the area enclosed by the speed-time curve is proportional to the distance travelled and the coordinates are proportional to the square root of the enclosed area. It is convenient, therefore, to plot a full series of curves for one distance, preferably one stop per mile, that is, a distance of 5,280 ft. run, and to apply the results so obtained for any other distance by using a factor expressing the relation of the square roots of the distance travelled. This is shown in Fig. 21, where *A*, *B*, *C*, *D*, represents an area of 1 mile, or one stop per mile, *A*, *F*, *I*, *L*, two stops per mile with a factor of $1/\sqrt{2} = 0.707$; *A*, *E*, *H*, *K*, four stops per mile with a factor of $1/\sqrt{4} = 0.5$, and *A*, *G*, *J*, *M*, one stop in 1½ miles with a factor of $\sqrt{1.5} = 1.225$.

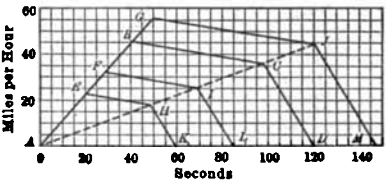


FIG. 21.—Similar speed-time curves (varying distances).

Referring to Fig. 19, it is obvious that a similar sheet could be prepared for any elapsed time other than 120 sec., using the same train resistance and braking values of 15 and 150 lb. per ton respectively.

44. Imposed time limits. In Fig. 22 is shown the time limits imposed by 15 lb. per ton train resistance, and 150 lb. per ton braking for any length of run and any rate of acceleration. The dotted curves indicate the loci of the several maximum speeds reached with different accelerating rates for a run made in a given elapsed time. Thus the dotted curve terminating at 80.7 lb. per ton is a reproduction of the similar dotted curve, *A*, *B*, given in Fig. 20, and gives the maximum speed reached with any rate of acceleration for a run of 5,280 ft. in 120 sec. with 15 lb. per ton train resistance and 150 lb. braking effort. Similarly, the dotted curve terminating at 100.4 lb. per ton gives the limiting maximum speeds reached, with any rate of acceleration, when a run of 5,280 ft. is accomplished in 110 sec., using the same values of train resistance, braking, etc.

45. Time limits with and without coasting. The full line *C*, *D*, gives the angle made by a coasting line when the rate train friction is 15 lb. per ton. Thus, in a run completed in 120 sec., the minimum accelerating rate corresponds to 80.7 lb. per ton (gross), with no coasting introduced, for here braking commences as soon as acceleration ceases.

Example: Given a distance of 8,000 ft., train resistance 15 lb. per ton, braking effort 150 lb. per ton, tractive effort gross 67.4 lb. per ton (including 15 lb. per ton train resistance), what is the minimum time required to perform the run and what maximum speed is reached?

Solution: From Fig. 22, minimum elapsed time with 67.4 lb. tractive effort is 130 sec. with no coasting. Ratio of distances $= \sqrt{8{,}000/5{,}280} = 1.23$. Hence for 8,000 ft. time of run $= 130 \times 1.23 = 160$ sec.; maximum speed for 5,280 ft. $= 55.6$ miles per hr.; hence for 8,000 ft. speed $= 55.6 \times 1.23 = 68.5$ miles per hr.

47. In actual practice, a certain amount of coasting is necessary; hence, the run of 8,000 ft. (Par. 46), would be made in somewhat more than the minimum possible limit of 160 sec., or else the tractive effort should be increased to allow for a higher rate of acceleration that would permit of some coasting. Fig. 22 is of universal application as it is not limited to any particular type of motive power, having its own peculiar speed characteristics. Moreover, the values of 15 lb. and 150 lb. chosen for train resistance and braking effort respectively are conservative operating values obtaining in practice.

48. The maximum speed reached during the performance of a service run will be little influenced by the type of motive power and its curve characteristics (See Par. 42). The values indicated in Fig. 22 will hold approximately true in service operation with series motors of either the alternating-current or direct-current types, and hence, the curves given constitute a set of fundamental data by means of which it becomes possible to attack any acceleration problem and determine the data required.

49. Electric motors used in railway service are of the following types:

(1) Series-wound direct-current motors,
(2) Single-phase alternating-current motors,
(3) Polyphase alternating-current induction motors.

In addition to the above, there have been several attempts at operating shunt-wound direct-current motors, but as such motors have not come into even partial use, owing to the superior qualities of other types, the shunt-wound motor will not be discussed.

50. Direct-current series-wound motor characteristics and applications. The direct-current series motor has the general characteristics shown in Fig. 23. Applying this motor characteristic to the performance of a car, it becomes necessary to reduce the motor voltage during the starting or accelerating period of the car in order to limit the tractive effort to a value that will not slip the driving wheels. In other words, if full voltage were to be applied to the motor at standstill, the resulting current would be enormous, would produce a torque that would slip the wheels, and would far exceed the safe commutating capacity of the motor. Hence, the necessity of introducing external starting resistance in successive steps during acceleration, with the result that the starting current is maintained practically constant at the full-load rating of the motor.

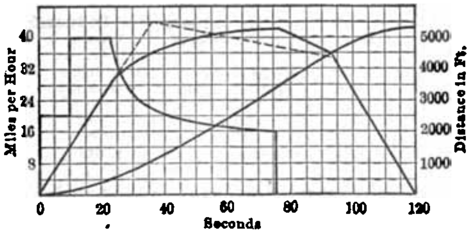


FIG. 24.—Typical speed-time curve with motor-curve acceleration.

51. A speed-time curve with direct-current series-wound motor is shown in Fig. 24, indicating a constant current input up to a speed of 28 miles per hr. At higher values of speed, the motor has full voltage applied

58. Table of accelerating rates

Locomotives		
Steam locomotives, freight service	0.1 to 0.2	miles per hr. per sec.
Steam locomotives, passenger service	0.2 to 0.5	miles per hr. per sec.
Electric locomotives, passenger service	0.3 to 0.6	miles per hr. per sec.
Motor Cars		
Electric motor cars interurban service	0.8 to 1.3	miles per hr. per sec.
Electric motor cars city service	1.3 to 1.8	miles per hr. per sec.
Electric motor cars rapid transit service	1.5 to 2.00	miles per hr. per sec.
Highest practical rate	2.00 to 2.5	miles per hr. per sec.

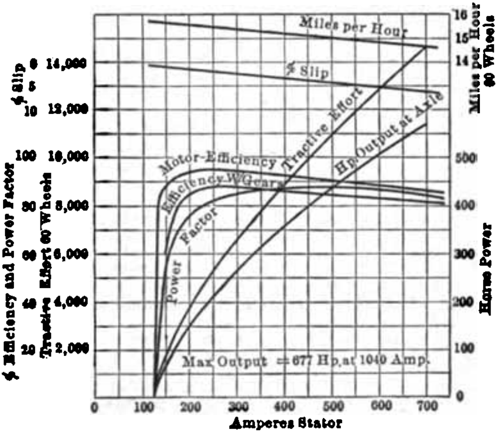


FIG. 26.—Typical polyphase induction motor performance.

59. Limits of acceleration rate. The rates given in Par. 58 apply only to that part of the accelerating period during which the current is maintained practically constant by means of cutting out successive sections of the external starting resistance. The higher rates from 1.0 to 2.5 miles per hr. per sec. demand a gradual increase to those values in order to avoid the discomfort to passengers that would surely result from a sudden application or cessation of such rates.

The coefficient of adhesion (Par. 26) also determines the accelerating rate by limiting the available tractive effort, thus giving rise to the values given above for locomotive practice. As the practice is common to run locomotives very close to the limit of adhesion for full-speed operation, it leaves but a small excess of tractive effort available to accelerate the train. High acceleration demands that all axles shall be equipped with motors, and if trains are run, that all cars must be motor cars, that is, no trailers are permissible when extreme accelerating rates are required to make the schedule desired.

60. Limits of braking rate. The limits reached in acceleration hold equally true in braking. As a matter of fact, acceleration may be at a higher rate than braking, for two reasons: first, discomfort to passengers is greater during braking of cross-seat cars, as the inertia of the passenger tends to carry him away from his seat and he lacks the supporting back that prevents discomfort during rapid acceleration when his body is pressed backward; second, in braking a train to standstill, it is necessary for the operator to stop within a distance of a few feet of a fixed spot, and the skill shown in judging speed and distance will determine the braking rate. During acceleration no such limit exists; the motorman has absolute freedom; in fact, a

67. The relation between schedule and maximum speed with varying frequency of stops is expressed in Fig. 27, which indicates the schedule speed possible to make with trains having a free running speed of 30, 45, 60 and 75 miles per hr. respectively.

Thus with a train geared for a free running speed of 60 miles per hr. it is possible to make a schedule of 45.5 miles per hr. with one stop in four miles, 37.5 miles per hr. with one stop in 2 miles, etc.

For frequent-stop service, a low free-running speed is desirable as it is easier on the equipment, calls for less motor capacity and less energy consumed in performing the service. Hence, it is advisable to use the lowest maximum speed that will give the schedule desired.

68. Effect of acceleration on frequent-stop service. When using Fig. 27, it should be recognized that where stops are more frequent than one per mile, the rate of acceleration becomes a controlling factor, and as shown in the curve, when the frequency of stops approaches three or more per mile,

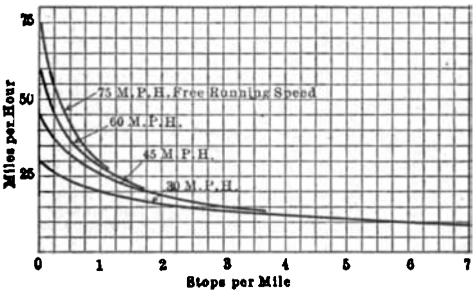


FIG. 27.—Relation between maximum and schedule speed and stops per mile.

the maximum free-running speed of the equipment does not have any appreciable effect upon the possible schedule speed. Hence, for frequent stop service where it is of great importance to attain the highest possible schedule speed, recourse should be had to Fig. 22, in order to determine the advantages of higher rates of acceleration than the 120 lb. gross which forms the basis of Fig. 29.

69. Effect of track curves on rapid service. In all classes of service, due recognition should be paid to the effect of curves of such short radii as to demand slowing down while rounding them. The safe speed at which a curve may be taken will depend upon the elevation of the outer rail, but a greater elevation than 8 in. is not common. Also curves having a spiral approach will ride much easier than those in which the tangent leads directly into the curve.

70. Safe maximum speed on track curves

Radius of curve, ft.......	10,000	5,000	2,000	1,000	500	200	100	50
Speed, miles per hr.......	100	75	50	35	25	15	10	6

The above values apply only when full elevation may be given outer rail. Speeds will be less when operating in city streets where such elevation is not possible, and where wheel flanges of three-quarters of an inch or less are the rule.

71. Limitations of theoretical schedules. On any road abounding in curves of short radius, it will not be possible to reach the schedules given in Fig. 27. No general rule can be given to fit all cases, as each problem must be treated according to local conditions. There is sufficient leeway in the schedules given in Fig. 27 to allow for irregularities of stops, as there is included a period of 10 sec. coasting that may be cut out when a stop has

Acceleration, expressed in miles per hr. per sec. = $[(32.2 \times 0.682)/2{,}000] \times$ lb. per ton = (lb. per ton)/91.2. The above value of (lb. per ton)/91.2 applies only to the net lb. per ton available for car acceleration only. In this particular problem assume 7 per cent. of the accelerating tractive force as being required to overcome the inertia of the rotating parts, then the factor of acceleration expressed in miles per hr. per sec. = (net lb. per ton)/(91.2×1.07) = (lb. per ton)/97.5. Hence—acceleration = 122/97.5 = 1.25 miles per hr. per sec.

Assume that car resistance remains constant at all speeds up to 27 miles per hr., as error introduced thereby is so small as to make it unnecessary to plot the curve step by step until motor-curve running is reached at 27 miles per hr.

The several relations may be calculated as given in Par. **76**.

76. Relation of speed, distance, amperes and time (Par. 74); example of detailed calculations

1	2	3	4	5	6	7	8	9	10	11
	27	1,090	116	974	1.25	21.6	21.6	428	428	140
2	29	980	119	861	1.10	1.82	23.4	75	503	130
2	31	790	126	664	0.85	2.25	25.6	99	602	112
2	33	640	133	507	0.65	3.08	28.7	145	747	97
2	35	540	140	400	0.51	3.92	32.6	196	943	86
2	37	440	147	293	0.37	5.40	38.0	286	1,229	76
2	39	370	155	215	0.28	7.15	45.2	410	1,639	68
2	41	310	163	147	0.19	10.5	55.7	633	2,272	61
2	43	270	172	98	0.13	15.4	71.1	952	3,234	57
2	45	230	180	50	0.06	34.4	105.0	2,230	5,464	52

NOTE.—1. Speed increment of 2 miles per hr. 2. Sum of speed increments. 3. Gross tractive effort as obtained from motor characteristics (Fig. 22). 4. Car friction per motor (Fig. 9). 5. Net tractive effort available for gross acceleration after deducting car friction. 6. Acceleration as obtained by dividing net accelerating force (column 5 reduced to lb. per ton) by acceleration factor as determined (97.5). 7. Time increment as determined from 1 and 6. 8. Total elapsed time summation of 7. 9. Distance increment as determined from 2 and 7. 10. Total distance traveled, summation of 9. 11. Amperes as determined from motor characteristics. Values in 3, 5, 6 are average values obtaining during increase of speed increment in 1.

77. Example of calculation of speed-time curves; effects of track curves, grades and coasting. The above example is worked out on basis of level tangent track. The calculation of speed-time curves is generally based upon this assumption. Where it is necessary to predetermine the performance of a motor operating over grades and around curves, add or deduct tractive force so consumed from gross tractive effort and proceed as in Par. **76**. Also see Par. **22** and **23**.

Completing the speed-time cycle by introducing coasting and braking requires the same treatment as in Par. **76** except that both coasting and braking are equivalent to negative acceleration. Another method of plotting speed-time curves is given by Mailloux in Proceedings American Institute of Electrical Engineers, June, 1902.

ENERGY AND POWER CONSUMPTION

78. The energy consumed in moving a train at constant speed is expended in overcoming train resistance (Figs. 9 to 14 inclusive) and internal motor losses. It is customary for manufacturers to give the net efficiency of railway motors after having carefully determined their internal losses from stand tests, and hence, the railway operator is concerned only with the

85. Train input for constant-speed running on level tangent track, motor-car service

(*Input values expressed in kilowatts*)

Train weight	Speed (miles per hr.)									
	10	20	30	40	50	60	70	80	90	100
2–20 ton cars.....	9.3	22.4	42.5	72.5	116.0	...	...	...	......	......
2–30 ton cars.....	11.5	27.4	51.4	87.0	137.0	206	...	...	......	......
2–40 ton cars.....	13.2	31.6	59.0	99.3	156.0	234	336	...	......	......
2–50 ton cars.....	14.8	35.5	66.3	111.0	175.0	261	374	520	699	......
2–60 ton cars.....	16.3	38.8	71.7	119.0	185.0	274	390	540	720	945
20 ton car........	6.5	16.2	32.0	56.7	93.5	...	...	...	......	......
30 ton car........	8.0	19.5	38.4	67.3	109.0	167	...	...	......	......
40 ton car........	9.4	23.1	44.1	76.2	124.0	188	276	...	......	......
50 ton car........	10.4	25.6	49.2	84.8	137.0	210	305	430	584	......
60 ton car........	11.5	27.9	52.8	90.2	144.0	218	316	442	599	792
3–20 ton cars.....	11.4	27.2	50.9	84.1	136.0	...	...	...	......	......
3–30 ton cars.....	14.0	33.3	61.8	103.0	162.0	240	...	...	......	......
3–40 ton cars.....	16.3	38.7	71.5	119.0	185.0	271	391	...	......	......
3–50 ton cars.....	18.4	43.7	80.6	134.0	206.0	308	437	602	805	......
3–60 ton cars.....	20.1	48.0	87.4	144.0	222.0	326	460	635	925	1,092
5–20 ton cars.....	14.8	35.3	65.4	109.0	171.0	...	...	...	......	......
5–30 ton cars.....	18.3	43.5	80.0	133.0	205.0	303	...	...	......	......
5–40 ton cars.....	21.3	50.8	93.2	154.0	237.0	348	493	...	......	......
5–50 ton cars.....	26.2	61.9	112.0	183.0	279.0	406	568	773	1,026	......
5–60 ton cars.....	31.3	72.8	130.0	208.0	312.0	448	622	835	1,100	1,415

86. Train input for constant-speed running on level tangent track, locomotive passenger service

(*Input values expressed in kilowatts*)

Gross train weight	Speed (miles per hr.)									
	10	20	30	40	50	60	70	80	90	100
200 tons.	17.5	41.2	75.8	124	196	277	398	530	710	920
300 tons.	26.1	60.5	108.0	172	258	369	511	689	905	1,160
400 tons.	32.0	79.0	139.0	219	330	462	635	840	1,100	1,405
500 tons.	41.0	99.0	170.0	268	395	563	755	995	1,295	1,645
600 tons.	50.0	118.0	203.0	315	464	645	875	1,150	1,489	1,890
700 tons.	59.0	135.0	235.0	363	530	735	996	1,305	1,682	2,132
800 tons.	69.0	154.0	267.0	410	596	828	1,117	1,460	1,878	2,375
900 tons.	77.0	173.0	300.0	459	663	920	1,238	1,615	2,070	2,620
1,000 tons.	85.0	193.0	330.0	507	730	1,011	1,358	1,771	2,261	2,860

87. Power required on grades. The values of power required to drive a car at any speed, apply only for constant speed on tangent level tracks. On up grades there is required an additional tractive effort of 20 lb. per ton for each 1 per cent. grade. Hence, to calculate power required on grades, proceed as follows:

The total train resistance is $F_0 = F + F_g$, in lb. per ton; wherein F is the train resistance in lb. per ton found from the curves, and F_g the tractive effort due to the grade (F_g = per cent. grade × 20). Then the power input is

$$P = \frac{2WF_0V}{1,000\eta} \qquad (16)$$

tion curves, as it eliminates the question of motive power with its internal losses, and considers only the moving train itself.

90. The energy required to move a train from rest to a given velocity is represented by

$$W = \frac{ms^2}{2} + F_0 L \qquad \text{(ft-lb.)} \qquad (18)$$

wherein m is the mass; s the velocity in ft. per sec.; F_0 the total train resistance in lb., and L the distance in ft. covered.

The most convenient form of expressing energy values is in watt-hours per ton-mile. Fig. 29 has been constructed from the speed-time data in Fig. 22, giving the energy consumption for any rate of acceleration and elapsed time for a distance of 5,280 ft. or 1 mile run. This set of curves is plotted with train resistance = 0, and hence represents the value of the energy of acceleration only.

91. Energy dissipated in braking. In bringing a train to rest by means of brakes, the energy stored in the train during acceleration and represented by $ms^2/2$ is all wasted in heating the wheels and brake shoes, and the values in Fig. 29 therefore represent the energy thus dissipated as heat. The curves have no value as applying directly to service conditions as all moving trains have more or less running resistance, but they are useful as indicating the energy required to accelerate the mass, all of which reappears as heat in the brake shoes and car wheels, unless some method of regenerative braking be used (Par. **115**). At best, however, such regenerative methods are vastly inefficient and the energy values given in Fig. 29 represent the price paid for a high schedule speed coupled with frequent stops.

92. Curves of energy consumption. Unless the train reaches a speed of more than 40 miles per hr. it is a sufficiently close approximation for preliminary calculations to assume a constant rate of train resistance of from 10 to 15 lb. per ton, the latter figure being the more conservative value. Hence, Figs. 30 and 31 are plotted with a constant value of train resistance at all speeds of 10 and 15 lb. per ton respectively. These curves used in conjunction with the speed-time curves of Fig. 22 permit of the complete solution of any acceleration problem so far as relates to performance of the train and its net energy consumption. For convenience, both speed-time and energy curves are made up with the same elapsed time for a mile run as abscissa, this distance run being chosen as being a convenient basis for comparison.

Having determined the watt-hours per ton-mile for a mile run, the same value holds true for any other distance run as long as the speed-time curve is entirely similar in every respect and the areas are proportional to the respective distances run. Thus, a mile performance in 120 sec. with a tractive effort of 90 lb. per ton (including 15 lb. per ton train resistance) will require an output rate of 73 watt-hr. per ton-mile, and the same energy, 73 watt-hr. per ton-mile, would be required to perform a run of half the distance in $1/\sqrt{2}$ times 120 sec., or 84.8 sec.

Thus while the speed-time curves must be changed in area proportional to the distance travelled, the value of energy consumption found for one distance holds equally true for any other distance made with a similar speed-time curve.

93. Example of calculation of energy consumption. Given a run of 1,760 ft. to be made in 75 sec., train weight 100 tons, 33.5 per cent. on drivers, coefficient of adhesion 12 per cent., train resistance 15 lb. per ton. Find energy consumption.

Available tractive effort $= 200{,}000 \times 0.335 \times 0.12 = 8{,}000$ lb. $= 8{,}000/100 =$ 80 lb. per ton.

To reduce to mile basis $\sqrt{5{,}280/1{,}760} \times 75 = 130$ seconds. (See Par. **43**.)

From Fig. 31, 1 mile in 130 sec. with 80 lb. tractive effort gives 60 watt-hr. per ton-mile.

The same value, 60, is true for 1,760 ft. made by similarly shaped speed-time curve in 75 sec.

94. Motor-curve acceleration. Instead of being able to accelerate a train at a uniform rate until maximum speed is reached, all types of electric motors operate best with a certain amount of motor-curve acceleration at a rate constantly falling off from the initial or straight-line acceleration which is only carried part way to full speed. Also, the electric motor has internal losses, electrical and mechanical, which together with certain losses inherent to its system of control make it necessary to add a greater or less percentage to the net energy-consumption curves given in order to obtain the *input* to the train. The different types of motors have their distinctive internal losses and type of control, and the performance relation of the several motor equipments to the net energy-consumption curves is best expressed by the efficiency of acceleration of the several systems.

95. The efficiency of acceleration is the percentage of the net energy consumption of motor output, to the gross input of the train. The values given in Figs. 30 and 31 hold true as the net output of any type of motor and control system, hence, given the efficiency of acceleration of any system, the net energy values form the basis of calculating train inputs for any operating conditions. See Par. 98, 108 and 118.

The losses in the motor equipment during acceleration are divided into: internal motor losses including loss in gears, and losses incident to method of control.

96. Internal motor losses consist of copper I^2R in armature and field, hysteresis and eddy-current losses in the iron circuit, brush-friction and I^2R loss, bearing friction and gear losses. All these losses are included in the curves furnished by the manufacturers for normal 500 volts constant potential at the brushes, but no such values are readily available for fractional-voltage operation during the accelerating period.

97. Starting resistance losses. It is customary to assume full-load current of a railway motor during the straight-line acceleration period, and at standstill the IR drop in the motor copper will approximate 50 volts. It is necessary, therefore, to provide sufficient starting resistance in series with the motor to take up the remaining 450 volts or the difference between the line potential and the motor copper drop. This starting resistanc is cut out in successive steps as the motor armature gains speed and establishes its own counter-electromotive force, until a period is reached, when the starting

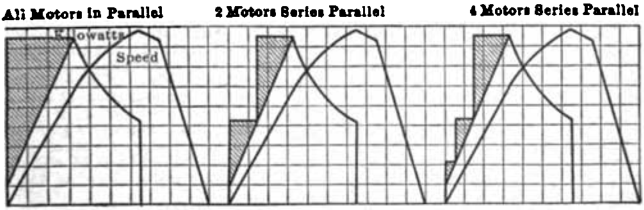


FIG. 32.—Direct-current control of series-wound motors (shading shows loss in starting rheostat).

resistance is entirely short-circuited and the full line e.m.f. is just sufficient to maintain full-load current through the motor. This period completes the straight-line acceleration, as after this point the series-wound motor will still accelerate the train, but at a constantly decreased rate, until full constant speed is attained. It is evident then, that a large amount of power is consumed in the starting resistance and to reduce this excessive loss at starting, the method was introduced of connecting two motors in series during half the period of straight-line acceleration, thus reducing the amount of starting resistance required (Par. 80).

A current-input curve is plotted for the three methods of control of direct-current railway motors in Fig. 32 the shaded portion indicating the energy lost in heating the starting resistances, and showing the economy gained by starting with motors in series. This economy is expressed numerically in Par. 98.

er hr. per sec. assumed. As a high rate of acceleration is undesirable with igh-speed equipments, the rates given in the table should not be greatly ex-eeded unless there are strong local reasons making such high rates necessary.

102. Interruptions to service treated as "equivalent stops." The ıble of schedule speed includes little or no leeway to make up for lost time, nd where such interruptions of service are liable to occur they should be reated as additional stops per mile, and the proper schedule speed, maxi-ıum free-running speed, etc., should be taken for the *equivalent* number of tops per mile, including actual stops, slow-downs for curves, crossings, etc., nd a margin for unexpected delays. Thus, with one actual stop of 15 sec. uration occurring every 2 miles, there may be slow-downs for curves, etc., ıaking the equivalent number of stops approximate one per mile, in which ase a 24-mile per hr. schedule with 40 miles per hr. maximum speed of quipment would be a safer estimate of speed possible than the 32 and 45 niles per hr. respectively given for one stop in 2 miles. In other words, eep the maximum speed of the equipment at the lowest value that will dmit of maintaining the schedule desired with the frequency of stops given. Not only is there a saving in energy consumption resulting from the use of owest possible maximum speed, but, as will be shown later, there is also a arge saving in the capacity of motor required to perform the service.

103. Train input in kw., frequent-stop service, tangent level track

Stops per mile	1/8	1/4	1/2	1	2	3	4	5	6	7
Schedule speed, miles per hr.	50.0	40.0	32.0	24.0	18.5	15.5	13.7	12.5	11.7	11.0
Maximum speed, miles per hr.	65.0	55.0	45.0	40.0	30.0	25.0	23.0	21.0	20.0	19.0
Stops, seconds.......	30.0	20.0	15.0	12.0	10.0	9.0	8.0	7.0	6.0	5.0
Eff. of accel., per cent.	75.0	75.0	75.0	74.0	72.0	70.0	69.0	68.0	67.0	65.0
Accel., miles per hr. per sec.	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7

The above data are common to all trains.

Stops per mile	⅛	¼	½	1	2	3	4	5	6	7
20 ton car.....			51	36	29	26	24	23	22	22
30 ton car.....		96	69	51	40	36	33	32	31	31
40 ton car.....	176	119	85	63	51	45	43	41	40	40
50 ton car.....	195	130	94	73	61	55	52	50	49	49
60 ton car.....	200	140	106	82	70	64	62	60	59	58
2–20 ton cars..			78	60	50	45	43	41	40	40
2–30 ton cars..		137	104	80	69	64	62	60	59	58
2–40 ton cars..	228	160	124	103	89	82	79	77	76	75
2–50 ton cars..	255	183	147	125	111	103	99	97	95	94
2–60 ton cars..	282	202	165	144	127	117	115	113	111	110
3–20 ton cars..			102	76	67	63	61	60	59	58
3–30 ton cars..		173	135	112	97	90	88	86	84	83
3–40 ton cars..	280	200	164	140	127	117	115	113	111	110
3–50 ton cars..	300	236	198	172	155	145	142	139	137	136
3–60 ton cars..	342	263	219	191	175	167	163	160	158	157
5–20 ton cars..			144	124	110	102	98	97	95	94
5–30 ton cars..		238	196	171	154	145	142	139	137	136
5–40 ton cars..	370	292	246	216	197	188	183	180	178	176
5–50 ton cars..	438	350	302	270	250	236	228	225	222	220
5–60 ton cars..	495	400	352	314	290	280	275	271	266	263

These train resistances corresponding to the different train weights agree with Figs. 9 to 14.

poor power-factor during the starting or fractional speed period, and also entails a prohibitive I_2R loss in the secondary, if this be of the short-circuited (squirrel-cage) type. Voltage variation is only used in special cases where the excessive size of the required motor is no handicap.

Secondary-resistance control of three-phase slip-ring motors is the method ordinarily employed. The rotor winding is terminated in three rings, which allow the insertion of non-inductive resistance in the rotor circuit. This resistance is decreased as the motor comes up to speed, and the rings short-circuited at approximately 10 per cent. below synchronous speed. This method of starting results in a poor efficiency of acceleration (Par. 112).

112. Concatenation control may be employed to increase the efficiency of acceleration of three-phase slip-ring motors. As the speed of the induction motor is fixed by its frequency of supply and not by its impressed e.m.f. it is not possible to connect two such motors in series. It is possible, however, to connect the stator winding of motor No. 1 to the line, the rotor winding of motor No. 1 to the rotor winding of motor No. 2 short-circuiting the stator winding of motor No. 2; this constitutes the concatenated method of connecting induction motors and corresponds in results to the series connection of direct-current series-wound motors. With induction motors so connected, stability is obtained with half-speed of the rotors and a concatenated set can be treated in all respects as a single induction motor having double the number of poles in its field.

Concatenation is feasible only with motors of low frequency, 25 cycles or less, owing to the low power-factor incidental to such a combination. In general, however, concatenation is used with railway induction motors, not to effect a possible increase in the efficiency of acceleration, but to provide a second efficient running speed for the low-speed requirements in terminal yards.

113. Efficiency of acceleration; three-phase induction motors

Per cent. straight-line acceleration...............	100	90	80	70	60	50	40	30	20	10	0
Efficiency per cent..........	40	43	46	49	52	55	58	61	64	72	75

The accelerating efficiency of an induction-motor railway equipment is indicated for parallel operation only, concatenation not being considered. As straight-line acceleration will constitute fully 50 per cent. of the total period during which power is supplied in a typical rapid-transit run, an induction-motor equipment will have an efficiency of acceleration not to exceed 55 per cent. This represents the power efficiency and does not include the power-factor which will approximate 80 per cent. during acceleration with non-inductive resistance inserted in the secondary circuit, thus making the *apparent* efficiency of acceleration approximately 44 per cent.

Hence, for acceleration problems involving a consideration of railway induction motors of the polyphase type, divide energy values given in Figs. 30 and 31 by 0.44 to obtain the volt-amp. input at the train and *not including* any trolley or distribution losses. The proper field of the induction motor is the haulage of trains at constant speed behind locomotives and the use of this motor will be further discussed under Locomotion.

114. Regenerative (dynamic) braking. In service calling for frequent starting and stopping of trains, it is evident that the $mS^2/2$ constituting the energy loss in heating brake-shoes and wheels, forms a considerable percentage of the total energy input to the train. As the electric motor is reversible, that is, can absorb power and give out mechanical energy, or can give out electric power when mechanically driven as a generator, it seems feasible to expect that some means of control can be designed which will enable a train to be braked electrically with reduced wear and expense of brake-shoe maintenance, besides returning to the line a considerable percentage of the energy delivered to the train during acceleration. Also on roads having excessive continuous grades, it is desirable to return energy to the line partly for the economy thus effected, but largely in order to reduce the danger that goes with braking long heavy trains by means of brake-shoes.

115. Motor capacity for regenerative braking. The standard direct-current motor, being of the series-wound type, cannot be used directly as a stricted space thus available makes it imperative that the weight and outside dimensions of railway motors shall be scaled to the lowest possible limit consistent with the average and momentary output demanded by service requirements. It is customary, therefore, in railway-motor design, to force the density of the magnetic circuit far in excess of what is considered good practice in the design of stationary motors. The effect of this high saturation of the iron circuit is to entail an iron hysteretic and eddy-current loss of such a high value as to preclude the possibility, in many cases, of running the motor continuously at full voltage without overheating it due to the iron loss alone. It is evident, therefore, that recourse must be had to methods of comparative rating of railway motors other than the usual continuous running at full voltage, obtaining in the case of stationary motors. On locomotives these space restrictions have been largely overcome by use of the side-rod drive with the motor mounted above the wheels.

120. The nominal rating of a railway motor shall be the mechanical output at the car axle, measured in kilowatts, which causes a rise of temperature above the surrounding air not exceeding 90 deg. cent. (162 deg. fahr.) at the commutator, and 75 deg. cent. (135 deg. fahr.) by the thermometer, at any other normally accessible part after 1 hr.'s continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature, as measured by resistance, shall not exceed 100 deg. cent. (180 deg. fahr.) during the test.

The statement of the nominal rating shall include the power, voltage and armature speed at rated volts and kilowatts.

121. The continuous-rating input of a railway motor shall be defined by the current in amperes at which it may be operated continuously at half, three-quarters and full voltages respectively, without exceeding the specified temperatures, when operated on test stand with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation, it will be necessary in each case to define the system of ventilation which is used. In case motors are cooled by external blowers, the volume of air on which the rating is based shall be given.

122. The maximum load on railway motors does not usually exceed 150 per cent. of the nominal rating.

123. Two factors determine the capacity of railway motors, namely: commutation and heating. During the accelerating period the current input demanded by a railway motor is always considerably in excess of the current afterward required to run the car at full speed on level tangent track. The value of this current will depend upon the several conditions entering into the problem, weight of train, schedule speed, and frequency of stops, these factors determining the rate of acceleration and maximum speed required as previously outlined. A motor must be selected which can commutate the abnormal current required during the accelerating period without excessive sparking at the brushes.

124. Division of load between motors. For close calculations it is necessary to plot the actual speed-time curves obtaining with any individual motor. In dividing the total current input to the train by the number of motors, in order to obtain the current per motor, it can be assumed that each motor will take its equal share of current at all speeds, provided the motors are of the same type and capacity, and have the same gear ratio.

125. Effect of acceleration rate and maximum speed on capacity. It is evident from working out a few examples, that high rates of acceleration can be used only when low maximum speeds are possible, and that an abnormally large motor capacity will be essential if high rates of acceleration are demanded in connection with high maximum speeds. Thus, although motor equipments of the direct-current series-wound type can always furnish enough current to slip the driving wheels, such high current inputs will be demanded as will considerably exceed the safe rated commutating capacity of motors operating cars at the 50 miles per hr. or more, common to interurban high-speed service. Various devices have been brought out for the purpose of limiting starting currents to safe predetermined values, and the current-limiting device now forms a component part of certain types of control equipment.

rating is given in amperes at half, three-fourths and full voltages. To determine the sufficiency of the motor for a given service, a typical speed-time run should be plotted and from that the square-root-of-the-mean-square (r.m.s.) current should be obtained. This should correspond to the rated continuous current. With the modern self-ventilated motors, this practically controls the temperature, since the increased speed that goes with higher core losses, also causes a better circulation of air through the motor and carries off more heat. It is found that ventilated railway motors carry practically the same current at all voltages. Enclosed motors carry 5 to 10 per cent. more current at the lower speeds corresponding to low voltages and frequent stopping service than at higher speeds and voltages corresponding to interurban service.

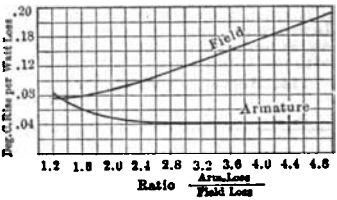


FIG. 35.—Thermal characteristics.

130. Application of thermal-capacity curves. Any given service operation, although made up of short and long runs, can be resolved into a single typical speed-time curve which will call for the same internal losses and the same distribution of motor losses as would obtain under service conditions. By utilizing data as given in the thermal capacity curve, Fig. 35, for a given motor, it is possible to predict, with reasonable accuracy, the temperature rise of a motor for any operating conditions coming within the limits of the motor capacity. As such calculations demand a vast number of experimental runs, the expense of which can only be borne by railway-motor manufacturers, some better form of expressing the relation of railway motor capacity and service performance is necessary for approximation work. Owing to the fact that railway motors of the direct-current series-wound type have become standardized along certain lines, it is possible to establish a working relation between the commercial 1-hr. rating of a motor and its ability to do work under service conditions.

131. Service capacity curves. Applying results similar to Fig. 35, to a series of speed-time curves for different distances run, a curve similar to Fig. 36 is obtained for an equipment having a fixed gear ratio, in this case proportioned for a maximum speed of 45 miles per hr. on tangent level track. This curve, called a service capacity curve, gives directly the temperature rise for a given equipment, in this case a 125-h.p. motor, for any schedule speed that can be performed with a varying number of stops per mile, the equipment being geared for 45 miles per hr. maximum speed when running free.

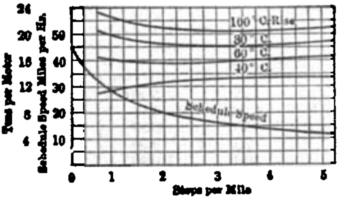


FIG. 36.—Motor service capacity.

132. Application of service capacity curves. It will be noted that the tons train weight per motor for a given temperature rise do not vary greatly over the whole range from five stops per mile down to less than one stop per mile. In other words, a railway motor equipment of fixed gear ratio when mounted on a car of fixed weight, will attain approximately the same temperature rise above the surrounding air, irrespective of the number of stops per mile demanded by service conditions. Thus from Fig. 36 16 tons per motor gives temperature rise of 60 deg. cent. for the motor under consideration, and this temperature rise holds good whether the car is making a schedule speed of 11.5 miles per hr. with five stops per mile, or 29 miles per hr. with one stop per mile.

This fact furnishes a means of simplifying the expression giving the relation between the 1-hr. commercial capacity test and service capacity of the railway motor. It is sufficient for purposes of approximation to rate a

These tables are based upon the temperature rise of 60 deg. cent. above surrounding air, assumed to be 25 deg. cent. The horse-power capacity required conforms to the commercial rating of railway motors, that is, the 1-hr. horse-power rating which will occasion a temperature rise of 75 deg. cent. above surrounding air, taken at 25 deg. cent

The capacities given are approximate only, and are intended as a guide in preliminary calculations. Where accuracy is demanded, or where operating conditions are abnormal, it is necessary to plot speed-time and distance-time curves for the particular motor characteristics nd conditions obtaining, from which the motor temperature should be calculated from a detail knowledge of the motor thermal constants. The method is indicated previously in this description.

135. Division of train horse-power capacity. The horse-power capacity given for any train weight may be split up into the required number of units. Thus, a train composed of five 40-ton cars running at 45 miles per hr. requires 1,180 h.p. motor capacity. This may be divided into six units of 200 h.p. each, that is, three motor cars equipped with double 200 h.p. motors hauling two trailers, or each car of the train may be a motor car and be equipped with a pair of 120-h.p. motors. Approximately the same temperature rise will obtain in either case.

Certain motors of modern construction provide for longitudinal ventilation either with blower on armature or with external blower. In either case, the armature and field losses are carried off independently of each other by the introduction of external air, hence the ratio of losses in such motors becomes of secondary importance.

136. Division of capacity for single cars and trains. For single-car operation a four-motor equipment is preferred for double-truck cars, this being especially true where snow or heavy grades are characteristic of the service. For train operation, two-motor equipments are used, as the disabling of a single unit will not incapacitate the train.

The horse-power capacity specified in Par. **134** for train operation should be made use of only when cars are always operated in trains and never singly. For example, five 40-ton cars operating in a train at 60 miles per hr. require a motor capacity of 1,770 h.p., or 354 h.p. per car, a motor capacity too low for single car operation, which demands 525 h.p. Hence, where cars are run indiscriminately, singly and in trains, the full motor capacity per car should be taken as given in the table of single-car operation.

137. Power requirements with single-phase equipment. Owing to the short period during which single-phase motors have been operated, their design has not yet become standardised, nor is there sufficient operating data upon which to base anything more than general conclusions of the horse-power required for a given service. The single-phase motor is essentially a high-speed motor, having a high copper loss and low core loss, hence, is more particularly adapted to constant-speed running, and suffers in comparison with the direct-current series wound motor when used for acceleration work. There is no lack of starting torque with the alternating-current motor, but a large tractive effort is obtained only at the expense of a large copper loss, so that alternating-current motors are unsuitable for rapid transit service demanding repeated high rate of acceleration, not because such motors cannot furnish the tractive effort required, but because the copper loss incident to such high tractive efforts will heat the motors unduly if used exclusively for acceleration service. Thus the alternating-current motor becomes much heavier than the direct-current motor on the basis of service performed with frequent stops.

138. Single-phase equipment for a service embracing infrequent stops. In interurban or express service with infrequent stops, the smaller core loss of the alternating-current motor brings it more nearly on a par with the direct-current series wound motor as regards output per pound weight of motor. It is possible therefore to use the figures of Par. **134** as applying to alternating-current motor capacity, where stops are not greater than one in 2 miles. However, the table should not be used in connection with higher frequency of stops given, as then the resulting motor capacity indicated in the table must be largely increased when applied to alternating-current motors.

Owing to the fact that the chief advantage of the single-phase motor lies in its ability to utilise the benefits of trolley potentials of 11,000 to 15,000 volts as compared with the 600 to 3,000 volts used with direct-current

141. *Continued.* **600-volt direct-current commutating-pole type**

Type	H.P. 500 volt	H.P. 600 volt	No. motors	Type control	Weight motor (lb.)	Weight total equipment (lb.)
200	33	40	2	K-36	2,120	5,490
			4	K-35		9,880
			4	Mult. Unit		10,410
216	40	50	2	K-36	2,900	7,000
			4	K-35		13,200
			4	Mult. Unit		13,450
203	40	50	2	K-36	2,665	6,450
			4	K-35		12,100
			4	Mult. Unit		12,350
219	40	50	2	K-36	2,890	6,833
			4	K-35		13,140
			4	Mult. Unit		13,390
201	55	65	2	K-36	2,885	7,000
			4	K-35		13,180
			2	Mult. Unit		7,690
			4	Mult. Unit		13,280
210	60	70	2	K-36	3,370	7,750
				K-34		15,710
				Mult. Unit		8,690
				Mult. Unit		15,680
218	60	70	2	K-36	3,200	8,100
			4	K-34		15,000
			2	Mult. Unit		8,330
			4	Mult. Unit		14,960
214	65	75	2	K-35	3,805	9,282
			4	K-34		17,414
			2	Mult. Unit		9,430
			4	Mult. Unit		17,240
233	65	80	2	K-35	3,350	8,370
			4	K-34		15,700
				Mult Unit.		15,940
205	90	110	2	K-35	3,865	9,200
			4	K-44		18,330
			2	Mult. Unit		9,800
			4	Mult. Unit		18,300
225	95	115	2	Mult. Unit	3,860	10,200
			4	Mult. Unit		18,769
222	115	140	2	Mult. Unit	4,100	10,710
			4	Mult. Unit		19,900
207	135	165	2	Mult. Unit	5,160	13,050
			4	Mult. Unit		25,950
212	195	225	2	Mult. Unit	6,200	14,800
			4	Mult. Unit		29,780

149. The distinctive feature of cylinder (drum) control is that the various electrical connections are made and broken manually, by means of a hand controller. This consists of an upright cylinder upon which are mounted the contacts and against which stationary fingers press. When the cylinder is rotated (by means of a handle) the contacts connect the proper fingers to form the required electrical connections.

150. Cylinder (drum) controllers are classified as follows: Type "*K*" Controllers are of the series-parallel type and include the feature of shunting and short-circuiting one motor or group of motors, when changing from series to parallel connection.

Type "*L*" controllers are of the series-parallel type, but completely open the power circuit during transition from series to parallel connection.

Type "*R*" Controllers are of the rheostatic type and are designed to control one or more motors by means of resistance only. Certain of these controllers are arranged so that the motors may be grouped either in series or in parallel at the option of the operator, but as this must be accomplished by throwing a separate lever, these controllers are not used as series-parallel controllers and their field is limited.

Type "*B*" controllers may be either of the rheostatic or the series-parallel types, but they differ from the ordinary rheostatic or series-parallel controllers by having the contacts arranged so that if desired, the power may be cut off, the motors reversed and then short-circuited through a variable resistance, the motors thus acting as series generators. Beside the braking effect of the motors acting as generators, use is sometimes made of magnetic rail brakes or axle brakes, the coils of these magnetic brakes being in series with the short-circuited generators.

151. The rated capacity of drum controllers is based upon the maximum horse-power of the motors with which they can be used, the motors being rated in accordance with standard practice, that is, the 1-hr. or nominal rating as defined in the standardization rules of the American Institute of Electrical Engineers. This rating is usually based upon a pressure of 500 volts, so that controller ratings are based upon a nominal potential of 500 volts. If the controllers are used with motors wound for lower voltages, the horse-power ratings will, in general, be proportionately less.

152. Standard series-parallel controllers

Title	Capacity at 500 volts	Controlling points	Maximum potential
K–10	2–40 h.p.	5 series 4 parallel	600 volts
K–11	2–60 h.p.	5 series 4 parallel	600 volts
K–12	4–30 h.p.	5 series 4 parallel	600 volts
K–28	4–40 h.p.	5 series 5 parallel	600 volts
K–34	4–75 h.p.	6 series 4 parallel	750 volts
K–35	4–55 h.p.	5 series 3 parallel	750 volts
K–36	2–60 h.p.	4 series 4 parallel	750 volts
K–51	2–60 h.p. (Field control motors)	5 series (1 with short field) 4 parallel (1 with short field)	750 volts

153. Auxiliary contactor control. In order to increase the reliability and efficiency of drum types of controllers there has been developed a system whereby the main power circuit is broken by means of remote-control switches mounted under the car, when the controller is moved to the "off" position. The use of these additional power-operated switches relieves the main controller fingers of the serious arcing and burning, especially when opening the circuit under overload conditions.

156. Multiple-unit control. The distinctive features of multiple unit ontrol are: the various main circuit connections are made and commutated y means of individual power-operated switches (either electrically operated r electropneumatically operated); the various switches are controlled by neans of secondary or control circuits. The multiple-unit type of control vas brought out primarily for the control of motors in a service requiring hat cars be operated singly or severally coupled together in a train and oper- ted simultaneously. This control is also used very extensively at present n car equipments where the motors have a capacity of 60 h.p. or more at 00 volts. When several cars are coupled together in a train, the control ' train lines" of the cars are connected together by means of jumpers between ars so that if the train-line wires are energized from any master controller n any car, similar control circuits in each car are energized, thus causing the simultaneous operation of all motor cars. The control circuits of each car are arranged so that when operating in trains, the movement of all cars will be in the same direction regardless of whether any of the cars are turned end for end. See Fig. 38.

The principal pieces of apparatus which, in general, make up a multiple unit control equipment are as follows:

Main circuit apparatus	Control circuit apparatus
Current collectors Switches and fuses A number of remotely controlled switches mounted in groups Resistors Reverser	Control switches Master controllers Junction boxes Receptacles Jumpers Relays (if necessary)

Two general types of multiple unit control are used in this country, these two types differing chiefly in the method of operating the individual switches. The control system manufactured by the Westinghouse Elec. & Mfg. Co. operates the main switches pneumatically, whereas that manufactured by the General Electric Co. closes the main switches by means of solenoids. Both companies manufacture automatic as well as manually operated control for multiple-unit acceleration.

157. General Electric multiple-unit control is described in detail in Par. **158** to **167**. In the automatic system the acceleration is effected by current-limiting relays and interlocking switches on the contactors. The multiple-unit system of control with hand-operated or manually controlled acceleration is in general use both for train and single-car operation. It is, in effect, identical with the hand-operated cylinder type of control except that instead of combining all the various circuit-breaking contacts upon a single cylinder operated by hand, it divides each contact into a separate circuit-breaker or contactor, and actuates these electrically through train wires by means of a small master controller. The motor control therefore comprises those parts which handle motor current, all of these parts being electrically operated and located underneath the car.

158. The master controller (Par. **157**) Fig. 39 comprises those parts which switch the control current operating the motor-control apparatus. The master controller (Par. **159**) is operated by hand, and is located in the vestibule at either end of the car. The motor control is local to each car, and current for this circuit is taken directly from the trolley or third-rail through the contactors, starting resistance and reverser to the motors, thence to the ground. Where it is necessary to operate with a gap in the third-rail system, it is sometimes customary to install such a train line that any car may supply the motor current for the other cars of the train.

The master control includes train wires (Par. **167**) made continuous throughout the train by means of couplers between the cars. On each car the operating coils of the motor control are connected to this train line through a cut-out switch, these train wires being energized in proper sequence by the hand-operated master controller on the platform. Current for the master control is taken directly from the trolley or third-rail through the master controller, which is being operated by the motorman, to the train-line, and wires of the train line, for energising the operating coils of the motor control. The value of the current required is very small, not exceeding 2.5 amp. for each car in the train. The master controller is provided with two handles, one for operating and one for reversing the train movement.

The operating handle is provided with a button which must be kept down except when the handle of the controller is in the off position, as releasing this button permits an auxiliary circuit to open, cutting off the supply of current to the master controller, and thus de-energising the train-line and opening up the motor-control apparatus. This button is intended to serve as a safety appliance in case of physical failure of the motorman.

The reverser handle is connected to a separate cylinder which establishes control connections for throwing the electrically operated reverser either forward or reverse position when the master-controller handle is on the off point. The operating circuit for the reverser is so interlocked that unless the reverser itself corresponds to the direction of the movement indicated by the reverser handle of the master controller, the line contactors on that car cannot be energised.

160. The contactor (Par. 157) is a switch operated by solenoid coils, and each contactor may be considered as the equivalent of a finger and its corresponding cylinder segment in the hand-operated "*K*"-type controller. It consists of an iron magnet frame with an operating coil and two main contacts, one fixed and the other directly connected to the movable finger. These main contacts open and close in a moulded-insulation arc chute provided with a powerful magnetic blowout. Interlocks are provided for making the necessary connections in control circuits to ensure proper sequence in operating the different contactors.

All of the contactors are mounted in a box placed beneath the car, this box being provided with a sheet-iron cover lined with insulating material.

161. The reverser (Par. 157) is a switch, the movable part of which is a rocker arm operated by two electromagnets working in opposition. The coils receive their energy from the master controller through the train-line, and the connections are such that only one coil can be operated at a time. Leads from the motors are connected to the main reverser fingers, and by means of copper bars on the rocker arm, the proper relations of armature and field windings are established for obtaining forward or backward motion of the car. Also see Par. 173.

162. Circuit couplers between cars (Par. 157) are so designed as to give a corresponding connection of train wires, this being secured by means of proper mechanical design of plug and sockets, it being rendered impossible to insert the plug in the socket improperly.

163. Automatic multiple-unit control. Sprague General Electric (Par. 157) provides for the acceleration of the train at a predetermined value of current in the motor, this feature being provided without preventing the manual operation of the master controller at less than the predetermined current if desired.

The operation of the contactors is controlled from the master controller, but is governed by a notching or current-limit relay in the motor circuit, so that the accelerating current of the motors is substantially constant.

This is accomplished by having small auxiliary interlocking switches on certain of the contactors, the movement of each connecting the operating coil of the succeeding contactor to the control circuit. The contactors are energised under all conditions in a definite succession, starting with the motors in series and all resistance in circuit; the resistance is subsequently cut out step by step; the motors are then connected in parallel with all resistance in circuit, and the resistance again cut out step by step. The progression can be arrested at any point, however, by the master controller, and is never carried beyond the point indicated by the position of the master controller. The rate of the progression is governed by the current-limit relay, so that the advance cannot be made at a rate so rapid that the current in the motors will exceed the prescribed limit. One of these relays is provided with each car equipment, so that while the contactors on each car of a train are controlled from the master controller in use for the application and removal of power, the rate of progression through the successive steps is limited by the relay on each car independently, according to the adjustment and current requirements of that particular car.

169. The HL system of control (Westinghouse) is widely used for the control of direct-current motors on city and interurban cars and is described in detail in Par. 170 to 179. A standard car equipment for the control of 4–40-h.p., 500-volt motors arranged for double end operation in trains includes the following part:

Main circuit apparatus	Control apparatus
2 Trolleys	2 Master controllers
1 Lightning arrester	2 Control and reset switches
1 Main knife switch	1 Control resistor
1 Main fuse box	3 Train line junction boxes
1 Switch group	2 Train line receptacles
1 Reverser	1 Train line jumpers
1 Main grid resistor	1 Set of pneumatic details

In Fig. 41 is shown the control connections of the above apparatus. This system of control uses the shunting method of transition from series to parallel for the smaller sizes of motor equipments, but for the larger equipments, the bridging method is used Par. 148.

170. The main knife switch (Par. 169) is arranged for mounting underneath the car and is enclosed in a box, which protects it from the weather, and insures against accidental contact.

The **main fuse box** (Par. 169) is of the magnetic-blowout, copper-ribbon type, arranged for mounting under the car. The connection of this fuse box in the main circuit is shown clearly in Fig. 41.

171. Switch group. The various main-circuit connections are made by means of a number of independent switches known as unit switches, each provided with a strong magnetic blowout, and normally held open by a powerful spring. Each switch is closed, when desired, by compressed air acting on a piston. This action forces the switch jaws together against the spring pressure, the force being sufficient not only to compress the spring, but also to apply a heavy pressure at the switch jaws. The air is admitted to or exhausted from the cylinder through a valve which is operated by means of a solenoid in the control circuit. The switch group consists of a number of these unit switches mounted with blowout coils, in a common frame, and completely enclosed by removable sheet-iron covers lined with asbestos. Switches for cutting out damaged motors are mounted on one end of the group, and the overload trip relay is mounted on the other end.

172. Line switch. In larger equipments, where it is necessary to have a larger number of switches, two of the switches are mounted in a separate frame with the overload trip. This assembly constitutes what is termed a line switch.

The **overload trip** mechanism (Par. 169) consists of a core, which is drawn into the end blowout coil of the switch group or line switch, when an excessive current passes through this coil. The core is normally held out by means of a spring, but when drawn into the blowout coil, is latched and must be released either manually or by energising a reset coil. When actuated, the trip opens the control circuits of certain switches which cut off the power. Calibration for various currents is accomplished by an adjustment of the air gap.

When the position (whether closed or open) of a switch necessitates a change in the control circuits, an interlock must be employed to effect this change. This **interlock** consists of a block carrying contacts so mounted on the switch that it will be moved from one position to another according to the position of the switch. Pressing against this block are stationary fingers to which the control wires are attached.

173. Reverser (Par. 169). The direction of rotation of the motors is changed by reversing the main fields. The reverser consists of the necessary number of main circuit fingers mounted on a stationary base, and arranged to press against contacts carried on a movable drum. The drum with its contacts is moved to the forward or to the reverse position by one or the other of two pneumatic cylinders closely resembling those in the switch

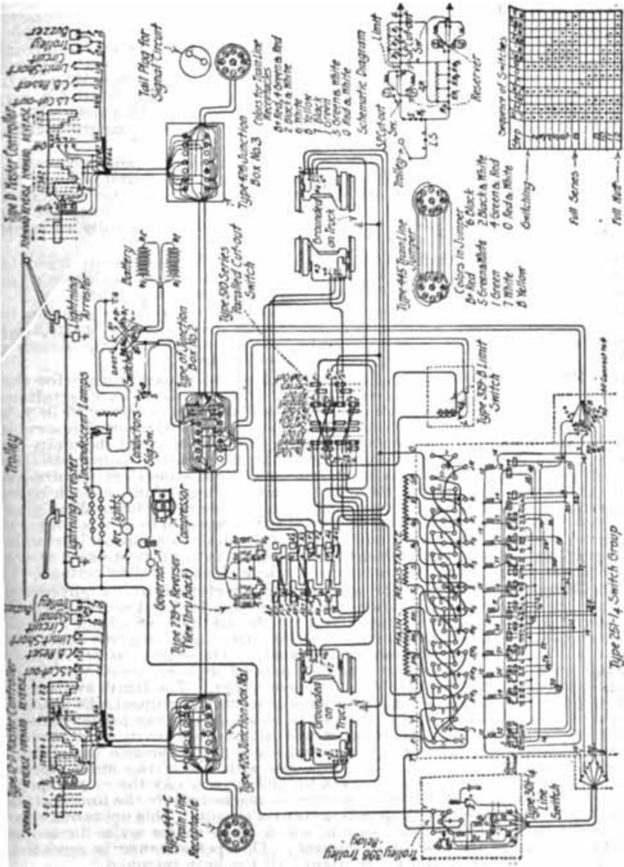


FIG. 42.—Westinghouse main and control wiring.

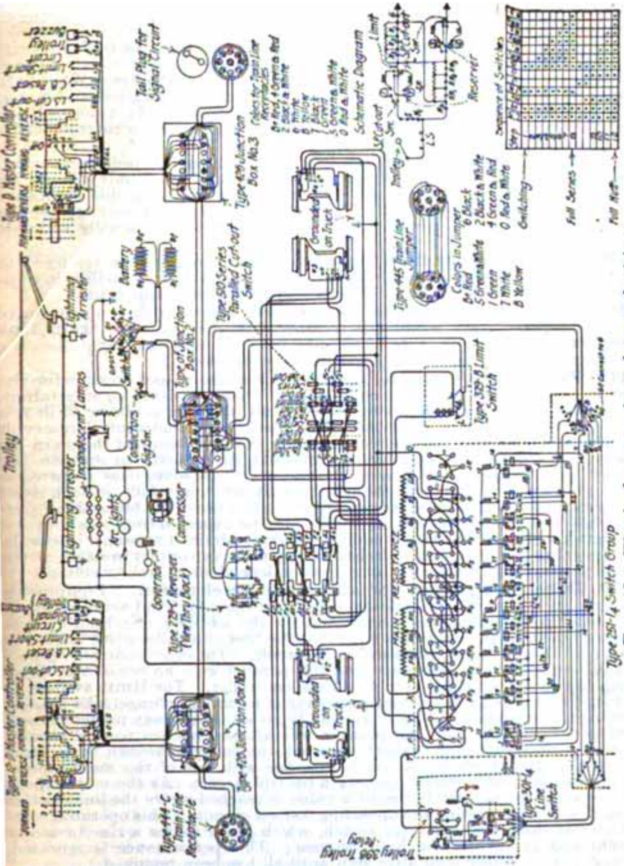


FIG. 42.—Westinghouse main and control wiring.

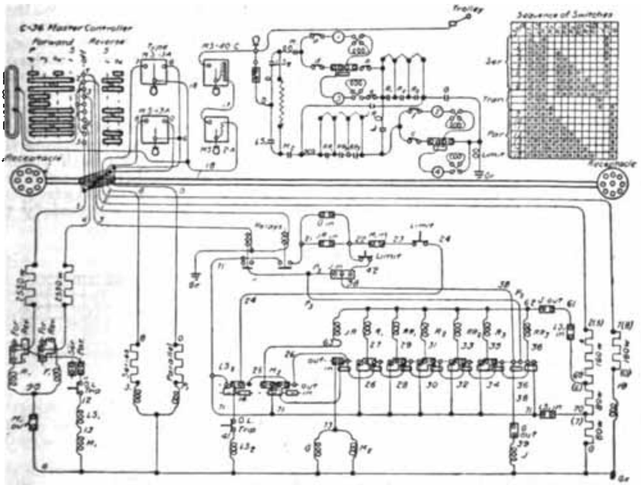


FIG. 43.—Westinghouse 600-volt direct-current motor-car main and control schematic.

180. Tap-potential control of single-phase motors. The single-phase motor is essentially the same in its characteristics as the direct-current series-wound motor, and can be started at low voltage by means of inserting series resistance according to the direct-current standard method. With alternating-current supply, however, it is possible to obtain fractional voltage without sacrificing efficiency, as the step-down transformer forming part of the alternating-current car equipment can be constructed with taps so that it will furnish fractional voltage without the necessity of introducing starting resistance. The universal method of starting single-phase motors is, therefore, by the so-called tap-potential control, and the function of the control, whether it be hand-operated "*K*" type or multiple unit, is to connect the motor terminals successively to transformer taps of increasing potential while starting.

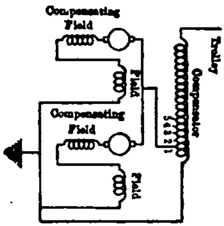


FIG. 44.—Tap control.

181. The hand-operated control of single-phase motors is identical with the type "*K*" controller used with direct-current motors, except that advantage is taken of the fact that alternating-current arcs of considerable size can be broken in the air without the aid of the magnetic blowout. Where the cars are to be operated from both alternating-current and direct-current trolley with the same equipment, the hand-operated control is provided with magnetic blowout for direct-current operation, using the same controller without the magnetic blowout for alternating-current operation, unless the motor equipment be of large capacity.

182. Control of single-phase motors for combined alternating-current and direct-current service. The control of single-phase motor is effected by connecting the motor terminals to transformer taps of increasing potential in order to vary the speed, while reversal is effected by reversing the series field-winding connections, thus calling for practically the

185. Number of starting points. Owing to the fact that the alternating-current motor characteristic is more drooping than even that of the direct-current series-wound motor, fewer starting points are required for alternating-current control. The General Electric Company uses five steps, and the Westinghouse uses six steps when the speed does not exceed 40 to 45 miles per hr. maximum. As each point on the controller, with potential-tap control, constitutes a running point at full efficiency, it is not necessary to use series-parallel connection of motors as is done with direct-current motors.

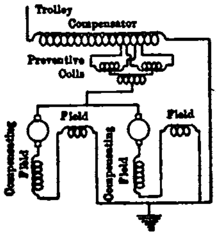


FIG. 46.—Westinghouse tap control.

186. Multiple-unit control equipments for single-phase motors differ somewhat from direct-current equipments in the general plan of operation. This difference is confined chiefly to the main circuits and main-circuit apparatus. The high-tension current passes from the overhead collector through an oil circuit-breaker, to a transformer. Low voltage currents are fed to the main motors through a group of unit switches, which can be arranged for automatic or non-automatic acceleration. Fig. 45 shows the connections for a typical type "*AB*," 11,000-volt single-phase equipment.

TYPES OF RAILWAY MOTORS

187. Direct-current series-wound motor. Wound for potentials of from 500 to 1,200 volts is the standard railway motor. Motors of from 500 to 600 volts are used in and around large cities, 1,200-volt motors being adopted on interurban electrified lines. Armature and field windings are connected in series and the use of motors of the commutating pole type is increasing. All motors designed for street, interurban and rapid transit car or train service have four field poles, the structure being entirely enclosed with hand hole covers making it waterproof. Such motors transmit power by single-reduction gear, motors being suspended at one end upon the car axle and spring suspended at the other end.

For locomotive work, the General Electric Company has brought out a two-pole gearless motor, which design is also adapted for high-speed single-car service calling for large motor outputs. The two-pole series motor is especially adapted to very high speed service; it minimizes cost of repairs and operates with decreased noise and greatly increased efficiency for express service. For further description of gearless motors see locomotives (Par. 260).

188. The single-phase series motor has been developed along several lines of which the series-wound compensated motor is the one most generally used in the United States. The single-phase motor differs from the direct-current series-wound motor in having two fields, the series or energizing field and the **compensating field.** The office of the latter is to compensate for or neutralize the inductance of the armature produced by the alternating current therein. Compensation may be the means of raising the power-factor of a single-phase motor to values closely approximating 100 per cent., and having an operating value above 95 per cent.

This compensating field may be either conductively or inductively produced, depending upon whether the winding is traversed by the main motor current, or by the current produced in its own short-circuited winding by the alternating armature flux. So far as concerns operation from alternating-current supply, one form is about as efficient as another, but the conductive compensation is an aid when the alternating-current motor is called upon to operate as a direct-current motor.

The series-field winding of the single-phase compensated motor is connected in series with the armature, and the direction of rotation can be reversed by reversing the field-winding connections similar to direct-current operation. The series-field winding may be distributed in a number of slots in the field-magnet structure similar to the compensating-field winding, or it may take the form of a concentrated winding, in which case it is similar to the winding of a direct-current series motor embracing inwardly projecting poles. The concentrated field winding is largely used in alternating-over a regular profile, either level or up a uniform gradient, in other words, where there is no combination of slow-speed grade haulage and high-speed level service.

192. The single-phase induction motor has been used for railway purposes on experimental roads, but owing to the zero starting torque of this motor it is necessary to operate it in conjunction with an auxiliary starting device and throw the motive power into action by mechanical clutches or other means after full motor speed has been obtained. This type of motive power is very limited in its field of application.

193. The split-phase converter system comprises a method of obtaining polyphase current from a single-phase trolley, for the operation of polyphase motors. It consists of a phase converter which is essentially a polyphase induction motor the capacity of which is approximately 75 per cent. of the capacity of the motors it supplies. As the phase converter is operated from one phase only, it requires a starting motor to bring it up to near synchronous speed. In all applications of this principle, the single-phase current has been converted into two-phase current. In the Norfolk & Western locomotives, these two phases are changed to three-phase by a connection similar to the well-known Scott system. The advantage claimed for the three-phase is that the motor has a better performance and is also better for pole changing while it entails no more regulating switches and has fewer leads.

BRAKING

194. Retarding factors. In order to bring a moving train to a stop, it is evident that some external force opposed to the motion of the train must be applied. The ideal force would be applied at the centre of gravity of the car (producing no tendency for the car to rotate) and would be sufficient to stop the train in case of emergency in the shortest possible time, without undue shock to passengers or equipment. With the exception of a few instances, such as short cable roads up a mountain side, the only available force which may be utilized in stopping a train is the friction which exists between the wheels and the rails. This force, besides being applied at the lower rim of the wheel and consequently not at the centre of gravity of the car, is also a variable quantity of uncertain magnitude, and therefore not an ideal retarding force. For instance the adhesion between a dry rail and wheel may be equal to about 30 per cent. of the pressure between wheel and rail, whereas with a wet rail it may be only half that amount. The addition of sand to a slippery rail will increase the adhesion from 15 per cent. to about 25 per cent. of the weight on the rails, and this amount can usually be relied upon in making emergency stops. This force of 25 per cent. of the weight on the rails applied to a car will produce a retardation equal to one-quarter the acceleration due to gravity, or 8.04 ft. per sec. per sec., or nearly 5.5 miles per hr. per sec. If it were possible to apply this force instantly and uniformly throughout the stops, a stop from an initial speed of 60 miles per hr. could be made in about 11 sec., or in a distance of 480 ft. This force, however, is only available when the wheels are rolling on the rails, for as soon as slipping occurs the adhesion rapidly decreases. Therefore the force which opposes the revolution of the wheels, namely the brake-shoe friction, must never exceed that which is keeping the wheels turning, namely the adhesion between the wheels and rails. This opposing force is obtained in several different ways, the most familiar being by applying brake-shoes to the rim of the wheels with considerable force by means of hand or power brakes. Another method, which is applicable in electric traction, is known as electric braking, as distinguished from mechanical braking, and consists in opposing the revolution of the wheels with the counter-torque of the motors or by the friction of electrically operated brake discs.

195. Tests to determine friction coefficients. About the first systematic tests to determine the value of the **coefficient of friction between brake shoes and wheel**, and between wheel and rail were conducted by Sir Douglass Galton and Mr. George Westinghouse in 1878 and 1879 on the London, Brighton & South Coast Railway, England. A report of these tests appears in the proceedings of the Institute of Mechanical Engineers of London, for April, 1879. The table in Par. **196** gives the results of these tests:

wherein f is the coefficient of friction at beginning of application: f' the coefficient of friction after brake application of T sec.

200. General laws affecting friction coefficient. The absence of more extended observations and the complex nature of fluctuations of the coefficient of friction make it impossible to formulate a practical mathematical equation which will determine the rate of retardation under varying conditions. However, the results of the tests shown in the tables above indicate a law of variations which may be briefly stated as follows, regardless of the materials used.

(a) The coefficient of friction increases with the decrease in speed;

(b) Decreases with the increased distance through which brakes are applied, and

(c) Decreases with the increase of pressure.

201. To obtain a uniform braking effort throughout the stop, the brake-shoe pressure must be varied to compensate for the fluctuations in the coefficient of friction, that is, the brake-shoe pressure must be decreased as the diminution in speed increases the coefficient of friction, and increased as the distance of brake application decreases the coefficient of friction, and further increased to compensate for the decrease of the latter with increased pressure.

For certain speeds the increase in coefficient of friction with decrease in speed is practically neutralized by a decrease due to increased distance of frictional contact. For lower speeds, however, the increase from the former cause is more rapid than the decrease from the latter, necessitating an almost abrupt decrease in brake-shoe pressure near the end of a stop, in order to avoid slipping the wheels on the rails and discomfort to passengers.

202. Efficient emergency braking. For the same pressure, the coefficient of brake-shoe friction at 60 miles per hr. is only about half that at 20 miles per hr. It is therefore evident that an emergency stop for high speed is less efficient than for a low speed, since an emergency application implies that the maximum pressure which will not slip the wheels near the end of the stop, is instantly applied at the very outset. A considerably shorter stop may be made if the pressure applied during the earlier periods of the stop is greatly in excess of that which will slip the wheels at low speed, but in the absence of the motorman's skill, some means must be provided to decrease the pressure near the end of the stop, in order that the limits of rail friction will not be exceeded, and the efficiency of the stop thereby decreased. This provision, however, requires additional apparatus, which on general principles is objectionable unless the showing is so favorable as to warrant further complications.

203. Application of the retarding force. Thus far, attention has been devoted to outlining methods for overcoming the obstacles presented by the complex nature of the fluctuations of the coefficient of brake-shoe friction which prevent the utilization of the theoretically possible retarding forces, The nature of the application of these forces imposes difficulties which prevent the full utilization of the weight on the trucks and wheels, thereby directly affecting the braking force.

At the present time it is customary to equip double-truck cars with either two motors or four motors, depending upon the nature of the service. In the former case both motors are usually placed on one truck thus permitting the use of a lighter truck for a trailer. The pressure which may be safely applied to the wheels of the motor truck without causing the wheels to slip, cannot be applied to the wheels of the trailer truck. Hence the brake rigging must be so proportioned that the greatest portion of the braking is done upon the wheels of the motor truck. Considering, however, the case where the normal distribution of weight is equal for all wheels, it is found that, during braking, a greater pressure may be applied to the wheels of the forward truck without causing them to slide than may be applied to the wheels of the rear truck. The explanation is somewhat simplified when considering single-car operation, since draw-bar forces may be eliminated.

204. Vertical thrust on forward truck. The resultant of all the parallel forces, which act on the elementary masses of the car tending to keep it in motion, is equal to the sum of all these forces acting through the center of gravity of the car and in the direction of motion. Directly opposed to the motion of the car is the wind pressure, which is exerted normal to the eleof the centre of the shoe, in order to compensate exactly for the rotating influence of the car body, is too involved for presentation here. For this reason reference is made to Mr. R. A. Parke's excellent paper in the Proceedings of the American Institute of Electrical Engineers, Vol. XXII, Dec., 1902.

207. A common form of hand brake consists of a vertical shaft at each end of the car fitted at the top with a ratchet handle or crank, or geared to a hand wheel. By means of this mechanism, the motorman can wind up a chain, one end of which is fastened to the lower end of the vertical shaft and the other end to a rod which connects with a system of brake levers. By means of a pawl (or dog) which engages in a ratchet wheel on the vertical shaft near the floor of the car, the motorman is enabled to maintain a pressure on the brake-shoe while he gains a more favorable purchase for applying more pressure, or until such times as he desires to release the brakes. This

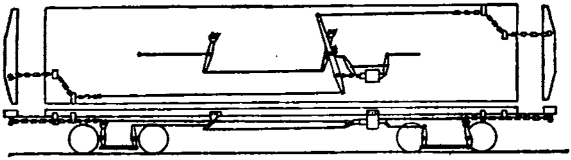


FIG. 54.—Diagram of brake rigging.

brake has been found capable of supplying sufficient braking power for the safe control of light cars running at moderate speed, but for heavy cars and high speeds the physical effort and time required to properly apply the brakes render it necessary to provide other means of supplying the proper force in a minimum length of time. Hand brakes, nevertheless, are always provided as an additional safeguard, even though the cars may be equipped with power brakes, as it is always customary to set up the hand brakes on all cars when they are left standing.

208. Air-brakes (Par. 209 to 229) in some form, have been universally adopted on all steam roads for braking both passenger and freight trains, and the results have been attended with such success that modifications and improvements of the old steam-railroad air-brake system have been developed and adopted by a vast majority of electric lines operating heavy high-speed interurban cars, either singly or in trains. On account of the varying character of the service on different electric roads, it has been found necessary to develop several systems, or modifications of the same system which will be best adapted for the service in hand.

The most familiar types at present are known as the following: *the straight air-brake system* (Par. 209), recommended for single-car operation only; *the emergency straight-air system* (Par. 215), suitable for two-car operation, particularly when one is operated single most of the time and with a trailer added during rush hours; *the automatic air-brake* (Par. 218), suitable for electric trains of three cars or more; *the combined straight and automatic air-brake* (Par. 227), designed for locomotive operation, no matter whether steam or electric; *the electropneumatic air-brake* (Par. 228), at present in an experimental state, but particularly adapted to train operation, inasmuch as the time element in the application and release of the brakes on the rear end of a long train is practically eliminated.

209. The straight air-brake system described in detail in Par. 210 to 214, consists essentially of a source of compressed air (either a tank filled at intervals from a compressor at charging stations, or an air compressor, motor or axle driven, located upon the car); a reservoir which receives the air from the charging tanks or from the compressor and in which the pressure is maintained practically constant by means of a reducing valve, or by a governor which automatically controls the operation of the compressor; a brake cylinder, the piston of which is connected to a system of brake levers in such a manner that when the piston is forced outward by air pressure the brakes are applied; an operating valve mounted in each vestibule by means of which the compressed air is either admitted or released from the brake cylinders; a pipe system connecting the above parts, including cut-out valves, extra hose, to insure that air will apply throughout the entire train. All the cut-out cocks must be open except those on the rear of the last car, and the front of the first car.

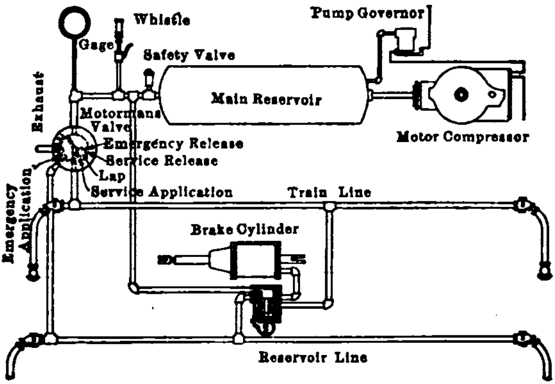


FIG. 56.—General Electric emergency straight-air brake system.

214. Field of application (Par. 209). So far as single-car operation is concerned, the straight air-brake system is very satisfactory, as the desired flexibility in the matter of graduations of applications and release of the brakes with due regard to the passengers standing can readily be secured, and this apparatus is usually so simple in construction that the motorman may become familiar with its operation to such an extent that accurate stops may be secured with a minimum amount of instruction. In trains of considerable length, however, the response of the brakes on the rear cars is too slow, since all the air must pass from the main reservoir on the front car through the opening in the motorman's valve to the brake cylinders of each car. As the addition of each car adds to the volume of the brake system, the main reservoir on the first car must be considerably increased. The reservoir capacity must be so proportioned that the pressure will not be reduced to such an extent that the brake application will be insufficient and result in overrunning the desired stopping place. These latter objections would not necessarily prevent the use of this type of air-brakes on short trains of two or three cars, but add to the objection that a broken hose connection or leaky train pipe renders the brakes on the whole train inoperative.

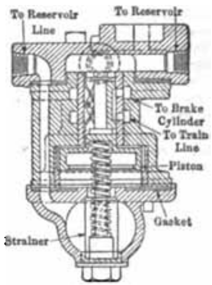


FIG. 57.—Emergency valve.

215. The emergency straight air-brake, described in detail in Par. 216 and 217, differs from the straight air-brake in the details of the motorman's valve and in the addition of an emergency valve and reservoir line which connects the motorman's valve with the emergency valves (Figs. 56 and 57). In the case of a trail car, an auxiliary reservoir (Par. 217) is also added, as shown in Fig. 58.

In the ordinary operation of single cars or short trains, the emergency valve is seldom brought into play. It is necessary, however, to provide a short direct passage from the reservoir to the brake cylinder in order to ensure the quickest possible action in time of emergency and to provide some means of automatically braking the rear cars should a break occur in the train line. At other release them, whereas in the latter, air is admitted to the train pipe to apply the brakes and exhausted to release them.

219. The apparatus required (Par. 218) for this system in addition to that already mentioned for the straight air-brakes is as follows: a set of duplex pressure gages, which indicate simultaneously the pressure in the main reservoir and in the train pipe; an auxiliary reservoir, for storing the air used by each car in braking; a triple valve, the function of which is to admit air from the auxiliary reservoir into the brake cylinder and to release it therefrom (in release position, the auxiliary reservoir is recharged), and an air-whistle reservoir, with suitable check valve for supplying air to the air whistle.

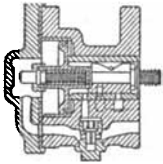


Fig. 59.—S. I. triple valve.

This system is capable of a great many refinements which may be added or omitted as requirements of a particular service may prescribe. The main points of difference between particular automatic air-brake equipments will generally be found in the details of the triple valves, and the addition of pressure maintaining and reducing valves. These features are essential in certain classes of grade work in order to prevent brakes "leaking off." These particulars have been intentionally omitted from this consideration in order to avoid undue complexity. Two forms of triple valves, however, need to be considered here inasmuch as the plain triple valve, Fig. 59, is only used on comparatively short trains, about five cars in length, whereas the quick-action triple valve, Fig. 60, is designed to be used on much longer trains.

220. Emergency application (Par. 218). For the emergency position shown in diagram, Fig. 60, the train line is open to the atmosphere, allowing auxiliary reservoir pressure on the right of the slide-valve piston forcing it to the left against the graduating spring, compressing it and uncovering the brake cylinder port. Air is thus permitted to flow from the auxiliary reservoir directly into the brake cylinder; at the same time the ports leading to the atmosphere and to the train pipe are closed.

221. To release the brakes (Par. 218), the main reservoir air is admitted through the train to the chamber at the left of the slide-valve piston, forcing it to the right, and connecting the brake-cylinder port to the exhaust pipe. At the same time, air at the main reservoir pressure raises the check valve and recharges the auxiliary reservoir to main reservoir pressure.

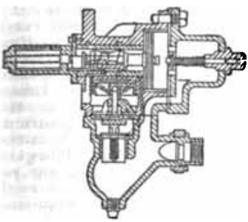


Fig. 60.—K triple valve.

A **graduated release** of the brakes may be obtained with this type of valve, by piping the exhaust from the triple valve to the motorman's valve where a movement of the valve handle will release the air the same as in the straight air-brake.

222. Necessary train-line reduction (Par. 218). A service application requires only a slight reduction in train-line pressure (from 5 to 7 lb.) which is sufficient to permit the slide-valve piston to slightly compress the graduating spring and partially open the brake-cylinder port. When the auxiliary reservoir pressure has been reduced to about the same value as the train-line pressure, the graduating spring will return the slide valve to lap position, closing all the ports before the brakes are fully applied. The auxiliary reservoir and brake cylinder are usually so proportioned that the brakes are fully applied when the brake piston displacement is sufficient to reduce the auxiliary reservoir pressure about 15 lb. Therefore, a train pipe reduction greater than 15 lb. fully applies the brakes and is wasteful of air, because the train pipe and the auxiliary reservoir must be fully charged after each application.

223. The quick-action triple valve (Par. 218), shown in Fig. 60, is designed to be used on freight trains of considerable length, its function is to apply and release the brakes on the rear cars so quickly that the running in and out of the slack is avoided. Fig. 62 is a diagrammatical section of the through the charging grooves before opening a small port in the slide valve, would permit the train line pressure to raise the check valve and slowly re-charge the auxiliary reservoir. The function of the charging device (shown on the outside of the valve in Fig. 60) is to prevent the inertia of the slide valve from forcing it to the extreme right of its travel when the valve piston is brought up against its stop. The restricted area at the left end of the exhaust cavity of the slide valve partly closes the exhaust port, and allows the brake-cylinder air to flow slowly into the atmosphere. On account of the friction in the train pipe, it is impossible to re-charge the train line at the rear of the train faster than the air will flow through the charging grooves of the triple valves. As a result, only the triple valves of the foremost cars move to retarded release, the others remaining in full release, which releases the brakes on the rear cars quickly.

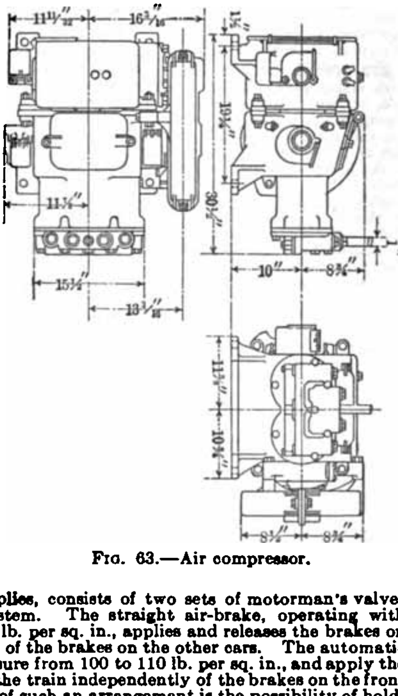


FIG. 63.—Air compressor.

226. Emergency application with quick-action triple valve (Par. 218 and 223). The sudden reduction of train pipe pressure in the emergency position of the engineer's valve, moves the slide-valve piston to the left, compressing the graduating spring and opening a port directly to the brake cylinder, and also opening another port to the emergency chamber which unseats the emergency valve. At the same time the train-line pressure opens the check valve and air flows from the train line directly into the brake cylinder, applying the brakes with maximum pressure. The quick venting of the train line insures the rapid serial action of the brakes on the rear cars.

227. The combined straight and automatic air-brake, as the name implies, consists of two sets of motorman's valves for the control of each system. The straight air-brake, operating with pressure between 55 and 70 lb. per sq. in., applies and releases the brakes on the front car independently of the brakes on the other cars. The automatic brakes operate with air pressure from 100 to 110 lb. per sq. in., and apply the brakes on the remainder of the train independently of the brakes on the front car. The chief advantage of such an arrangement is the possibility of holding the brakes on the locomotive applied while the train brakes are released for the purpose of re-charging the auxiliary reservoirs.

228. The electropneumatic system is practically the same as the present automatic system, except that the valves are operated by solenoids in much the same way as the contactors in the multiple-unit train control. At the present time air control is retained as a safeguard in case of failure of the electric control. With electric traction, the possibilities of this system seem to be unlimited and automatic retardation as well as acceleration is quite feasible.

229. The air reservoirs should have a capacity sufficient to supply air for three or four applications without reducing the pressure more than from 12 to 15 lb. Otherwise every ordinary application of the brake will throw ported upon **elliptic and coil springs** designed to take up the shock resulting from riding over uneven track. Single-truck cars are limited to a maximum length of about 30 ft. over all and a maximum weight including car body and trucks, but exclusive of electrical equipment of approximately 15,000 lb.

233. The double-truck car is equipped with two distinct trucks joined together through the medium of the car-body framing. The swivel or **bogie truck** consists essentially of two or more axles centred in common side frames which are joined by a cross piece or bolster carrying a centre plate and also side-bearing plates upon which the car body rests.

The bogie truck may comprise two or more axles mounted in a single structure. the prevalent type, however, is composed of two axles for cars weighing up to 50 tons total weight. For very high-speed service or for heavy cars, three-axle trucks are to be recommended.

234. Classification of bogie trucks. The standard four-wheel bogie truck is built along different lines depending upon the service which it is to perform. As the weight of the car body is carried upon the cross piece or **bolster** connecting the side frames, it is evident that the construction of this bolster and its support offers a means of cushioning the effect of shocks given the car wheels when riding over uneven track. There are three general types of bogie trucks, namely: the rigid-bolster type (Par. **235**), the floating-bolster type, (Par. **236**); and the swinging-bolster type (Par. **237**).

235. The rigid-bolster type (Par. **234**) is suitable for locomotive work only, as the cushioning effect of the car body by means of springs is not carried to sufficient length for easy riding qualities. The bolster is solidly fastened to the side frames and forms an integral part therewith. The spring-suspended car superstructure is sustained by means of box springs

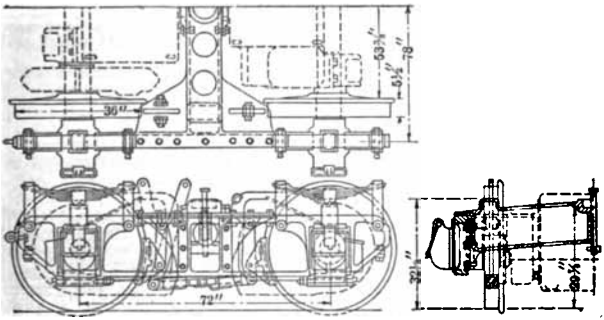


FIG. 65.—Motor, locomotive-frame, rigid bolster.

placed between the side frames and the journal boxes. These springs may be of semi-elliptic (Fig. 65) or spiral type (Fig. 68). This type of construction offers no compensation for the swaying of the superstructure, and is therefore not adapted for high-speed or passenger service.

236. The floating-bolster construction (Par. **234**), comprises in part a bolster mounted upon elliptic springs which rest upon the side frames. The bolster thus has an independent vertical movement, and travels in ways in the side frame. This type of construction is best adapted to locomotive trucks designed for slow-speed service, as the superstructure is not sufficiently cushioned to provide easy riding for high-speed passenger service.

237. The swinging-bolster construction (Par. **234**) comprises a movable bolster traveling in a guide or transom and mounted upon elliptic springs, a construction very similar to the floating-bolster type. In the former, however, the elliptic springs do not rest directly upon the side frames, but rest in a saddle hung from the transom or side-frame construction in such a manner that opportunity is provided for a transverse swing of the super-

238. Construction of bolster and side frames. The truck bolster may be made of wood or metal, and both the centre plate and side-bearing plates which it carries, may be ball or roller bearings, in order to reduce the friction and permit the truck to respond readily to the demands of track curvature. The side frames may be built up of steel plates riveted together, or forged or cast in a single piece. The construction is rigid and provides for good alignment of the axles.

239. Maximum traction trucks are designed for city service at speeds not much exceeding 30 miles per hr., and are useful where it is desired to mount a single motor on a truck providing for four wheels, having a short wheel base, and carrying 70 per cent. of the total car weight upon the driving wheel, which is larger in diameter than the trailing wheel. Maximum traction trucks are not suitable for high-speed service.

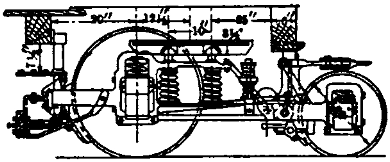


FIG. 69.—Maximum-traction truck (Brill Co.).

240. Classification of car bodies. Car bodies differ in construction according to local requirements. They may be divided into two general types, namely: open cars, and closed cars. The dividing line between these two types is not sharply defined owing to the introduction during the past few years of the convertible and semi-convertible type of car body, which permits the complete closing in of the car body sides, or partial removal thereof according to climatic conditions. The true type of open-car body is arranged with cross seats which will seat five passengers per seat and in the larger cars seating 75 passengers per car.

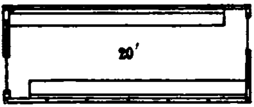


FIG. 70.—Seat capacity 24.

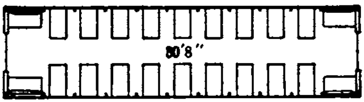


FIG. 71.—Seat capacity 44.

Besides the convertible and semi-convertible type of closed cars, a combination open and closed car is used for warm climates, as it offers the greatest advantages for all-the-year operation.

241. Arrangement of seats. The closed-body car may be provided with either longitudinal or cross seats, the former being used in the shorter cars of 30 ft. overall and under, and the latter in the larger city and suburban cars. In general it may be stated that longitudinal-seat cars are suitable only for short runs and medium rates of acceleration, and transverse seats should be used in order to provide comfort for the passenger where the accelerating rates are high or the run extended.

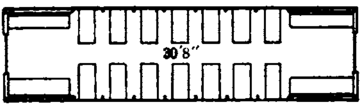


FIG. 72.—Seat capacity 44.

The prevalent type of transverse-seat car is indicated in Fig. 71, and usually contains short longitudinal end seats in addition. Owing to the possibility of crowding at the car entrance, it has been found advisable to provide more standing room at these points. This leads to a composite type of car having longer longitudinal end seats and providing transverse seats in the centre portion of the car only.

In some instances it is necessary to provide narrow city cars, and insufficient space is allowed for transverse seats capable of seating to people on the side. A modification of transverse-seat car is constructed for such cases having the longitudinal aisle and providing a two-passenger seat on one side and a one-passenger seat on the other.

249. The gas-electric car (Fig. 76) claims as its advantage the elimination of all mechanical troubles by substituting electric drive through generator and motors. Such cars are in service to a limited extent where operating conditions are favorable. Gas-electric locomotives are possible only when the service demand can be taken care of by the maximum output of the gas motor, not much exceeding 250 h.p. The possibilities of the gas-electric drive are not yet fully worked out or appreciated by operating men, and the use of such equipment is influenced largely by the possibility of using a cheap fuel. Cars are now in interurban service that consume approximately 4/10 gal. of gasoline per car-mile.

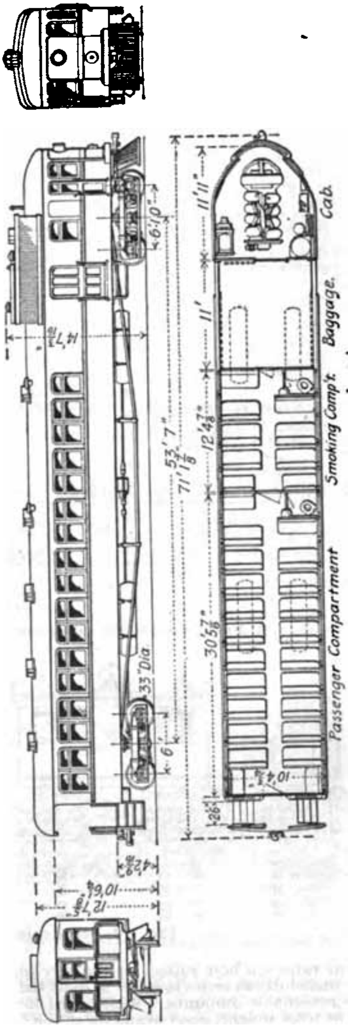


Fig. 76.—General Electric gas-electric car.

ELECTRIC LOCOMOTIVES

250. Classification. Electric locomotives may be divided into four general classes as follows: a, miscellaneous interurban freight service; b, yard-shifting and interchange freight; c, main-line freight; d, main-line passenger.

251. Locomotives for interurban lines are all of the same general type of construction and comprise a cab carried on two four-wheel trucks upon which are mounted single-geared motors in the usual manner. The locomotive is of construction similar to interurban cars, except as to superstructure and gearing of motors. The service performed by electric locomotives on suburban and interurban lines can generally be taken care of by a locomotive weighing from 30 to 50 tons, all weight being disposed on the drivers, and equipped with four geared motors of standard types. These motors have an aggregate capacity not greatly exceeding 1,000 h.p. at a 1-hr. rating. The trains hauled may reach 15 or 20 cars, totalling 500 to 800 tons as a maximum, while the average service comprises the movement of freight trains of considerably less number of cars. The duty of interurban locomotives is very variable and is of such an intermittent character as seldom to require accurate predetermination of motor capacity.

253. Main-line freight locomotives present a great variation in design and motor equipment. Main-line service demands a locomotive equipment capable of withstanding a large sustained output, and hence calls for different motor characteristics than those which meet the requirements of city and interurban-railway service. Steam-locomotive practice provides for a locomotive rating on ruling grade, based upon a tractive effort corresponding to a coefficient of adhesion of approximately 18 per cent. of the weight upon the drivers. This is exceeded somewhat under favorable rail and climatic conditions, but a lower rating is found necessary during winter months in cold climates. Hence assumption of 18 per cent. coefficient of adhesion may be considered good practice in determining electric locomotive rating on ruling grades.

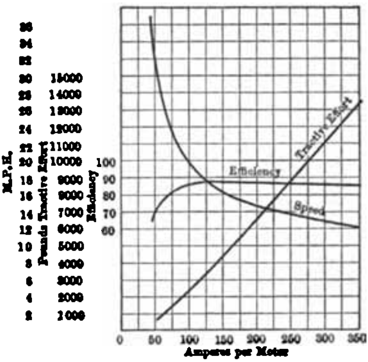


FIG. 80.—Motor characteristics Butte Anaconda & Pacific direct-current locomotive.

254. Example of calculation of permissible trailing load. An electric locomotive weighs 100 tons, all weight being disposed on drivers, what trailing load rating can it be given on 1 per cent. grade?

	Lb.
Tractive effort due to grade of 1 per cent. =	20
Tractive effort due to train resistance =	6
Total,	26
Locomotive tractive effort = 200,000 × 18 per cent. =	36,000

36,000/26 = 1,385 tons gross train weight
1,385 − 100 = 1,285 tons trailing

In Fig. 80 are presented the characteristic performance curves of the Butte, Anaconda and Pacific type of locomotive motor. This operates with direct-current supply at 1,200 volts (two in series for 2,400 volts).

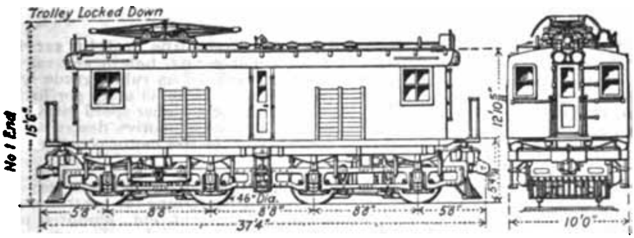


FIG. 81.—Butte Anaconda and Pacific 2,400-volt, direct-current locomotive.

255. The maximum tractive effort of a main-line freight locomotive should correspond to a coefficient of adhesion of 30 per cent., as this value is reached under good rail conditions with electric locomotives. The difference between 18 per cent. and 30 per cent. gives the range in tract-

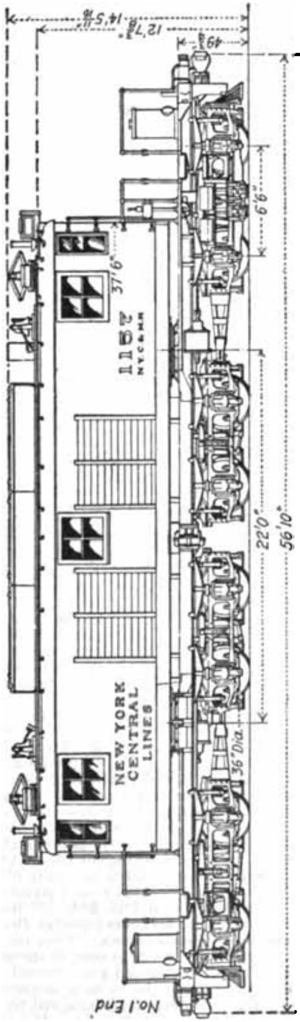


FIG. 83.—New York Central 600-volt, direct-current gearless locomotive (type of 1913, 8 motors).

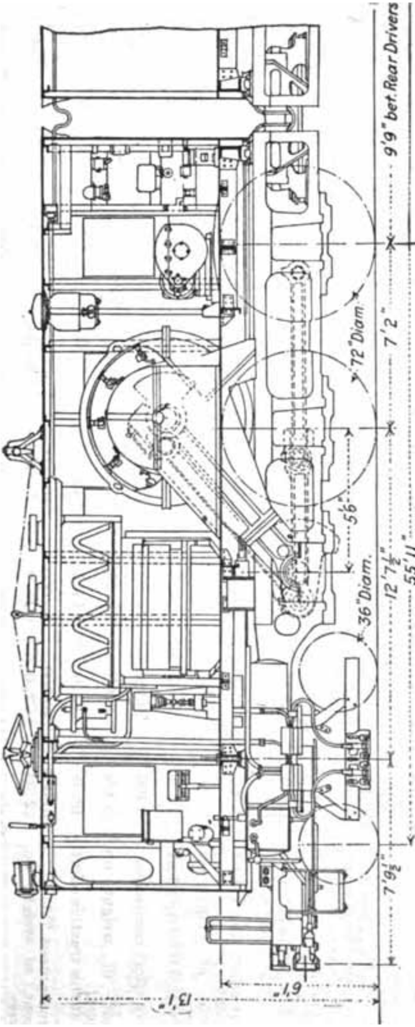


Fig. 85.—Pennsylvania locomotive (cross-section).

262. Tabulation of General Electric locomotives

Locomotives	B. A. & P.	B. A. & P.	Gt. Nor.	B. & O.	D. R. T.	D. R. T.	N. Y. C.	N. Y. C.
Service	Pass.	Frt.	Frt. 0440	Frt. & pass.	Frt. & pass.	Frt. & pass.	Pass.	Pass.
Type	0440	0440	Three-	0440	0440	0440	484	4444
Type motor	2,400 V.d.c.	2,400 V.d.c.	phase	600 V.d.c.	600 V.d.c.	600 V.d.c.	600 V.d.c.	600 V.d.c.
Total weight	80	80	115	100	100	120	115	125
On drivers	80	80	115	100	100	120	71	125
Wt. electrical equipment	59,800	59,800	109,000	65,000	65,000	54,180	60,000	83,000
Wt. mechanical equipment	100,200	100,200	121,000	135,000	135,000	185,820	170,000	167,000
Diameter, drivers, in.	46	46	60	50	48	48	44	30
No. of motors	4	4	4	4	4	4	4	8
Type of motor	GE–229	GE–229	GEI–506	GE–209	GE–209	GE–209	GE–84	GE–91
One hr. h.p. rating 75 deg. cent.	1,280	1,280	1,500	1,100	1,100	1,100	2,200	2,600
Contin. h.p. rating 75 deg. cent.	1,090	1,090	1,400	660	660	660	1,050	2,000
Tractive effort 1-hr. rating 75 deg. cent.	20,200	30,600	37,200	24,500	34,400	34,400	20,600	20,400
Per cent. of weight on drivers	12.6	19.1	16.3	12.3	17.2	14.3	14.5	8.2
Tractive effort continuous	16,500	25,000	34,800	12,200	17,200	17,200	7,100	13,840
Per cent. of weight on drivers	10.3	15.6	15.1	6.1	8.6	7.2	5.0	5.5
Speed at this tractive effort	24.5	16.2	15.18	20.1	14.3	14.3	56.0	54.5
Rated voltage	2,400	2,400	6,600	600	600	600	600	600
Gear ratio	3.2	4.83	4.25	3.25	4.37	4.37	Gearless	Gearless
Quantity	2	15	4	4	6	4	47	16
Date	1913	1913	1908	1910	1909	1914	1906	1913

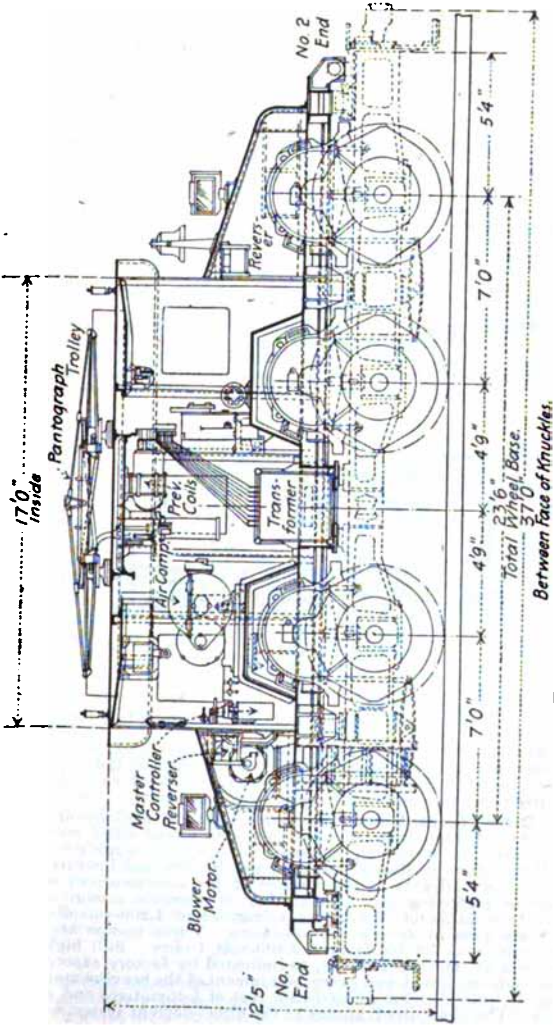


FIG. 87.—Single-phase switching locomotive.

advantages of this system include simplicity, low cost and high efficiency of the locomotives, the option of trolley or third-rail distribution, the choice of locomotive or multiple-unit trains, the benefits of bi-polar gearless-motor construction, and the use of balanced three-phase power supply of any frequency and entailing no serious telephone or telegraph interference.

Large direct-current locomotives are in service upon the following main-line electrifications.

P. R. R. New York Terminal	600 volts
B. & O. Tunnel Railway	600 volts
New York Central Railway	600 volts
Detroit Tunnel Railway	600 volts
Butte, Anaconda & Pacific Railway	2,400 volts
Canadian Northern Railway	2,400 volts
Chicago, Milwaukee & St. Paul Railway	3,000 volts

DISTRIBUTING SYSTEMS

267. Train diagrams represent in graphic form the movement of all trains over a given division during the 24 hr. of operation. Such diagrams are usually plotted with distance as ordinates and elapsed time as abscissas, and they are of the greatest value in determining the average and maximum sustained demands upon the distributing and generating systems.

The average train input for a given service is determined according to methods outlined in Par. 78 to 118, so that a train diagram is useful for indicating the local demand upon any part of the distributing system during any period of 24 hr. The train diagram also furnishes means of obtaining the total average load upon the entire division covered by the diagram, by plotting in curve form the total average kilowatts demanded by the several train movements intersecting equally spaced ordinates. Thus, referring to Fig. 89, representing a typical train diagram wherein is depicted the per-

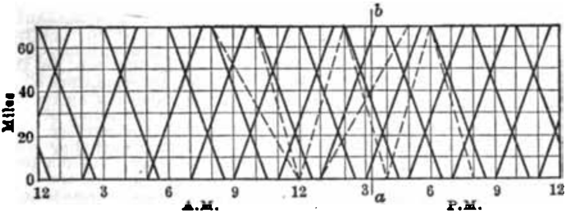


FIG. 89.—Typical train sheet (suburban service).

formance of both local and express trains, the ordinate, $a-b$, intersects the graphs of five trains. Assume that the various trains demand the following average input:

Local passenger	100 kw.
Express passenger	130 kw.
Freight	210 kw.

The line, $a-b$, intersecting the various train movements, therefore, calls for a station output at 3:15 P.M. as follows:

Three local passenger trains	300 kw.
One express passenger train	130 kw.
One freight train	210 kw.
	640 kw.

268. Calculated load curve. By erecting other ordinates upon the 24-hr. performance sheet it becomes possible to plot a detailed generating-station load curve for the 24 hr. with the train movements as predetermined. This train load curve does not show momentary fluctuations, and these must also be considered in determining the character of the distribution system,

273. The conductance of the circuit between motors and bus bars, is seldom determined by its proper relation with interest on first cost of the conducting system and the cost of energy lost, as the first cost of the distribution conductors so determined is considerably in excess of current practice in this respect. In city systems the average and momentary maximum drop are practically the same owing to the small effect of the starting current of any one of the large number of cars controlled by one feeder. In interurban systems, where generally but two cars are controlled by one feeder, the maximum fluctuation is much in excess of the average drop.

274. Relation of trolley wire and feeders. Feeders are differently grouped according to the demands of the service and the physical arrangement of the trolley sections. The simplest conducting system to the car upon the track consists in that shown in Fig. 91, wherein the trolley is connected through circuit-breakers directly to the positive bus bar with no auxiliary

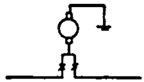


FIG. 91.—No feeders.

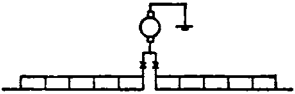


FIG. 92.—Single feeder.

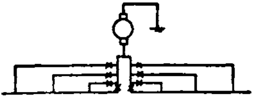


FIG. 93.—Multiple feeders.

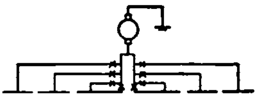


FIG. 94.—Sectionalised trolley wire.

feeders, and the negative bus is connected to the track return. The trolley is generally sectioned at the station and each section controlled by an independent feeder panel.

Where the trolley conductor itself has not a sufficiently high conductivity, it is reinforced with auxiliary feeders connected to it at frequent intervals. See Fig. 92. The result of such feeder reinforcement is simply to increase the conductivity of the trolley circuit, and corresponds to an enlargement of the cross-section of the trolley conductor itself. This grouping is best fitted for feeding a small number of units, and is more useful in the operation of suburban or interurban systems than in city work.

275. The most economical copper distribution for feeding a large number of train units would consist in a separate feeder to each train so proportioned that the drop in all feeders would be equal to the maximum drop permissible. As this would be impossible without too great a multiplicity of feeders, the arrangement in Fig. 93 is adopted. A better arrangement of the same feeder connection is shown in Fig. 94 which is identical to that in Fig. 93, except that the trolley itself is sectioned so that each feeder independently controls a single section of trolley and the cars drawing energy from that section (Par. **276** and **277**).

276. Length of trolley wire sections. Trolley sections may be from a few hundred yards to 2 miles or more in length in city service, depending upon the lay-out of the streets and the importance of sectionalising different streets or sections of the same street in such manner as to occasion the least possible interruption to general traffic in case of failure of any one trolley section or its feeder.

277. Segregated trolley-wire sections. The trolley wire may be solid throughout as shown in Fig. 93, or preferably sectionalised as shown in Fig. 86, in which case the different sections are entirely independent and each feeder and each trolley section is calculated to give the limiting IR drop when feeding the maximum group of cars drawing energy from that section of the trolley. The direct-current feeder distribution shown in Fig. 94, applies more especially to city systems and may be elaborated to any extent required by the complexity of a large-city trolley system. Sectionalising the trolley is desirable from the standpoint of localizing the effect of trolley breaks or

c. **Booster** in the supply station, which can be connected in series with any feeder extending to a temporarily overloaded section for the purpose of supplying the added voltage required to compensate for the excessive feeder and trolley drop.

d. **Track return**, consisting of the track rails, bonded at the joints.

e. **Track return feeders**, consisting of copper conductors reinforcing the track at points of greatest drop or at points where the track is negative to the neighboring pipes.

f. **Pressure wires** extending to important points on both trolley, track and pipes, and serving to indicate at all times the potential of the several parts of the distribution system.

Such large city systems are a matter of growth and not of calculation, as the practice giving good results in one city may not be directly applicable to the different conditions obtaining in another city.

282. Feeders for underground trolley or conduit systems. Such systems are described in Par. 334. The trolley conductors are two in number and are located underground between the two rails. These conductors are of opposite polarity, and there is no track return circuit. The arrangement, therefore, necessitates double the number of feeders required with the sectionalized overhead trolley used with track return. As both positive and negative rails are insulated from ground, the conduit systems practically eliminate any stray currents and electrolysis. Conduit systems are installed to avoid the unsightliness of the overhead trolley, and can only be considered in the largest cities owing to the enormous expense of their installation.

283. Primary distribution comprises the location of substations and the high-tension overhead transmission lines or underground cables connecting the substations to the generating-station bus bars. Primary transmission systems invariably employ alternating-current, and where synchronous converters or motor-generator sets are used, this primary current is of the three-phase type transmitted over three wires or in multiples of three if duplicate circuits are provided. Owing to the novelty of single-phase railway-motor distribution systems and the close interconnection of secondary and primary distribution systems when applied to alternating-current motor operation, this subject will be considered later (Par. 285).

284. Methods of serving direct-current substations. Substations for direct-current systems are located at strategic points along the line of travel best suited for secondary distribution. These substations may be fed from a common trunk line to which all substations are connected; this is common practice in suburban and interurban railways operated by direct-current motors. In such cases the trunk line preferably consists of two independent circuits, each of which may be used alone, providing, thereby, for continuity of service in case of the accidental grounding of one set of lines. It is also common practice to interrupt the transmission line at each substation, providing both incoming and outgoing line panels at each substation in order that the transmission-line troubles may be localized between two adjacent subs rather than that a whole trunk line be put out of commission due to the fault of any portion thereof.

In city systems or in interurban systems where the traffic is very heavy and where freedom from interruption of service that is of greatest importance, it is good practice to connect each substation to the generating-station bus bars through its own individual transmission line or underground cable. In fact, if the substation is very large, this divisibility of the transmission circuit is sometimes carried to the extreme of providing each substation with several cables connected either to individual synchronous converters or to different bus-bar sections. If this bus-bar segregation is resorted to each section is allowed to control two or more synchronous converters. It is evident that this multiplicity of high-tension transmission lines or cables can be made use of only in very large and important cities, or in interurban systems taking care of a very congested traffic.

285. Single-phase generation and transmission. Alternating-current single-phase railway-motor systems are best energized by single-phase generation and transmission, owing to the simplicity of single-phase connections throughout the system. The method of connecting the various alternating-current substations to the generating station consists usually in tying all substations to a single trunk line through circuit-breakers designed to open on short-circuit only. Individual transmission lines to

288. Three-phase, two-phase transformer connection (Sec. 6) can be used where the road is of limited extent. This method consists in employing the three-phase two-phase connection of substation transformer, feeding the two-phases to adjacent trolley sections, so that corresponding phases will be fed to a given trolley section from the transformer substation at its terminals. This system of connections will not provide perfect balance upon the three-phase side of the transformers unless the loads are balanced upon the several trolley sections. Sufficient balancing, however, may be obtained in the majority of cases, and this system of connection is in quite extended use.

289. Two-phase generation and single-phase distribution. Two-phase generators may be used to supply single-phase railway distribution systems by sending out transmission lines from the two phases in different directions, thus amounting in principle to two separate single-phase transmission systems. This method of connection is open to the objection that unless the loads are perfectly balanced upon the two phases, the voltage regulation will be very poor, and in cases of generators having poor inherent regulation, it may reach such proportions as to endanger the lamps and the general operation of the equipments.

290. General considerations in design of a new single-phase motor system. In general a new railway system, favorable for the operation of single-phase motors, operates to best advantage with the single-phase system of generation and transmission, provided the contemplated road has no future connections with neighboring systems and is free from entanglements, such as power distribution, operation of synchronous converters, etc., requiring multiphase generation and distribution. Where it is advisable to provide for the future utilisation of three-phase power, three-phase generators may be installed, operating either on one leg as single-phase generators, or using all three legs in connection with three-phase two-phase transformer connections in the substations in order to provide for reasonably good balancing of the three-phase primary distribution.

291. Three-phase, induction-motor systems may employ the same method of substation connections and primary distribution as outlined under the head of synchronous converter substations for direct-current motor systems. Owing to the fact, however, that transformer substations of all kinds may be operated without attendance, such substations are best connected to a main trunk line through circuit breakers operated by relays designed to open only on short-circuit. Where the control of the substation is extremely important, attendance should be supplied, or each individual substation should be connected to the generating station by separate transmission lines having automatic control at the generating end only. In all cases the trolley or secondary connection to the transformer substation should be safeguarded by automatic switches designed to open on short-circuit.

292. Resistance of trolley wire circuits is dependent upon the weight of trolley copper and track rail, and also upon the composition and bonding of the latter. Trolley conductors are either 000, or 0000 A.W.G., the smallest size being seldom used owing to its lack of strength and the difficulty of clamping its small diameter.

293. Trolley wire and track resistance per mile

Track rail	Ohms resistance 2 rails	000 Trolley and 2 rails	0000 Trolley and 2 rails
50 lb. per yd......	0.053	0.383	0.313
60 lb. per yd......	0.044	0.374	0.304
70 lb. per yd......	0.038	0.368	0.298
80 lb. per yd......	0.033	0.363	0.293
90 lb. per yd......	0.030	0.360	0.290
100 lb. per yd......	0.027	0.357	0.287
110 lb. per yd......	0.024	0.335	0.284

000 Trolley = 0.33 ohms. 0000 Trolley = 0.26 ohms.

porting steel towers joined by very heavy catenary construction, the whole combination being thoroughly anchored to withstand stresses, or else the

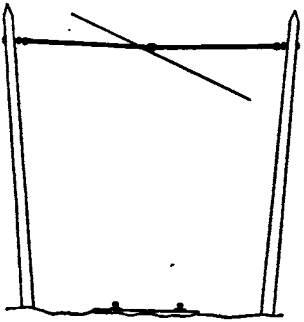


Fig. 101.—Cross suspension.

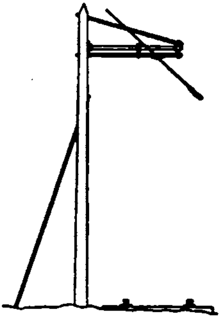


Fig. 102.—Bracket suspension.

side towers should be joined by a light steel truss, forming a bridge construction, this latter being used in steam-railroad electrification where the number of tracks exceeds two.

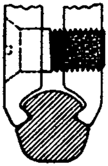


Fig. 103.—Trolley clamp.

301. Trolley wires generally have a cross-section equal to 3,000 or 4,000 cm. A.W.G., and are drawn in three sections; round, figure 8, and grooved. The use of round wire is objectionable owing to the difficulty of securely clipping it to the hangers without forming a projection on the wire itself which will tend to throw off the current collector in high-speed operation.

The use of figure 8 wire is open to the objection that owing to its unsymmetrical cross-section it is very difficult to handle during installation, although it affords a ready means of fastening and leaves a clean unbroken undersurface suitable for high-speed operation.

The grooved trolley wire (Fig. 103) is in greatest use and consists of a round wire grooved on opposite sides sufficiently deep to permit gripping by adjustable clamps or hangers. Owing to its round

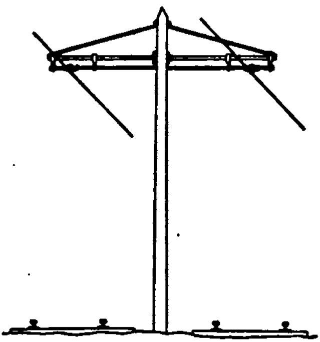


Fig. 104.—Two-track bracket construction.

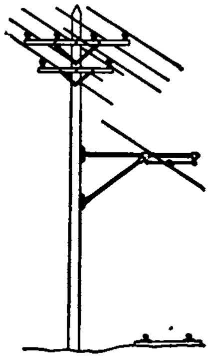


Fig. 105.—Combination pole.

between supports than is customary with the self-supporting trolley wire construction.

305. Distance between trolley-wire supports on tangents

Self-supporting trolley	110 ft.
Catenary wooden-pole bracket construction	150 ft.
Catenary steel-pole bracket construction	200 ft.
Catenary steel-bridge construction	300 ft.

The only limit placed upon the distance between supports in catenary construction on tangent track is the likelihood that long spans will have considerable lateral sway. This is corrected in part by suspending the trolley from a double catenary construction, thus forming a triangular truss of considerable rigidity. Catenary construction is only adapted to tangent track and curves of long radius, as it requires additional pull-off poles attended with considerable expense in order to be adapted to sharp curves.

306. Pole guying. With wooden-pole bracket construction it is customary to anchor the poles on curves, often on tangents.

307. Duplication of primary circuits. Primary transmission circuits may be carried upon the same poles that serve as a support for the trolley. The transmission line so supported may be supplemented by a separate transmission line hung on independent poles, in order to provide greater assurance for continuity of service.

308. Standard trolley potentials in use are as follows: 600 volts direct-current, 1,200 volts direct-current, 3,300 volts alternating-current, 6,600 volts alternating-current, 11,000 volts alternating-current.

An alternating-current trolley potential of 3,300 volts has been used in several installations but is being superseded by 6,600 volts in the smaller, and 11,000 volts in the larger installations.

309. Overhead collecting devices for use with trolley may be divided into three classes: wheel (Par. **310**), roller (Par. **314**), and sliding-bow (Par. **316**).

310. The trolley wheel consists of a grooved wheel of composition metal ranging from 3.5 in. to 6 in. in diameter, depending upon whether the service is low or high speed. Wheels are carried on a self-lubricating bearing and press against the trolley at pressures from 15 to 40 lb. depending upon the maximum speed of the equipment, this pressure being maintained throughout a wide range in height of trolley wire in order to provide for reduction in standard height of 22 ft. made necessary when going beneath bridges, culverts, etc.

311. Approximate life of trolley wheels

City service 25 miles per hr. maximum	11,000 miles
Suburban service 35 miles per hr. maximum	6,000 miles
Interurban service 50 miles per hr. maximum	3,500 miles
High-speed service 60 miles per hr. maximum	2,000 miles

312. The current capacity of the trolley wheel is determined by its speed and the pressure of contact between wheel and wire, the higher the speed the greater the pressure necessary to maintain contact without arcing. High speed also demands a very nicely balanced wheel and the maximum speed at which trolley wheels are used, corresponds to a car speed of 60 miles per hr.

Following are the current-carrying capacities of trolley wheels at various speeds.

Speed in miles per hr.	5	10	20	30	40	50	60
Current capacity in amperes	1,000	850	650	550	400	300	200

This table is compiled on the basis of maximum current-carrying capacity at the different speeds with trolley and wheel in good condition. The wheel is balanced for the higher speeds and the contact pressure varies from 20 to 40 lb. between trolley and trolley wheels.

313. Flexible trolley-wire suspension for the higher speeds. At the higher speeds it is absolutely necessary that the trolley suspension be very flexible, preferably hung from a catenary and with the clip fastening the trolley wire of as light weight as possible in order to minimise the blow of the trolley wheel striking it.

all heights by means of the so-called pantograph construction. The pantograph bow is preferable for alternating-current roads as it permits reversal of the car direction without reversing the trolley, and furthermore, by reason of the parallel motion introduced, it does not interfere with trolley construction.

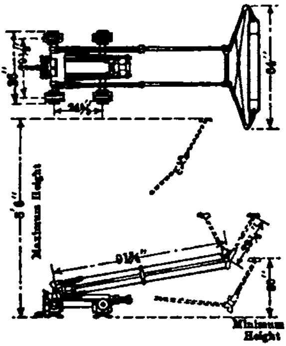


FIG. 110.—Sliding bow.

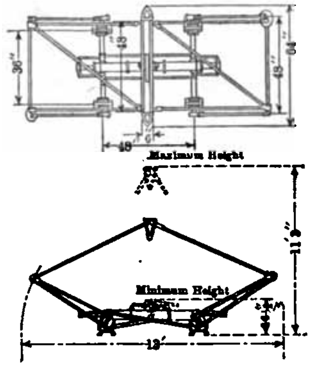


FIG. 111.—Pantograph bow.

317. Third-rail construction may be divided into two broad classes: *a*, overrunning contact (Par. **318**); *b*, underrunning contact (Par. **324**).

Third-rail voltages of 600 and 1,200 volts (Central California Traction) are in operation and still higher potentials are being proposed. The limiting third-rail voltage has not yet been reached, and it is probable that the development of improved forms of construction will result in the use of higher voltages for steam-road electrifications. Costs are given in Par. **355** and **356**. **Bonding** of the third-rail is treated in Par. **339**.

318. Overrunning-contact third rails were the first introduced and are in more general use. The construction consists essentially in supporting a steel rail, of either standard track or special composition, upon insulators placed every 10 ft. These insulators rest on supports carried upon projecting ties. Rails are joined loosely by fish plates, are bonded, and at intervals are thoroughly anchored to prevent creepage. Contact is made with the collecting surface of the rail by means of a third-rail shoe suspended from the trucks of the car or locomotive.

FIG. 112.—Unprotected third-rail.

FIG. 113.—Protected third-rail.

319. Protected third-rail construction is a modification of the above, and consists in providing a wooden or metal shield over the rail in order to protect it from snow and sleet or accidental contact, the rest of the construction being identical with that outlined above. The wood or iron construction is supported by uprights placed every 10 ft. or more, and such protection is usually substantial enough to bear the weight of a man midway between supports.

o provide sufficient clearance through tunnels, etc. The distance from rack gage line to centre of third-rail varies from 20 in. to 28 in. and he height above track is from zero inches to nearly 8 in. The smaller istances apply to elevated and subway roads operating only one class of olling stock, and the greater distances apply to interurban lines or elecrified steam lines where provision must be made for the passage of all lasses of freight cars and possible steam locomotives.

322. Third-rail jumpers are used to connect the third rail severed at rossings and consist of copper cables bonded to the rail and extending hrough underground conduits. Jumper cables are heavily insulated, are ead covered, and enter the ground through solidly-constructed concrete tructures.

323. Third-rail insulators consist either of impregnated wooden blocks, ·econstructed granite or porcelain insulators designed to be held in chairs astened to elongated ties and forming a loose support for the third rail. In order to provide for elongation of third rail caused by extremes in temperature there is no solid fastening between the third rail and its insulating support, and jumpers must be of sufficient length to allow for creepage.

FIG. 115.—Underrunning third-rail.

324. Underrunning third-rails of the protected type, first installed on the New York Central R.R., offer some advantage over the overrunning type in regard to better protection against accidental contact and against sleet and snow. The contact surface being the under side, is self cleaning, and this form of third rail has successfully operated through heavy snows completely covering the third-rail structure. The Central California Traction Co. operates an underrunning third-rail at 1,200 volts.

325. Leakage from third-rail is extremely small and may be neglected unless the road bed should be deeply impregnated with salt. Even though the third-rail be covered with snow it is found that the leakage is too small to constitute a noticeable item of expense.

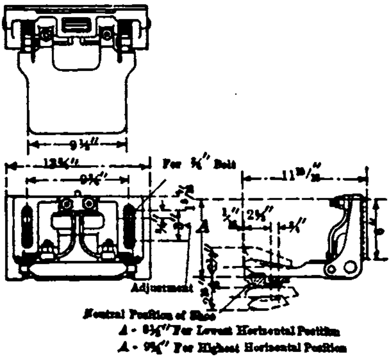


FIG. 116.—Shoe for standard and inverted rail.

326. Third-rail shoes (Par. 327) are of two general types: those acquiring their pressure by gravity and those actuated by means of springs. The unprotected overrunning third rail was first used in conjunction with gravity shoes, and in many installations this form of shoe is still in operation. Where rails are protected it is necessary to provide a form of shoe which will operate and insulators in good condition together with the upkeep of jumpers and the cables. This expense has been found in practice to be very small and the low maintenance charge of third-rails together with the possibility which such a system offers for handling unlimited current values at any speed constitute the strongest arguments in favor of its adoption.

333. Protection of third rail against sleet and snow is affected directly by the various forms of protected third rail, and it has been found that especially the underrunning type can operate in snow entirely surrounding the third rail without difficulty, owing to the fact that the under contact surface of the rail is self cleaning. With the various forms of exposed overrunning rail it has been found that the accumulation of sleet may be prevented by the use of calcium chloride mixed with water in the proportion of 1 lb. to 5 gal. and sprayed upon the rail at intervals of not more than 2 hr. during the continuance of the storm.

334. Underground trolley or conduit systems are in use only in the very largest cities owing to the enormous expense of their installation. Such systems consist in the location of two third-rails or conductors placed in a conduit located between the track rails, contact being established by means of a plough extending through a slot opening of the conduit. As the plough carries both the positive and negative contacts, there is no track return and hence the conductivity of the track as a return feeder is lost.

Underground trolley systems are installed in city streets where the congestion of travel is sufficiently heavy to warrant the large expense and where the use of overhead wires is objectionable. As conduit systems are essentially double-trolley systems, the feeder network is double that required for an overhead trolley with track return. Both conductor rails are controlled by separate feeders and are divided into sections as previously indicated for city trolley systems. Each section, with its feeders, is controlled by double-throw switches so that it may be made either positive or negative at will. With this arrangement of double-throw switches it becomes possible to throw all temporarily grounded sections on a bus of the same polarity and thus prevent possible short-circuits due to simultaneous grounding of a positive and a negative conduit conductor.

335. Double-trolley systems are installed to a very limited extent in city streets in order to prevent any liability to electrolysis possible with the single-trolley track-return system (Par. **453**). Such systems call for double collectors and double-trolley construction, which becomes complicated and expensive to maintain in city streets. One trolley is positive and the other negative, so that the track is not utilized for return and hence need not be bonded.

336. Three-phase double-trolley systems or double third-rail systems are sometimes used in conjunction with three-phase induction motor equipments requiring three conductors, in which case the track acts as the third leg of the triangle. Such systems usually carry several thousand volts upon the trolley wires, employ the catenary overhead construction, and are as yet in very limited use.

337. Three-wire systems comprise two overhead trolleys having a potential difference of 1,200 volts between them and 600 volts each to ground. In this case the car equipment consists of two separate 600-volt motor equipments including control, connection being established with the track as a neutral. Such systems can therefore operate either as 600-volt from either or both trolleys, or as a straight 1,200-volt system trolley-to-trolley with the track acting as a neutral and carrying practically no current. Where there is no restriction placed upon the voltage drop in track return, such systems suffer in comparative first cost with the single-trolley system.

338. Track return. It is almost the universal custom in electric railway systems to utilize one or both rails of the tracks as a return circuit to the generating station. It was early found that the ground itself or even adjacent bodies of water constituted a return circuit of such high resistance as to be of little practical use, hence the necessity for a carefully bonded track-return circuit, reinforced by feeders where necessary. Data on conductivity and the resistance of standard rails is given in Par. **328** and **331**.

339. Rail bonding (Par. **340** to **354**) consists in establishing contact, rail to rail, in order to utilize to the fullest extent the conductivity of the rail as a tion holds only when the bonding is installed and maintained in first class condition.

347. Double bonding is resorted to in many instances in order to insure a path of good conductivity in case of failure of a single bond. Where double bonding is not required to provide additional current capacity in order to keep temperature rise within reasonable limits, it is better engineering to install a single bond of sufficient capacity from a temperature rise standpoint and maintain this bonding in good condition. Double bonding is open to the objection that one of the two bonds may give imperfect contact and be practically useless, and such a method of installation usually results in the operation of the road with practically single bonding throughout.

348. Single bonding for suburban roads where the service is infrequent and current demands do not momentarily exceed 1,000 amp., is to be recommended provided rails are frequently cross bonded and all bonded joints are regularly inspected and maintained in their original good condition.

349. The heating of bonds will determine the size and number of bonds to be used on roads over which there is a large volume of traffic, and where the moving units demand a large kilowatt input, such as trains hauled by locomotives, etc. Following are given values of temperature rise at different current strengths:

Current amperes	500	1,000	1,500	2,000	2,500
Temperature rise deg. cent.	10	35	78	135	210

This table of heating constants applies only to bonding exposed to the air and not covered by fish plate, in the latter case the heating will be somewhat increased. The values given in the table apply only to bonds maintaining good contact with the rail. As one of the integral rails composing the track return may become useless owing to failure of a single bond, each rail must be bonded with the prospect of carrying the full return current. The heating of the bond varies approximately proportional with the square of the current value and extremes in temperature are to be avoided owing to the unequal expansion of copper and rail. It is therefore desirable that the greatest conservatism be used in selecting the bonds for a given service. This holds especially true where soldered bonds are concerned, as too high a temperature will melt the connection between rail and bond. Brazed and electrically welded bonds will, of course, withstand a larger current value and higher temperature without danger of falling off.

350. Amalgam bonds have been used with some success, the most modern comprising a spiral spring approximately 1 in. in diameter containing a soft amalgam, the whole being designed to be placed between the thoroughly cleaned fish plate and rail, and held in place by the bolts extending between them. This type of bonding is easy of application and is useful where a concealed bond is desired.

351. Welded joints in general give the greatest satisfaction where it becomes necessary to bond the rail to its full current-carrying capacity as when the bond is called upon to carry a very high value of current. Welding is obtained by three methods: Cast (Par. **352**), electric (Par. **354**), and thermit (Par. **353**).

All forms of welding are necessarily somewhat expensive, and are not well adapted to the requirements of suburban roads, using T rails laid on ties in the open, because of the inability of such joints to allow for rail expansion.

352. Cast welding is secured by pouring the metal in a mould surrounding the rail joint, thoroughly cleaned for the purpose. Such joints will have no expansion, are somewhat likely to crack, and are best suited for use in city streets where the track is held rigidly in place by the pavement.

353. Thermit welding is accomplished in very much the same manner except that a relatively small amount of metal is required. This process is not as yet in very general use.

354. Electric welding at the rail joint is perhaps best secured by welding a steel strap to each rail, the joint not being continuous between strap and rail but maintained at one or two points of contact. Electric welding has proved very satisfactory in the past, and gives good satisfaction where great current-carrying capacity is desired.

Labor

Quantity	Operation	Cost Unit	Cost Total
640	Installing ties	0.35	$224
640	Installating brackets	0.10	64
1-mile	Installating rails and protection	....	250
320	Installing bonds	0.55	176
12	Installing approach blocks	0.50	6
	Distributing ties and rails	....	50
	Distributing other material	....	50
	Total for labor	....	$920

For jumpers at cross-overs and street crossings 300 ft. of 1,000,000-cir. mil cable per mile. When this is installed in fibre conduit embedded in concrete cost will be approximately $1.80 per ft.

Total for jumpers	540
Superintendence and engineering 10 per cent	505
Total cost per mile installed	$5,535

357. Approximate cost of installation for 600-volt direct-current span construction per mile

Based on 100 ft. pole-spacing on tangents—wooden poles—standard direct-current construction—allowance made for 10 per cent. track curvature—track and road bed not included.

	Single track	Double track
Poles, 35 ft. long, 8 in. tops at $5.50	$620.00	$620.00
Line material	325.00	450.00
Wire and cable exclusive of trolley	126.00	189.00
Trolley wire 4/0 at 18 cents	656.00	1,312.00
Material	$1,727.00	$2,571.00
Labor	1,050.00	1,450.00
Labor and material	$2,777.00	$4,021.00
Engineering and superintendence	302.00	451.00
Total cost per mile	$3,079.00	$4,472.00

358. 600-volt direct-current trolley bracket construction, cost per mile

Based on 100 ft. pole-spacing on tangents—wooden poles—standard direct-current construction—allowance made for 10 per cent. curvature—track and road bed not included.

	Single track	Double track
Poles, 32 ft. long, 8 in. tops, at $4.75	$269.00	$307.00
Line material	250.00	500.00
Wire and cable exclusive of trolley	73.00	115.00
Trolley wire 4/0 at 18 cents	656.00	1,312.00
Material	$1,248.00	$2,234.00
Labor	775.00	1,290.00
Material and labor	$2,023.00	$3,524.00
Engineering and superintendence	227.00	402.00
Total cost per mile	$2,250.00	$3,926.00

Labor

40	Additional for erecting longer poles	20.00
40	Gaining roofing and setting cross arms	30.00
	Pulling and tieing in 2 trans. wire	50.00
	Pulling and tieing in 1 ground wire	35.00
	Extra guying and grounding cable	10.00
40	Distributing poles extra for long poles	10.00
	Telephone cradles, etc	20.00
	Distributing material other than poles	10.00
	Total for labor	$185.00
	Labor and material	$928.00
	Engineering and superintendence	55.25
	Total cost per mile	$983.25

363. Bill of material and cost per mile of 33,000-volt three-phase transmission line

On same poles as direct-current trolley 100 ft. spacing on tangent—40-ft. poles, 3/16-in. steel cable for lightning protection—3 wires on one cross-arm—3 ft. between wires.

Quantity	Material	Cost, Unit	Cost, Total
60	Extra cost of poles	$2.00	$120.00
60	Cross arms 5 in. × 6 in. × 10 ft. 6 in.	1.00	60.00
120	Braces 2¼ in. × ¼ in. × 3 ft. 6 in.	0.22	26.40
60	Bolts for cross arms ⅝ in. × 14 in.	0.25	15.00
120	Bolts for braces ½ in. × 6 in.	0.06	7.20
60	Lags for braces and poles	0.045	2.70
60	Parts for attaching ground wire	0.04	2.40
180	Insulators and pins	0.90	164.00
40	Lb. No. 8 B. & S. insulator ties 4 ft. long	0.255	10.20
30	Lb. No. 6 B. & S. tinned copper for grooved connections	0.255	7.65
5,300	ft. 3/16-in. galvanised cable for ground wire	0.01	53.00
1,000	ft. ⅜-in. galvanised cable for guy (rest included with trolley material)	0.014	14.00
8	Splicing sleeves, solder, etc		7.00
	Material for double arming at curves		50.00
	Material exclusive of wire		$539.55
	Wire 3 miles No. 2 B. & S. at 18 cents		600.00
	Total material per mile		$1,139.55
	Labor		
60	Additional for erecting longer poles	0.50	30.00
60	Gaining roofing and setting cross arms	0.75	45.00
	Pulling and tieing in 3 trans. wires	20.00	60.00
	Pulling and tieing in 1 ground cable		35.00
	Extra guying and grounding ground cable		10.00
60	Distributing poles—extra for long poles	0.25	15.00
	Distributing material other than poles		20.00
	Telephone cradles, etc		20.00
	Total for labor		$227.00
	Labor and material		$1,366.55
	Engineering and superintendence		55.45
	Total cost per mile		$1,422.00

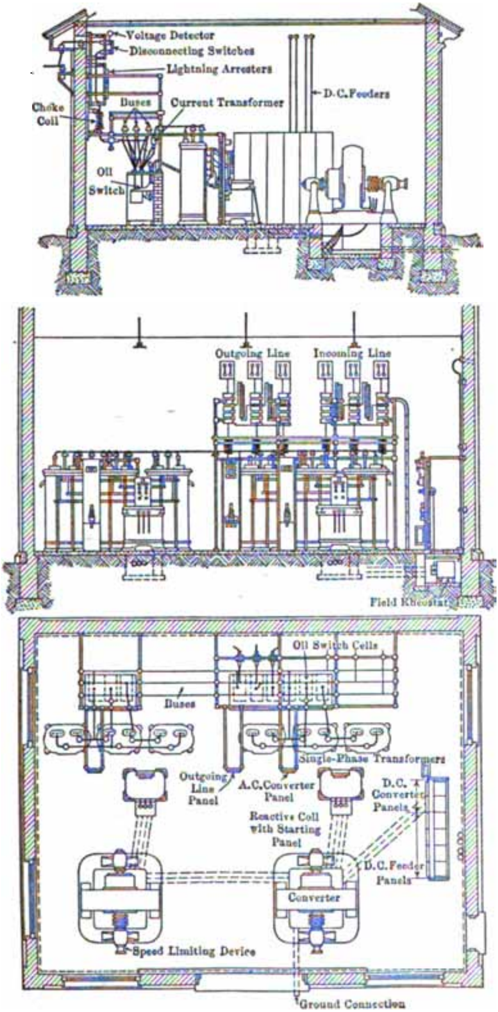


FIG. 117.—Synchronous converter substation.

current side of the converters; f, synchronous converters (see Sec. 9); g, direct-current outgoing feeders; h, switchboard panels controlling both the alternating-current and direct-current side of the converter as well as both alternating-current and direct-current incoming and outgoing feeders.

372. Ratio of conversion of synchronous converters varies somewhat with the construction of the machine, being in general as follows: three-phase converters 370 volts alternating-current to 600 volts direct-current; six-phase converters, 430 volts alternating-current to 600 volts direct-current. Machines having long pole arcs have a somewhat higher ratio of conversion than those of shorter pole arcs. In order to provide for the differences in types of machines and also for the varying drops in the primary distribution system to which rotary converter substations are connected, it is customary to provide five primary taps of 2.5 per cent. each in the step-down transformers. One of these taps is 2.5 per cent. above the receiving potential in order to take care of the high ratio of conversion of longer pole-arc converters.

373. Substation voltages. A typical step-down transformer (Par. 374) will have primary and secondary ratios as follows: primary voltages 19,600—19,100—18,600—18,150—17,700—17,200 secondary voltage 370. Such a transformer would be adapted to operate a three-phase 25-cycle rotary converter from a "Y"-connected 33,000-volt transmission line.

Standard primary substation voltages are 11,000 volts, 19,100 volts, 33,000 volts, 66,000 volts. It is customary to use **delta transformer connections** for both 11,000 and 19,000 volts and "Y"-transformer connections with grounded neutral for 33,000 volts and higher. Many substations now operating at 19,100 volts delta are doing so temporarily pending a change to 33,000 volts "Y" for which higher potential the transformers are insulated.

374. Step-down transformers are of several types, as follows: A. B. or air-blast transformers, O. C. or oil-cooled transformers, W. C. or water-cooled transformers, oil transformers self-cooled, F. O. or forced-oil transformers.

Any or all of these several types of step-down transformers can be built three-phase or single-phase, in which latter case three transformers are required for either "Y" or delta connection with each converter.

375. Comparison of transformer cooling methods. Air-blast transformers when used call for the construction of an air chamber over which they are placed and from which they receive air at a pressure of from ½ oz. to 1 oz. Air is supplied by a duplicate motor-driven fan feeding into the air chamber. This type of transformer is very generally used up to and including potentials of 33,000 volts. For higher potentials and for small transformer units oil is resorted to for cooling by a variety of means.

The design of the small self-cooled (oil) transformer is especially adapted to the smaller sizes, owing to its cheapness. For larger sizes it becomes necessary to cool the oil either by means of a cooling coil placed in the transformer and through which water is circulated, or by providing means of circulating the oil itself through an outside pipe coil, in order to reduce its temperature. In general the air-blast type of transformer is preferred for potentials not exceeding 33,000 volts on account of its freedom from fire risk in case of a short circuit or "burn out." For very small single-converter units or those having connection to the higher primary potentials, some form of oil-cooled transformer is to be preferred.

376. The general arrangement of apparatus in substations is somewhat similar in all cases, as such buildings are usually designed for the purpose. In general the wiring scheme consists in providing the shortest and most direct path from the incoming primary lines to the outgoing direct-current feeders, and the interior-wiring scheme is carried out with the object in view of preventing any crossing of circuits or doubling back upon themselves.

377. Duplicate apparatus in a substation may or may not be installed, depending upon local requirements. The manufacture of synchronous converters, transformers, and general substation apparatus, has been so far perfected that failures in such apparatus are very infrequent. It is, therefore, quite customary to install substations containing but a single converter and set of transformers, although it is always good engineering to provide duplicate converter, transformers, switchboard, etc., throughout. This practice is

379. Alternating-current substations designed for use with alternating-current railway motor equipments are generally designed for operation without attendant (Par. **285** to **288**). Such substations comprise a

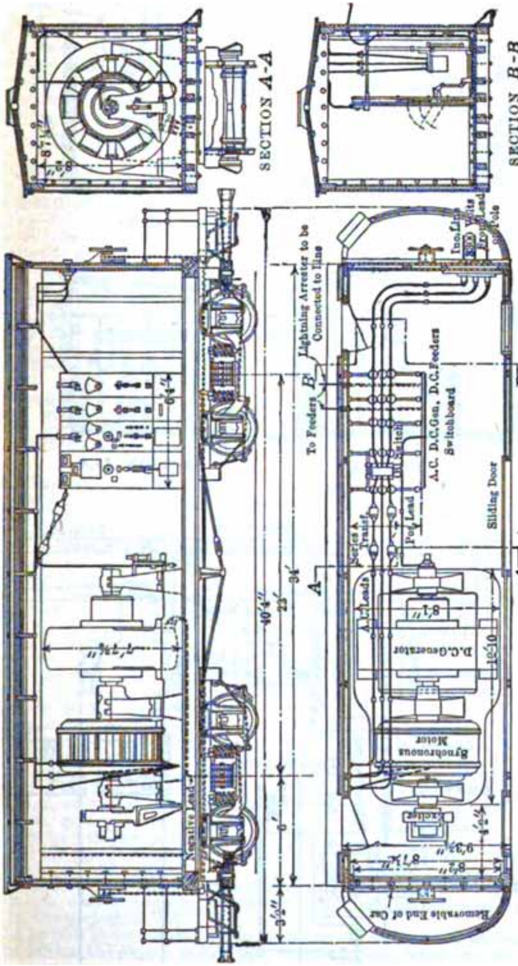


FIG. 120.—Motor-generator portable substation.

small fireproof building containing step-down transformers, generally in duplicate, together with the necessary switchboard apparatus. Both primary and secondary transformer circuits are provided with automatic

›il switches designed to open on short-circuit or extreme overload only [hese automatic switches serve merely as a safety device to protect the trans-ormers from burn out. As such substations have no operator and are ubject to violent fluctuations in load greatly exceeding the average, it is ıecessary that all protective devices be limited in their function in order to ;uard against short-circuit and not overload.

In order to facilitate the location of faults, alternating-current transformer ubstations are commonly supplied with both voltmeter and ammeter ›esides being equipped with lightning arresters upon both the high-tension and ow-tension incoming and outgoing feeders. Step-down transformers are of he self-cooling oil type.

AUTOMATICALLY OPERATED TRACK SWITCHES

380. Advantages of automatic track switches. The practice of ›urning switches with switch bars from the front platform of cars has been nade practically impossible by the addition of the vestibule and fender, and nany roads have undertaken to install electrically operated switches. Thus he inconvenience and waste of time occasioned by requiring a motorman or :onductor to get off the car and turn switches, or employing a switch tender. Jsually the hand-operated switches are held in place by a block of rubber or ›iece of steel to prevent splitting the switch as often happens in case of louble-truck cars, and these small blocks frequently require considerable nanipulation before they are taken out and the switch turned. An electric-ılly operated switch is turned at will by the motorman running over an nsulated section of the trolley with power on, or left on its original position ›y coasting over this section. Perhaps the simplest manner by which ıutomatic track switching may be accomplished is by placing two solenoids ›etween the tracks at the switch and connecting their cores to the switch-›oints. By energising either of these solenoids the switch will be turned in ›ne way or the other, and it remains to place two insulated sections in the rolley wire whereby a car can cause current through one or the other, or ıeither.

381. Operation of automatic track switch. The following are the vays in which the switch may be operated: a, a motorman desiring to go in he direction, "A" (Fig. :22), may find the switch et for track, "A," in vhich case he may either :oast over both insulated ›ections or traverse, under ›ower, that section which vill not disturb the switch ınd coast over the other, or f the sections are in proper ›equence he can run over ›oth with power on; b, if he switch is set against ıim, the motorman must ›elect the insulated section vhich will turn the switch, ınd traverse it with power ›n. If it is the last section ıe can run over both sec-ions with power on; c, ikewise, if he wishes to run n the direction, "B," but f the sections are arranged or all the combinations mentioned above for the direction "A," there will ›e one less combination by which the switch can be operated by the cars ;oing in the direction, "B."

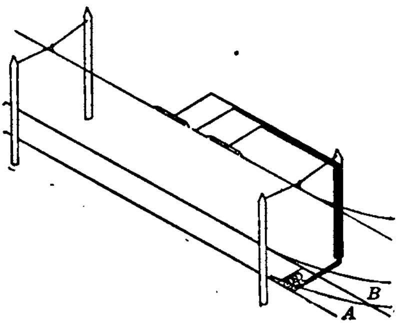


FIG. 122.—Electrically operated track switch.

If the switch is on a down grade for approaching cars the arrangement of ›ections before the switch points proves satisfactory, since the car can coast ›ver both sections if necessary. If, however, the approach to the switch is ›n a considerable up grade, it would be difficult to coast very far at the speed ›ermissible on the grade. Hence one insulated section is sometimes placed n the trolley beyond the switch, in which case a car will run over the first of installation, signalling naturally divides itself into two classes, namely *interlocking* (Par. 404 to 420) and *block signalling* (Par. 421 to 426).

TYPES OF FIXED SIGNALS

387. Targets and lamp signals. In American practice, targets of various forms are generally used to show the positions of switches except where the latter are operated from interlocking plants. The signals generally used in interlocking practice, as well as for train-order signals and block signals, are of the **semaphore** type, in which an arm, composed of a casting on which are mounted colored glasses called roundels and a wooden blade, is pivoted about a horizontal axis so that it may be moved either manually or by power, from a horizontal position to an inclined or vertical position in order to indicate the various conditions affecting the movement of trains. All fixed signals, in addition to their day indications, are provided at night with lights of prescribed colors. With semaphore signals, one light is provided for each signal arm and is so placed that as the arm moves to its various positions, the different colored glasses will move in front of the lamp to show red, yellow, green, white or purple light as desired. For block signaling, signals of the enclosed-disc type are used to some extent, although the semaphore affords more distinctive indications.

"Light signals," consisting of electric lamps placed behind suitably colored lenses and so shaded as to permit their colors to be distinguished by day, have been introduced to some extent on electric railways, and have been recently developed to considerable efficiency.

The American Electric Railway Association's Committee on block signals has recommended as the preferred type of signals for electric roads, a semaphore moving in the upper left-hand quadrant as viewed from an approaching train; the arm in the horizontal position indicating "Stop;" in the inclined position, 45 deg. upward, indicating "Caution;" and pointing vertically upward, indicating "Proceed." It is considered that less interference with the view of signals by pole lines adjacent to the track will thus result than if the steam railroad practice of displaying the blade to the right of the mast, as seen from an approaching train, is followed. This is based on the American practice of locating signals to the right of the track which they govern (Fig. 123).

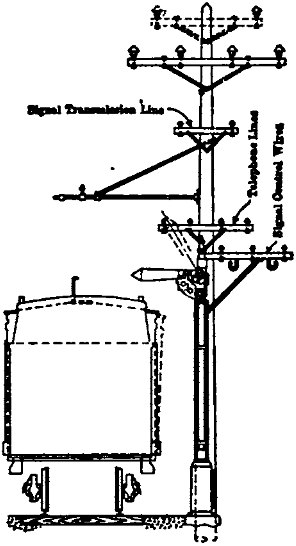


Fig. 123.—Standard location of signal (right of track).

388. The usual type of automatic signal is the electric-motor semaphore. The arm comprising the blade and the casting carrying the colored glass roundels is pivoted near the top of the post, the shaft to which it is connected carrying a crank or arm connected to the "up and down" rod placed inside of the tubular iron signal post. The lower end of this rod is connected to the mechanism proper which consists of an electric motor and gearing whereby the motor transmits motion to the up and down rod. A device called a "slot" which comprises a magnet and latch is so arranged that if the magnet is energised the motion of the motor is transmitted to the signal arm, but if the magnet is de-energised, mechanically disconnects the motor from the up and down rod allowing the signal to go to the stop position by gravity. Signal mechanisms of the "top-post" type have the motor mounted adjacent to the semaphore-arm shaft at the top of the post.

may retain continuous and direct control of a signal while occupying any portion of the track protected by the signal.

393. The function of the closed track circuit is to maintain a relay normally in an energized state; the influence of the train upon the rails is to de-energize this relay by shunting or short-circuiting the generator, a process as effectively accomplished by a single car as by a train of considerable length. On account of the low insulation resistance between the rails, due to the conductivity of the ties and ballast, track circuits are susceptible to influence from excessive leakage of current from rail to rail. This leakage may approach, in its effect, the value of current conducted by the wheels and axles of a train. Obviously a failure of the source of energy or a break in the circuit, whether in the rails themselves or in the wires connecting the battery

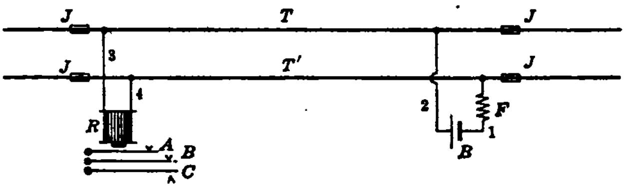


FIG. 124.—Track-circuit.

B, Source of energy, as two gravity-battery cells in multiple, or one storage-battery cell with series resistance F to limit current output when rails are short-circuited by wheels and axles of a car, or a transformer, 2 to 8 volts where alternating current is used. J, Insulated rail joint. T T′, The track rails included within the block, adjacent rails being bonded. R, Relay, normally energized by current from B. A B, Contacts carried by armature of relay R and closed when R is energized. C, Contact carried by armature of relay R and closed when armature falls by gravity upon R being de-energized. The path of current is from B through wire 1, resistance F (if used) track rail T′, wire 4, magnet coils of relay R, wire 3, track rail T, wire 2 to B. The distributed leakage of current between track rails T and T′, through the ties and ballast, is in multiple with relay R.

or the relay to the rails, produce the same effect upon the relay as if a train were running or standing on the rails. The contacts carried by the armature of the track relay (Fig. 124), which are closed only when the relay is energized, are included in the circuits which control the signals themselves. These circuits must be closed in order that the signals may indicate "proceed." Thus the track circuit conforms to the principle demanded by sound practice, namely, that the signals shall invariably display the "stop" indication when their operating or controlling energies cease to be active from any cause.

394. Requisite performance of the electrical equipment. The source of energy supplying current to a track circuit should do so at the least e.m.f. that is practicable. The current capacity should not be excessively great nor yet too limited. When a train is so far advanced within the block from the relay end as to constitute a somewhat imperfect shunt upon the relay, stray currents sometimes find a path through it from adjacent rails through damp or defective rail insulations. Relays should not be sufficiently sensitive to respond to these currents. In excessively long blocks and where the likelihood of such occurrences exist, one of the remedies is to locate a relay at each end of the section and supply current to the centre of the circuit, so that as the shunting effect of the train recedes from one relay it approaches the other. Naturally the resort to this device entails additional cost and complication, for the operating circuit of the signal is carried through the entire block for control by both relays.

395. Low e.m.f. impressed upon track circuits is advantageous for two reasons: first, to minimise the break-down effect of the e.m.f. upon rail joints of defective insulation or upon damp ties and ballast and other parts that afford a normal leakage of current from rail to rail in wet weather; second, to reduce to a minimum the energy normally discharged through

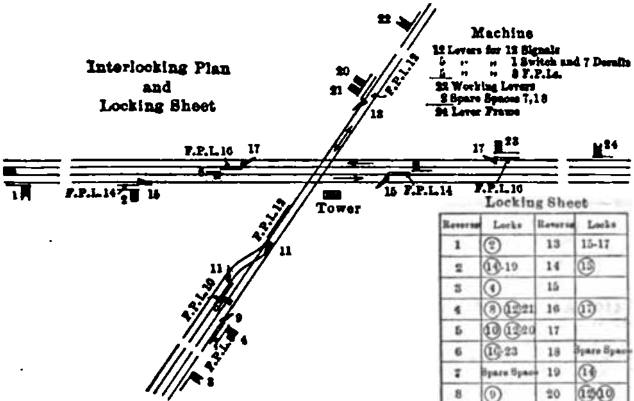
400. Impedances and power-factors per 1000 ft. of track
(Union Switch and Signal Co.)

Weight of rail	Bonding	27.5-ft. rails				30-ft. rails				33-ft. rails			
		25 cycles per sec.		60 cycles per sec.		25 cycles per sec.		60 cycles per sec.		25 cycles per sec.		60 cycles per sec.	
		Impedance	Power-factor	Impedance	Power-factor	Impedance	Power-factor	Impedance	Power-factor	Impedance	Power-factor	Impedance	Power-factor
100 lb.	Total capacity..	0.10	0.40	0.25	0.40	0.10	0.4	0.25	0.40	0.10	0.40	0.25	0.40
	2 No. 6 copper..	0.13	0.72	0.28	0.56	0.13	0.7	0.28	0.56	0.13	0.69	0.27	0.54
	1 No. 8 iron 1 No. 6 copper	0,17	0.83	0.30	0.65	0.16	0.82	0.30	0.63	0.15	0.79	0.29	0.62
	2 No. 6 c.c.–40 per cent.	0.19	0.87	0.30	0.69	0.19	0.86	0.32	0.69	0.17	0.84	0.31	0.68
	2 No. 6 c.c.–30 per cent.	0.25	0.91	0.36	0.75	0.22	0.91	0.35	0.74	0.20	0.88	0.34	0.73
	2 No. 8 iron....	0.40	0.97	0.50	0.88	0.36	0.96	0.47	0.87	0.34	0.96	0.44	0.85
90 lb.	Total capacity..	0.10	0.43	0.26	0.43	0.10	0.43	0.26	0.43	0.10	0.43	0.26	0.43
	2 No. 6 copper..	0.14	0.73	0.29	0.58	0.13	0.72	0.28	0.58	0.13	0.70	0.27	0.54
	1 No. 8 iron 1 No. 6 copper	0.17	0.83	0.31	0.67	0.16	0.82	0.31	0.64	0.16	0.80	0.29	0.62
	2 No. 6 monnot–40 per cent.	0.19	0.87	0.33	0.71	0.19	0.87	0.33	0.70	0.17	0.84	0.31	0.68
	2 No. 6 monnot–30 per cent.	0.23	0.91	0.36	0.76	0.26	0.91	0.36	0.76	0.20	0.89	0.34	0.73
	2 No. 8 iron....	0.40	0.97	0.51	0.89	0.37	0.97	0.48	0.88	0.35	0.96	0.45	0.86
85 lb.	Total capacity..	0.10	0.46	0.26	0.46	0.10	0.46	0.26	0.46	0.10	0.46	0.26	0.46
	2 No. 6 copper..	0.14	0.74	0.29	0.60	0.13	0.73	0.29	0.59	0.13	0.71	0.28	0.58
	1 No. 8 iron 1 No. 6 copper	0.17	0.84	0.32	0.68	0.17	0.83	0.31	0.67	0.16	0.81	0.30	0.65
	2 No. 6 monnot–40 per cent.	0.19	0.88	0.33	0.72	0.19	0.87	0.33	0.69	0.18	0.85	0.32	0.70
	2 No. 6 monnot–30 per cent.	0.23	0.91	0.37	0.77	0.23	0.91	0.36	0.77	0.21	0.89	0.35	0.76
	2 No. 8 iron....	0.41	0.97	0.52	0.89	0.37	0.97	0.49	0.88	0.35	0.96	0.46	0.84
80 lb.	Total capacity..	0.11	0.48	0.26	0.48	0.10	0.48	0.26	0.48	0.11	0.48	0.26	0.48
	2 No. 6 copper..	0.14	0.75	0.29	0.62	0.14	0.73	0.29	0.60	0.13	0.72	0.29	0.60
	1 No. 8 iron 1 No. 6 copper	0.17	0.84	0.32	0.69	0.17	0.84	0.31	0.68	0.16	0.82	0.31	0.67
	2 No. 6 monnot–40 per cent.	0.20	0.88	0.34	0.73	0.20	0.88	0.34	0.73	0.18	0.85	0.33	0.71
	2 No. 6 monnot–30 per cent.	0.23	0.91	0.38	0.78	0.23	0.91	0.37	0.78	0.21	0.89	0.36	0.76
	2 No. 8 iron....	0.41	0.97	0.53	0.89	0.37	0.97	0.49	0.88	0.35	0.96	0.47	0.87
70 lb.	Total capacity..	0.11	0.52	0.27	0.52	0.11	0.52	0.27	0.52	0.11	0.52	0.27	0.52
	2 No. 6 copper..	0.15	0.77	0.30	0.65	0.14	0.76	0.30	0.65	0.14	0.75	0.30	0.64
	1 No. 8 iron 1 No. 6 copper	0.18	0.86	0.33	0.72	0.17	0.85	0.33	0.71	0.17	0.82	0.32	0.70
	2 No. 6 monnot–40 per cent.	0.20	0.89	0.36	0.75	0.20	0.89	0.35	0.75	0.18	0.86	0.34	0.74
	2 No. 6 monnot–30 per cent.	0.24	0.92	0.39	0.80	0.24	0.92	0.38	0.81	0.22	0.90	0.37	0.78
	2 No. 8 iron....	0.42	0.97	0.54	0.90	0.38	0.97	0.51	0.89	0.36	0.96	0.48	0.87

Resistance of bond wires	27.5-ft. rails	30-ft. rails	33-ft. rails	
2 No. 6 copper..............	0.057	0.052	0.048	Bond wires 48 in. long. No allowance is made for conductance by the splices.
1 No. 6 copper and 1 No. 8 iron.	0.098	0.089	0.082	
2 No. 6 monnot–40 per cent..	0.124	0.112	0.103	
2 No. 6 monnot–30 per cent..	0.166	0.150	0.138	
2 No. 8 iron................	0.348	0.315	0.291	

406. Mechanical processes involved in interlocking. In all interlocking machines the desired sequence of operations is secured by means of the dogs, bars, or tappets which constitute the mechanical locking. These parts are so interrelated that if any lever in the machine is reversed (that is, moved from its normal position), the act of the signalman in unlatching this lever will cause parts of the locking so to operate that no other lever in the frame can be moved which would allow a train movement conflicting with the train movement controlled by the first lever. The mechanical locking between the levers of the machine also provides for the movement of the levers in proper sequence when the route for a train is being set up, by assuring that the switches must first be properly set and must then be locked in the proper position before the signal governing the route can be cleared.

407. Prevention of switch operation while train is passing. Long bars of steel, called **detector bars**, are held by clips along the outside of the head of the rail at switches. They are of a length greater than the maximum distances between any of the adjacent wheels of a train, and are so mounted that they must move upward above the level of the top of the rail before the switch may be unlocked. They generally are mechanically connected to and operated simultaneously with the lock plungers which pass through holes or notches in the lock rods of switches to lock them in proper position. This method of protection may prove unsatisfactory owing to the increasing width of rail heads, and, especially on electric roads, the relatively narrow wheel treads of which may fail to engage the top of the detector bar while the vehicle is passing over it. Electric track circuits controlling electric locks mounted on the levers of the interlocking machine itself, are becoming quite generally used as a substitute for detector bars in the prevention of switch movement while trains are passing.



Locking Sheet

Reverse	Locks	Reverse	Locks
1	2	13	15-17
2	14-19	14	15
3	4	15	
4	8 12 21	16	17
5	10 12 20	17	
6	16-23	18	Spare Space
7	Spare Space	19	14
8	9	20	12 10
9	11-15-17	21	12 8
10	11	22	21
11	15-17	23	16
12	13 11 11	24	23

FIG. 125.—Typical interlocking plan and locking sheet.

408. Arrangement of mechanical interlocking plant. The plan of a single-track line crossing a double-track line is shown in Fig. 125. There is a siding switch on the single line, located so near the double-track line that it is necessary to include it in the interlocking. Derails are shown on all tracks.

the switch lever and others in the frame, allowing movement of the latter to be made in proper sequence.

411. The Electric-Pneumatic Interlocking System of the Union Switch and Signal Company. This system is so named because compressed air is employed to shift the switches and signals, while electricity is used to control or direct the admission and discharge of pressure to and from the cylinders by which the shifting is performed. The system is comprised of the following elements: an air compressor (preferably in duplicate for reserve) which, especially in terminal station plants, is often used for many other duties; a main air pipe extending throughout the interlocking system with branch pipes connecting it with each switch and signal to be operated; a double-acting cylinder at each switch which, through a motion plate, operates and mechanically locks the switch in its two positions by movement of the piston; a slide valve for each switch cylinder used to direct the pressure to either side of the piston in order to effect the movement of the latter (Par. 412); a single-acting cylinder, operating the signal (Par. 414); a source of energy (Par. 415).

412. Arrangement and operation of the switch-cylinder slide valve (Par. 411). There are two miniature cylinders employed for shifting the slide valve; two pin valves, operated by electromagnets, control the movement of the pistons in these cylinders. Mounted over the slide valve is a third small cylinder, also under the control of a magnet and pin valve. The piston of this small cylinder engages with and locks the slide-valve against movement save when the magnet is energised and the pin-valve is actuated to permit the pressure to withdraw the lock.

By energising and de-energizing the magnets in proper sequence, the slide valve is unlocked, shifted, and again locked by the operating and indicating strokes of the lever. During this process each movement of the valve is accompanied by a corresponding unlocking, shifting, and relocking of the switch through the resulting operation of the switch enforced by the piston of its own cylinder. The three magnets are directly connected with contacts that are actuated by one of the levers in the interlocking machine, a separate wire being used for each magnet.

413. Indicating system (Par. 411). In the latest development of this system, a circuit controller is employed which is actuated by each switch movement. When the switch is in one of its extreme positions and locked there, this controller allows a current *of given polarity* to traverse two wires which connect it with a polarised relay in the tower. Conversely, when the switch is moved to and locked in its opposite position, a current of the *reverse polarity* is sent through the relay. During transit of the switch, and, in fact, when the switch is in any position and unlocked, the controller establishes a shunt or short circuit between these two wires. This short circuit renders the apparatus immune, at such times, to the effects of any stray current which might energise the relay. The circuit controller or pole changer, the relay in the tower, and the two wires joining them substitute the fundamental elements of the indication system of this type of power interlocking.

The polarised relay frees one or the other of two electric locks which, previous to this action, has been arresting the *complete* movement of the switch lever in the tower. This incomplete movement of the lever from full "normal" or full "reverse" involves about two-thirds of its total movement. After the partial movement has been made, the *complete* lever movement can be consummated only in the event of one of the two locks which previously restricted the lever's movements becoming energised. The energisation of this lock can occur only when the indicating relay has shifted its armature in response to a reversal of current in the two indicating wires. Such reversal is only possible when the switch has fully moved and become locked in response to the incomplete lever movement. After the lever has been released, its movement may be completed. Following the processes involved in a final execution of the lever stroke, the mechanical interlocking between switch and signal levers permits the shifting of the proper signal lever for train movements over the switch. The current supply to each and every signal leading over the switch is carried through other contacts of the indicating relay, so that unless the relay is energised in the proper polarity and the lever and the switch correspond precisely in position, no signal whatever can be given over that switch. Conversely, should a signal be properly switch in either direction, a circuit controller is actuated in such a manner as to cut the motor out of circuit, and partly establish connections for the operation of the switch in the opposite direction when the proper lever movement is subsequently made.

The switch-indication circuit is in all respects the same as in the electropneumatic system. A polarized relay controlled by a pole-changer at the switch is used. The pole-changer is so arranged that in any position except the extreme ends of stroke, when the switch is locked, the wires feeding the polarized indication relay are short-circuited and disconnected from the source of energy.

For the operation of the units in this system, direct current at a potential of 110 volts is used. This is supplied to the switches and signals through heavy mains running from the storage battery in the tower. Current from these mains is fed to the motors through the electrically operated circuit controllers as already explained. These controllers are energized by current from the same battery at the same potential. The resistance of the various pieces of apparatus is such, however, that the current flowing in these control circuits is very small. Consequently the wires from the interlocking-machine levers to the units need never be of larger size than is required for mechanical strength. For the indication circuits, the potential is cut down by resistances, one at each switch or in series with each signal indication circuit, therefore the indication wires may also be small. The selection of signals and their control by the various switches in a route is accomplished through the polarised indication relays and combination contacts in the same manner as in electropneumatic interlocking. The indication magnets and the general design of the interlocking machine are the same in both systems.

417. The electric-dynamic indication interlocking system of the General Railway Signal Co. (see Par. **418** to **420**) was the earliest and is the most widely used system of electric interlocking. The source of power consists of a storage battery with its charging unit, which furnishes current at 110 volts for the operation of the switch and signal motors. Power-control apparatus is introduced between the battery and the interlocking machine. The interlocking machine proper is provided with levers, built generally in units so that any lever with its safety and indication magnets, accessories and housing may be removed from the frame without disturbing adjacent levers. The levers are of the sliding type which are pulled out or pushed in to operate the various units. The mechanical locking is of the vertical type, the tappet bars being moved vertically by the horizontal motion of the levers through the medium of a cam slot in each lever. Fig. 127 shows a cross-section of a unit-lever type electric interlocking machine, and Fig. 128 shows typical circuits for this interlocking system.

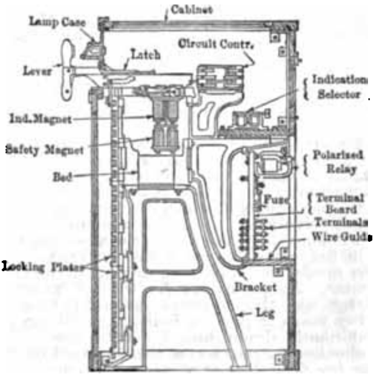


FIG. 127.—Electric interlocking machine.

Alternate levers have their handles turned upward and downward. Beside the interlocking machine, the system comprises the switch and signal mechanisms with their operating and indicating circuits and means for the prevention of unauthorized movement of any unit. Each switch or derail is thrown and locked by a switch and lock movement driven by a series-wound direct-current motor. Two wires are used for this control, one for the normal and the other for the reverse operation. These same wires are used for indicating purposes, the normal control wire being used for the reverse indication and the reverse control wire for the normal indication. The circuit is connected to the main common-return wire at each switch.

This circuit breaker controls the supply of current from the storage-battery to the interlocking machine. A check on the integrity of the cross-protection system is secured by having all necessary contacts and connections either on closed circuit or used in each process of operation and indication so that failure of any individual member would prevent operation and indication and would be promptly detected. A necessary feature in this system as in other electric interlockings, is the prevention of indication current from reaching any lever, while the unit normally under the control of that lever is being operated due to crossed wires from other units which may be indicating at the moment. This protection is secured by means of a safety magnet located below the indication magnet on each lever, Fig. 127. The windings of this safety magnet are included in the operating circuit of the lever, and its magnetic properties are so proportioned to those of the indication magnet, that if both were energised at the same instant, the safety magnet would overpower the indication magnet and prevent the latter from lifting its armature to trip the indication latch in the lever. Normally, the armature of the indication magnet rests upon the poles of the safety magnet. As a further safeguard, an indication selector is provided with its magnet coils in series with the safety magnet and in the control circuit. The function of this selector is to prevent possible receipt of an improper indication during the internal between the time that a lever is moved to the opposite position from that which it previously occupied, and the time the movement of the switch mechanism itself is complete.

420. Operation in reverse direction (Par. 417). The last portion of the stroke of the locking plunger at the switch mechanism operates the pole-changer which cuts off the operating current and puts the circuits into action for an operation in the opposite direction. The breaking of this circuit de-energizes the safety magnet, permitting the indication magnet to be energised by the current generated in the revolving motor armature. The operating circuits are so designed that the magnetic control of the pole-changer insures a correspondence in position between the lever in the machine and the operated unit outside.

THE BLOCK SYSTEM

421. Classification of block signaling systems. The block system provides for the division of the railroad into lengths of track of defined limits, over which railway traffic is controlled by block signals. Block signals and block-signaling systems may be classified as follows: a (Par. 422), manual, in which the signals are operated by hand on orders or information received by telegraph or telephone; b (Par. 423), controlled manual, in which some means (generally electrical) are employed to necessitate the cooperation of the signalmen at both ends of a block in order to clear the signal admitting a train on the block; c (Par. 424), automatic, in which the signals are power-operated and are controlled by the trains themselves through the action of their wheels upon electric circuits constituted by the rails of the track. Such signals indicate the presence of a train or single car or engine in the block and also such conditions as the presence of a broken rail, an open switch or a car standing upon a siding within fouling distance of the main track.

422. In the manual block system, when a train has passed into any block, the signalman sets his signal to the "stop" position behind it, and notifies the signalman at the entrance to the next block of the approach of the train. This second signalman in turn consults his record to see if the signalman controlling the entrance of the third block has reported the passing of all trains out of the second into the third block which previously have been admitted to the second block. If such is the case, the signalman at the entrance of the second block will set his signal to indicate "proceed" and permit the approaching train to enter the second block. Such a system necessitates the use of very carefully prepared rules and is dependent for its safe and successful performance entirely upon the watchfulness of the signalmen and the precision with which they perform the duties prescribed for them by the rules. On single-track railroads, this system necessarily involves the protection of trains against opposing movements, and is in general supplemented by the issuance of train orders from the despatcher, which provide for the meeting of trains at other times or stations than those specified in the time-table.

of the signal; and thence back over a common wire to the other side of the transformer secondary.

Fig. 129 also indicates how a portion of one of the track rails on the siding is insulated from adjacent rails and bonded to the opposite main track rail. If a train or car on the siding moves to within fouling distance of the main track, it will thus shunt the relay of the track section in which the switch is located.

426. Automatic block signaling applied to electric railways. Fig. 130 shows a simplified form of automatic block signal circuit for one track of a double-track railway using direct-current propulsion and two-rail alternating-current track circuits, the signals themselves being operated by direct current from batteries. Alternating-current track relays are generally of the vane, galvanometer or induction-motor type. In the first named, an aluminum sector revolves between the poles of a C-shaped laminated core, in which the winding is placed. This winding is connected across the rails of the track circuit and receives current through the rails from the transformer

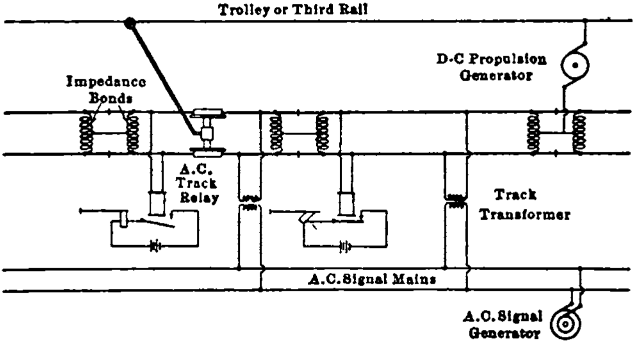


FIG. 130.—Typical circuits. Power supply for a.c. track circuits.

at the other end of the track circuit. The galvanometer type of relay has a set of fixed coils energised from a local source, and a movable coil energised from the track circuit. In the induction-motor type of relay both the track and the local windings are fixed, and the rotor is made to revolve by phase displacement in the current of the two windings. In all types the moving member carries or actuates contacts through which are controlled the circuits controlling the operation of the signals themselves.

The transformers which supply energy to the track circuit also supply energy to the local windings of motor-type track relays together with any line or secondary relays necessary in the circuits; in addition they supply energy for the operation of the signal mechanisms proper. The transformer secondary windings supplying current to the track rails are generally provided with a number of taps, so that the voltage impressed on the track may be regulated to suit the length or characteristics of the track circuit. The secondaries are naturally provided with series resistances which limit the current output when the secondary is short-circuited by the presence of a car in the block.

BIBLIOGRAPHY—RAILWAY SIGNALING

427. Association reports. Comparatively few books have been written on the subject of railway signaling, most of the available data being found in periodical technical literature, in publications of engineering societies, and in the bulletins and catalogues issued by the manufacturers of signal apparatus. The last mentioned source is voluminous, as such publications are frequently issued and contain much valuable technical information.

434. Distribution of potentials in rails and earth. For the simple arrangement illustrated in Fig. 131, the distribution of potentials is shown in Fig. 132. The following assumptions are made in the development of these curves: (a) the negative bus bar is connected to the rails at the power station by an insulated cable, with no other ground connections; (b) the line extends in one direction only; (c) the load is uniformly distributed over the line; (d) a pipe of uniform resistance lies in the earth parallel to these rails; (e) the resistance between the rails and pipe is everywhere the same. With these assumptions, the current in the rails will increase uniformly from zero at the end of the line to its greatest or total load value at the power station *O*. Taking the negative bus bar and this point *O* as the datum or zero of potential, the potential of the rails is represented by the parabola *OI*. The voltage *OD* is the total rail drop. There will be a neutral point *N* in the rails at a distance 0.42 of the total length of the line from the power station where these rails are at the ground potential. Between the power station and *N*, the rails are negative with respect to ground, and current flows from ground to the rails; while from *N* to the end of the line *E*, the rails are positive with respect to ground, and current flows from the rails to the ground.

The pipe of Fig. 131 will have a potential shown by the curve *A-H* in Fig. 132. Between *O* and *N* the pipe is positive, and this, therefore, constitutes a positive region. Conversely, between *N* and *E* the pipe is negative

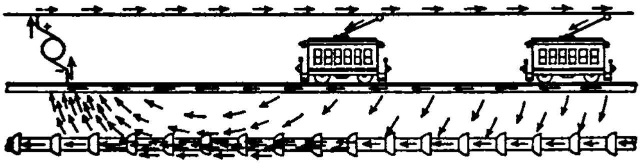


FIG. 131.—Conditions contributing to electrolysis.

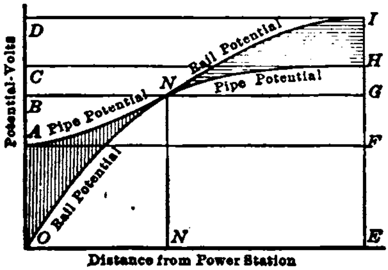


FIG. 132.—Distribution of potentials.

and this is a negative region. The current flow between pipe and rails is proportional to their potential difference. The total current flowing from rails to pipe, shown by the shaded area *N-I-H*, is equal to the total current flowing from pipe to rails, shown by the shaded area *O-A-N*. The current on the pipe will be a maximum at the neutral point *N*, and will be zero at the power station and at the end of the line. The greatest negative potential *C-D* of the pipe, with reference to the rails, will be at the end of the line; and the greatest positive potential *O-A* of the pipe will be at the power station. For the case assumed, the greatest positive potential will be twice the greatest negative potential. The total rail drop *O-D* is equal to the sum of the three voltages, the greatest positive pipe potential *O-A*, the greatest negative pipe corrosion may be considerably less than the theoretical rate. The amount of corrosion produced by electrolysis is independent of the applied voltage, except in so far as this voltage determines the amount of current flowing.

439. Corrosion of lead and tin. Where electric current leaves lead or lead alloyed with a small percentage of tin to flow to surrounding soil, the metal is oxidised by the electrolytic action, forming white or yellow salts. The rate of oxidation of lead by electrolysis under ordinary conditions is equal to approximately 74 lb. (34 kg.) for every ampere leaving the lead in one year. Where lead-sheathed cables are drawn in clay conduits, stray current may flow from the cable sheaths to water in the conduit or to the damp conduit itself. In such cases pittings are usually produced at the lower surfaces of the cable sheaths. Owing to the thin walls usual with lead cable sheaths, together with the high electrochemical equivalent of lead, such cable sheaths are damaged by electrolysis far more easily than are iron pipes.

ELECTROLYSIS SURVEYS

440. Nature of survey. The principal measurements generally made in an electrolysis survey of an underground pipe or cable system are as follows: a, voltage measurements between the pipes or cable sheaths and the rails (Par. 441); b, voltage measurements between the pipes or cable sheaths and other underground metallic structures (Par. 441); c, measurements of current flowing on the pipes or cable sheaths (Par. 442). In order to be able to completely judge the electrolytic condition of an underground metallic system and to be able to decide upon remedial measures, it is necessary in addition to make measurements of rail drop and of the resistivity of the soil in various parts of the system.

441. Potential survey. To make a potential survey, potential differences between the underground structures and rails are measured at a number of points along every street where these structures and electric railway tracks are located. With lead cable sheaths contact is made directly on these sheaths in manholes. With underground pipes contact may be made by means of service pipes, hydrants or drip connections. The connections used for the potential measurements may be tested for continuity by means of an ammeter momentarily connected between the contacts with a dry cell in series if necessary. Where there are a number of underground metallic structures which may be affected by electrolysis, it is desirable to make simultaneous measurements of potential difference between the rails and each of these structures, and from these results to compute the potential differences between each pair of structures.

442. Current survey. To determine the current on a pipe or cable sheath, the drop between two points on a continuous length of pipe or sheath is measured by means of a millivoltmeter. From tables of pipe and cable sheath resistances, as given on the following pages, the strength of current may be computed by Ohm's law. For convenience the currents corresponding to one millivolt drop in a 1-ft. length of pipe or cable sheath are also given in the tables. This figure for current, divided by the distance in feet between the millivoltmeter contacts, and multiplied by the reading in millivolts, is the actual value of the current flowing. Where great accuracy is required, the resistance of a pipe or cable sheath should be measured instead of computed from its dimensions. In the case of lead cable sheaths, the drop measurements can usually be made in manholes where the cables are exposed. In the case of iron pipes, the millivoltmeter leads must be connected directly to the metal of the pipe on which current is to be measured; and no joint must be included between the two contacts. Service pipe connections cannot be used for such current determinations. Temporary contacts are conveniently made by means of a sharpened piece of steel rod, fastened in a wooden handle, with connecting leads soldered to the rod inside of the handle. For permanent connections which can be used at any time for measuring drop on the pipe without again exposing the pipe, rubber-insulated wires may be soldered to brass plugs and these screwed into the pipe; the wires are then brought to the street surface, preferably inside of the curb, and the free ends left in drip or service boxes. It should be noted that small potential differences, such as 0.1 millivolt or less, may be caused by local galvanic or thermal action, and care should therefore be taken that such observations do not lead to erroneous conclusions.

443. Table for determining current on iron pipes from voltage drop in measured length of pipe.—(*Continued*)

Cast-Iron Gas Pipe American Gas Institute Standard—Adopted 1911 Weight, 1 cu.ft. = 450 lb. Resistivity, 1 lb-ft. = 0.00144 ohm.				Standard wrought-iron and steel pipe					
						Wrought iron resistivity 1 lb-ft. = 0.000181 ohm.		Steel resistivity 1 lb-ft. = 0.00021 ohm.	
Nominal diam. of pipe (in.)	Weight per ft. exclusive of bell (lb.)	Resistance per ft. exclusive of bell (ohm)	Current for 1 millivolt drop per ft. of continuous pipe (amp.)	Nominal diam. of pipe (in.)	Weight per ft. (lb.)	Resistance per ft. (ohm)	Current for 1 millivolt drop per ft. of continuous pipe (amp.)	Resistance per ft. (ohm)	Current for 1 millivolt drop per ft. of continuous pipe (amp.)
4	17.3	0.0000833	12.0	1/8	0.24	0.000754	1.33	0.000873	1.14
6	27.3	0.0000528	19.0	1/4	0.42	0.000431	2.32	0.000500	2.00
8	38.0	0.0000379	26.4	3/8	0.56	0.000324	3.09	0.000376	2.66
10	51.1	0.0000282	35.5	1/2	0.84	0.000216	4.64	0.000250	4.00
12	67.1	0.0000215	46.6	3/4	1.12	0.000162	6.18	0.000188	5.33
16	102.	0.0000141	70.9	1	1.67	0.000108	9.23	0.000126	7.95
20	140.	0.0000103	97.1	1 1/4	2.24	0.0000808	12.4	0.0000937	10.7
24	187.	0.00000770	130.	1 1/2	2.68	0.0000676	14.8	0.0000784	12.8
30	258.	0.00000559	179.	2	3.61	0.0000501	20.0	0.0000582	17.2
36	346.	0.00000416	240.	2 1/2	5.74	0.0000316	31.7	0.0000366	27.4
42	453.	0.00000318	314.	3	7.54	0.0000240	41.7	0.0000278	35.9
48	609.	0.00000237	423.	4	10.66	0.0000170	58.8	0.0000197	50.8
...	......	....	....	6	18.76	0.00000965	104.	0.0000112	89.4
...	......	....	....	8	28.18	0.00000643	156.	0.00000745	134.
...	......	....	....	10	40.07	0.00000452	222.	0.00000524	191.
...	......	....	....	12	49.00	0.00000370	271.	0.00000428	234.

445. Table for determining current on lead cable sheaths from voltage drop in measured length of sheath

COMPUTED BY ALBERT F. GANS

Resistivity, 1 ft. length, 1 sq. in. sectional area = 0.00010 ohm

Outside diam. of lead sheath (in.)	Thickness of lead sheath (64th in.)	Resistance of lead sheath (ohm per ft.)	Current for 1 millivolt per ft. (amp.)	Outside diam. of lead sheath (in.)	Thickness of lead sheath (64th in.)	Resistance of lead sheath (ohm per ft.)	Current for 1 millivolt per ft. (amp.)
0.50	4	0.001163	0.860	2.00	6	0.0001781	5.61
0.50	5	0.000965	1.036	2.00	7	0.0001538	6.50
0.50	6	0.000836	1.196	2.00	8	0.0001359	7.36
0.625	4	0.000906	1.104	2.125	6	0.0001672	5.98
0.625	5	0.000745	1.343	2.125	7	0.0001443	6.93
0.625	6	0.000640	1.563	2.125	8	0.0001273	7.86
0.75	4	0.000741	1.350	2.25	6	0.0001575	6.35
0.75	5	0.000606	1.650	2.25	7	0.0001359	7.36
0.75	6	0.000518	1.931	2.25	8	0.0001198	8.35
0.875	4	0.000627	1.594	2.375	6	0.0001488	6.72
0.875	5	0.000511	1.957	2.375	7	0.0001284	7.79
0.875	6	0.000435	2.300	2.375	8	0.0001132	8.83
1.00	5	0.0004419	2.263	2.50	7	0.0001217	8.22
1.00	6	0.0003750	2.668	2.50	8	0.0001073	9.32
1.00	7	0.0003268	3.061	2.50	9	0.0000959	10.43
1.00	8	0.0002913	3.437				
				2.625	7	0.0001156	8.65
1.125	5	0.0003892	2.569	2.625	8	0.0001019	9.81
1.125	6	0.0003294	3.037	2.625	9	0.0000911	10.98
1.125	7	0.0002866	3.491				
1.125	8	0.0002547	3.926	2.75	7	0.0001102	9.08
				2.75	8	0.0000971	10.30
1.25	5	0.0003476	2.876	2.75	9	0.0000868	11.53
1.25	6	0.0002939	3.404				
1.25	7	0.0002552	3.918	2.875	7	0.0001050	9.51
1.25	8	0.0002265	4.415	2.875	8	0.0000927	10.79
				2.875	9	0.0000828	12.08
1.375	5	0.0003142	3.183				
1.375	6	0.0002650	3.773	3.00	8	0.0000887	11.28
1.375	7	0.0002299	4.35	3.00	9	0.0000792	12.62
1.375	8	0.0002038	4.91	3.00	10	0.0000716	13.96
1.50	6	0.0002416	4.14	3.125	8	0.0000849	11.77
1.50	7	0.0002092	4.78	3.125	9	0.0000758	13.18
1.50	8	0.0001853	5.40	3.125	10	0.0000686	14.58
1.625	6	0.0002218	4.51	3.25	8	0.0000815	12.27
1.625	7	0.0001920	5.21	3.25	9	0.0000728	13.74
1.625	8	0.0001698	5.89	3.25	10	0.0000659	15.19
1.75	6	0.0002051	4.88	3.375	8	0.0000783	12.77
1.75	7	0.0001772	5.64	3.375	9	0.0000700	14.29
1.75	8	0.0001567	6.38	3.375	10	0.0000633	15.83
1.875	6	0.0001906	5.25	3.50	8	0.0000755	13.24
1.875	7	0.0001648	6.07	3.50	9	0.0000674	14.84
1.875	8	0.0001456	6.87	3.50	10	0.0000609	16.42

of a completely insulated return circuit, as obtained with a double-trolley system (Par. 451 and 452). The methods which have been tried for minimising electrolysis from stray railway currents may be divided into three classes: a, the **insulation method** (Par. 453 to 455), which is intended to increase the resistance of the path of the current through earth; b, the **drainage method** (Par. 453 to 456), which essays to remove the current harmlessly from structures by metallic connections or bonds between these structures and the railway return circuit; and c, the **return-feeder method** (Par. 458 to 460) which aims to reduce the voltage drop in the grounded rails.

451. Brief description of double-trolley systems and where used (Par. 452). Double-trolley railways (Par. 335) may be provided with positive and negative overhead trolley wires insulated from ground, as used for example in Washington, D. C., Cincinnati and Havana; with positive and negative conductors in underground conduits insulated from ground, as used on the surface lines on Manhattan Island and in Washington, D. C.; or with separate insulated third and fourth rails for the positive and negative conductors, as used on the Metropolitan District Railway in London.

452. Objections to double-trolley systems (Par. 451). The principal objection to the underground double-trolley system is the very high cost of installation, which makes this method practicable only in densely populated districts. The principal objections to the double-overhead-trolley system are the high cost of installation and the complication resulting from two overhead trolley wires, especially at crossings and where several lines meet and are on common tracks.

453. Insulation of rails. Where a road operates on a private right-of-way, the rails can often be practically insulated from ground, and the escape of current from the rails substantially prevented. For surface or subway lines this can be accomplished by placing the rails on wooden ties above ground and using broken stone for ballast. For lines operating on elevated structures substantial insulation may be secured by fastening the rails on wooden ties and keeping them out of metallic contact with the structure.

454. Insulation of pipes. Attempts have been made to insulate pipes from earth by paints, dips and insulating coverings. Practical experience as well as a large number of tests have however shown that no dip or paint will permanently protect a pipe against electrolysis in wet soil. The first difficulty is so to apply the paint that an absolutely perfect coating is formed. It is also necessary to prevent mechanical damage to the coating. Where imperfections exist or develop, aggravated trouble may result. Experience further shows that even where paints or dips are apparently intact, electrolytic action is not always prevented, and, in fact, very serious electrolytic pittings have been found under apparently good coatings. It has been found that in most cases the coatings applied have either been completely destroyed by the effects of the wet soil and the electric currents, or defects in the coating have developed, causing concentrated corrosion at such defective spots. The destruction of paints in wet soil where subjected to an electric current is probably due to a trace of moisture finding its way through the coating, giving rise to the flow of a feeble current and resulting in a very slight amount of electrolysis. The gases and other products of electrolysis then form blisters and finally rupture the coating. Pipes in positive districts covered with imperfect insulating coatings are in greater danger from electrolysis than bare pipes. Coating pipes in negative districts with insulating coverings does some good in reducing the amount of stray current which reaches the pipes. Where it is attempted to apply a heated material like pitch or asphaltum to a cold pipe, it is impossible to completely cover the pipe. The only kind of insulating covering which appears to afford certain protection is a layer of at least 1 or 2 in. of a material like coal-tar pitch or asphaltum, of such a grade that it is not brittle and so will not crack, but yet is hard enough to remain in place. The best way to apply such a layer is to surround the pipe with a wooden box, to support the pipe upon creosoted blocks of wood or upon blocks of glass, and then to fill the space between the box and pipe with the molten material. The cost of carrying out such an installation is however prohibitive except in a few special cases, such as service pipes in very bad localities, or in the case of some very important individual pipe lines of small size. Embedding a pipe in cement or concrete, even if this is several inches in thickness, will not protect a pipe from electrolysis, because damp concrete is an electrolytic conductor like soil.

the cable sheaths to render them at the same potential or slightly negative with respect to neighboring structures. The effectiveness of bonding as a protective measure depends upon the uniformity of the conductor to be protected. The method is therefore not generally applicable to underground piping systems, because these do not form continuous electrical conductors, but are more or less discontinuous networks. While lead-calked joints usually have a relatively low resistance, they frequently develop such high resistances as to make them practically insulating joints, due undoubtedly to the formation of oxide coatings.

457. Possible dangers from drainage connections. Drainage connections to underground metallic structures have the objection of paralleling the trolley rails by a low-resistance grounded conductor, thereby greatly increasing the total stray current through earth and on underground structures. Such drainage connections will generally result in greatly increasing the stray current flowing on the structure, giving rise to the danger of current shunting across high-resistance joints or shunting from one section of the system to an adjoining section. Also, where such connections are applied to a gas or water piping system, large stray currents are often caused to flow through buildings by way of the service pipes. These stray currents cause a serious danger from possible fires as well as from possible gas poisoning or gas explosions. Another serious objection is that such drainage connections make the structure negative in potential to all other underground structures, thereby setting up a tendency for current to flow from such other structures to the bonded structure. A piping or cable system which is bonded to the railway return circuit, thereby becomes a source of danger to all other structures which are not so connected, and this danger increases as the negative potential is increased.

Drainage connections to underground structures should never be used until the railway return circuit has been sufficiently improved, so that only small amounts of stray current are made to flow over such connections. With the construction of electric railways common in America, drainage connections to underground cable sheaths are generally necessary to protect the thin-walled lead cable sheaths against stray-current electrolysis. In the case of piping systems such drainage connections are however not to be used except in special cases, and then only as a final measure to remove small remaining currents.

458. Reverse-current switches for drainage connections. Cases arise where the polarity of underground structures reverses at times with reference to the railway return circuit. Consequently, where these structures are provided with metallic connection to the railway return circuit, current would be made to flow to these structures when these are negative in potential. To prevent this, automatic reverse-current switches are used in series with the drainage connection. The action of these switches is to keep this circuit open while the structures are of negative potential, and closed while they are of positive potential. Such reverse-current switches are frequently used in connection with drainage connections from telephone cables.

459. Insulated return feeder system. Since the drop in potential in grounded rails is the cause of the flow of stray current through the earth, the escape of stray currents will be reduced in the proportion that the drop in the rails is reduced. It is therefore desirable to use heavy rails of high electrical conductivity, and to maintain these rails perfectly bonded, so that they form continuous low-resistance conductors. The next important consideration is to limit the distance from the supply station to which this station delivers direct-current power, so that current is not returned through an excessive length of track; this is usually accomplished by the use of a number of distributed substations. Finally, the current should be removed from the rails by means of insulated return feeders connected to the rails. These feeders draw current from the rail at such points as are necessary to avoid both an excessive potential gradient in the tracks and through earth and an excessive total voltage drop in the tracks. Where it is necessary to bring current back from a distant point in the tracks, it is sometimes more economical to employ a negative booster in series with a return feeder of small cross-section, than to make this feeder of cross-section large enough to drain the required current from the tracks at the distant point. It may also be necessary to install resistances in short feeders. With such insulated track return feeders, part of the voltage drop is removed from the rails and is transferred to the insurails at the power station, with a resistance in the connection proportioned to maintain this point in the rails at the same potential as the other return-feeder connection points. The unit of leakage current is assumed as the amount which flows when the negative bus bar is grounded through a negligible resistance, the rails being connected to the negative bus bar only at the power station. In practice each return feeder would actually be connected to a number of points in the rails in the immediate neighborhood of the connection points shown.

460. Examples of installations of insulated return feeder systems. Such systems are in almost universal use in Germany and in Great Britain, and have given most satisfactory results. In America a considerable number of such systems have also been installed, the most prominent reported example being on the subway system of the Interborough Rapid Transit Company in New York City. Description of insulated return feeder systems installed in Springfield, Ohio, and in St. Louis, Mo., are given in Bureau of Standards Technologic Papers No. 27 and No. 32.

461. Advantages of the insulated return feeder system. This system is intended to relieve the tracks of current by insulated conductors, and thus tends to prevent the escape of current into earth. With a properly laid out return feeder system and properly bonded tracks, it is possible and practicable to reduce stray currents through earth and therefore stray currents on underground piping and cable systems to any desired minimum values and such currents may be made so small as to be negligible. This system, therefore, removes the cause of the trouble in that it minimises the escape of current into earth.

ELECTROLYSIS FROM GROUNDED ELECTRICAL DISTRIBUTION SYSTEMS

462. Grounded neutrals in three-wire direct-current systems. Direct-current electric-lighting systems in which the distribution is on the Edison three-wire plan, having the neutral conductor grounded, are, in American practice, provided with such large neutral conductors of copper that only negligible stray currents are produced from such systems. This grounding of the neutral is intended to serve only as a safety measure, and is not for the purpose of using the earth to carry current.

ELECTROLYSIS FROM ALTERNATING CURRENTS

463. Damage relative to direct-current electrolysis. A large number of laboratory tests have been made to determine whether electrolysis is produced when an alternating current flows between a metal and an electrolyte, as for example between a pipe and surrounding soil. These indicate that slight electrolytic corrosion may be produced; this effect is generally less than 1 per cent. of that which would be produced by a corresponding direct current. With alternating current, however, electrolytic corrosion is produced at both electrodes, while with direct current, electrolytic corrosion occurs only at the positive electrode.

464. Grounded transformer secondaries. The secondaries of transformers are frequently grounded, for the purpose of preventing a high and dangerous voltage from existing between the secondary circuit and ground. Such ground connections however do not produce flow of current to ground, and such grounding of transformer secondaries therefore does not cause danger from electrolysis.

ELECTROLYSIS IN CONCRETE

465. General effects. Concrete when damp is an electrolytic conductor having a resistivity of the same order as damp soil. When iron is embedded in damp concrete and an electric current flows from the iron to the concrete, the iron may be oxidised by the electrolytic action. The oxides of iron formed occupy more space than the original iron, with the result that an outward pressure is produced which in time may crack the concrete. An exhaustive investigation of the effect of electrolysis on iron embedded in concrete has been made at the Bureau of Standards in Washington, and the results of this investigation are published in Technologic Paper No. 18 of the Bureau of Standards. This investigation appears to show that when no chlorides are present, the iron is practically passive at temperatures below 45 deg. cent.

what is known as the Unification Ordinance, which also contains clauses relating to electrolysis. These divide the city into three zones, and prescribe different voltage limitations for each zone. The Board of Supervising Engineers is, however, authorized to modify these voltage requirements as may be deemed advisable. The above ordinances although not entirely in accord are both in effect in Chicago.

In a number of cities in Ohio electrolysis ordinances have been enacted in which the most important features are track voltage requirements. In these ordinances the average potential difference during any 10 consecutive minutes between any two points 1,000 ft. (0.305 km.) apart on the uninsulated return circuit must not exceed 1 volt, and the average potential difference during any 10 consecutive minutes between any two points more than 1,000 ft. (0.305 km.) apart on the uninsulated return circuit within the limits of the municipality must not exceed 7 volts.

472. Legal status of liability for electrolytic damage. There has been considerable litigation at various times with reference to damage from electrolysis. It has been held by various courts that no one utility can claim the exclusive right to use the earth as a return circuit, and that priority of such use is of no importance to either side of the controversy.

473. Peoria decision. In the celebrated Peoria case which was finally decided after having been in the courts for over 10 years, the railway company was enjoined and restrained from injuring the property of the water company by electric current escaping from the rails or structures of the railway company. No particular method for preventing escape of current is prescribed in the decree, because the court in its decision states that a court does not have the power to prescribe by injunction any specific system, and that this power resides only with legislative bodies. The decree also requires the water company to co-operate with the railway company to the extent of giving the railway company access to its piping system for the purpose of measuring flow of current upon its system and of determining whether injury from electrolysis is being continued, in order that the railway company may determine whether it is complying with the terms of the decree.

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SECTION 17

ELECTRIC COMMERCIAL VEHICLES

BY STEPHEN G. THOMPSON

Consulting Engineer

CONTENTS

(*Numbers refer to Paragraphs*)

permitting it to maintain a high average speed, and due further to its freedom from intricate mechanism for transmitting the motor energy to the wheels, and the absence of numerous reciprocating parts.

7. The gasoline motor vehicle finds its best field of application in short-haul deliveries where the mileage is beyond that safely and conveniently obtained from the electric vehicle, its economic value being governed entirely by the individual characteristics of the particular business to which it is applied.

8. Electric vehicles may again be divided into two general classes according to the character of service, viz., (1) commercial vehicles and (2) passenger vehicles. The source of energy supply permits another classification, namely, (1) storage battery vehicles and (2) the so-called **"trackless trolley"** consisting of a motor-propelled vehicle receiving its energy from an overhead double trolley system. Under the second classification, the storage battery vehicle is by far the more important at the present time. The highway trolley vehicle has not yet come into extended use in this country, although it is employed to a limited extent abroad.

9. Commercial electric vehicles at the present time form by far the more important class of electric vehicles, and receive practically exclusive consideration in this section. This is because of their economic value as a means for highway freight movement.

10. Passenger vehicles involve no engineering features which are not very well covered by the discussion of the fundamentals of vehicle engineering and their application to commercial types.

CHASSIS CONSTRUCTION

11. In design, the electric vehicle is of necessity a compromise, the selection of its component parts being governed principally by the question of economy of operation, rather than mechanical efficiency. Few standards are as yet established, machines of each make reflecting the individual ideas of the designing engineer as to what in his opinion constitutes the best practice.

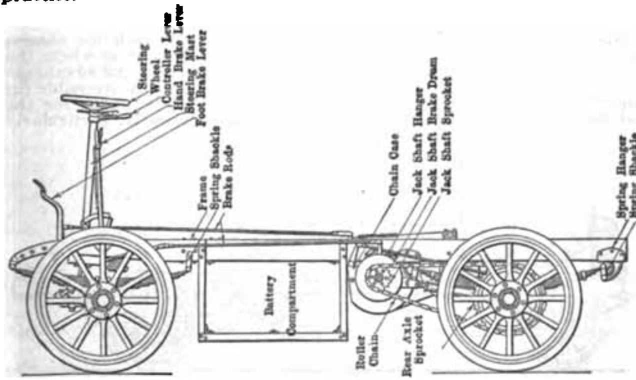

FIG. 1.—Baker chassis. Side elevation.

12. The chassis of the various makes differ only in peculiarities in design required by some special construction. The standard frame is rectangular, of structural or pressed steel, with lateral members for supporting the motor, battery compartment, and other equipment forming a part of the vehicle. Except in instances where the type of the drive employed requires that the axles themselves shall constitute a part of the mechanism, rigid axles are used. In the rear the ends of the axles terminate in spindles

17. The chassis capacity of an electric vehicle may be expressed as the sum of the body weight, plus the battery weight, plus the load weight at maximum speed. The **gross weight** is the sum of the chassis capacity plus the chassis weight. Variations in load, battery, and body weights are permissible so long as the gross weight moved at maximum speed does not exceed that prescribed by the manufacturers.

VEHICLE RESISTANCE AND ENERGY CONSUMPTION

18. The rolling resistance of a wheel is due to the yielding or indentation of the road, which causes the wheel continually to mount a slight incline. The resistance is measured by the horizontal force necessary at the axle to lift it over the obstacle, or to roll it up the inclined surface. The rolling resistance varies with (a) the diameter of the wheel; (b) the width and composition of the tire; (c) the speed; (d) the spring suspension; (e) the nature of the road surface. This resistance varies all the way from 3 lb. per ton with true steel wheels rolling on heavy clean rail, up to 200 lb. per ton in ordinary wagon wheels through sand.

19. Vehicle resistance. The best authorities* give the following values or vehicle resistance:

Steel-tired wheels on steel rail	3 to 5 lb. per ton.
Pneumatic-tired wheels on asphalt pavement	15 to 35 lb. per ton.
Solid-tired wheels	20 to 40 lb. per ton.
Steel-tired wheels on average road, about	50 lb. per ton.

20. Truck resistance. In conducting tests on trucks with different makes of rubber tires, results have been secured where the total resistance has run as low as 25 lb. per ton and as high as 60. all other conditions re-

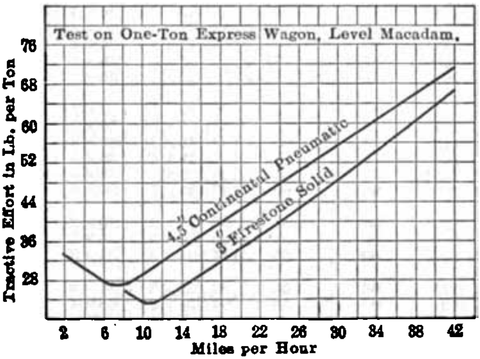

FIG. 4.—Curve showing tractive effort in pounds per ton at different speeds.

maining the same except the tire. This is due simply to a variation in the rubber compound, the low results being secured with a very high quality of rubber, whereas the high results were due to an inferior compound. (Also see Par. 24.) The loss in transmission here amounts to approximately 3 lb. per ton, friction and windage consume 5 lb. per ton, and the remainder is due to the tires.

* Whitney, F. E. "Electric Vehicle Tires;" Electric Vehicle Association of America, October 27, 1913.

Electric Vehicles
the manufacturers)

	Battery			Motor		Controller		
at-ery lb.)	Size compartment (in.)	Type and number of cells standard equipment	Kw-hr. capacity	Make	Type	Location of lever	No. f'rd speeds	Type of drive
,283	49×25½	Op. 42 L, 60 E	9.27L	Gen. Elec.	Series	Under wheel	5	Dble-reduction chain
,555	49×37	Op. 42 L, 60 E	11.58L				5	
,817	51×44½	Op. 42 L, 60 E	13.90L				5	
,414	63×55	Op. 42 L, 60 E	18.63L				5	
,350	30×43	Op. 42 L, 60 E	13.6 L	Gen. Elec.	Series		3	Worm
,700	37×46	Op. 42 L, 60 E	18.2 L				4	Two-motor concentric gear
,100	48×46	Op. 42 L, 60 E	22.7 L				4	
,650	54×48	Op. 42 L, 60 E	29.5 L				4	Four-motor, four-wheel
,080	71×46	Op. 42 L, 60 E	34.0 L				4	
900	For A- 4 E	60 E	10.8 E	Own	Series	On wheel	5	Dble-reduction chain
,260	For A- 6 E	60 E	16.2 E				5	
,820	For A- 8 E	60 E	21.6 E				5	
,250	For A-10 E	60 E	27.0 E				5	
,700	For A-12 E	60 E	32.4 E				5	
,125	36×45*	Op. 44 L, 60 E	10.8 E	Gen. Elec.	Series	On wheel	5	Flex. shaft and chain
,350	42×50*	Op. 44 L, 60 E	16.2 E				5	
,550	42×50*	Op. 44 L, 60 E	16.2 E				5	
,750	42×50*	Op. 44 L, 60 E	16.2 E				5	
,250	42×65*	Op. 44 L, 60 E	21.6 E				5	
,500	54×70*	Op. 44 L, 60 E	27.0 E				5	
,800	50×70*	Op. 44 L, 60 E	32.4 E				5	
,000	60×70*	Op. 44 L, 60 E	32.4 E				5	
875	For 48-A4, E	Op. 44 L, 48 E	9.1 L	Gen. Elec.	Series	Left of seat	4	Dble-reduction chain
,255	For 60-A5, E	Op. 44 L, 60 E	12.1 L				4	
,485	For 60-A6, E	Op. 44 L, 60 E	14.2 L				4	
,970	For 60-A8, E	Op. 44 L, 60 E	19.0 L				5	
,410	For 60-A10,E	Op. 44 L, 60 E	23.7 L				5	
,790	For 60-A12,E	Op. 44 L, 60 E	28.5 L				5	
800	30×20	30 L	8.28L	West'g-house	Series	Left of seat	4	Dble-reduction shaft and chain
,200	35×20	40 L	11.04L				4	
,500	44×20	40 L	13.20L				4	
,300	37×49	Op. 40 L, 60 E	16.2 E	Special	Series		4	Balance gear
,600	37×49	Op. 42 L, 60 E	16.2 E				4	Balance gear
,900	38×49	Op. 42 L, 60 E	21.6 E				4	Balance gear
,700	58×70	Op. 44 L, 60 E	27.0 E				6	Balance gear
,200	58×80	Op. 44 L, 60 E	32.4 E				6	Balance gear

D, dual. L, lead. E, Edison. Op., optional.

effort, owing to the superior ability of the pneumatic tire to adapt itself to surface irregularities.

23. Critical speed for minimum effort. It is noticeable that there is a critical speed at which the minimum tractive effort or draw-bar pull occurs, and that it varies with the type of tire used. The same effect has been observed and demonstrated in railway traction; this is attributed to wave motion in the rolling surface. In the case of the automobile it is caused by the kneading of the tires.

Solid tires	18 to 25 lb. per ton.
Electric special { single tube	15 to 23 lb. per ton.
Electric special { double tube	16 to 25 lb. per ton.
Standard double tube	30 to 35 lb. per ton.
Iron stud tread	31 to 36 lb. per ton.

These values apply to level running.

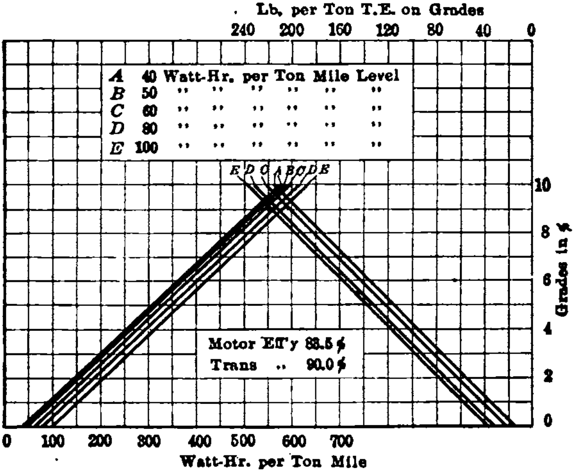

Fig. 6.—Wattage with varying grades and varying tractive effort for level running.

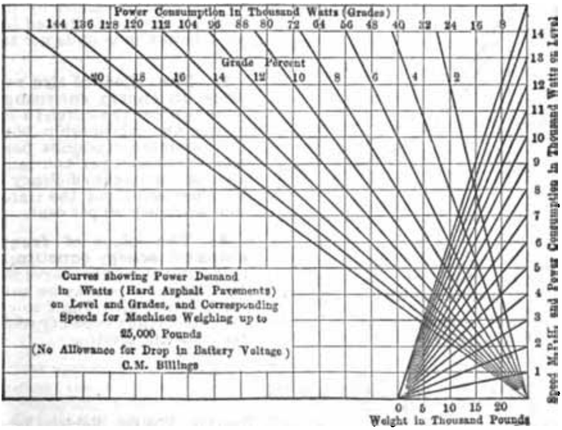

Fig. 7.—Graphs showing power demand in watts.

TRANSMISSION GEAR

35. Transmission of the motor energy to the wheels is accomplished by several methods in general use, but considerable difference of opinion exists as to what constitutes the most desirable method of motor application and the best transmission design. Without commenting upon the general features, as illustrated in the various types hereafter described, it may be stated that simplicity of construction and design should govern the selection of transmission gear so far as is possible, without sacrificing efficiency.

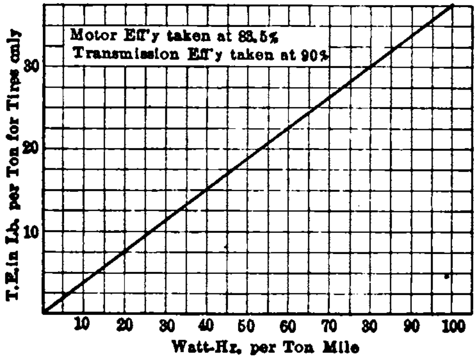

Fig. 9.—Diagram showing tractive effort in pounds per ton due to tires alone, with varying energy consumption of vehicle.

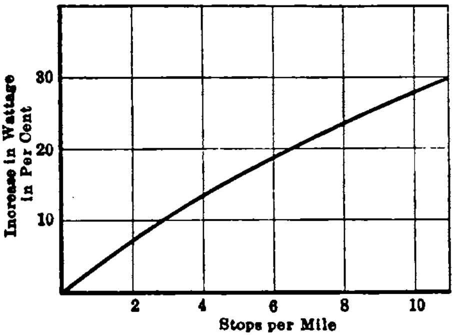

Fig. 10.—Curve showing per cent. increase of energy consumption due to stops.

36. The essential elements of a transmission gear comprise a means of reducing the high speed of the motor to the comparatively low speed of the propulsion or running wheels (reduction gear), and a **differential gear** which permits one wheel to turn faster than the other in propelling the vehicle in any curved path.

The **primary chain** *B* is enclosed in an oil-tight case, or, in some instances, protected from dust merely by an extension of the battery compartment. The former construction is preferable, as the life of the chain is increased by the better means afforded for lubrication.

The counter-shaft is usually assembled in such a manner as to permit its installation or removal as a complete unit. The differential gear is mounted on the differential housing. Adjustment of the silent chain is accomplished by a radius rod with an adjusting screw. For the roller chains, similar distance rods are employed. The armature shaft, jack shaft, and wheels are all equipped with anti-friction bearings. For counter-shaft assembly, see Fig. 12.

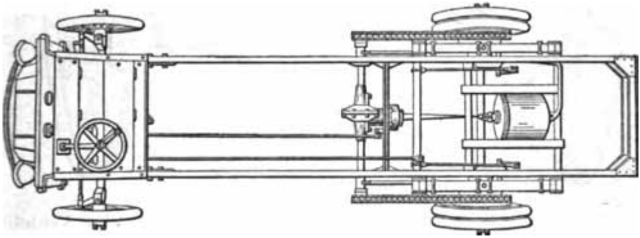

FIG. 13.—Top view of chassis showing drive assembly. (General Motors Company.)

38. The floating shaft and chain drive employs a flexible spring-steel blade for transmission from the motor to the counter-shaft. This shaft has a cross-section that permits torsional displacement or yielding under stress. The counter-shaft is of the floating type with bevel driving gear and pinion reduction. The power is transmitted from the counter-shaft sprockets by roller chains to the rear wheels. The motor is suspended in positive alignment with the chassis frame, with entire weight on frame members and supported at diametrical points. See Fig. 13.

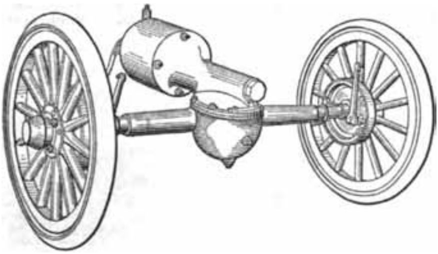

FIG. 14.—Rear axle assembly, spiral gear drive. (Commercial Truck Company.)

39. The spiral gear drive (Fig. 14) has the advantages of clean-cut appearance and compactness, few parts, good lubricating facilities, mechanical efficiency, and extremely quiet operation. Through a worm and gear drive the power is transmitted from the motor to the wheels by a single reduction, making an extremely simple mechanism.

The rear wheels are mounted on roller bearings entirely independent of the driving mechanism, and are driven by floating shafts engaging the outer ends of the wheel hubs. The inner ends of these shafts are squared into the hubs of bevel differential gears. The whole mechanism is immersed in oil, and gives noiseless operation. The rear axle unit consists of motor, gear pinions mounted on each end of the armature shaft to mesh with their respective halves of a "double" cog-rack near the periphery of the disc wheel. Thrust stresses arising from one bevel set are balanced by the other. A small number of parts make up the complete assembly. The arrangement lends itself to **four-wheel drive and steering,** features often required in special applications, where turning space is limited.

43. Other wheel systems which obviate the use of bevel gears and embody the double spur-gear reduction are shown in Fig. 17 and Fig. 18.

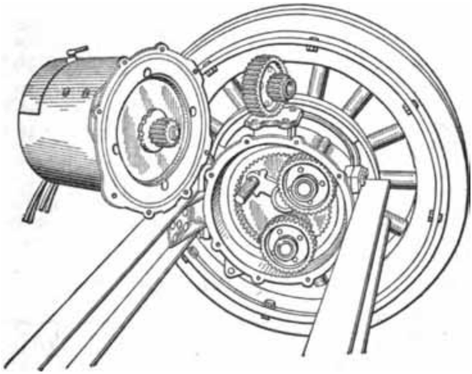

FIG. 17.—Concentric gear drive. (Commercial Truck Company.)

In the former, showing the **spur concentric form of gear,** the gear cases are mounted between two axle members, the extension of the case forming the axle spindle. The motor is bolted to the inner side of the gear case in a fixed position. The armature pinion engages spur gears which are carried

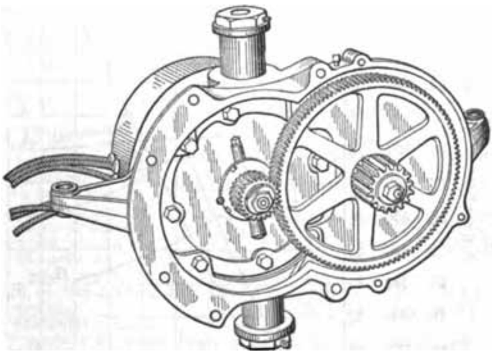

FIG. 18.—Double spur-gear reduction drive. (Commercial Truck Company.)

by studs integral with the driving shaft. The driving shaft passes through the axle spindle and connects with the outer end of the wheel hub through a square form in the hub cap.

The drive illustrated in Fig. 18 is employed with forged steel axles, which

45. Design. In order to meet the requirements of automobile manufacturers. vehicle motors are made in a number of different sizes, each of which can be supplied in several electrical ratings. The features of design follow closely after railway motor practice, since the conditions of vehicle service are very severe. Special attention is given to commutation, insulation, efficiency and reliability. These motors are all of the series-wound type.

46. Special torque characteristic. It is of paramount importance that the storage battery should be protected, and all motors are designed with this object in view. The current-torque curve has the property that doubling the current will approximately quadruple the torque, with reference to any given point on the curve.

During starting and acceleration an electric vehicle requires about five times the normal running torque. Again, the average **maximum grade** encountered in cities is about 7.6 per cent., to climb which also requires about five times normal torque.

47. General motor characteristics. The characteristic curves of torque, speed, current and output, for vehicle motors, are shown in Fig. 19 and Fig. 20, being representative of the products of two leading manufacturers.

48. Performance specification. The manufacturer (*B*) of the motor whose characteristics are shown in Fig. 20 gives the following performance specification:

Rating: The normal full-load rating of each motor is based on the specified voltage and amperes. Where series field coils are arranged for series and parallel connection, the rating is given with field coils connected in parallel.

Speed: The rated speed is based upon the speed of the motor at the end of the specified full-load temperature run. Speeds of individual motors may vary 5 per cent. above or below the speed shown on the specified curve. Approximate speeds for loads other than full or rated load are also shown on the specified curve.

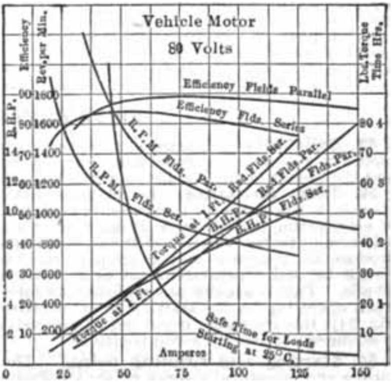

FIG. 20.—Characteristic curves of speed, torque and efficiency. (Make B.)

Efficiency: The efficiencies shown on the specified curve are to be calculated from I^2R losses in the armature and field windings, based on the measured resistance of these windings at a temperature of 50 deg. cent. and the measured core-loss and friction-losses, including brush and bearing friction and windage. These losses are to be determined separately for each load at which efficiency is desired. The efficiencies shown on the specified curve are approximate and represent the average of the manufactured product.

Commutation: Each motor will operate at rated full load with no sparking or burning of the brushes, and without blackening of the commutator. It will commutate any load encountered in normal operation without injurious sparking.

Temperature: After a continuous run (for four hours) at the specified voltage and current, no part of the windings will exceed a temperature of 50 deg. cent. above the surrounding air. Test to be made on stand with motor covers removed. Temperatures are to be measured by thermometer and rises specified are based on a room temperature of 25 deg. cent. For

55. Economical running points. Since it is apparent that the controlling factor in starting and accelerating is the torque, while for running the controlling factor is the speed, combined with torque for hill climbing, it would appear that the economical operating points on the controller are as follows: point 1 and point 2 for starting and acceleration; point 4 for running on level; point 3 for running on hills.

In pleasure vehicles the speed and the torque are similarly controlled, except that the manipulation of the fields, armature, and external resistance is planned to produce a smoother operation, which is required when personal comfort is a factor (see wiring development in Fig. 22).

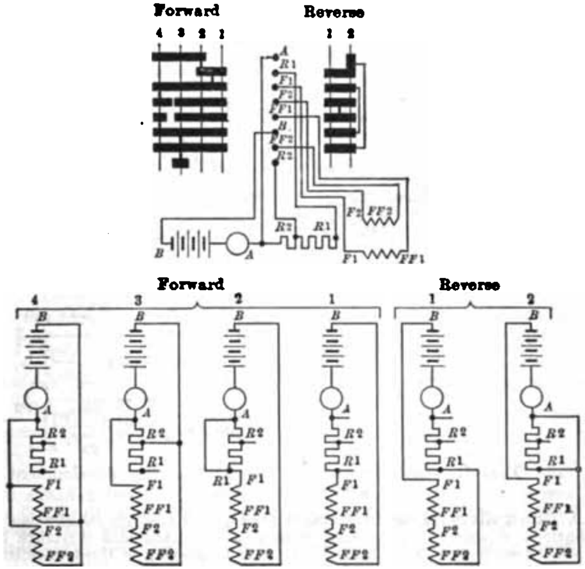

FIG. 21.—Controller connections and wiring development for commercial vehicles. (General Vehicle Company.)

56. Single-motor control is effected, in the standard arrangement, by means of series-parallel commutation of the field coils and the use of series resistance for starting and intermediate steps. At starting the fields are all in series, with all resistance in circuit.

57. Two-motor control is usually effected by series-parallel commutation of the motors, with series resistance for starting and intermediate steps. At starting the motors are in series, with all resistance in circuit.

58. The continuous-torque principle in two-motor control is an advantageous feature, because it insures smooth acceleration in changing from series to parallel connection of motors. The same principle is equally advantageous in single-motor control in passing from series to parallel connection of field coils (Fig. 21). Otherwise there is a sudden drop in torque, or jerk in acceleration, in making these changes.

64. Intermediate or "boosting" charges. Should it be desired to take advantage of any idle time of the vehicle for boosting charges, the rate for such charges may be determined by the following formulas:

(a) Rate for lead batteries:*

$$\text{Rate} = \frac{\text{ampere-hours discharged from battery}}{1 + (\text{time in hours available for boosting})} \qquad (1)$$

Note. See temperature limitations in Section 20.

Ninety per cent. of any total number of ampere-hours which may be charged into the battery in this manner can be added to the rated ampere-hour capacity to obtain the available ampere-hours during operation. For example: a battery of 150 amp-hr. rated capacity, if totally discharged, may be boosted for 1 hr. at 75 amp., or 75 amp-hr. returned; 90 per cent. of this added to the original capacity would give 217 amp-hr. as the total capacity during operation.

(b) Rate for alkaline batteries:

For 5 minutes at 5 times normal rate
For 15 minutes at 4 times normal rate —
For 30 minutes at 3 times normal rate (2)
For 60 minutes at 2 times normal rate

65. Precautions to be observed in applying boosting charges. The charging rates given in Par. 64 for alkaline batteries may be used under average conditions. However, the rate must not be such as to cause excessive heating, and its determination should be governed in each case by experience. Frothing is an indication that the charging has been carried too far (if the solution is at the proper height), and the boosting should be discontinued.

66. Battery renewals in vehicle service must be reckoned as much a part of the necessary operating expense as renewals of tires, bearings, chains or any other part of the equipment. The interval between periodic renewals is not at all a measure of the general efficiency of the battery, because the service in one case may be much more severe than in another. Economy and efficiency of vehicle operation, expressed in terms of dollars and cents, should govern the choice of a battery, assuming always that it is sufficiently standardized so that renewal parts can be obtained as desired.

INSTRUMENTS

67. Ammeters are covered, as a whole, in Sec. 3. This instrument is being largely displaced by the ampere-hour meter, for the reason that, while indicating the discharge flow from the battery, the information is of little value in operating. The switchboard meters at the garage are sufficient for determining the current-flow on charge.

68. Voltmeters are covered, as a whole, in Sec. 3. The ampere-hour meter has also displaced the voltmeter, as well as the ammeter, for the reason that the voltmeter does not indicate the condition of discharge of the battery (while running the vehicle) without the aid of a somewhat confusing mental calculation. The switchboard voltmeter, of course, is essential for determining the battery voltage while charging. **Low-reading portable voltmeters** are desirable for testing the condition of the individual cells of the battery, and are generally used in public garages and the larger private installations.

69. Ampere-hour meters are described, as a whole, in Sec. 3. This type of instrument is coming into general use in electric vehicles because it gives visual indication of the condition of charge of the battery, both while operating the vehicle and while charging. In Fig. 23 is shown a diagram of connections for the ampere-hour meter, with a differential shunt which compensates for the efficiency losses in the battery by retarding the reverse movement of the meter while charging.

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* Electric Storage Battery Co., Phila., Pa.

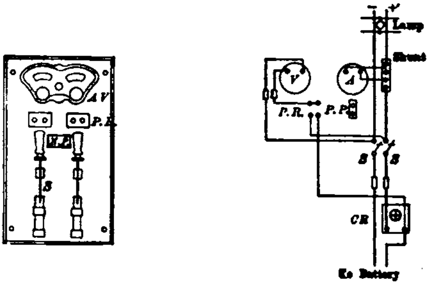
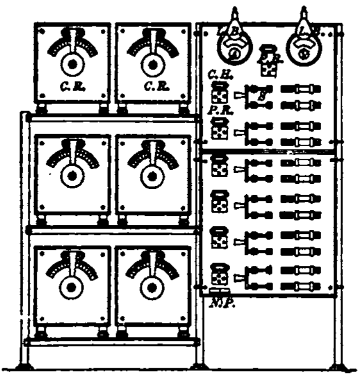


FIG. 24.—One-circuit charging panel and diagram of connections for small garage, direct-current service. (General Electric Company.)

CR, charging rheostat; *LB*, lamp bracket; A, ammeter; *V*, voltmeter; *PR*, potential receptacle; *S*, *d.p. d t.* lever switch with fuses; *NP*, name plate; *CH*, card holder.



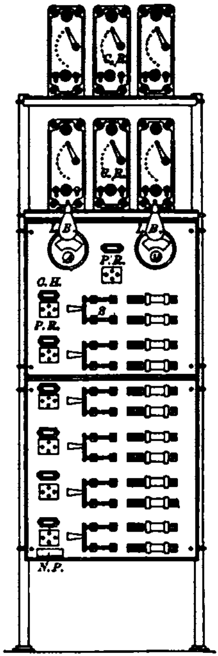


FIG. 25.—Heavy duty charging panels for public garages, direct-current 2-wire or 3-wire systems. (General Electric Company.)

74. Table of Data on Battery Charging Rheostats for Circuits up to 115 Volts Maximum
(General Electric Company)

Charging amperes		Type of cell	No. of cells	No. of steps	Total ohms
Start	Finish				
15	5	Lead	12-18	15	17
20	6	Lead	12-18	15	17
20	5	Lead	20-28	15	13
25	8	Lead	20-28	15	9
30	10	Lead	30-36	15	4
40	10	Lead	30-36	15	4
30	10	Lead	37-40	15	2.6
40	10	Lead	37-40	15	2.6
30	10	Lead	41-44	15	1.5
40	10	Lead	41-44	15	1.5
50	12	Lead	41-44	15	1.28
60	15	Lead	41-44	14	1.0
30	30	Edison A-4	20-40	15	2.8
30	30	Edison A-4	44-60	15	1.7
45	45	Edison A-6	20-40	15	2.0
45	45	Edison A-6	44-60	15	1.2
60	60	Edison A-8	20-32	14	1.4
60	60	Edison A-8	36-44	14	1.0
60	60	Edison A-8	48-60	14	0.72
75	75	Edison A-10	20-32	10	1.17
75	75	Edison A-10	36-44	10	0.81
75	75	Edison A-10	48-60	10	0.60
90	90	Edison A-12	20-32	10	0.96
90	90	Edison A-12	36-44	10	0.68
90	90	Edison A-12	48-60	10	0.48

75. Special rheostats for use in charging alkaline batteries, either at normal or double the normal rate, have been designed and their principal characteristics are given in the table in Par. 76.

76. Table of Data on Special Battery Charging Rheostats for Edison Cells, at Normal or Double Normal Rate

	Charging amperes		Type of cell	Number of cells	Number of steps	Total ohms
	Double rate	Normal rate				
Private garage	60	30	Edison A-4	60	14	0.56
	90	45	Edison A-6	60	14	0.34
	120	60	Edison A-8	60	10	0.26
	150	75	Edison A-10	60	14	0.235
	180	90	Edison A-12	60	14	0.23
Public garage	180	30	Ed. A-4-6-8-10-12	60	14	0.565
	120	30	Ed. A-4-6-8	60	10	0.63
	180	90	Ed. A-10-12	60	14	0.23

77. Charging from alternating-current sources necessarily involves a conversion from alternating to direct current. Four types of conversion apparatus are available, according to the needs of the case, as follows: (1) Synchronous polyphase converters, requiring two-phase or three-phase supply, are not available in standard ratings except for relatively large ections for starting, as a single-phase commutator motor, are shown in Fig. 28; the normal running connections are shown in Fig. 29.

Voltage control on the direct-current side is effected solely by changes in the value of the alternating-current voltage impressed on the slip-rings. Taps in the secondary of the transformer are provided for different numbers of cells, these taps being tagged, not for voltage, but arbitrarily, as S_1, S_2, etc. A table of the proper connections for the number of cells under charge is provided by the manufacturer.

81. Table of Standard Ratings of 60-cycle Single-phase Synchronous Converters

(Wagner Electric Mfg. Co.)

Normal charging capacity in amperes	Number of cells for which taps are provided	Possible voltage variations on d.c. side		Direct current fuse capacities	Capacities in h.p. as motor
		Min.	Max.		
16	32–44	67– 92	86–119	35	1.5–1.75
16	46–52	97–109	124–140	35	2.25
25	20–30	42– 63	54– 81	35	1.5–1.75
25	32–36	67– 75	86– 97	35	2.25
25	38–48	80–100	103–130	35	2.5–3.00
35	18–26	38– 55	49– 70	45	2.5–3.00
35	28–34	59– 72	76– 92	45	2.5–3.00
35	36–42	76– 88	97–113	45	3.0–3.50
50	18–24	38– 50	49– 65	60	2.5–3.00
50	26–30	54– 63	70– 81	60	3.50
50	32–42	67– 88	86–113	60	3.5–5.00
50	44–50	92–105	119–135	65	6.0–7.50
70	22–32	46– 67	60– 86	90	3.5–7.00

82. Protective devices form a most essential portion of the charging equipment. These consist of a reverse-current relay (controlling a main

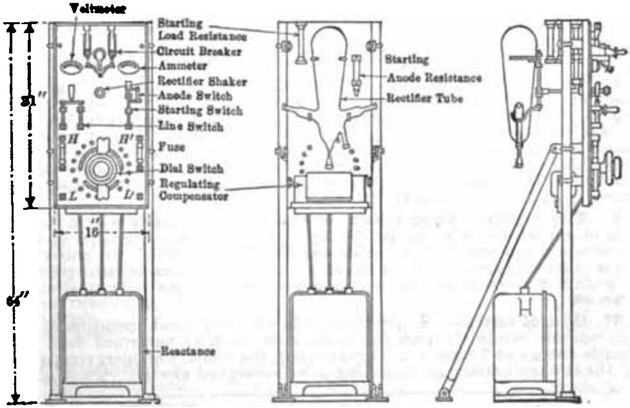


FIG. 30.—Mercury arc rectifier—front, rear and side elevations. (General Electric Company.)

tons' capacity constitutes less than 10 per cent. of the entire operating cost of the machine. Under these conditions, the path of future development lies not so much in the direction of increased efficiency, from the viewpoint of energy consumption, as through a better coordination of the parts employed.

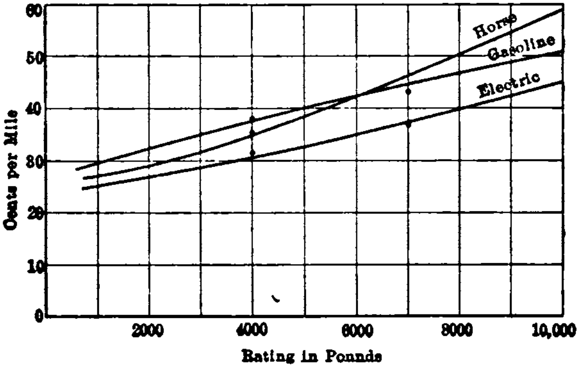


FIG. 31.—Curves of comparative cost per mile in delivery service by electric gasoline, and horse equipment.

88. Table showing Comparative Performance of Electric and Gasoline, Vehicles Operating within the Electric Zone

Conditions of test	Electric	Gasoline
Total weights (gross)	5,230 lb.	2,840 lb.
Diameter of wheels	34 in.	36 in.
Rated speed (m.p.h.)	10 to 12	15 to 18
No. of stops per mile	9.47	9.47
Power equipment	Exide storage battery and GE-1,026 motor, 85 v. 28 amp., 1,200 r.p.m. rating.	Horizontal single-cylinder gasoline engine 4½ in. bore, 6 in. stroke, rated 10 to 12 h.p.*
Test No. 1 (duration of stops, 2 min. each):		
Ton-miles per hour	25.18	11.43
Speed (m.p.h.):		
Level running	10.76	9.41
Up-grade	7.08	8.85
Down-grade	11.12	7.20
Average speed	9.65	8.48
Test No. 2 (duration of stops, 1 min. each):		
Ton-miles per hour	26.13	12.88
Speed (m.p.h.):		
Level running	11.40	10.08
Up-grade	6.90	7.83
Down-grade	11.80	10.56
Average speed	10.03	9.49
General average speed	9.84	8.98

* Engine was running continuously throughout tests.

90. Maintenance costs. In an extended investigation of the operating sts of gasoline and electric machines in several similar lines of business, the ata collected showed that for the electric vehicle the average cost per carile for maintenance increased only 13.3 per cent. over a period of 4 years, hile that of the gasoline car increased 363 per cent. in the same time; and, rther, at the end of the 4-year period the maintenance cost for the electric ehicle was less than 50 per cent. of that of the gasoline machine (Par. 91).

1. Table Showing Comparative Maintenance Costs per Car-mile for Electric and Gasoline Vehicles

	Number of machines reported	Average maintenance cost per car-mile after 7 months' operation	Average maintenance cost per car-mile after 48 months' operation
Gasoline....	54	4.0 cents	18.5 cents
Electric....	69	7.5 cents	8.5 cents

These figures were obtained from the records of the operators themselves nd include all items chargeable to the replacement of mechanical parts, torage batteries and tires.

92. The greater economy of the electric vehicle is accounted for by he absence of a multiplicity of wearing parts, and the lower operating speed f the machine itself. To compete successfully with horses, a power truck not required to run at touring car speeds. The average speed of a 3-ton orse-drawn truck is about 2.5 miles per hour, and the average mileage not ver 12 miles to 15 miles per day. Therefore, a 3-ton motor truck operating t 7.5 miles per hour will not only compete very successfully with a horserawn vehicle, but its maintenance cost will be low.

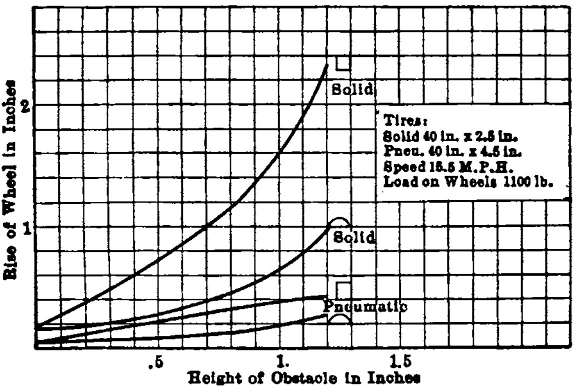


FIG. 32.—Graphs showing vertical lift of axle caused by different shaped obstacles.

93. The relation of speed to maintenance costs. As the speed of a vehicle progressively increases, the force of impact on tires, wheels, axles and springs caused by rough road surface also increases, and very rapidly. This effect is very well shown in Fig. 32 and Fig. 33, plotted from results of tests made by Welles and Michelin.* It is obvious from these results that

* Report of Standardization Committee, Electric Vehicle Association of America, October 7, 1912.

fessor Pender,* and in commercial electric vehicle applications in similar service as observed by the author. It is noticeable that the relative time values for loading and unloading do not vary in proportion to the amount of merchandise handled. This is accredited to the tendency of the machine to "speed up" the men.

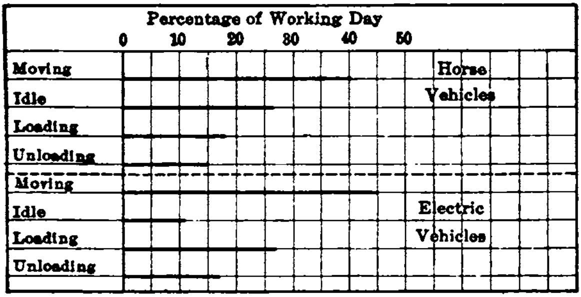


FIG. 34.—Analysis of daily performance of horse-drawn and electric vehicles.

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† Obtainable from the office of the Electric Vehicle Association of America, 29 W. 39th St., New York.

SECTION 18

ELECTRIC SHIP PROPULSION

BY HENRY M. HOBART

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CONTENTS

(Numbers refer to Paragraphs)

$$\text{Frictional resistance} = 24{,}000 \times \left(\frac{14}{20}\right)^2 \times 8 = 94{,}000 \text{ lb.}$$

$$\text{Output from propeller} = \frac{94{,}000 \times 14 \times 6{,}080}{60 \times 33{,}000} = 4{,}040 \text{ thrust h.p.}$$

Of course in actual service, these values will vary tremendously with wind, wave, tide, condition of ship's bottom, disposition of cargo, arrangement of superstructure and other varying conditions. Furthermore the values given correspond with normal designs of average vessels. It is to be observed, however, that reasonable extremes in type of vessel do not occasion great departures from representative values of the frictional resistance.

5. Ship momentum. When increasing the speed of a ship, power must be expended in order to provide the greater momentum associated with the higher speed. This power is in addition to that required to overcome friction. Consider the acceleration of a 24,000-ton* ship from rest up to a speed of 14 knots. The formula for E, the energy of momentum, is:

$$E = \frac{1}{2}\frac{W}{g}V^2 \qquad (1)$$

where: W = weight in pounds,
g = acceleration of gravity in feet per second per second (= 32.2),
and V = speed in feet per second.

In our example we have:

$$W = 24{,}000 \times 2{,}240 = 53{,}800{,}000 \text{ lb.}$$

$$V = \frac{14 \times 6080}{3600} = 23.6 \text{ ft. per second.}$$

$$E = \frac{53800000 \times 23.6^2}{2 \times 32.2}$$

$$= 467{,}000{,}000 \text{ ft-lb.}$$

[1 h.p. = 33,000 ft-lb. per minute.
$\therefore$ 1 h.p-hr. = 33,000 × 60 = 1,980,000 ft-lb.]

$$\therefore E = \frac{467}{1.98} = 236 \text{ h.p-hr.}$$

6. Acceleration. If the acceleration is accomplished in 3 min. and at the uniform rate of $\left(\frac{23.6}{3 \times 60} = \right)$ 0.131 ft. per second per second, then the output from the propeller for providing this acceleration is:

$$(60/3) \times 236 = 4{,}720 \text{ thrust h.p.}$$

We have already seen (Par. 4) that, at a speed of 14 knots, an output of 4,040 thrust h.p. is required for overcoming the frictional resistance. Consequently when accelerating the ship from rest up to a speed of 14 knots in 3 min. the output from the propeller gradually increases from 4,720 thrust h.p., at the moment the ship starts, up to 4,720 + 4,040 = 8,760 thrust h.p., at the completion of the acceleration, and then decreases to 4,040 thrust h.p., when constant speed is attained.

In practice, the acceleration is not at a uniform rate but gradually decreases as the ship gathers speed.

7. Retardation. It is interesting to consider the conditions attending an emergency reversal when the ship (Par. 6) is proceeding at a speed of 14 knots. In order to bring the ship to rest in 3 min. (neglecting the losses in the machinery and the resistance of the ship), the propellers must, after reversal, *impart to the water* 236 h.p-hr. of energy. It may be assumed that 30 sec. is occupied in bringing the propellers up to speed in the reverse direction and that, during this time, the ship travels: (30/3,600) × 14 × 6,080 = 710 ft.

For the remaining 2.5 min. (150 sec.) the propellers must impart to the water nearly 236 h.p-hr. (say 200 h.p-hr.) of energy. The average output from the propellers is: (60/2.5) × 200 = 4,800 thrust h.p. If the retardation is uniform, the average speed during these 150 sec. is: 23.6/2 = 11.8 ft. per second and the distance traversed is: 150 × 11.8 = 1,770 ft., the total dis-

* Throughout this section the 2,240-lb. ton will be employed.

through locks, and in general conform to the requirements of such service. The "**beam draught**" ratio (B/H), and the "**displacement length**" ratio $D \div (L/100)^3$, are also amongst the criteria employed in this connection.

12. The admiralty formula. Naval designers and marine engineers (especially in Great Britain), have made considerable use of the "admiralty formula," and although it dates from the period before the advent of the marine steam turbine, it is still widely used. The "admiralty formula" expresses the indicated horse-power (i.h.p), in terms of the two-thirds power of the displacement, the cube of the speed, and a factor, C, known as the "**admiralty displacement coefficient.**" The formula is:

$$\text{indicated horse-power} = \frac{D^{\frac{2}{3}} \times V^3}{C} \tag{3}$$

It will be seen that the length (L) of the ship does not enter directly into this formula but is embodied in C, the "admiralty displacement coefficient."

Other formulæ and data relating to ship resistance, and to the power required for propulsion, are given in Taylor's "Speed and Power of Ships;" John Wiley & Sons, New York, 1910, and in Chapters II and IV of Hobart's "Electric Propulsion of Ships;" D. Van Nostrand Co., New York, 1911.

PROPELLER CHARACTERISTICS

13. General. The screw propeller was first employed for ship propulsion thousands of years ago by the Chinese. The steam-driven screw propeller came into wide use during the last half of the nineteenth century. The first quarter of the twentieth century will witness the extensive adoption of electrical transmission from the steam engine or oil engine to the propeller. This will permit various advantages which will be set forth in later paragraphs. At present it is desired to dwell on the very important advantage that the method will permit greater freedom in the choice of propeller speed.

14. Propeller thrust, diameter and speed. It will be impossible to touch upon more than the mere elements of the characteristics of propellers. In Par. 4, we briefly discussed a 24,000-ton ship for operation at a speed of 14 knots. At this speed the output required from the propeller for overcoming frictional resistance was estimated to be 4,040 thrust h.p.; now assume that 5,000 thrust h.p. will be provided. At a speed of 14 knots the corresponding thrust will be:

$$\frac{5{,}000 \times 33{,}000 \times 60}{14 \times 6{,}080} = 116{,}000 \text{ lb.}$$

It is usual in large ships to design the propellers for a **pressure** of not over **12 lb. per square inch of projected surface.** The projected surface of a propeller is the component of the area of the blades corresponding to a surface normal to the axis of the shaft. Therefore the projected area should be $116{,}000/12 = 9{,}700$ sq. in.

The surface ratio is the ratio of the projected area to the area of a circle whose diameter is equal to that of the tips of the propellers blades. We may assume that we shall employ a design having a surface ratio of 0.35. Consequently in the present instance we must provide a gross area of $9{,}700/(0.35 \times 144) = 192$ sq. ft. If we employ a **single propeller,** its diameter should be: $\sqrt{(4 \times 192)/\pi} = 15.6$ ft. For a peripheral speed of 6,000 ft. per minute we arrive at a rotational speed of $6{,}000/(15.6 \times \pi) = 122$ r.p.m.

For the alternative of employing **two propellers,** and again assuming a surface ratio of 0.35, a pressure of 12 lb.per square inch of projected area and a peripheral speed of 6,000 ft. per minute, we arrive at a diameter of $(0.707 \times 15.6 =)$ 11.0 ft. and a speed of $(1.414 \times 122 =)$ 173 r.p.m.

Many other considerations enter into the determination of the preferable design. The number of blades, and their shape, size and pitch, have a far-reaching influence on the result, as have also the peripheral speed and the pressure per square inch of projected area. The determination of the most favorable disposition of the propellers with reference to the hull and to one another, is another matter of much importance. The range of practicable diameters is also affected by the size of the ship and by its lines. If the propellers are to be well immersed in all weathers the permissible diameter is quite limited in ships with shallow draught.

18. Limits of propeller size and power. It is well to call attention to the enormous power which can be delivered by a single propeller. In driving the "Mauretania" at 26 knots, an average speed at which she has made complete journeys across the Atlantic, the total thrust horse-power amounts to fully 36,000 h.p., or if equally distributed among the four propellers 9,000 h.p. per propeller. This corresponds, with her present equipment of four-bladed screws, to an output of 2,250 h.p. per blade. The propeller diameter is 15 ft., corresponding to a gross area of 176 sq. ft. The output may thus be reduced to: 9,000/176 = 51 thrust h.p. per square foot of gross area. Taking the projected area, in the case of the Mauretania's latest propellers, as probably being some 40 per cent. of the gross area at the pitch circle, we have also: 51/0.40 = 127 thrust h.p. per square foot of projected area. No significance is to be attached to these large values, as they result from the employment of propellers of a speed distinctly too high to be compatible with good efficiency, and which have, furthermore, too small an area for effective manœuvring.

The turbines of the British battle cruiser "Tiger" will deliver 100,000 shaft h.p. at the vessel's maximum speed of 31 knots. Her four high-speed propellers will hardly have an efficiency of over 50 per cent., giving a thrust horse-power of some 50,000 h.p. or 12,500 h.p. per propeller.

19. Multiple propellers. In the early stages of the development of the marine steam turbine, engineers failed to realize that its natural speed was far in excess of speeds consistent with good propeller characteristics. Consequently vessels were equipped with propellers of such small diameters as to embody merely the necessary mechanical strength at high speeds, and the necessary area was obtained by resorting to the use of several (multiple) small propellers. In certain instances this was carried to the extreme of installing more than one propeller on a single shaft.

In 1894 on the occasion of the first trial of the historical "Turbinia" (of 45 tons displacement), she was fitted with only one shaft and a single two-bladed propeller of 30 in. diameter and 27 in. pitch. As thus fitted, the "Turbinia" was quite inoperative owing to intense cavitation. The slip was 49 per cent. She was then re-fitted with three propellers on the same or single shaft; these propellers were spaced from each other by three diameters and yielded a vessel speed of 20 knots, the propeller slip being 38 per cent. In 1896 the "Turbinia" was again re-fitted, three turbines being installed. Each of the three shafts carried three 18-in. diameter screws with a pitch of 24 in. She attained a speed of 34 knots with a turbine speed of 2,200 r.p.m. and slips of 17 per cent. on the middle shaft and 25 per cent. on the side shafts. In 1903, the "Turbinia," after having her *nine* 18-in. propellers replaced by *three* propellers of 28 in. diameter with a 28-in. pitch (there being one propeller on each shaft), was again tested, and showed about the same economy up to a speed of 17 knots, and a quite considerable increase in speed for a given steam consumption, for all speeds between 18 knots and 28 knots. Further particulars of the "Turbinia" tests may be found in a paper by Parsons, read before the Institution of Naval Architects on June 26, 1903.*

SYSTEMS OF PROPELLER DRIVE

20. Reciprocating steam engines. There are three leading advantages possessed by the reciprocating engine for marine propulsion. These are:

(a) The natural speed of the marine type of reciprocating steam engine is of the same order as the natural (most efficient) speed of the screw propeller.

(b) The reciprocating steam engine may be designed for good economy over a wide range of speeds and loads, and for best economy at some intermediate speed and load.

(c) The reciprocating steam engine may readily be reversed and may exert great power during astern running. It is susceptible of ready control at all speeds including "dead-slow" speeds, and consequently endows the ship with excellent manœuvring ability.

The case for the reciprocating engine for marine propulsion, with special reference to the requirements of the United States Navy, has been very ably presented by Capt. C. W. Dyson, U. S. N., in a paper entitled "Engineering

* Stevens and Hobart. "Steam Turbine Engineering," Chap. XXIII, Whittaker & Co., London, 1906.

While the reciprocating engine has a decided advantage in the features of weight and space required, under present conditions these advantages would disappear should the necessary power to be developed be increased considerably above what is now asked for, and the advantage would rest with the turbine." . . . . . "Basing the choice between reciprocating engines and turbines for battleship propulsion under existing conditions of speed and power upon the above comparison of relative advantages of the two types, the advantage appears to rest most decidedly with the reciprocating engines."

22. Relative economy of steam engines. In the case of large, compound, triple-expansion and quadruple-expansion marine engines the economy falls but little behind that obtained in modern, high-speed land steam turbines for the same power, and is much better than that of steam turbines designed to operate at *speeds so low* as to permit direct connection to the propellers.

23. Examples of steam-engine economy. In a paper by C. Waldie Cairns* the result of 1.70 lb. of coal per indicated horse-power-hour with triple-expansion engines was given for a 36-hour trial of the 10-knot "Cairngowan" on Feb. 6, 1913. The corresponding water consumption was 15.2 lb. per indicated horse-power-hour; steam pressure, 175 lb. per square inch; vacuum, 26.8 in.; propeller speed, 61.7 r.p.m.; displacement, 9,950 tons, draft, 23 ft. 10 in.; length, 371 ft.; beam, 51 ft. See Par. **34** and **35**.

Elsewhere it has been stated on excellent authority that there are many ships which, even without superheaters, are working at 1.3 lb. and 1.4 lb. per indicated horse-power-hour (triple expansion) for all purposes.† In an editorial on p. 349 of *Shipbuilding and Shipping Record* for March 19, 1914, allusion is made to the estimate that with the combination of a reciprocating unit exhausting into a low-pressure turbine geared to a propeller shaft the water rate for large ships could be cut down to 8.5 lb. per horse-power per hour.

24. Internal-combustion engines. The only types of internal-combustion engine as yet developed which can come in for reasonable consideration for marine propulsion are those employing oil as fuel. The impracticability of providing space on board ship for gas producers and auxiliary plant precludes gas engines from consideration, so far as can be foreseen at present. Indeed it is the elimination of any equivalent to the steam-raising plant which is chiefly instrumental in giving the oil engine any standing as a prime-mover for ship propulsion.

Space and weight are factors of supreme importance on board ship, and it is the consideration that four-tenths of a ton of crude petroleum (or probably even of residue), will suffice for supplying the same number of shaft horse-power-hours to the propellers as would be supplied by burning 1 ton of coal‡ under boilers in a steam plant, that is proving so attractive to marine engineers and shipowners, even though the outlay for 0.4 ton (120 gal.)§ of crude petroleum will be much greater than for 1 ton of good coal. The advantage of the space and weight saved is of no small account, and for medium-sized and small-sized ships it should often outweigh the accompanying handicap of the increased outlay for fuel and the very great initial outlay for engines requiring the finest of workmanship in their manufacture and skilled attendance and adjustments during service. It is characteristic of oil engines as at present developed, that the weight of an engine of twice the capacity of a reference engine is, for the same speed, usually

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* Cairns, C. W. "A Comparative Trial between the Triple-expansion Engine and Geared Turbine in Cargo Steamers." Also see *Shipbuilding and Shipping Record*, Apr. 3, 1913; p. 6.

† *Engineering*, London, July 19, 1912; p. 91.

‡ Crude petroleum is taken as having 19,000 B.t.u. per pound and coal as having 15,000 B.t.u. per pound. $0.4 \times 19{,}000/15{,}000 = 0.51$. Thus the statement in the text is based on obtaining with the oil engine only twice the efficiency from fuel to shaft, as in the steam plant. While better results are guaranteed and obtained, it is desirable at so early a stage in the development of the internal combustion engine to be conservative in estimating its performance.

§ The U. S. gallon, equal to the volume of 8.35 lb. of water or about 7.5 lb. of crude petroleum, is taken here.

(double-acting, two-stroke-cycle) weigh only some 110 lb. per horse-power. Mr. Dugald Clerk in the discussion of Dr. Diesel's paper gave the table of weights in Par. 28 and also the curves which appear in Fig. 1 and Fig. 2.

It is the order of magnitude of these weights, relating to four-stroke-cycle engines, which has occasioned the strong tendency to develop the larger capacities in two-stroke-cycle engines.

A single acting, four-stroke-cycle, low-speed, 800 b.h.p. Diesel engine is considerably heavier than any of the engines shown in Fig. 2, as it has a weight of some 600 lb. per brake horse-power. Retaining the same low speed,

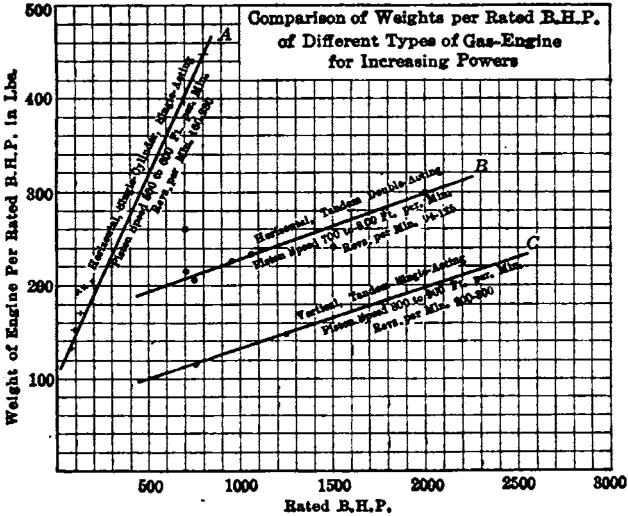

FIG. 2.—Comparison of weights per rated brake h.p. of different types of gas-engine for increasing powers.

but resorting to a double-acting two-stroke-cycle, the weight comes down to 238 lb. per brake horse-power; and in recent high-speed Diesel engines of the double-acting two-stroke-cycle type, the weight is brought down to 116 lb. per brake horse-power. The above data of weights of Diesel engines present a striking contrast to the low weights per brake horse-power which are being obtained in large steam turbines.

27. Diesel marine engines. The "Selandia," "Fionia" and "Jutlandia" are sister ships; each is 370 ft. long and 53 ft. beam. Each ship is fitted with two four-stroke-cycle vertical, single-acting Diesel engines and each of the two engines comprises eight cylinders and has a rated capacity of 1,250 i.h.p., or a total of 2,500 i.h.p. per ship. The speed at sea is 130 r.p.m. In a paper by Mr. I. Knudsen entitled "Results of Trials of the Diesel-engined Sea-going Vessel 'Selandia,' read on March 28, 1912, before the Institution of Naval Architects, the results of the trial trips are given. It is stated that reversal of the engines from full speed ahead to full speed astern can be carried out in 20 sec. The fuel oil is stored in the double bottom of the vessel, and sufficient storage capacity is provided for a continuous journey of about 30,000 miles. After three short trial trips the "Selandia" made a journey across the North Sea from Copenhagen to Aalborg with a cargo consisting of about 2,000 tons of cement. The fuel consumption (including all oil used for auxiliaries, but excluding that used for heating the vessel), was finally have the result of high efficiency and cheap fuel. When supplied in the form of coal dust, 3 cents per million B.t.u. is a fair relative figure for the fuel cost. Assuming as the sea efficiency from fuel to shaft:

(a) 14 per cent. for boiler plant and steam engine or turbine,
(b) 28 per cent. for oil engine,
(c) 21 per cent. for producer plant and gas engine,
(d) 28 per cent. for coal-dust engine,

and assuming for the price of fuel per million B.t.u.:

(a) 9.4 cents for coal for the steam-engine equipment,
(b) 28.2 cents for oil for the oil-engine equipment,
(c) 9.4 cents for coal for the gas-engine equipment,
(d) 3.0 cents for coal for the coal-dust engine equipment,

then the costs per million B.t.u. given out at the shaft and per brake horse-power-hour given out at the shaft, work out as shown in Par. 30.

30. Summary of Comparative Fuel Costs for Marine Prime Movers

	Fuel cost per million B.t.u. at shaft, cents	B.t.u. per h.p-hr.	Fuel cost per brake h.p-hr., cents
I. Steam plant	67	2,545	0.171
II. Oil-engine plant	101	2,545	0.257
III. Gas-engine plant	45	2,545	0.115
IV. Coal-dust engine plant	11	2,545	0.028

The attractively low fuel cost in the case of the coal-dust engine would be futile in marine propulsion unless attained with an engine of small weight and of low cost and upkeep.

31. Low-speed, direct-connected turbines. Ever since the advent of the steam turbine into engineering work on land, there has been gradual but uninterrupted progress toward the employment of ever higher speeds. This progress has been accompanied by a great decrease in weight per horse-power and a very satisfactory decrease in steam consumption per brake horse-power-hour. In marine applications the difficulties encountered at an early date with respect to propeller efficiency, and the attainment of satisfactory operating characteristics of the propeller, imposed restrictions on the speeds employed. Consequently marine steam turbines have been much more heavy and less economical than land turbines for equivalent outputs.

The steam turbines of the "Mauretania" run at a speed of 188 r.p.m. and (exclusive of condensing plant) represent a weight of about 40 lb. per shaft horse-power. The steam consumption per shaft horse-power-hour during the full-speed trials was just over 12 lb.* Each of the four main turbines delivers about 17,000 s.h.p. Land turbines for twice this output can now be built with speeds of 1,800 r.p.m. and there is thus obtained, not only an enormous reduction in the weight per horse-power, but also a very satisfactory improvement in the steam consumption per shaft horse-power-hour.

32. Improved economy of high-speed turbines. By using 250 deg. fahr. of superheat, the firm of Messrs. Parsons will obtain on a 750-r.p.m., 25-cycle, 25,000-kw. set which they have constructed, a steam consumption (guaranteed) of only 11 lb. per kilowatt-hour, which (allowing for an efficiency of 97 per cent. for the electric generator) is equivalent to 8.0 lb. per brake horse-power-hour from the steam turbine. High superheats can be used much more successfully in high-speed turbines, since with their relatively small diameters they are more rigid and more free from the difficulties consequent upon expansion than is the case with large, slow-speed, steam turbines. When tested with 220 deg. fahr. superheat, a pressure of 184 lb. per square inch at the boiler side of the pressure stop valve, a condenser pressure of 0.72 in., and a load of 9,000 brake-horse-power, a 40-

* See p. 463 of *Engineering* for April 4, 1913.

51 ft. On the trial run, the displacement was 9,950 tons; block coefficient, 0.779. The steamer fitted with triple-expansion engines, the "Cairngowan," a a sister ship to the "Cairnross," has practically the same dimensions, the same propeller speed, and was loaded to the same displacement as the "Cairnross" during the 36-hr. trial. The results of the trials appear in Par. 34.

36. Alquist mechanical gearing. A very recent development in speed-reduction gearing is the Alquist mechanical gear for large powers, incorporating the feature of flexibility to the extent necessary to overcome the grave difficulties associated with rigid mechanical gears operating at high tooth speeds.

37. Electrical transmission for marine propulsion. Although mechanical speed-reduction gearing is quite appropriate for ships of low power, making long journeys at a fairly constant speed, it is inferior in a number of respects to the plan of interposing electric transmission between the prime-mover and the propeller. The electrical plan provides effectively for: (1) obtaining the desired speed reduction for operating a low-speed propeller from a high-speed steam turbine; (2) dispensing with any additional turbines for astern running, since the electric motor provides the reversible attribute. As to the first feature, the electrical method greatly excels the mechanical method in the respect that ratio of reduction can be varied to any extent desired, thus permitting the operation of the ship economically at various speeds, while the prime-mover is preferably operated at substantially constant speed. Moreover, a greater ratio of speed-reduction is practicable with the electrical system than with mechanical gearing, and more favorable speeds can be adopted both for the steam turbine and for the propeller.

The second feature, the ability to reverse the ship by reversing the electric motors which drive the propellers, has not only the advantage of eliminating the additional turbines for astern running and thus lightening and cheapening the equipment, but there is the further advantage that in all manœuvring operations the full power of the main turbines is available, instead of the limited power of the astern turbines. Thus electrically-driven ships will be characterised by their prompt and decisive manœuvring abilities.

38. Relative weight and efficiency of electrical gearing. For a given speed-ratio, the interposed electrical machinery will usually be heavier and more expensive than mechanical reduction gearing, but electrical gearing permits employing a *greater* speed reduction than is practicable with mechanical gearing. Consequently, with the electric drive, the prime-mover is lighter and more efficient than when the mechanical gearing is employed, and this greater saving as regards the main prime-movers is increased by the complete elimination of the astern turbines. It must be admitted, however, that the overall efficiency of the electrical machinery is rarely above 90 per cent. to 92 per cent. as compared with 98 per cent. efficiency of the mechanical gearing. But here again it will be found that the inferiority of some 6 per cent. to 8 per cent. efficiency is fully made up by the increased economy in the steam consumption of the prime-mover, because of its higher speed, and the improved efficiency of the propeller, because of its lower speed.

39. General conditions under which electric propulsion is best adapted. The general tendency is in favor of mechanical gearing for small ships, of low power, making long journeys at full speed, and electrical gear for large ships, and for ships requiring different speeds on different occasions, including those ships which frequently navigate inland waterways and crowded harbors and consequently require excellent manœuvring ability.

40. Special advantages of electrical gearing for ships operating at variable speeds. The most important reasons for operating ships electrically relate to the introduction of certain principles which, in land central stations for the generation of electrical energy, are recognized as having fundamental commercial importance. These principles can be well illustrated by considering the case of a battleship. Such a ship must be equipped with enough propulsive machinery to provide some stipulated maximum speed. This may require an aggregate capacity, say, of 32,000 h.p. If the ship is equipped with steam turbines direct-connected to the propellers, probably there would be four turbines, each of 8,000 h.p., connected to each individual propeller. But the ship will be driven at its full speed only a small portion of the time. Its cruising speed is only some six-tenths of the

44. Ocean liners. Although each year witnesses increases in the size of ocean liners, the most recent vessels are equipped for slightly lower speeds than the 26-knot "Mauretania" and "Lusitania" of the Cunard Line. These two ships have an overall length of 790 ft., a breadth of 88 ft., a draught of 33 ft. 6 in., and a displacement of 38,000 tons. At full speed their turbines, of which there are four, develop some 68,000 shaft h.p.

The new Hamburg-American liner "Imperator" has an overall length of 920 ft. and an extreme breadth of 98 ft.; height, 100 ft. from keel to boat-deck and 246 ft. from keel to masthead; displacement, about 57,000 tons; propelled by four Parsons turbines, driving four screws of 16.5 ft. diameter, and four blades each. The total shaft output is about 62,000 h.p., corresponding to a draught of 35 ft. 6 in. and to a sea speed of some 22.5 knots; the corresponding propeller speed is 175 r.p.m. The coal bunkers have a capacity for over 8,500 tons. Full complement of passengers, 4,000; total ship's company, 1,180.

The Hamburg-American turbine liner "Vaterland" has an overall length of 905 ft. and a breadth of 100 ft.; the turbines develop 61,000 h.p. at about 180 r.p.m., corresponding to a sea speed of about 22 knots; accommodates 5,700 persons including the crew.

The Cunard liner "Aquitania" has an overall length of 901 ft.; breadth, 97 ft.; and draught, 34 ft.; depth from keel to boat-deck is 92 ft.; propelled by steam turbines driving four screws; speed, 23.5 knots—corresponding to 60,000 h.p.; displacement, 50,000 tons.

45. Oil boats. The largest oil-carrying vessels have capacity for 15,000 tons of oil. The "San Fraterno,"* when fully loaded with 15,700 tons of oil, has a draught of 28 ft.; length, 542 ft.; breadth, 66 ft. 6 in.; contract speed, 11½ knots (exceeded in trials); propelled by a quadruple-expansion engine; equipped for oil burning.

46. Ore and Grain Boats. Similar in general shape and capacity (Par. 45) are the ore carriers which transport cargoes of ore or grain between the Great Lake ports. The limitations of the depth of waterways through which they pass sometimes require a draught of less than 20 ft. On routes where such limitations do not hold, these vessels are often loaded to a draught of 24 ft. Their length is of the order of 600 ft.; beam, 58 ft; and moulded depth, 32 ft. They can accommodate a cargo of some 20,000 tons of ore or coal, or nearly half-a-million bushels of wheat, and can be loaded at the rate of 8,000 tons per hour. They are propelled at a speed of some 10.5 knots by a single screw, usually driven at about 120 r.p.m. by a triple-expansion engine of some 2,200 h.p.

47. Tug-boats are of course designed for towing service, mainly in sheltered waters. The three essential requirements are: (a) high speed when running free; (b) fair speed when towing; (c) high thrust or pulling effort at practically zero speed. If attention is paid first to the second requirement, the others will usually take care of themselves.

48. Battleships. The modern battleship has a length of from 550 to 600 ft., a breadth of some 90 ft. and a displacement of the order of 25,000 tons. A battleship is usually equipped for a maximum speed of about 21 knots; the cruising speed is about 12 to 14 knots. At maximum speed the engines are required to develop some 30,000 shaft h.p. Effectiveness in a battleship outweighs all questions of cost. Consequently a general movement is taking place toward the practice of burning oil fuel. By this plan, not only can a greater weight of fuel be stored in a given volume than with coal, but a ton of oil has a calorific value some 33 per cent. greater than a ton of coal. Consequently, with oil fuel, the radius of action is greatly increased. Furthermore, the use of oil fuel ameliorates the almost intolerable conditions in the stokehold. Every gain in economy is important, not from the standpoint of money actually to be saved, but on account of the increased radius of action on a single supply of fuel.

49. Battle-cruisers. Ships of this class constitute a modern development. They differ from battleships in the respect of being equipped for much higher speeds. This entails a certain sacrifice in armament and in armouring. The United States Navy has no battle-cruisers. As examples of battle-cruisers may be mentioned the following:

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* *Shipbuilding and Shipping Record*, April 24, 1913, p. 149.

be capable, their horse-power per ton of displacement is usually much higher than for vessels of any other class. Take for instance the British torpedo-boat destroyer "Velox"; the displacement is only 440 tons, but at maximum speed of 36.6 knots (see page 70 of Hobart's "Electric Propulsion of Ships"), the vessel requires some 12,000 shaft h.p. This small boat has four propellers, and an engine capacity of about (12,000/440 =) 27 h.p. per ton of displacement, whereas scout cruisers have only some 4 h.p. per ton of displacement. Battleships are provided with only 1.0 h.p. to 1.3 h.p. of engine capacity per ton of displacement. The *cruising* speed of the "Velox" is only 11.3 knots, which requires merely some 300 h.p.

Thus a noteworthy characteristic of this class of ship is the great ratio of the power required at maximum speed to that required at cruising speed. In the case of the "Velox" this ratio is 12,000 : 300 = 40 : 1.

ELECTRIC PROPULSION

55. Consequences of the self-contained feature in a ship-propulsion installation. There is one very important aspect of the proposition of driving a ship electrically, which should facilitate its introduction in marine practice. Each ship represents an independent, self-contained proposition. There is no particular need for, or advantage in, a rigid adherence to some one particular system. There are usually several alternative methods of dealing with any engineering problem and it is often difficult to determine which is the best. Generally, one can definitely discard several methods as less suitable for some particular case, but there will usually remain two or three methods between which it is difficult to choose.

In undertaking the electrification of a railway, this may well constitute a great embarrassment, since it is important to have standardisation and interchangeability of rolling stock over extensive systems. But in the case of ship propulsion, comparisons of various types of engine equipment, of propeller designs and speeds, of locations of propellers, of number of propellers, of kinds of fuel, etc., are continually being made on ships of otherwise identical characteristics. The rapid progress which is continually in evidence in marine engineering is largely a consequence of this established policy. It is easy to foresee that the application of electrical methods to ship propulsion will be more readily accomplished (so far as it is demonstrated to realize the economic advantages that are claimed for it), than has been the case with railway electrification.

The engineer's task will include determining upon a thoroughly appropriate installation in each case. It will be entirely unnecessary for him to adopt any other than the economically appropriate solution in any case, out of consideration for uniformity with the machinery employed in some other case.

Various combinations of machinery for the electric propulsion of ships have been worked out, and some of them have crystallized into "systems." But there are many sound plans and principles of proved appropriateness which have been employed in electric-power applications on land which are equally entitled to be designated as "systems" appropriate for ship propulsion. It is therefore not considered desirable to devote any space to detailed descriptions of "systems." The reader may care to refer to Chapters XIII to XVI, inclusive, of Hobart's "Electric Propulsion of Ships" for descriptions of various systems which have been proposed by Mavor, Emmet, Durtnall, Day, Hobart, and others.

56. Turbines versus internal-combustion engines in electric propulsion. For anything over 4,000 h.p. it would appear that for electrically-driven ships the economic advantage will be greater when the steam turbine is employed as prime-mover than when the oil engine is employed. In the first place, the cost of steam turbines is only a matter of some 20 cents per pound, as compared with some 50 cents per pound for oil engines. Furthermore, the weight per horse-power for oil engines of large output is several times the corresponding figure for steam turbines of the same output. The handicap in the matter of cost is so great that it is far from being offset by the cost of the steam-raising plant in the case of the steam turbine. Moreover, the fuel cost per brake horse-power-hour is at present much greater for oil than for coal. In electric propulsion, the very highest turbine speeds may be adopted, since in a self-contained plant such as that on board ship, the particular periodicity employed is of no consequence.

each of two propeller shafts), the same vessel speed could be obtained by supplying only 45,500 shaft h.p. to the two 86-r.p.m. propellers as is now obtained by supplying 69,000 h.p. to the four 188-r.p.m. propellers which are actually fitted to the ship.

The calculations in Ljungström's comparison are given in tabular form in his letter and include cost estimates.

58. Study of electric drive for the destroyer "Hugin." Ljungström has also worked out estimates for an electric drive for the 348-ton Swedish destroyer "Hugin," which is now equipped with Curtis turbines of 10,400 shaft h.p., 850 r.p.m., and direct-connected to the propeller shafts. The corresponding vessel-speed is 31.2 knots. By substituting a Ljungström turbo-electric transmission, it is estimated that the propelling power would be reduced to 6,500 shaft h.p. and the coal consumption to 42 per cent. of its present value; the weight would be decreased by 75 tons and the floor space by 33 per cent. This turbo-electric alternative comprises three turbo-generators driving electric motors at 500 r.p.m. normal speed.

59. Study of electric drive for the cargo boat "Vespasian." Ljungström has also described an electric transmission which he proposed for the cargo boat "Vespasian." He states that "the electric motors, intended for 100 periods, are two in number and *geared* to the shaft." On p. 106 of Hobart's "The Electric Propulsion of Ships," this same plan was earlier advocated in the following words: "The disabilities of low-speed induction motors may be escaped and advantage may be taken of their good qualities by arranging that high-speed motors shall drive the propeller-shafts at low speeds through double-helical speed-reduction gearing. The pinions of two (or even more) motors could be arranged to gear with a single low-speed gear-wheel on the propeller shaft, quite analogously to the way in which two steam turbines drove the 'Vespasian's' shaft in the tests made by Parsons. Usually the 2 per cent. loss in the gearing would be largely offset by the higher efficiency of the high-speed induction motor, and the weight and cost of the gearing would be partly offset by the lesser weight and cost of high-speed as compared with low-speed induction motors. The difficulties associated with finding space in ships for large diameters are also eliminated by this plan."

60. W. L. R. Emmet on electric propulsion. Mr. W. L. R. Emmet has read papers on electric ship propulsion before various engineering societies. References to these papers are given in the bibliography (Par. 78). In 1909 Mr. Emmet designed an electrical equipment for the battleship "Wyoming" and a proposal embodying these designs was made to the Government. Since that time Mr. Emmet has submitted several designs to the Government relating to equipments of battleships which have been built. In the spring of 1913 Mr. Emmet submitted a design which applied to a case like that of the "Pennsylvania." The estimates as to the results of this equipment as compared with those which will be accomplished by the equipment which is being put into the battleship "Pennsylvania" are shown by the following table:

	R.P.M. at 21 knots	H.P. required at 21 knots	Pounds of steam per hour, turbines alone, 21 knots	Pounds of steam per hour, turbines alone, 15 knots	Weight of driving machinery in tons
Turbine drive with geared cruising turbines as adopted.	222	31,700	374,000	106,000	749
Turbo-electric drive..........	160	29,200	205,000	91,000	598

Mr. Emmet states* that if in 1909 his first design for a warship had been accepted by the Navy Department, the vessel produced would have been

* In a paper read on Dec. 11, 1913, before the Society of Naval Architects and Marine Engineers.

30 h.p. each, and operating at a speed of 1,700 r.p.m. One end of the shaft f each of these turbines is connected to a large centrifugal fire pump and the ther end is connected to a 200-kw. direct-current generator. The boats are ropelled by twin screws and the speed and direction of each motor is con-rolled by manipulation of the field of the generator which drives it."

These Chicago fire boats have a length of 120 ft. and are of 28 ft. beam nd 10 ft. draught. On page 389 of *Engineering* for Sept. 20, 1912, will be ound scale drawings of the general arrangement of the machinery in these oats.

Mr. Emmet has made tests directed toward studying the propeller charac-eristics of these boats and has published the results in a paper presented in Jew York in November, 1911, before the Society of Naval Architects and Marine Engineers.

67. The "Electric Arc." In 1910 and 1911 Mr. Henry A. Mavor quipped with electric gearing a 50-ft. steel-built vessel, and subjected it to a series of tests. This boat, the "Electric Arc," was launched in February, 1911. See description in Par. **68.**

68. The "Multiple" squirrel-cage motor. The generator supplied three-phase current to a squirrel-cage induction motor, also of a type in-vented by Mr. Mavor (British Patent No. 12,917 of 1909) and to which he applies the designation of "multiple" motor. This motor drives the propeller at one or other of two speeds, in accordance with the following plan:

The stator is provided with two independent windings for two different pole numbers. At its normal speed, the generator provides periodicities which bear to one another the ratio of these two different pole numbers. By connecting the winding of higher pole number to the supply of lower periodicity an efficient running speed of low value is obtained. For higher speed and power, the winding of higher pole number is transferred to the supply of higher periodicity and the winding of lower pole number, which was idle for the lower speed and power, is connected to the supply of lower periodicity. Consequently, at full speed and power, both sources of supply and both motor windings are fully utilised, and cooperate in driving the propeller. With this "multiple" motor it is thus possible to integrate in a single motor the power from several prime movers and also to obtain two or more efficient speeds without resorting to a motor with moving contacts.

69. The United States Collier "Jupiter." Certain leading data of this vessel have already been given (Par. **53**) and an illustrated description appeared in an article entitled "Electrical Equipment for the Propulsion of the U. S. Collier Jupiter," by Mr. Eskil Berg at page 490 of the *General Electrical Review* for August, 1912. The "Jupiter," a vessel of 20,000 tons displacement and designed to carry about 12,000 tons of coal and oil, was built at the Mare Island Navy Yard. The contract for the equipment was awarded to the General Electric Co., in June, 1911. The machinery was designed by, and constructed under the direction of, Mr. W. L. R. Emmet. The contract price of the electrical propelling machinery was stated in the article in the *General Electrical Review*, to be $13.75 per horse-power. The turbo-electrical propelling machinery comprises a 9-stage, 2,000-r.p.m. Curtis turbine driving a 2-pole, three-phase, 2,300-volt, 33⅓-cycle, 5,500-kv-a. generator. The two 36-pole, 110-r.p.m. induction motors each have a normal rating of 2,750 h.p. The rotors are provided with three-phase windings leading to slip rings. By means of these slip rings, the rotor current, at starting, reversing and manœuvring, is carried to water-cooled resistors which are short-circuited when the ship is pro-ceeding normally. The heat is removed from the active material of these resistors by the circulation of sea water through them.

An interesting feature of the arrangement of the machinery relates to the provision of sheet-metal ducts so connected to the air outlets from the generator and motors as to lead the heated air to the suction of the fire-room blowers, thus avoiding needless heating of the engine room.

70. Performance of the "Jupiter." The "Jupiter" was put in com-mission September 15, 1913. After a period of preliminary trials in San Francisco Bay and at sea, the ship was docked. After cleaning her bottom, a set of standardization runs and a 48-hour unofficial trial were made.

of Glasgow, a canal-type tank barge for service on the Canadian lakes and through the Welland Canal. The vessel was built for operation by the Montreal Transportation Company, and was designed and fitted under the supervision of Messrs. John Reid and Henry A. Mavor. The "Tynemount" was described, with drawings, in a paper by these gentlemen read in June, 1913, before the Institution of Naval Architects and entitled "A Case for Electric Propulsion." The power equipment consists of two four-stroke-cycle, 400-r.p.m., 6-cylinder, Diesel engines, each direct-connected to a three-phase 235-kv-a., 500-volt generator. These two generators are wound respectively with 6 and 8 poles and thus constitute sources of different periodicity, the one supplying 20 cycles per second and the other 26.6 cycles per second. An exciter is fitted on an extension of the shaft of each generator. Each exciter gives normally about 30 amp. at 100 volts and is capable of supplying a considerable overload. The propeller is driven by a "multiple" motor of the type invented by Mr. Mavor and already decribed (Par. 68). This motor is of the squirrel-cage induction type and is

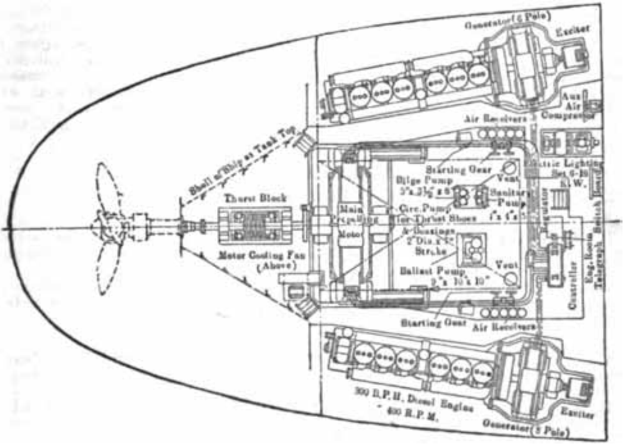

Fig. 4.—Plan of arrangement of the "Tynemount's" machinery.

provided with two stator windings for 30 and 40 poles respectively. At the vessel's normal speed the power of the two Diesel engines is integrated at this motor, the 20-cycle supply being absorbed in the 30-pole winding and the 26.6-cycle supply in the 40-pole winding. Under these conditions the synchronous speed is 80 r.p.m. Allowing for slip in the rotor of this motor the propeller speed is about 78 r.p.m. By changing the 40-pole winding to the 20-cycle generator and leaving the 30-pole winding of the motor and the 26.6-cycle generator out of circuit, the speed is lowered to 75 per cent. of full speed, *i.e.*, to some 58 r.p.m. The 26.6-cycle set may then be shut down thus leaving the 20-cycle set alone to propel the ship and consequently providing as good economy at this low speed and load as at the higher speed and load. The vessel is designed to carry about 2,400 tons dead weight of cargo, fuel, fresh water and stores on a 14-ft. mean draught in fresh water. On, p. 412 of Engineering for Sept. 27, 1912, the cost of the Tynemount is given as £30,000 ($150,000).

The dimensions of the ship and of her propeller are determined by the dimensions of the canal locks through which she must pass. The system adopted has permitted of increasing the carrying capacity to 250 tons more than would have been practicable with steam equipment. This saving is a consequence of:

H. M. Hobart.—"The Electric Propulsion of Ships." Harper Brothers London, and D. Van Nostrand Co., New York (1911).

W. L. R. Emmet.—"Automatic Record of Propeller Action in an Electrically Propelled Vessel." (Paper read on Nov. 16, 1911, before the Soc. of Naval Architects and Marine Engineers of New York.)

1912

B. Ljungstrom.—"Electric Ship Propulsion with Ljungström Turbo-Generators." *Engineering*, April 19, 1912, p. 536.

Eskil Berg.—"Electrical Equipment for the Propulsion of the U. S. Collier Jupiter." (Article on p. 490 of the *General Electric Review* for August, 1912.)

H. A. Mavor.—"Marine Propulsion by Electric Transmission." (Paper read in September, 1912, at the Dundee meeting of the British Association. Published on p. 1023 of *The Electrician* for September 27, 1912.)

W. L. R. Emmet.—"Contribution to a discussion at a meeting of the North East Coast Institution of Engineers and Shipbuilders on Apr. 26, 1912." Contains weight and cost estimates for a 17,000-h.p. liner with electric propelling machinery and data of the Jupiter equipment.

1913

Editorial.—"The Electric Propulsion of Ships." *Engineering*, Jan. 17, 1913, p. 89.

John Reid and H. A. Mavor.—"A Case for Electric Propulsion." (Paper read before the Institution of Naval Architects in June, 1913.)

——————"The Electric Motor Ship 'Tynemount.'" *The Engineer*, Oct. 10, 1913, p. 381. (A description of the "Tynemount" accompanied by twelve illustrations.)

W. L. R. Emmet.—"Electric Propulsion on the U. S. S. 'Jupiter.'" (Paper read before the Society of Naval Architects and Marine Engineers at meeting held in New York, December 11, 1913.)

1914

Editorial.—"Electric Propulsion and Steam Engine Efficiency." *Shipbuilding and Shipping Record*, March 19, 1914, p. 349.

SECTION 19

ELECTROCHEMISTRY

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CONTENTS

(*Numbers refer to Paragraphs*)

The figures placed below the chemical symbols are the molecular weights. The equation states that when 56.1 kg. of burned lime combine with 36 kg. of coke, there are formed 64.1 kg. of calcium carbide and 28 kg. of carbon monoxide. Instead of kilogram, we could use just as well any other unit of weight (pound, ton, etc.), since the chemical equation gives only the *relative* weights of combination. The table of atomic weights is given in Sec. 4.

RELATION BETWEEN VOLUME, PRESSURE AND TEMPERATURE IN GASES

6. Avogadro's law. If any of those substances taking part in a reaction at a certain temperature is in the gaseous state and we know the pressure, we can find its volume directly from the equation of the reaction; or if we know its volume we can directly find the pressure. According to Avogadro's rule, equal numbers of molecules of different gases fill equal volumes under the same conditions of temperature and pressure. One gram-molecule of any gas (for instance, 2 g. hydrogen, H_2, or 32 g. oxygen, O_2) at atmospheric pressure (760 mm. mercury) and at a temperature of 0 deg. cent. fills 22.42 liters. One kilogram-molecule fills 22.42 cu. m.

Example: The 28 kg. of carbon monoxide gas set free in the formation of 64.1 kg. of calcium carbide according to the above equation (Eq. 1, Par. 5) are 1 kilogram-molecule and will therefore fill 22.42 cu. m. when brought to a temperature of 0 deg. cent. and to a pressure of 1 atmosphere.

7. Boyle-Mariotte-Gay-Lussac law. To calculate the volume for other temperatures and pressures, the Boyle-Mariotte-Gay-Lussac law is to be applied, according to which

$$p\,v = \mathrm{R\,T} = \mathrm{R} \times (273 + \text{deg. cent.}) \tag{2}$$

In this equation p is the pressure, v the volume; hence $p\,v$ the work done in the expansion of the gas. T is the absolute temperature = temperature in degrees centigrade plus 273. R is the gas constant. If we measure the pressure in atmospheres and the volume in liters, then Avogadro's rule states that for $p = 1$ and $\mathrm{T} = 273$, 1 gram-molecule of gas fills the volume $v = 22.42$, hence $\mathrm{R} = 22.42/273 = 0.0821$. Hence for 1 gram-molecule, if we give

$p\,v$ in liter-atmospheres, $\mathrm{R} = 0.0821$
$p\,v$ in kilogram-meters, $\mathrm{R} = 0.848$
$p\,v$ in gram-calories, $\mathrm{R} = 1.987$.

For n gram-molecules the value of $p\,v$ is n times the value found from the above equation.

Example: If we electrolyse a dilute acid or alkaline solution for the purpose of producing oxygen and hydrogen gas and if we wish to use the hydrogen, for instance, for filling a balloon, then the main reaction is simply the decomposition of water.

$$H_2O = H_2 + O; \tag{3}$$

i.e., 1 kilogram-molecule or 18 kg. H_2O are decomposed into 1 kilogram-molecule or 2 kg. H, occupying 22,420 liters at 0 deg. cent. and atmospheric pressure, and 0.5 kilogram-molecule or 16 kg. O, occupying 11,210 liters under the same conditions of temperature and pressure. If the hydrogen gas is contained in a balloon which is to rise in the atmosphere, it will be under atmospheric pressure, and the hydrogen produced from 18 kilograms of water, will under this condition fill 22,420 liters at 0 deg. cent. If the temperature is higher, for instance t deg. cent., and the pressure less, for instance, $760 - x$ mm. of mercury (when the balloon rises), then the volume in liters $= \dfrac{22{,}420 \times 760 \times (273 + t)}{(760 - x) \times 273}$.

8. Units employed. The calculation is quite as simple for English units instead of metric units. As J. W. Richards[1] has remarked, the same numerical factor can be used as in the metric system. This coincidence is due to the fact that there is practically the same relation between an ounce (av.) and a kilogram, as between a cubic foot and a cubic meter, the difference being negligible. Hence 1 ounce-molecule of a gas (for instance 28 oz. carbon monoxide) at 0 deg. cent. and 1 atmosphere fills 22.42 cu. ft.

9. Gas mixtures. If we have a mixture of different gases in the same space, two different views are *a priori* possible. Instead of $p\,v = \mathrm{R\,T}$ we

[1] Richards, J. W. "Metallurgical Calculations," 1912; Vol. I, p. 3.

freely to the outside—just as a gas inside a reservoir exerts a pressure on the walls, because it cannot follow its tendency to pass outward. Moreover, for the osmotic pressure and the gaseous pressure the same numerical law holds true as shown above (Par. 13). In the case of the sugar solution the osmotic pressure exerted by the dissolved sugar molecules is numerically equal to the gas pressure which the same molecules would exert if the same weight of sugar existed in gaseous form in the same volume and at the same temperature. This is the foundation of **Van't Hoff's theory of solutions.** Instead of measuring the osmotic pressure directly, it is possible to calculate it from the changes of the vapor pressure or of the freezing point, due to the addition of the solute to the solvent.

15. Electrolytes form an exception. However, the above law does not hold good in general and all aqueous solutions which are electrolytes form an important exception, if we base the calculation on ordinary molecular weights in the same way as in the above case of sugar. This discrepancy is removed by the hypothesis of an electrolytic dissociation in solutions (Planck and Arrhenius). According to Arrhenius not all the molecules of the dissolved substance are electrolytically active, but only those which are "dissociated" into electrically charged ions; this is the foundation of the **electrolytic dissociation theory.** In applying the laws of the osmotic pressure to electrolytes a larger number of molecules must therefore be assumed according to the degree of dissociation.

RELATION BETWEEN MASS AND ELECTRIC QUANTITY IN ELECTROLYTIC REACTIONS

16. Faraday's first law gives the exact relation between the weight of the products of electrolysis and the quantity of electricity passing during the electrolysis. There are always two reactions. One is the anodic reaction, its product or products appearing at the anode. The other is the cathodic reaction, its product or products appearing at the cathode. Faraday's first law states that if nothing but the one desired reaction occurs at the anode or cathode as the result of the passage of the electricity, the quantities of material changed at the anode or cathode depend only on the quantity of electricity which passes, measured in coulombs or ampere-seconds; in other words, these quantities depend only on the product of the current in amperes and the time. With i amperes the same quantities of chemicals are changed in t seconds, as with i/n amperes in nt seconds, where n may be anything; the quantities depend only on the product of current and time and not on anything else, for instance, not on the voltage or on the size of the electrodes or on the temperature, etc. This should not be misunderstood; all these statements are valid under the supposition placed at the beginning of our statement of Faraday's first law, namely that nothing but the one desired reaction takes place. As long as this is true, the quantities of materials changed are strictly proportional to the quantity of electricity passing. But if, for instance, by raising the voltage, a new reaction is started, the conditions are of course changed.

17. Faraday's second law gives the numerical relation between the quantity of electricity and the quantity of material changed. It can be most easily expressed for the special case that the chemical reactions occurring at the anode and cathode are simply a liberation of a gas or a deposition of a metal. For this case Faraday's second law states that the quantity of gas set free or of metal deposited is proportional to the **equivalent weight** of the gas or metal, and that 96,540 coulombs deposit or set free 1 **gram-equivalent** of metal or gas. The equivalent weight, or gram-equivalent is defined as the atomic weight divided by the valency. For instance, 63.6 is the atomic weight of copper; the equivalent weight is $63.6/2 = 26.8$ for a bivalent salt, like copper sulphate, and 63.6 for a monovalent salt like cuprous chloride. Hence 96,540 coulombs deposit 26.8 g. of copper from copper sulphate, but 63.6 g. from cuprous chloride.

18. Faraday's law stated in general form. Faraday's law will now be stated in what appears to the writer to be the most general and complete form. It is valid for all electrolytic processes and all such processes require essentially direct current.

In any electrolytic process there is chemical reduction at the cathode and chemical oxidation or perduction at the anode. Reduction means a loss of bonds, perduction a gain of bonds. Exactly as many bonds are lost at the illustrated by a comparison of this process with that of Hoepfner which was devised later to compete with the Siemens and Halske process. While sulphate solutions are used in the latter, Hoepfner proposed to use a chloride solution. The ferric sulphate and cupric chloride are used for leaching the ore.

23. Example. The scheme of the **Hoepfner copper process** was essentially to deposit copper on copper cathodes from a cuprous chloride solution and oxidise simultaneously the cuprous chloride to cupric chloride at carbon anodes, the essential reaction being

$$\underset{198.1}{2CuCl} = \underset{134.5}{CuCl_2} + \underset{63.6}{Cu} \tag{7}$$

The figures placed below the chemical symbols represent again the weights, found from the table of atomic weights. In this case Cu in the cuprous chloride CuCl, has one positive bond, while it has two positive bonds in cupric chloride $CuCl_2$. At the cathode the reduction of one CuCl to metallic Cu (which has no bonds) involves therefore a loss of one positive bond. At the anode the oxidation of one CuCl to $CuCl_2$ involves the gain of one bond. Hence in this case, we have a monovalent reaction, the change of bonds being 1, and we find that when 96,540 coulombs pass through the cell, 198.10 grams of CuCl are changed into 134.5 grams $CuCl_2$ and 63.6 grams Cu. The metallic copper is the principal product in the process, 96,540 coulombs deposit 63.6 grams of copper or 100,000 coulombs deposit 65 grams of copper, *i.e.*, just twice the amount obtained with the same current and in the same time by the Siemens and Halske process.

24. Explanation of different outputs in the two examples. (Par. 22 and 23.) It is quite clear from the above argument what causes the different output of both processes; it is simply the fact that Cu has two bonds or is bivalent in $CuSO_4$ and has one bond or is monovalent in CuCl. It is also clear that to find the amount of an element set free from a compound it is not necessary to write down the whole equation of the reaction, as was done above for the sake of completeness. We can state that if 1 gram-atom of a metal is deposited in free metallic state by electrolysis, 96,540 coulombs are necessary for deposition from a monovalent compound (like CuCl), twice as many from a bivalent compound (like Cu_2SO_4), three times as many from a trivalent compound, etc. But this rule is only a special case and does not give any information, for instance, on the quantity of ferrous sulphate oxidised to ferric sulphate in the Siemens and Halske process.

25. Procedure in calculations. The **method of writing** down the whole **equation**, determining the number of bonds lost and gained and applying the above rule gives complete information in all cases on the relation between the quantity of electricity, which passes a cell and all the quantities changed thereby in chemical composition.

26. Method of calculation under the electrolytic dissociation theory. The above method of calculation becomes easier if we use the picture of the electrolytic dissociation theory. The equation of the Siemens and Halske process is then written in the form

$$Cu^{\cdot\cdot} + SO_4'' + 2Fe^{\cdot\cdot} + 2SO_4'' = Cu + 2Fe^{\cdot\cdot\cdot} + 3SO_4'', \tag{8}$$

that is, instead of $CuSO_4$ in solution we write $Cu^{\cdot\cdot} + SO_4''$, the copper sulphate being dissociated into its ions, the positive copper ion $Cu^{\cdot\cdot}$ and the negative ion SO_4''. Each dot at the top of $Cu^{\cdot\cdot}$ represents a positive electric charge. Each stroke at the top of SO_4'' represents a negative electric charge. Each such charge, positive or negative, is 96,540 coulombs, if the chemical symbols represent gram-atoms or as we now say, gram-ions. The gram-ion $Cu^{\cdot\cdot}$ is bivalent and charged with $2\times96,540$ coulombs. Each gram-ion $Fe^{\cdot\cdot}$ (ferrous) is bivalent and charged with $2\times96,540$ coulombs. The gram-atom Cu (metal deposited on the cathode) is not charged. Each gram-ion $Fe^{\cdot\cdot\cdot}$ (ferric) is trivalent and charged with $3\times96,540$ coulombs. The above ionic equation may be somewhat simplified by writing

$$Cu^{\cdot\cdot} + 2Fe^{\cdot\cdot} = Cu + 2Fe^{\cdot\cdot\cdot} \tag{9}$$

If this equation shall be right, not only the chemical symbols but the dots must balance on both sides, since otherwise free electrostatic charges would appear somewhere. In this case we see $Cu^{\cdot\cdot}$ has 2 charges and each of the two $Fe^{\cdot\cdot}$ has also 2 charges, hence the total sum is 6 charges on the left side of the equation. On the right side Cu has no charge, each of the two $Fe^{\cdot\cdot\cdot}$ has 3 charges, hence the total sum is again 6 charges.

while the cathodic reaction is $Cu^{\cdot\cdot} = Cu + 2F$, one Cu ion giving off its two positive electrons to the cathode.

33. Use of larger units in practical work. In the above we have based the calculation on 96,540 coulombs as the charge of 1 gram-ion. This is the laboratory unit, but although universally used in discussions of Faraday's law, it seems too small for practical purposes. If one monovalent gram-ion carries 96,540 coulombs, then one monovalent kilogram-ion carries a charge of 96,540,000 coulombs or 26,817 amp-hr. Hence, if the symbols in the equation of the reaction represent kilogram-atoms, then the reaction requires 26,817 amp-hr. if monovalent, $2 \times 26{,}817$ amp-hr., if bivalent, etc.

34. Practical use of the gram-equivalent. Finally the above numerical relations may be very briefly stated by using the term **gram-equivalent** which means gram-ion divided by the valency, so that one gram-equivalent equals a gram-ion if it is monovalent, but one-half gram-ion if it is bivalent as already explained in Par. 24. In the same way the term kilogram-equivalent means kilogram-ion divided by valency. Then Faraday's law states that 1 gram-equivalent of any chemical composition whatever carries an electric charge of 96,540 coulombs. One kilogram-equivalent carries an electric charge of 26,817 amp-hr.

35. Johnson's rule for balancing equations. In the procedure recommended above for the application of Faraday's law a difficulty may be found in writing down the equation of the reaction. Since in any electrolytic process we have to do with reduction and oxidation the following rule of Prof. O. T. Johnson for **balancing equations** of this kind may be found useful. This rule states that "the number of bonds changed in one molecule of each shows the number of molecules of the other which must be taken," the words "each" and "other" referring to the oxidising and reducing agents. One example may illustrate this rule, which appears to be purely formal from a chemical point of view, while its electrical meaning will be shown below. In the Bunsen cell Zn is oxidised; it becomes $ZnSO_4$. The metal Zn has no bond. Zn in $ZnSO_4$ has two bonds, hence the increase in bonds is two. There are several actions possible at the other electrode. We may consider that NO is developed. N in HNO_3 has five positive bonds, while in NO it has two positive bonds, hence the decrease in bonds is three. Now Johnson's rule states that we have to take three molecules of Zn and two molecules of HNO_3 and we get the equation

$$3Zn + 3H_2SO_4 + 2HNO_3 = 3ZnSO_4 + 2NO + 4H_2O. \tag{12}$$

36. Application of Johnson's rule. This rule becomes self-evident if applied to an electrochemical action. It simply means that just as much electricity passes from the anode into the electrolyte as from the electrolyte into the cathode. In the case of the Bunsen cell if the chemical symbols represent gram-atoms, then, as Zn gains two bonds and as we have three Zn atoms, $3 \times 2 \times 96{,}540$ coulombs pass into the electrolyte from the anode. On the other hand, N loses three bonds, and, as two N are reduced, $2 \times 3 \times 96{,}540$ coulombs are given off to the cathode. Of course we may also consider HNO_3 to be ionised into H and NO_3 ions, both monovalent, etc. The result is the same. Johnson's rule for balancing equations enables one to write down the equation which represents the electrochemical action, and in the further calculation there is no mistake possible if one keeps in mind that each bond corresponds to 96,540 coulombs, providing the chemical symbols represent gram-atoms.

37. Faraday's law is always exactly fulfilled in the sense that the anodic oxidation and cathodic reduction of given quantities of materials require a certain amount of coulombs, not more nor less. For instance, the deposition of 1 gram-atom or 63.6 g. of copper from the solution of a monovalent cuprous salt requires 96,540 coulombs. But this does not mean that if we send 96,540 coulombs through such solution, we must always deposit 63.6 g. of copper on the cathode. It may be that we have a second reaction at the cathode besides copper deposition, for instance, evolution of hydrogeu gas. The conditions may be such that, say 75 per cent. of the coulombs only deposit copper; then we get $0\,75 \times 63.6 = 47.7$ g. of copper. The other 25 per cent. of the coulombs deposit hydrogen and therefore evolve 0.25 gram-atom = 0.25 g. hydrogen. Thus Faraday's law is fulfilled, but in practice we are interested in this case only in the copper temperature. In such cases the following consideration is often useful, if the specific heats of all substances which are represented in the equation are known. Suppose a certain reaction evolves a calories at the temperature, t_1, and we want to find the reaction heat at the higher temperature, t_2. Then we consider the materials on the left hand of the equation, *i.e.*, the starting materials, and raise them from t_1 to t_2; the heat, necessary for this purpose, may be b calories and is directly found from the specific heats of the starting materials and the temperature difference, t_2-t_1. That is b more calories are now stored in the system than were in it at the temperature, t_1. We now let the desired chemical reaction go on at the temperature, t_2. This may evolve, x, calories, which is the figure to be determined. If we finally cool the system back to the temperature, t_1, it gives out a certain amount of heat, c, which can be found for the temperature difference, t_2-t_1, and the specific heats of the end products. Then we know that the system has stored in it $(b-x-c)$ more calories than at the start, which according to the principle of the conservation of energy must be equal to $-a$, or $x=a+b-c$.

CHEMICAL AND MECHANICAL ENERGY

44. Definition of liter-atmosphere. If as a result of a reaction between solid or liquid bodies a gas is evolved, work is done against the pressure of the atmosphere. The work done by the evolution of 1 liter of gas under atmospheric pressure is 1 liter-atmosphere.

$$
\begin{aligned}
1 \text{ liter-atmosphere} &= 10.333 \text{ kg-m.} \\
&= 24.2 \text{ g-cal.} \\
&= 101.3 \text{ watt-sec.} \\
&= 0.136 \text{ horsepower-second.}
\end{aligned}
\tag{15}
$$

45. Work performed by evolution of gas. For instance, if hydrogen and oxygen gas are produced under atmospheric pressure by electrolysis of a dilute acid or alkaline solution, 18 kg. water yield 2 kg. H, occupying 22,420 liters at 0° C, and the work done in expanding the hydrogen gas against the pressure of the atmosphere is 22,420 liter-atmospheres = 543 kg-cal. = 2,271 kw-sec. Simultaneously 16 kg. O, occupying 11,210 liters, are evolved and the work done in expanding the oxygen gas against the pressure of the atmosphere is 11,210 liter-atmospheres = 271 kg-cal. = 1,135 kw-sec. Hence the total work done in expanding both gases to 33,630 liters is 814 kg-cal. = 3,406 kw-sec. This energy consumed is, of course, not to be confounded with the energy required for the electrolytic decomposition of the water. It is simply the mechanical work performed in expanding the gases against the pressure of the atmosphere.

A very simple way to calculate this work approximately is to remember the formula $pv = RT$, in which R very approximately = 2, if pv is given in gram-calories and the mass of 1 gram-molecule is considered. In words, the work done in expanding 1 gram-molecule of any gas from a solid or liquid to gas at the absolute temperature T is 2T g-cal.; for instance, at 0 deg. cent. or 273 deg. absolute temperature it is 546 g-cal. (as compared with 543 found above). In the reverse change from gas to solid the same amount of work is performed upon the system or the same amount of energy is gained by the system.

46. Expansion of gas at constant pressure. The characteristic feature of processes like those just described is that they take place at constant pressure. In general if a gas expands at constant pressure, p, from volume, v_1 to v_2, the work done is $p\ (v_2-v_1)$. In the special case that a gas expands from a solid or liquid, the volume of the solid or liquid, which disappears is negligible compared with the gas formed and $v_1=o$, from which results at once the above calculation.

47. Expansion of gas at constant temperature. An entirely different case is the calculation of the work done when a given mass of gas expands its volume at constant temperature, the pressure decreasing correspondingly. For 1 gram-molecule, expanding from volume v_1 to volume v_2 at constant temperature, T, this work is

$$\mathrm{R\,T}\, \log_e \frac{v_2}{v_1}, \tag{16}$$

where $\log_e$ means the natural logarithm. In view of the parallelism between gaseous pressure and osmotic pressure in solutions, the above statements on gases may be made in an analogous way for solutions.

At ordinary temperatures this rule is, in general, approximately fulfilled and is therefore exceedingly useful for making a first approximate calculation.

54. Terminal voltage. The voltage, e, is the e.m.f. absorbed or produced in the electrochemical process. It is different from the voltage at the terminals. The voltage at the terminals of a battery equals the e.m.f., e, minus the voltage drop due to internal resistance. The voltage at the terminals of an electrolytic cell through which electricity is passed from an outside source, equals the e.m.f., e, of the reaction plus the voltage drop due to internal resistance.

CHEMICAL ENERGY, ELECTRICAL ENERGY AND HEAT

55. Error in Thomson's rule. Thomson's rule is wrong in principle because in an electrochemical action we never have an interchange of chemical energy and electrical energy alone, since heat is always involved. This does not mean the Joulean heat which, of course, is also present. We may assume we have an electrolytic system of such dimensions and design that its internal resistance is so small that the Joulean heat developed in it is negligible compared with the amount of energy involved in the reaction. Under such conditions we know from experience that the cell while electricity passes through it, either tends to cool or to heat. To maintain the temperature constant it is therefore necessary to supply heat from the surroundings or to carry it off to the surroundings. In the case of a battery, if it tends to cool, and we supply heat to maintain the temperature, not only chemical energy but also the heat supplied during discharge are changed into electrical energy; hence the e.m.f. at that temperature has a greater value than that found from Thomson's rule. If the battery tends to give up heat during the passage of the electricity, heat is given off to the surroundings, and the e.m.f. is smaller than found by Thomson's rule.

56. Distinction between energy of reaction and capacity for performing work. This question is intimately connected with the essential difference between the total energy of a reaction at a certain temperature, as defined in Par. **38 to 48** and its capacity of performing work. The reason is that among all different forms of energy, heat has an exceptional place. We can always change all other kinds of energy completely into heat, but we cannot do the reverse. In case of a chemical reaction we can change the chemical energy completely into heat and this is exactly what we are doing in thermochemistry when we determine the heat or **energy of a reaction.**

57. The capacity of performing work (mechanical work in the expansion of gases or electric work in case of a battery) is something different. As an example, let us assume a concentration cell, consisting of two different concentrations of the same salt solution, each containing an electrode made of the metal of the salt. If then the reaction is that at the anode metal is dissolved and forms more salt, while simultaneously salt disappears at the cathode, metal being deposited, then the energy corresponding to the solution of metal from the anode and deposition of exactly the same amount of metal on the cathode is zero. If we assume further that we have to do with solutions so diluted that the energy of further diluting them is zero, then the energy corresponding to the concentration changes in the cell is also zero. Hence the total chemical energy of the reaction in the cell is zero. Nevertheless the cell will give out electricity and will perform work, the electricity produced being in such a direction as to equalize the concentrations (*i.e.*, the electricity passes in the cell from the dilute to the concentrated solution, because under this condition more salt is formed in the dilute solution from the anode, while the concentrated cathode solution is diluted by metal being deposited on the cathode). Of course, the energy must come from some source, and under the conditions of the experiment it must come from heat; *i.e.*, the cell while giving out electricity tends to cool down, and heat must be supplied from the outside to keep the temperature constant. This is therefore a case in which the chemical energy of reaction is zero, but its capacity of performing work has a positive value; correspondingly the e.m.f. would be zero according to Thomson's rule, but has in reality a positive value.

58. Helmholtz equation of energy. If W = energy of the chemical reaction at a certain absolute temperature T and if W_0 is the maximum amount of work which it is capable of performing at that temperature under and radiation per unit of the surface of the furnace, *i.e.*, on the kilowatts lost per square meter. Hence if the size of an electric furnace is increased, then *ceteris paribus* the generation of heat from electricity increases as the third power of the dimension, and the losses as the square of the dimension; hence the thermal efficiency of an electric furnace is the higher, the larger the size. The maximum size of a furnace is limited by the consideration that the more we increase the size, the greater becomes the difficulty of maintaining uniform conditions of operation.

ENERGY BALANCE, REFRACTORIES

63. Analysis of energy required. The energy per unit of mass is, in general, consumed in five different items, viz.:

(*a*) To produce the heat necessary to raise the starting materials to the temperature of the reaction.

(*b*) To provide the energy required for any change from solid state to liquid or from liquid to gas or from solid to gas.

(*c*) To provide the energy for the chemical reaction.

(*d*) To supply the heat lost by conduction.

(*e*) To supply the heat lost by radiation.

64. Heat necessary to raise starting materials to operating temperature. The heat necessary to raise the starting materials, if cold, to the temperature of the reaction (Par. 63a) equals the weight of charge multiplied by temperature difference multiplied by mean specific heat.* To reduce this item of energy as much as possible, the starting materials are often preheated by waste gases, etc. It is often advantageous to divide the heating of the charge into two stages, the lower ranges of temperatures being obtained by burning fuel and only the higher range of temperatures from electrical heat.

65. Heat necessary for change of state. The heat required for a change of the charge from solid to liquid or from liquid to gas or from solid to gas (Par. 63b) is equal to the weight of the charge multiplied by the latent heats (see J. W. Richards, "Metallurgical Calculations," Vol. I). This item of energy expense should also be eliminated wherever possible. For instance, for electric steel refining, the steel is preferably supplied to the electric furnace in molten state from the open-hearth furnace or Bessemer converter. If a gas is evolved from solid materials, the work done in the expansion of the gas must also be considered. See (44).

66. The energy required for the chemical reaction (Par. 63c) at the temperature of the reaction (Par. 48 to 54), is an item of expense, only if the reaction absorbs energy. If the reaction evolves energy, this energy is added to that of the electric current and changed into useful heat, so that the amount of electrical energy to be supplied from the outside is reduced.

67. The loss of heat by conduction (Par. 63d) depends on the difference of temperature inside the furnace and outside and on the thermal conductivity of the furnace walls. To reduce this loss as much as possible, the furnace walls are built up of highly insulating refractory materials. In the choice of the material its heat-insulating property must be taken into consideration as well as the maximum temperature which it is intended to stand and the chemical nature of the reactions for which the furnace is to be used; further, the ability to withstand expansion and extraction must be taken into consideration. See Par. 69 to 89.

68. The loss of heat by radiation (Par. 63e) is treated in Par. 90.

69. Loss of heat through terminals. All electric furnaces, except the induction furnace, have terminals (often called electrodes) for introducing the electrical energy into the furnace, and these represent the weakest point in the heat insulation. But the conduction of heat through an electrode (due to the temperature difference between its two ends) is a more complicated phenomenon than the single heat conduction through the refractory wall, because in the former case each particle of the electrode is not only a conductor of heat, but a seat of generation of new heat (from electrical energy). There is a superposition, therefore, of two phenomena; first, simple heat con-

* For tables of specific heats see J. W. Richards, "Metallurgical Calculations," Vol. I, also Sec. 4.

lating properties of the silico-carbide. Further, if the article is exposed at high temperatures to an oxidising atmosphere the carbon residue which acts as the binding agent is burnt out. If this happens the article will disintegrate, unless the temperature and oxidising conditions are such as to cause oxidation of the silico-carbide and consequent binding together of the particles. When, therefore, the article is exposed to oxidizing actions at a comparatively low temperature, it is better to use sodium silicate as the binding agent. But where the conditions are such that neither oxidation or serious current leakage is to be feared, the tar bond is very satisfactory, giving articles of considerable mechanical strength.

When an article of great mechanical strength is required, and the use of tar is objectionable, the best method of making the article is, according to FitzGerald, to cause the particles of the silico-carbide to frit together by oxidation. To accomplish this result the silico-carbide is mixed with some temporary binding agent, such as a solution of glue in water and then heated to a high temperature for several hours in a strongly oxidising atmosphere. By this treatment the grains of the silico-carbide are superficially oxidized.

75. Siloxicon. When siloxicon is heated to, or above, 2,674 deg. fahr. (Acheson) or 1,468 deg. cent. in an oxidizing atmosphere, decomposition takes place. If the siloxicon be in the form of a brick or other moulded mass the reaction occurs on the surface, producing a vitreous glase. In the absence of free oxygen or in a reducing atmosphere, no such decomposition occurs, and the temperature may be raised to the point of the formation of carborundum, approximately 5,000 deg. fahr. (Acheson) or 2,760 deg. cent., solid crystalline carborundum remaining while the vapors of silicon and carbon monoxide are given off. For higher temperatures carborundum is a useful refractory; it is suitable up to such temperatures where it decomposes.

76. Refractories for very high temperatures. When the temperature to which the refractory material is submitted may be up to or above that of the formation of carborundum, it may be advisable, according to FitzGerald, to use **cyrstalline silicon-carbide** in the first place, allowing it to be converted into **carborundum** in situ. If this is done the silico-carbide should first be analyzed to determine whether oxygen compounds are present or not. If oxygen compounds are present in appreciable quantities the silicocarbide may be unsuitable for the work, since at the temperature of the formation of carborundum, silicon will be reduced and the refractory lining will be impregnated with metallic silicon, or the furnace will be filled with silicon vapor. When the presence of the silicon is unobjectionable this reaction may be disregarded; otherwise there are two courses open; the silica may be removed or a material free from silica obtained; or from the analysis of the material the amount of carbon necessary to eliminate the oxygen and to form carborundum may be added to the mixture.

77. Carborundum as a refractory material. When it is desired to use carborundum directly as a refractory material the binding agents suggested in Par. **73** and **74**, for silico-carbides may be used. Carborundum may also be made into a strong article by the oxidation or fritting method described in **74.** Another method of making articles of carborundum is by recrystallisation. The carborundum in the form of grains or powder is mixed with some adhesive substance, such as a solution of glue in water, the mixture moulded in the desired form and the article then placed in an electric furnace and heated to the temperature of formation of carborundum. This causes a recrystallization of the carborundum and forms a strong article which preserves perfectly the form in which it was moulded. Neither the **silicocarbides** nor **carborundum** can be used as refractory materials where they come **in contact with fused alkalies**, since these produce rapid decomposition. They are also attacked by chlorine at high temperatures.

78: Binder for carborundum refractories. For using **carborundum** (silicon carbide) **as refractory**, E. K. Scott (*Electrochemical and Metallurgical Industry*, Vol. III, p. 140) recommends that the carborundum be ground up very fine and mixed in the proportion of three parts by weight of carborundum to one part by weight of silicate of sodium (water-glass). After thoroughly brushing the newly set fire-brick to get rid of dust, etc. (the mixture will not stick to a surface which has already been fired), the carborundum is painted on to the depth of about half a millimeter. It is then left for 24 hr. to dry, and afterward the firing started up gradually.

rochem. and Met. Ind., Vol. III, 1905, p. 291, and S. Wologdine and A. L Queneau, *Electrochem. and Met. Ind.*, Vol. VII, p. 383. The figures taken from Hutton are marked (H); most of the granular powders tested by Hutton and Beard just passed through a sieve with 600 meshes per sq. cm. The figures taken from Wologdine are marked (W). All the conductivities λt are given in centimeter-gram-second units, *i.e.*, each figure represents the quantity of heat in gram-calories, which is transmitted per sec. through a plate 1 cm. thick per sq. cm. of its surface when the difference of temperature between the two faces of the plate is 1 deg. cent. The thermal conductivity of various other substances is given elsewhere (see index). The figures under t represent the ranges of temperature in deg. cent. within which the conductivity figures are valid. The figures found by different investigators are considerably at variance. Probably those marked (W) are the best available at present for the grade of refractory materials on the marked for everyday furnace work. Concerning the method of measuring the thermal conductivity of refractories see Clement, *Met. and Chem. Eng'ing*, Vol. VIII, p. 414.

84. Table of Thermal Conductivities of Various Substances

Substance	t	λ_t
Graphite brick (W)	100°–1000°	0.025
Carborundum brick (W)	100°–1000°	0.0231
Gas-retort carbon, solid	0°–100°	0.01477
Magnesia brick (W)	100°–1000°	0.0071
Magnesia brick	0°–1300°	0.00620
Chromite brick (W)	100°–1000°	0.0057
Masonry	—	0.0058 0.0036
Fire brick (W)	100°–1000°	0.0042
Checker brick (W)	100°–1000°	0.0039
Gas retort brick (W)	100°–1000°	0.0038
Building brick (W)	100°–1000°	0.0035
Bauxite brick (W)	100°–1000°	0.0033
Fire-brick	0°–1300°	0.00310
Fire-brick (Clement)	400°–750°	0.0021 to 0.0036
Glass pot (W)	100°–1000°	0.0027
Terra cotta (W)	100°–1000°	0.0023
Alumina brick	0°–700°	0.00204
Silica brick (W)	100°–1000°	0.0020
Kieselguhr brick (W)	100°–1000°	0.0018
Marble, white	—	0.0017
Water, uncirculated	—	0.0016 0.0012
Glass	10°–15°	0.00150
Fire-brick	0°–500°	0.00140
Plaster of Paris	—	0.0013
Water	—	0.00120
Clinker, in small grains	0°–700°	0.00110
Slate	—	0.00081
Cork	—	0.00072
Pumice	—	0.00060
Oak wood	—	0.00060
Quartz sand	18°–98°	0.00060
White Calais sand (H)	20°–100°	0.00060
Coarse carborundum (H)	20°–100°	0.00051
Fine carborundum (H)	20°–100°	0.00050
Magnesia "Mabor" brick, powder (H)	20°–100°	0.00050
Carborundum sand	18°–98°	0.00050
Rubber	—	0.00047
Pine wood	—	0.00047
Magnesia, fused, granular (H)	20°–100°	0.00047
Magnesia calcined, Grecian, granular (H)	20°–100°	0.00045
Powdered coke	0°–100°	0.00044

87. Example of thermal calculations. As an illustration of the simplicity of the calculations when these units are used, let the inside of a small furnace be a 6-in. cube; let the wall consist of a 4-in. layer of silica brick on the inside and 4 in. of brick on the outside. The true average cross-section of the layer of silica brick perpendicular to the heat flow (namely, the geometric mean, that is, the square root of the product of the extreme sections) for the whole furnace will be 504 sq. in. If its resistivity from the above table is 47 thermal ohms, its resistance will be

$$R = \frac{r \times l}{S} = \frac{47 \times 4}{504} = 0.37 \text{ thermal ohm.}$$

A similar calculation for the outside layer of fire-brick having a resistivity of 22 thermal ohms gives its resistance as 0.048 thermal ohm. Hence, the total is the sum of these two, which is 0.42 thermal ohm. Incidentally, it shows what a very much smaller insulating effect this much larger outside layer has.*

Suppose the drop of temperature through the wall to be 1,500 deg. cent. Then, according to the thermal ohm's law, the loss of heat will be

$$W = \frac{T}{R} = \frac{1{,}500}{0.42} = 3{,}580 \text{ watts, or about 3.6 kw.}$$

The analogy between heat flow and electric flow has been analysed very carefully by E. F. Northrup† with applications of the results to an analysis of methods for measuring thermal resistances.

88. Formulas for flow of heat through plates. The ordinary formula for the flow of heat through plates or rods of solid materials may be written:

$$W = (A/t)k\ (T - To) \tag{23}$$

Where W = the heat flow, expressed in watts, A = area of plate or cross-section of the rod, t = thickness of the plate or length of the rod, $T - To$ = the difference of temperature between the two sides of the plate or between the ends of the rod, and k = heat conductivity of the material of the plate or rod in watts per cm. per deg. In most practical cases of heat flow the problem is more complicated than this. Usually the heat is not flowing between parallel surfaces, or at least the areas of the two bounding surfaces are different. The above equation as it stands, applies only between parallel surfaces through a body of uniform cross-section. For bodies of other shapes Langmuir treats the case as follows. While A will vary along the path of heat flow, yet if the area of inflow and outflow is fixed, the ratio A/t will have a definite value, depending only on the shape of the body. This quantity Langmuir terms the shape factor, and represents it by S. The formula (Eq. 23) thus becomes:

$$W = Sk\ (T - To) \tag{24}$$

In case the heat conductivity is a function of the temperature, the equation should be written:

$$W = S \int_{To}^{T} k\,dT \tag{25}$$

S, the shape factor, is a quantity of the dimension of a length which depends only on the shape and size of the body and the position of the surfaces by which the heat enters and leaves the body.

Langmuir‡ has given formulas for the shape factor for parallel places, concentric cylinders, concentric spheres, square edges, square corners, plane edges, plane corners, small square rods, small cubes, and for rec-

* A series of articles on heat insulations of furnace walls and the flow of heat through furnace walls has been published by Carl Hering in *Met. and Chem. Eng'ing*, Vol. IX, p. 189, 590, 652 (where there is a further table of thermal resistivities in thermal ohms); Vol. X, p. 97 and 159; Vol. XI, p. 183. On heat losses of electric furnaces see also F. A. J. FitsGerald, *Trans.* Am. Electrochem. Soc., Vol. XX, p. 281, and *Met. and Chem. Eng'ing*, Vol. X, p. 286.

† *Transact.* Am. Electrochem. Soc., Vol. XXIV, p. 85.

‡ *Transact.* Am. Electrochem. Soc., Vol. XXIV, p. 53.

contained a special carbon crucible in which the material to be heated was placed. The upper block was slightly rounded out directly above the arc. By the strong heat of the arc the surface of the lime was fused and highly polished so as to form a perfect reflector sending all the heat down upon the crucible.

94. Direct and indirect arc furnaces. In the former the furnace charge is directly exposed to the arc, in the latter it receives the heat of the arc by radiation and by reflection from the roof and walls. It is clear that in many cases there is combined direct and indirect heating. A typical example of indirect arc heating is the **Stassano furnace.** For operation by three-phase currents, there are three electrodes at the top. The arcs play between the ends of the three electrodes and heat the metallic bath below by radiation (there being no arcs between the electrodes and the bath itself). To mix the charge thoroughly, the furnace is built revolvable. (*Electrochem. & Met. Ind.*, Vol. VI, p. 315.)

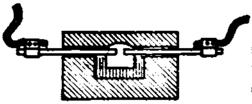

Fig. 1.—Moissan Arc Furnace.

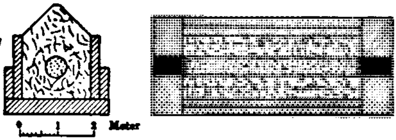

Fig. 2.—Acheson Carborundum Furnace.

95. A typical resistance furnace is the carborundum furnace of E. G. Acheson, shown in plan and vertical section in Fig. 2, the dimensions referring to a capacity of 750 kw. The charge which consists of carbon, silica sand and salt, surrounds a carbon core which acts as resistor and is placed in the centre of the furnace. It runs through the furnace from end to end and is connected at both ends with the carbon terminals or electrodes in the end walls of the furnace. (For further details see F. A. J. FitzGerald, *Electrochem. and Met. Ind.*, Vol. IV, p. 54.) The current through the resistor produces heat which passes outward into the charge, resulting in the production of carborundum.

96. Resistance furnaces may again be **subdivided** according to the nature of the resistor, whether the electric heat is produced in the charge itself or in a special resistor, in contact with the charge. The former is possible only if the charge itself is a conductor of electricity; an example is the induction furnace for melting steel, etc. In case the furnace charge is not itself a conductor of electricity, a special resistor must be provided in contact with the charge; the electricity takes a predetermined path in passing through the resistor in which the heat is thereby developed. An example is the carborundum furnace described above. Finally it is possible to so arrange the resistor that it is not in direct contact with the charge, but is arranged above it and heats the charge by radiation.* Concerning materials suitable for resistors see Par. 111.

No sharp distinction is always possible between the two subclasses of resistance furnaces with or without a special resistor. For instance, in the Acheson furnace for changing carbon electrodes into graphite electrodes, the electrodes are embedded in granular graphite; most of the heat is developed in the latter, but since the electricity also passes through the electrodes themselves, some heat is also directly produced within the same. An example of a furnace operation which changes in character during a run is Acheson's furnace for producing graphite in bulk; in the centre of the anthracite coal, coke, etc., to be graphitized the resistor in form of a series of carbon rods, is placed through which the electricity first passes exclusively; when the anthracite coal next to the core is changed by the heat into graphite, the electricity also passes through it and so on. Therefore, while the electricity had first only a restricted definite path, its path gets broader and broader during operation.

97. Pinch phenomenon. A peculiar limitation of the temperature obtainable in that class of resistance furnaces in which the charge itself forms

* FitzGerald. *Met. & Chem. Eng'ing*, Vol. VIII, p. 317; Vol. IX, p. 29.

furnace. It is essentially a transformer, the secondary of which is a single turn, represented by an annular channel which contains the charge. It is necessarily operated by alternating current which is fed to the primary winding, thus setting up an alternating magnetic flux in the transformer core of laminated iron; this again produces alternating current in the furnace charge in the secondary annular channel, thus heating the charge directly by the Joulean effect. A tilting induction furnace for melting metals (A. E. Colby, F. A. Kjellin) is shown diagrammatically in Fig. 4.

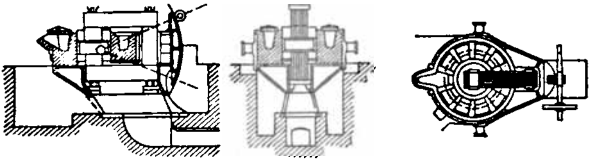

FIG. 4.—Colby-Kjellin Induction Furnace.

The **chief advantage** of this type of furnace lies in the fact that there are no electrodes which could contaminate the bath, so that the chemical composition of the bath can be absolutely controlled by carefully selecting the raw materials. The nature of the atmosphere in which the reaction takes place is also in absolute control of the operator. It is also possible to heat up such a furnace very quickly. (FitzGerald, *Electrochem. & Met. Ind.*, Vol. VII, p. 10, 1909.)

The **losses of energy** in transfer from the primary to the secondary are calculated exactly as in the case of the ordinary transformer (Sec. 6). The induction furnace differs (quantitatively, not qualitatively) from commercial alternating-current transformers, since it has necessarily considerable magnetic leakage fluxes due to the necessity of careful insulation of the fused-bath channel from the primary winding. The **power-factor** is low, due to two causes: the low resistance of the secondary and its high self-induction, due to its wide separation from the primary. The power-factor can be improved by any of the following means: decreasing the frequency of the alternating current, or increasing the ohmic resistance of the fused charge, or increasing the magnetic reluctance of the two leakage fields.

103. The Roechling-Rodenhauser combination furnace is a modification of the simple induction furnace. It is heated by a superposition of two heating effects: firstly, according to the simple induction principle; secondly, an auxiliary secondary circuit is provided, the ends of which are connected to metallic pole plates embedded in the furnace walls. When the furnace is started, it is first heated by induction alone. When the refractory layer which separates the pole plates from the metallic bath thereby becomes hot, it becomes an electric conductor and supplementary heat is now produced by the electric current passing between the pole plates through the furnace charge. The advantages of this furnace over the simple induction furnace are that it can be used for refining (not only melting) purposes and that it can be built with ordinary commercial frequencies for large charges so as to operate with a good power-factor. (*Electrochem. & Met. Ind.*, Vol. VI, pp. 10, 143, 438, 458; *Met. & Chem. Eng'ing*, Vol. VIII, p. 338, Vol. X, p. 263, Vol. XI, pp. 99 and 599; *Transact.* Am. Electrochem. Soc., Vol. XX, p. 293.) Another combination of arc and resistance furnace is the "paragon furnace" (Harden, *Met. & Chem. Eng'ing*, Vol. IX, p. 38, 595).

104. Electrodes. If the electrical energy is introduced into the furnace through terminals, they consist almost always either of amorphous carbon or of graphite, at least for large furnaces. In this country amorphous carbon electrodes are generally made from petroleum coke, while in Europe electrodes made from anthracite coal are also used. However, artificial graphite electrodes made by the Acheson process in the electric furnace, are very extensively employed now. They are more expensive, but can be easily machined into any shape (C. E. Collens, 2nd, *Transactions* of the American Electrochemical Society, Vol. I; *Electrochemical Industry*, Vol. I, p. 26 and Vol. II, p. 277; W. McA. Johnson, *Electrochemical Industry*, Vol. II, p. 345), *Transactions* Am. Electrochem. Soc., Vol. XV, p. 279, Vol. XVI, p. 329, *Electrochem. & Met. Ind.*, Vol. VII, pp. 358, 389; E. F. Roeber, *Transactions* Am. Electrochem. Soc., Vol. XVI, p. 363; J. Forssell, *Met. & Chem. Eng'ing*, Vol. VIII, pp. 26 and 177; A. E. Kennelly, *Proc.* Am. Inst. Elec. Eng., March, 1910, p. 267.

106. Regulation of the heat production is of greatest importance; this is, of course, identical with regulation of the electric energy supply. In arc furnaces this is obtained by adjusting the position of the electrodes, which may be done either by hand or automatically. A simple automatic method in case of a furnace with one electrode, the crucible forming the other terminal, is to control the position of the electrode by an electromagnetic device, the magnet winding being in shunt with the crucible and the electrode, so that the exciting current of the magnet depends on the current through the furnace. In the single-phase Héroult steel furnace which has two electrodes, there being current from one electrode through the slag to the other electrode, it is important to know that both arcs are playing properly. For this purpose a voltmeter is connected in parallel with each of the electrodes and the molten furnace charge; one terminal of the voltmeter is connected with the electrode and the other with some contact in the molten steel charge. Each voltmeter may, of course, be provided with an automatic regulating attachment.

107. In the operation of resistance furnaces it is a fact of great importance that the resistance is a variable quantity during the run of the furnace, both on account of variation of temperature and of the chemical changes in the charge. In order to work economically, it is usually important that the maximum power available be used throughout the furnace run, and if the resistor changes its resistance it is necessary to provide some means of regulating the voltage, and the maximum and minimum voltages attainable must have to each other the ratio of the square roots of the maximum and minimum resistance of the resistor (FitzGerald). If carbon is used as a resistor, it is advisable to raise it previously to the maximum temperature to which it will be submitted in practice. The best plan is to use graphitized carbon, for that form of carbon is stable in its physical characteristics so that the only change that is experienced when using it as a resistor is temporary and due to the increase in temperature.

108. Direct current and alternating current may both be used for operation of an electric furnace, but alternating current has two advantages: first, electrolytic effects which are not desired in pure electric-furnace reactions, are excluded; second, alternating current permits easier regulation. The induction furnace always requires alternating current.

109. Rheostats. As rheostats for voltage regulation, water rheostats or granular-carbon rheostats are suitable. (For details see F. A. J. FitzGerald, *Electrochemical and Metallurgical Industry*, Vol. III, p. 9).) Rheostat design, see Sec. 5).

110. Tube furnace. A special type of resistor furnace for experimental work which permits very exact regulation of temperature, is the tube furnace, *i.e.*, an electric furnace in which the resistor has the form of a tube. For various designs of such furnaces see Hutton and Patterson, *Electrochemical and Metallurgical Industry*, Vol. III, p. 455; S. S. Sadtler, *Electrochemical and Metallurgical Industry*, Vol. IV, p. 434; S. A. Tucker, *Electrochemical and Metallurgical Industry*, Vol. V, p. 227; J. A. Harker, *Electrochemical and Metallurgical Industry*, Vol. III, p. 273; William C. Arsem, *Transactions* American Electrochemical Society, Vol. IX; and especially the elaborate designs of H. N. Potter, U. S. Patents, 715507; 715508; 715509; Dec. 9, 1902; 719507, Feb. 3, 1903; 756891, April 12, 1904; 770312, Sept. 20, 1904; 814726 and 814727, March 13, 1906. Tube furnaces may be so constructed as to carry out the reaction either under increased or reduced pressure, as in the furnace of Arsem and the last two patents of Potter.

111. In another special type of resistor furnace, due to FitzGerald and Thomson, the charge is heated by radiation from a resistor above the charge; this furnace has been applied for zinc smelting (*Met. & Chem. Eng'ing*, Vol. VIII, pp. 289, 317). Various materials are suitable for the resistors, according to the special design of the furnace, such as granular carbon ("kryptol"), carbon rods, silundum rods, platinum strip or wire, nickel strip

860 kg-cal. from burning $\frac{10}{m}$ kg. coal is $\frac{a}{90.7\,m}$ dollars. On the other hand, if the cost of 1 kw-hr. is b cents and if the efficiency of producing heat from electrical energy is n per cent. then the cost of 860 kg-cal. from $\frac{100}{n}$ kw-hr. is $\frac{b}{n}$ dollars. Hence electric heat will be cheaper than heat produced by combustion of fuel if an is greater than 90.7 bm.

If we assume efficiency figures which are not unfair under practical conditions, namely an efficiency $m = 25$ per cent. for fuel heating and an efficiency $n = 75$ per cent. for electric heating, then electric heat is cheaper than fuel heat if a is larger than 30.2 b, *i. e.*, if the cost of 1 ton of coal in dollars is more than 30.2 times greater than the cost of 1 kw-hr. in cents. For instance to compete with coal at $6 per ton, the electric kilowatt-hour would have to cost less than ¼ cent. This shows that were it not for its other important features, electric heat could not compete with fuel heat under ordinary conditions. If we had an electric furnace process which would work continuously with full load all year, then the cost of the electric horsepower-year will be 65.7 b dollars; hence electric heat will be cheaper than fuel heat if the cost of 1 ton of coal in dollars is more than $\frac{30.2}{65.7}$ or say, one-half the cost of the electric horsepower-year. This is apparently a more favorable view of the situation, especially in neighborhoods where fuel is expensive and water-power is really cheap (say below $10 per electric horsepower-year). But unless absolute continuity of the process is assured, it is safer to base such calculations on the cost of the kilowatt-hour instead of the horsepower-year.

COMMERCIAL PRODUCTS OF THE ELECTRIC FURNACE

118. A brief summary of the most important commerical products of the electric furnace will now be given. Concerning the production of various modifications of carbon (including artificial diamonds) and the production of chromium, manganese, molybdenum, tungsten, uranium, vanadium, zirconium, as well as carbides, silicides, borides, phosphides, arsenides and sulphides on an experimental scale, see Moissan's "Electric Furnace." A very useful bibliography on borides and silicides may be found in O. P. Watts, "Investigation of the Borides and the Silicides," Bulletin University of Wisconsin, No. 145. A. Stansfield's "Electric Furnace" is a reliable and concise descriptive book. Askenasy's "Einführung in die technische Elektrochemie," Vol. I (Electrothermie) contains valuable information on various electric furnace processes. Concerning new proposed applications of the electric furnace the reader is referred to the current abstracts of new electrochemical patents in *Met. & Chem. Eng'ing.* The following list includes only the most important products which are made in the electric furnace on an industrial scale.

119. Artificial graphite is made by the processes of E. G. Acheson in three forms: hard graphite in bulk, suitable for paint, pigment, etc.; artificial graphite electrodes for electric furnace and electrolytic work; soft graphite suitable as lubricant, stove polish, etc. See descriptions of the three processes in *Electrochemical and Metallurgical Industry,* Vol. III, p. 416 and Vol. IV, p. 502, Vol. VII, p. 187.

Concerning the conditions of transformation of amorphous carbon into graphite see Arsem, *Trans.* Am. Electrochem. Soc., Vol. XX, p. 105.

120. Silicon Carbide* (trade names carborundum, crystolon) is made by the process of E. G. Acheson from a charge of carbon, sand and salt, the essential reaction being $SiO_2 + 3C = SiC + 2CO$. The chief uses of carborundum are as an abrasive and a refractory.

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*Descriptions of the silicon carbide furnace in *Electrochem. & Met. Ind.* Vol. IV, p. 53; Vol. VII, 189; *Met. & Chem. Eng'ing,* Vol. X, p. 519, 685. Concerning the temperature of the silicon carbide furnace, see Saunders. *Met. & Chem. Eng'ing,* Vol. X, p. 287.

V, p. 407). Concerning the electric distillation of turpentine see F. T. Snyder, *Transactions* Am. Electrochem. Soc., Vol. XIII.

129. Calcium carbide (CaC_2) production is one of the largest and most important electric-furnace industries (T. L. Wilson, H. Moissan, L. M. Bullier). The reaction is

$$CaO+3C=CaC_2+CO, \tag{27}$$

the furnace charge consisting of burnt lime and ground coke. The chief use of calcium carbide is the production of acetylene gas C_2H_2 for lighting according to the equation:

$$CaC_2+H_2O=CaO+C_2H_2, \tag{28}$$

acetylene gas being developed when calcium carbide comes into contact with water.* **Calcium cyanamide** is made from calcium carbide and nitrogen. See Par. **263**.

130. The application of the electric furnace in other branches of non-ferrous metallurgy is largely experimental.† Experiments have been made on electric smelting of copper ores,‡ nickel ores,§ and tin ores.‖

131. Ferro-alloys,¶ as well as other alloys, like copper-silicon, are made in the electric furnace according to the old process of A. H. Cowles, by treating a mixture of pig iron (or copper in the case of copper alloys), an oxide of the element to be alloyed with the iron (*e.g.*, silica in the case of ferrosilicon) and carbon. Various variations are possible. The production of ferro-alloys in the electric furnace is a commercial success; various alloys, especially those of high percentage and low in carbon, can only be made in the electric furnace. The usual reducing agent is carbon. But silicon or ferrosilicon or carborundum have also been proposed for the production of other ferro-alloys, free from carbon.

132. In the steel industry** the electric furnace is rapidly increasing in importance for three purposes. The first†† is the manufacture of high-grade steel in competition with the crucible steel process, being considerably cheaper on account of larger units and smaller wages, while the product of the electric furnace is as good as that of the crucible steel process and it is not necessary to use as pure and expensive starting materials. The second application‡‡ is a more recent one, for the refining of molten Bessemer converter metal or molten open-hearth metal for large-tonnage products, like rails of improved quality. For steel refining in the electric furnace the possibility of producing a higher temperature in the slag§§ is important, but of

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* Concerning the thermodynamic theory of the process see Thompson, *Met. & Chem. Eng'ing*, Vol. VIII, pp. 279 and 324.

† Concerning possible applications of the electric furnace to Western metallurgy, see Lyon and Keeney, *Met. & Chem. Eng'ing*, Vol. XI, p. 577. As to vacuum furnace metallurgy for the treatment of rebellious ores, such as sulphite, Nipissing ore, for the production of antimony from stibnite, see Fink, *Met. & Chem. Eng'ing*, Vol. X, p. 296. As to the use of the electric furnace for the treatment of tin dross concentrates from cyanide mills, etc., see Wile, *Met. & Chem. Eng'ing*. Vol. X, p. 495.

‡ Stephan, *Met. & Chem. Eng'ing*, Vol. XI, p. 22; Lyon and Keeney, Vol. XI, p. 522.

§ Morrison. *Transact.* Am. Electrochem Soc., Vol. XX, p. 315.

‖ Harden. *Met. & Chem. Eng'ing*, Vol. IX, p. 453.

¶ G. P. Scholl. *Electrochem. Ind.*, Vol. II, pp. 349, 395, 449; Keeney, *Transact.* Am. Electrochem. Soc., Vol. XXIV, p. 167. Concerning ferrosilicon see Pick and Conrad's German monograph, also Copeman, Bennett & Hake, *Met. & Chem. Eng'ing*, Vol. VIII, p. 133.

** A very good review of the situation in 1909 may be found in the symposium of papers on the electrometallurgy of iron and steel in *Transact.* Am. Electrochem. Soc., Vol. XV. See also Eugene Haanel's first Canadian Government report of 1904, and Neumann's Electrometallurgie des Eisen.

†† For instance, *Met. & Chem. Eng'ing*, Vol. VIII, p. 563.

‡‡ Description of South Chicago plant of the U. S. Steel Corporation, *Met. & Chem. Eng'ing*, Vol. VIII, p. 179. See also Walker, *Met. & Chem. Eng'ing*, Vol. X, p. 371, and Osborne, *Transact.* Am. Electrochem. Soc., Vol. XIX, p. 205.

§§ As to the function of slag see Amberg, *Met. & Chem. Eng'ing*, Vol. X, p. 601.

there is nothing but a heat effect. At the junction of a metal and an electrolyte there is either chemical oxidation or reduction according to the direction of the current. At the junction of two electrolytes there is neither oxidation nor reduction, though there may be a chemical change (*e.g.*, at the junction of NaCl and KOH, if the current is directed from the former to the latter, there will be formation of NaOH).

137. The most important electrolytes for industrial applications are: first, **solutions**, and especially aqueous solutions or solutions in water, and second, **fused salts**.

138. Cells. An electrolyte with two electrodes represents either a **galvanic cell,** *i.e.*, an electrochemical system through which a current will be voluntarily established when the two electrodes are electrically connected through an outside circuit (in other words an electrochemical system which can be used as a source of electricity), or an **electrolytic cell,** *i.e.*, an electrochemical system through which an electric current will be established if the outside circuit connected to the two electrodes contains a sufficiently strong source of electrical energy.

139. Galvanic cells. In the case of a galvanic cell or battery the **energy equation** written on the basis of Thomson's rule states that the chemical energy consumed in the cell is partly lost in form of Jourlean heat within the cell ($I^2R\times$time) the balance being available in form of electrical energy in the outside circuit between the terminals of the cell. If this energy equation, the symbols of which represent gram-equivalents, is divided by 96,540 coulombs, *i.e.*, the electric charge of 1 gram-equivalent, the voltage equation is obtained which states that the electromotive force of the cell in volts equals the loss of the volts within the cell due to internal resistance (IR), plus the voltage available at the terminals of the cell. This is correct for a monovalent change. If the change of valency is n, the energy equation is to be divided by $96{,}540\times n$.

140. Electrolytic cells. In the case of an electrolytic cell through which electricity is forced from the outside, the energy equation states that the electrical energy impressed upon the cell at its terminals from the outside is partly changed into the chemical energy required for the chemical process in the cell and partly changed into Joulean heat ($I^2R\times$time). In many cases, when the process requires an elevated temperature, especially in the electrolysis of fused salts, this evolution of Joulean heat serves a useful purpose, since it is the easiest way of providing the requisite high temperature (as in the Bradley "internal heating" patent of the aluminium process). The corresponding voltage equation states that the voltage impressed at the terminals of the cell from the outside equals the electromotive force required for the chemical reaction according to Thompson's rule plus the volts lost in the cell due to internal resistance.

141. The model of migrating ions is a picture of electrolytic phenomena. It is a dynamical model which has been found exceedingly useful to illustrate what happens in an electrolytic cell. Any electrolyte contains positive ions or cations and negative ions or anions.

142. Typical anions are:

(a) **monovalent** (each gram-ion carrying a negative charge of 96,540 coulombs):

Br	in hydrobromic acid and bromides,
Cl	in hydrochloric acid and chlorides,
I	in hydriodic acid and iodides,
Fl	in hydrofluoric acid and fluorides,
OH	(hydroxyl ion) in hydroxides or hydrates,
BrO_3	in bromic acid and bromates,
ClO_3	in chloric acid and chlorates,
IO_3	in iodic acid and iodates,
NO_3	in nitric acid and nitrates,
CN	(cyanogen radical),
CHO_2	in formates,
$C_2H_3O_2$	in acetates.

(b) **bivalent** (each gram-ion carrying a negative charge of $2\times96{,}540$ coulombs):

SO_4	in sulphates,

146. The method of determining the mobilities, u and v, separately consists in determining their sum and their ratio. According to Faraday's law if q coulombs pass through a cell, $\frac{q}{96{,}540}$ positive monovalent gram-ions (or $\frac{q}{2\times 96{,}540}$ positive bivalent gram-ions, etc.) are concerned in the reduction at the cathode and the same number of negative gram-ions in the oxidation at the anode. According to the picture of migrating ions this means that when q coulombs pass, the sum of the number of positive monovalent gram-ions passing through any imaginary cross-section of the cell toward the cathode and of the number of negative monovalent gram-ions passing through the same cross-section in the opposite direction is $\frac{q}{96{,}540}$.

147. Conductivity proportional to the sum of the mobilities. In other words, when there is a current of i amperes through an electrolytic cell, the sum of the numbers of positive and negative monovalent gram-ions passing per sec. in opposite directions through any imaginary cross-section of the cell is $\frac{i}{96{,}540}$. This sum of the numbers of positive and negative gram-ions passing per sec. is, of course, directly proportional to the sum of their speeds or to the voltage drop per unit length of electric line of force multiplied by the sum of their mobilities. Hence, the sum of the mobilities, $u+v$, is proportional to the current in amperes divided by the voltage drop, hence proportional to the conductance and also proportional to the conductivity of the electrolyte.

148. Constant of proportionality. The statement that $u+v$ is proportional to the conductivity will now be supplemented by finding the constant of proportionality. For this purpose we necessarily need a further hypothesis as to the number of ions we have to assume for a given number of molecules.

149. Equivalent ionic concentration. Formerly it was silently assumed that in a fused salt all the molecules of the salt participate equally in the transport of electricity, while in the case of solutions the solvent (for instance, water) was assumed to be inert, and all the molecules of the solute (the dissolved salt) were assumed to participate equally in the transport of electricity. Hence for a fused salt the equivalent ionic concentration was defined as the number of positive monovalent gram-ions per c.c. = number of negative monovalent gram-ions per cu. cm. = number of gram-molecules of the fused salt multiplied by valency per cu. cm. For a solution the equivalent ionic concentration was defined as the number of positive monovalent gram-ions per cu. cm. = number of negative monovalent gram-ions per cu. cm. = number of the gram-molecules of dissolved salt per volume multiplied by valency per cu. cm.

150. Dissociation theory. For fused salts our conceptions have not yet been decidedly changed, while a decided change has been brought about for solutions by Arrhenius' electrolytic dissociation theory. According to him only a certain number of the dissolved salt molecules are ionised and only these are active in the transport of the electricity, while the non-ionized dissolved salt molecules, like the molecules of the solvent, are electrically inert. If we write j for the ratio of the number of ionized molecules to the total number of dissolved molecules where j is smaller than unity, the equivalent ionic concentration is defined as the number of positive monovalent gram-ions per cu. cm. = number of negative monovalent gram-ions per cu. cm. $= j\,c$, where c is the number of gram-equivalents of dissolved salt per cu. cm.

151. Universal formula for use in calculations. We render our calculations general by using the factor j. For fused salts we have to make $j = 1$, while for solutions we are free to take our choice. If we make $j = 1$, we follow the old conception, while if we make j smaller than unity we are on the basis of the electrolytic dissociation theory. For a given fused salt of uniform constitution, c, has a fixed value depending on the density, while for a solution c is variable according to the degree of concentration. As can be easily shown, in the statement that conductivity is proportional to the sum of mobilities, the constant of proportionality has the value $96{,}540\,j\,c$. In other

156. Equivalent Conductivities of Aqueous Solutions at 18 Deg. Cent.

Gram-equivalents per liter	KCl	NaCl	KNO_3	$AgNO_3$	½ $CuSO_4$	½ H_2SO_4	HCl	CH_3COOH	KOH	NH_3	Liters in which gram-equivalent is dissolved
0.0001	129.07	108.10	125.50	115.01	109.95			107.		(66)	10000.
0.0002	128.77	107.82	125.18	114.56	107.90			80.		53.	5000.
0.0005	128.11	107.18	124.44	113.88	103.56	(368)		57.		38.0	2000.
0.001	127.34	106.49	123.65	113.14	98.56	361.	(377)	41.	(234)	28.0	1000.
0.002	126.31	105.55	122.60	112.07	91.94	351.	376.	30.2	(233)	20.6	500.
0.005	124.41	103.78	120.47	110.03	80.98	330.	373.	20.0	230.	13.2	200.
0.01	122.43	101.95	118.19	107.80	71.74	308.	370.	14.3	228.	9.6	100.
0.02	119.96	99.62	115.21		62.40	286.	367.	10.4	225.	7.1	50.
0.05	115.75	95.71	109.86	99.50	51.16	253.	360.	6.48	219.	4.6	20.
0.1	112.03	92.02	104.79	94.33	43.85	225.	361.	4.60	213.	3.3	10.
0.2	107.96	87.73	98.74		37.66	214.	342.	3.24	206.	2.30	5.
0.5	102.41	80.94	89.24	77.5		205.	327.	2.01	197.	1.35	2.
1. (normal)	98.27	74.35	80.46	67.6	25.77	198.	301.	1.32	184.	0.89	1.
2.	92.6	64.8	69.4			183.0	254.	0.80	160.8	0.532	0.5
3.	88.3	56.5	(61.3)			166.8	215.0	0.54	140.6	0.364	0.33
5.		42.7				135.0	152.2	0.285	105.8	0.202	0.2

Doubtful values are given in parentheses.

157. The increase of equivalent conductivity with increasing dilution may be interpreted in different ways on the basis of the picture of migrating ions. Since conductivity $= 96{,}540\, j\ c\ (u+v)$, equivalent conductivity $= 96{,}540\ j\ (u+v)$.

First, according to the old view, all dissolved gram-equivalents participate equally in the transport of the electricity and $j = 1$; hence equivalent conductivity $= 96{,}540\ (u+v)$. Since the equivalent conductivity increases with increasing dilution, we must assume that the sum of the mobilities simultaneously increases.

Secondly, according to Arrhenius' electrolytic dissociation theory, u and v do not change, but the degree of ionisation j changes with dilution. With increasing dilution, j must be assumed to increase until for infinite dilution it reaches a certain definite value. j is the ratio of the number of ionized molecules to the total number of dissolved molecules. For infinite dilution $j = 1$, *i.e.*, all molecules are ionized. The less the dilution or the higher the concentration, the smaller is j, *i.e.*, the smaller the degree of ionization or the smaller the proportion of dissolved gram-equivalents which are ionised.

158. Conductivity of electrolytes. Concerning the measurement of the conductivity of electrolytes see Kohlrausch and Holborn's "Leitvermögen der Elektrolyte." This book contains an enormous amount of detailed information and of figures of conductivities of aqueous solutions. Concerning fused electrolytes see R. Lorenz' "Electrolyse geschmolzener Salze," 3 volumes (figures of conductivities in Vol. II).

159. Determination of the ratio of u to v. From Faraday's law and

The net result in the anode compartment is the setting free of 1 gram-atom Cl gas and the loss in solution of 0.4 gram-molecule NaCl.

In the cathode compartment we have;

Loss, by gas evolution at cathode, of	1 gram-ion H,
Loss, by ionic export to anode compartment, of	0.6 gram-ion Cl,
gain, by ionic import from anode compartment, of	0.4 gram-ion Na,
gain, by chemical formation of NaOH of	1 gram-ion OH,
Loss, by the same reaction, of	1 gram-molecule H_2O.

The net result in the cathode compartment is the setting free of 1 gram-atom H gas, the loss in solution of 1 gram-molecule of water, while the solute NaCl has now been changed into a mixture of NaCl and NaOH since the positive ions have been increased by 0.4 Na gram-ions, while the negative ions have gained 1 OH gram-ion and lost 0.6 Cl gram-ion. This latter change we may chemically express in the statement that 0.6 gram molecule NaCl have disappeared and 1 gram-molecule NaOH has been formed. (For a somewhat different and more detailed discussion of this reaction see W. H. Walker, *Transactions* American Electrochemical Society, Vol. III, p. 177.)

162. Migration Mobilities of Cations

	u_{18}	α	β
H	318.	+0.0154	−0.000033
K	64.87	.0220	+ .000075
Na	43.55	.0245	.000116
Li	33.44	.0261	.000142
Rb	67.6	.0217	.000069
Cs	68.2		
NH_4	64.4	.0223	.000079
Tl	66.00		
Ag	54.02	.0231	.000093
½ Ba	55.10	.0239	.000106
½ Sr	51.54	.0231	.000093
½ Ca	51.46		
½ Mg	45.94	.0255	.000132
½ Zn	46.57	.0256	.000133
½ Cd	47.35		
½ Cu	47.16	.0240	.000107
½ Pb	61.10	.0244	.000114

163. Migration Mobilities of Anions

	v_{18}	α	β
OH	174.	+0.0179	+0.000008
F	46.64	0.0232	.000094
Cl	65.44	.0215	.000067
Br	67.63		
I	66.40	.0206	.000052
SCN	56.63		
ClO_3	55.03	.0207	.000054
BrO_3	46.2		
IO_3	33.87	.0233	.000096
NO_3	61.78	.0203	.000047
ClO_4	64.7		
IO_4	47.7		
MnO_4	53.4		
CHO_2	46.7		
$C_2H_3O_2$	35.0	.0236	.000101
$C_3H_5O_2$	31.0		
$C_4H_7O_2$	27.6		
$C_5H_9O_2$	25.7		
$C_6H_{11}O_2$	24.3		
½ $(COO)_2$	62.6		
½ SO_4	68.14	.0226	.000084
½ CrO_4	72.0		
½ CO_3	60.0	.0269	.000155

167. Electric endosmosis. Since the above reaction is that of the so-called diaphragm processes of brine electrolysis, it should be mentioned here that the introduction of a diaphragm into an electrolytic cell involves a further complication since it causes the phenomenon of electric endosmosis. Solution is bodily carried through the diaphragm, the amount depending on the nature of the diaphragm. This phenomenon may upset all results of calculation of concentration changes from the transport numbers of ions. This phenomenon is the reverse of the migration of colloids in solutions under the action of a current. The colloids correspond to the diaphragm in our former case, but the colloids are movable, while in our former case the diaphragm was fixed. Hence in our former case the liquid will be displaced with respect to the diaphragm. In the latter case the colloids move with respect to the stationary liquid.

168. Short-cut calculations of electrochemical reactions. It is strongly recommended to proceed in the way outlined above in making all calculations on electrochemical reactions; since in this way not only all questions as to details of the reaction are answered, but a clear picture of the mechanism of the reaction is obtained. With ordinary care it is then almost impossible to make a mistake. Nevertheless, for checking results thus obtained or for quick preliminary calculations, tables of electrochemical equivalents are found useful. We give two of them: Par. **166** referring to the electrochemical equivalents of all ordinary ions, Par. **170** to **172** to the electrochemical equivalents of the elements.

From Par. **166** one can find immediately by simple addition for most compounds of ordinary practice the **quantity of material involved in electrolysis.** For instance, for the reaction of sodium chloride electrolysis in a diaphragm cell

$$NaCl + H_2O = NaOH + Cl + H, \tag{33}$$

we find directly from the table that 1 amp-hr. produces 0.03759 g. H and 1.322 g. Cl. We can further find the quantity of NaCl decomposed per ampere-hour, by adding the figures 0.860 (Na) and 1.322 (Cl), which gives 2.182 grams NaCl. In the same way the quantity NaOH formed per ampere-hour is found by adding 0.860 (Na) and 0.634 (OH), which gives 1.494 g. NaOH.

An important precaution which one has to take in the use of this table, is to **select** the ion of the **proper valency.** Thus it will be seen that figures are given for the monovalent $Cu^{\cdot}$ and for the bivalent $Cu^{\cdot\cdot}$ ion. In case of the bivalent compound $CuSO_4$, for instance, one has to select the figure for $Cu^{\cdot\cdot}$ and finds the quantity of $CuSO_4$, decomposed per hr. $= 1.186 + 1.791 = 2.977$ g. (Concerning the necessity of using this table cautiously and judiciously, see also Par. **169.**)

Par. **170** to **172** are tables of electrochemical equivalents of elements and answers directly the question as to the **quantity of the element oxidized at the anode or reduced at the cathode.** Since oxidation and reduction are special cases of change of valency, column 4 is headed "change of valency," as this covers the most general case. In the special case that a metal is deposited from a solution or that a gas is evolved at an electrode, it is to be considered that the metal or the gas has no bonds in the free elementary state, so that in this case the change of valency is equal to the valency in the compound. For instance, in the reduction of Cu from CuCl the change of valency is 1, while in the reduction of Cu from $CuSO_4$, it is 2.

In column 4 those changes of valency are given which are most likely to occur in practice. Thus, for iron, Fe, the figures are given for the changes of valency 1, 2, 3. In the reduction of a ferric salt to a ferrous salt the change of valency is 1; in the reduction of a ferric salt to metallic iron it is 3; in the reduction of a ferrous salt to metallic iron it is 2. But for every element the figures are also given for the indefinite change of valency, n, so as to cover any possible case which may ever arise in practice. To give an example of the application of this table, let us assume that in the Bunsen cell nitric acid, HNO_3, is all reduced to nitric oxide, NO, and let us calculate the quantity of nitric acid thus consumed per ampere-hour. Since the valency of N is 5 in HNO_3 and 2 in NO, the change of valency of N is 3. From the table we find directly that for this change of valency 0.174 g. of N are involved in the reduction per ampere-hour. The amount of HNO_3 consumed and of NO produced is then found by the ordinary chemical method. The atomic weight of N is 14, the molecular weight of HNO_3 is $1 + 14 + 3 \times 16 = 63$, the

170. Electrochemical Equivalents of Elements.—(*Continued*)

1 Element	2 Symbol	3 Atomic weight	4 Change of valency	5 Grams per ampere-hour	6 Ampere-hours per gram
Chromium.........	Cr	52.1	3 n	0.648 1.943 $\div n$	1.544 0.515 $\times n$
Cobalt............	Co	59.0	2 n	1.100 2.200 $\div n$	0.909 0.4545 $\times n$
Columbium........	Cb	94.	2 n	1.753 3.505 $\div n$	0.571 0.2853 $\times n$
Copper............	Cu	63.6	2 1 n	1.186 2.372 2.372 $\div n$	0.843 0.4216 0.4216 $\times n$
Erbium............	Er	166.	3 n	2.063 6.19 $\div n$	0.4846 0.1615 $\times n$
Europium..........	Eu	152.	n	5.67 $\div n$	0.1764 $\times n$
Fluorine...........	F	19.0	1 n	0.709 0.709 $\div n$	1.411 1.411 $\times n$
Gadolinium	Gd	156.	n	5.82 $\div n$	1.719 $\times n$
Gallium...........	Ga	70.0	3 n	0.870 2.610 $\div n$	1.149 0.383 $\times n$
Germanium........	Ge	72.5	4 2 n	0.676 1.352 2.704 $\div n$	1.480 0.740 0.3699 $\times n$
Glucinum..........	Gl	9.1	2 n	0.1697 0.3393 $\div n$	5.89 2.947 $\times n$
Gold..............	Au	197.2	3 2 1 n	2.451 3.677 7.35 7.35 $\div n$	0.4080 0.2720 0.1360 0.1360 $\times n$
Helium............	He	4.0	n	0.1492 $\div n$	6.70 $\times n$
Hydrogen..........	H	1.008	1 n	0.03759 0.03759 $\div n$	26.60 26.60 $\times n$
Indium............	In	115.0	3 n	1.429 4.288 $\div n$	0.700 0.2332 $\times n$
Iodine.............	I	126.97	1 n	4.735 4.735 $\div n$	0.2112 0.2112 $\times n$
Iridium............	Ir	193.0	3 1 n	2.399 7.20 7.20 $\div n$	0.417 0.139 0.139 $\times n$
Iron...............	Fe	55.9	3 2 1 n	0.695 1.042 2.085 2.085 $\div n$	1.439 0.959 0.4797 0.4797 $\times n$

170. Electrochemical equivalents of elements.—(*Continued*)

1 Element	2 Symbol	3 Atomic weight	4 Change of valency	5 Grams per ampere-hour	6 Ampere-hours per gram
Potassium........	K	39.15	1 n	1.460 1.460÷n	0.685 0.685×n
Praseodymium....	Pr	140.5	3 n	1.746 5.24 ÷n	0.573 0.1909×n
Radium..........	Rd	225.0	n	8.39 ÷n	0.1192×n
Rhodium.........	Rh	103.0	2 1 n	1.921 3.841 3.841÷n	0.521 0.260 0.260×n
Rubidium	Rb	85.5	1 n	3.188 3.188÷n	0.3136 0.3136×n
Ruthenium.......	Ru	101.7	4 2 1 n	0.948 1.896 3.792 3.792÷n	1.055 0.5274 0.2637 0.2637×n
Samarium........	Sa	150.3	3 n	1.868 5.61 ÷n	0.535 0.1784×n
Scandium.........	Sc	44.1	3 n	0.548 1.645÷n	1.824 0.608 ×n
Selenium.........	Se	79.2	4 2 n	0.738 1.477 2.953÷n	1.354 0.677 0.3386×n
Silicon	Si	28.4	4 n	0.2648 1.059÷n	3.777 0.944 ×n
Silver............	Ag	107.93	1 n	4.025 4.025÷n	0.2485 0.2485×n
Sodium...........	Na	23.05	1 n	0.860 0.860÷n	1.163 1.163 ×n
Strontium........	Sr	87.6	2 n	1.633 3.267÷n	0.612 0.306 ×
Sulphur..........	S	32.06	2 1 n	0.598 1.196 1.196÷n	1.673 0.836 0.836 ×n
Tantalum.........	Ta	181.0	5 n	1.350 6.75 ÷n	0.741 0.1482×n
Tellurium.........	Te	127.6	4 2 n	1.190 2.379 4.758÷n	0.841 0.4203 0.2102×n
Terbium..........	Tb	159.2	3 n	1.979 5.94 ÷n	0.505 0.1684×n

To find **ampere-seconds per milligram** multiply ampere-hours per gram (column 6) by 3.6.

To find **grams per watt-hour** or **kilograms per kilowatt-hour**, divide grams per ampere-hour (column 5) by volts.

To find **watt-hours per gram** or **kilowatt-hours per kilogram**, multiply ampere-hours per gram (column 6) by volts.

To find **kilograms per horsepower-hour**, multiply grams per ampere-hour (column 5) by 0.74565 (about ¾) and divide by volts.

To find **horsepower-hours per kilogram**, multiply ampere-hours per gram (column 6) by 1.3411 (about ⁴⁄₃) and by volts.

To find **kilograms per electric horsepower-year**, multiply grams per ampere-hour (column 5) by 6,532 and divide by volts.

THE E.M.F. OF ELECTROLYTIC REACTION

173. E.m.f. and terminal voltage. We have before explained that it is necessary to distinguish clearly between the voltage at the terminals of an electrolytic cell, and the e.m.f. of the electrolytic process proper (Par. **140**). We have also shown how to calculate approximately the latter e.m.f. by means of Thomson's rule from the total energy of reaction, while it should strictly be calculated from the free energy of reaction (Par. **88**). The easiest method to determine the latter, however, is by measurements of potential.

174. Single potentials of elements are determined against normal electrodes or standard electrodes. The most usual normal electrodes are the **hydrogen electrode** (platinized platinum, saturated and covered with hydrogen gas, in an acid solution of normal concentration of the hydrogen ions), and the **calomel electrode** (mercury covered with calomel, HgCl, in contact with a normal KCl solution). In order to have a zero point in the potential series of elements, Nernst proposes to make the potential of hydrogen zero. On this supposition the calomel electrode has the potential −0.283; in other words if we form a cell of a calomel electrode and a hydrogen electrode, it has the e.m.f. −0.283, the current in the cell being directed from the latter to the former. On the basis of a theory of Helmholtz on the surface tension of polarized mercury, Ostwald has endeavored to determine "absolute potentials;" in the absolute series the hydrogen electrode has the absolute potential −0.277 volt and the calomel electrode the absolute potential −0.560 volt. But this theory is very doubtful.

175. Potential of Various Elements in Order of Their Nobility

	Potential against hydrogen electrode	Absolute potential
Mn	+1.075 volt	+0.798 volt
Zn	+0.770	+0.493
Cd	+0.420	+0.143
Fe	+0.344 (0.660)	+0.067 (+0.383)
Tl	+0.322	+0.045
Co	+0.232 (0.450)	−0.045 (+0.173)
Ni	+0.228 (0.600)	−0.049 (+0.323)
Pb	+0.151 (0.148)	−0.126 (−0.129)
H	±0.0 (by definition)	−0.277
Cu	−0.329	−0.606
Hg	−0.753 (0.750)	−1.030 (−1.027)
Ag	−0.771 (0.798)	−1.048 (−1.075)
Cl	−1.353 (1.400)	−1.630 (−1.677)
Br	−0.993 (1.095)	−1.270 (−1.372)
I	−0.520 (0.628)	−0.797 (−0.905)

176. Order of nobility of elements. The table in Par. **175** gives in the first column the series of elements in the order of their nobility; those above H are called less noble than H, those below H are called more noble than H. A less noble metal passes into solution when in contact with hydrogen ions, a more noble metal is not attacked. The second and third columns give the potentials of the elements in a normal solution of one of their salts, for instance, silver in a silver salt solution. In the second column Nernst's these tables rests in giving the "thermochemical constants" and the corresponding voltages separately for the basic elements and the acid elements and acid radicals. This separation of the two constituents of a salt in solution is possible on account of the experimental fact that taking the heats of formation of salts plus their heat of solution in excess of water (usually called "heat of formation to dilute solution"), these quantities are found to be additive in their nature, such being composed of the sum of two quantities, one characteristic once for all of the base, in all its combinations, and the other being characteristic once for all of the acid radical, in all of its combinations. There is thus for each basic element a thermochemical constant, which represents the amount of heat it contributes to the formation-heat of a salt, the latter taken in dilute solution; and for each acid radical a similar thermochemical constant, representing in a similar manner the part which it contributes; the sum of these two thermochemical constants is the formation heat of the salt, from its elements, to dilute solution. The thermochemical constant is nothing more nor less, in the case of a base, than energy drop which represents the decrease of energy in the element as it passes from the free, uncombined state into the dissolved (ionic) state in dilute solution; in the case of an acid element, the statement is entirely similar; in the case of an acid (or basic) radical, it is the total energy drop from free elements to the ionic state as a radical.

The arbitrary basis selected to which to refer these thermochemical constants is that of hydrogen constant equal to zero. This makes the thermochemical constant of every basic element the heat evolved when it displaces hydrogen from a dilute solution of acid; and that of an acid element or radical the heat of formation of the acid in dilute solution.

The "corresponding voltages" given are therefore those which according to Thomson's rule should be found against a "hydrogen electrode." The figures may therefore be compared with the table in Par. **175** of voltages of various metals against a hydrogen electrode. The difference between the values of the two tables correspond to the differences in the free energy and the total energy. For many elements the agreement is quite good. Thus for Zn the voltage corresponding to the free energy is 0.770, that corresponding to the total energy is 0.75.

181. Thermochemical Constants of Basic Elements per Chemical Equivalent and Corresponding e.m.f.

(J. W. Richards)

	Calories	Volts		Calories	Volts
Li	+62,900	+2.73	Cd	9,000	0.36
Rb	62,000	2.69	Co	8,200	0.36
K	61,900	2.69	Ni	7,700	0.33
Ba	59,950	2.60	Fe (ferric)	3,230	0.14
Sr	58,700	2.55	Sn	1,900	0.08
Na	57,200	2.48	Pb	400	0.02
Ca	54,400	2.36	H	0	0
Mg	54,300	2.36	Tl	− 900	−0.04
Al	40,100	1.74	Cu	− 7,900	−0.34
$(N+H_4)$	33,400	1.45	Hg	−14,250	−0.62
Mn	24,900	1.08	Pt	−19,450	−0.84
Zn	17,200	0.75	Ag	−25,200	−1.10
Fe (ferrous)	10,900	0.47	Au	−30,300	−1.32

The thermochemical constants in Dr. Richards' table are given in every case for *one* chemical equivalent and not for the number of equivalents which are designated by the number of dots (positive bonds) or strokes (negative bonds). In using these tables, it must be borne in mind that the sum of the thermochemical constants for the basic and acid constituents of any salts, gives the heat of formation of the salt from the constituent chemical elements, in dilute solution. Conversely, the heat of formation thus obtained is the energy necessary to separate the salt in dilute solution into its constituent chemical elements. The sum of the voltages, corresponding to this amount of chemical energy, is the voltage necessary to decompose the salt in solution into its constituents, free chemical elements. If these elements re-combine in the process of decomposition to form other chemical compounds, then the whole chemical reaction must be taken into

183. Thermochemical Constants of Acid Elements
(J. W. Richards)

	Per chemical equivalent, calories	Corresponding e.m.f. volts	Salt
F_2'' (gas)	+52,900	+2.30	Fluoride
Cl_2''(gas)	39,400	1.71	Chloride
Br_2'' (gas)	32,300	1.40	Bromide
Br' (liquid)	28,600	1.20	Bromide
Br' (solid)	27,300	1.18	Bromide
I_2''(gas)	20,000	0.87	Iodide
I' (liquid)	14,600	0.63	Iodide
I' (solid)	13,200	0.57	Iodide
S'' (solid)	− 5,100	−0.22	Sulphide
Se'' (met.)	−17,900	−0.78	Selenide

INDUSTRIAL ELECTROLYTIC PROCESSES

184. Electroanalysis. As to electroanalysis reference should be had to the book of Edgar F. Smith or to that by A. Classen. The chief reason why electroanalytical methods have found introduction into industrial laboratories is the great ease and the very considerable reduction in time required for an analysis as a consequence of recent improvements mainly due to E. F. Smith and his school. The chief features of these improvements are the use of a rotating anode and of a mercury cathode. The mercury cathode absorbs the metal of the salt solution which is electrolysed. The anode is generally made of such a substance as to absorb the anion. The anode is rapidly revolved to provide such a circulation of the electrolyte that a high current density may be used with a corresponding reduction in the duration of an analysis. Concerning rapid methods of electroanalysis see the latest edition of Smith's "Electroanalysis."

185. Electrotyping. The object of electrotyping is to reproduce printers set-up type, engravings, medals, etc. A mould of the object to be reproduced is first made, for instance of wax, by impressing the object in wax. If the mould is a non-conductor of electricity, as in the case of wax, its surface is made conducting by giving it, with a brush, a coating of plumbago (graphite). (Instead of a plumbago coating, the mould may receive a metallic coating, for instance of copper as follows: Pour copper sulphate solution over the surface of the mould and dust on it from a pepper-box very finely divided iron filings, brushing the mixture over the surface.) By suitable electrical connections of clamps or wire to the surface of the mould the latter is then made cathode in an electroplating bath, which is made up by preparing an 8 to 10 per cent. solution of sulphuric acid in water and dissolving in it copper sulphate until the resulting solution is saturated at ordinary temperatures. The solution is maintained saturated by adding some crystals of copper sulphate, or by using a copper anode. In the case of reproducing type matter, always two cases containing prepared moulds are suspended back to back between two large copper anodes so that the conducting surfaces of the moulds directly face the anodes. The thickness of the copper deposit depends on the product of current (in amperes) and time; a certain circulation of the electrolyte is useful for the same reasons as in electroplating (see below). The copper shell is then separated from the mould on which it is deposited, and in order to give it the necessary strength for further use it is backed with type-metal.*

ELECTROPLATING

186. General principles of electroplating. The object which is to receive a coating of a metal, is employed as cathode in a solution of a salt of this metal. The anode may either be soluble and consist of the same metal or it may be inert; the object of the former arrangement is to get as much metal dissolved from the anode as is deposited upon the cathode

* Description of a modern electrotyping plant in *Met. & Chem. Eng'ing*, Vol. X, p. 442.

hydrogen) is plated out. The exact calculation of the decrease of concentration at the cathode resulting from the passage of a certain number of ampere-hours, for copper-plating with copper anodes and a sulphate solution was given before in the discussion of Hittorf's transport numbers. In any case, the higher the current density the quicker is the loss from the solution at the cathode of the metal ions to be plated out and the smaller is the chance for diffusion and convection currents to bring fresh concentrated solution to the cathode surface where it is needed. The higher the current density, the greater is, therefore, the importance of artificial circulation or stirring; for this purpose either one or both electrodes may be revolved or a special stirring device may be employed in the solution. It seems, for instance, that with a smooth copper, zinc or nickel cathode, a good copper, zinc or nickel deposit can be obtained, however high the current density may be raised, if only the cathode is revolved at an increasing and sufficiently high speed. Heating also aids circulation.

190. Junction between the metals. In contradistinction to electrotyping it is very important in electroplating to get a deposit which will stick to the metal on which it is plated. There must be an intimate junction between the two metals and, according to L. Kahlenberg (*Electrochemical Industry*, Vol. I, p. 201), this requires that the two metals form an alloy together. Thus nickel may be successfully plated on copper and its alloys (brass, bronze, etc.), since with these nickel alloys readily. On the other hand, if an object of lead is to be nickeled, it is first copper plated and then the nickel is deposited on the copper because copper alloys better with lead than does nickel.

191. In order to make the deposit stick to the metal underneath, it is also of fundamental importance that the surface metal before being plated is carefully cleaned both mechanically and chemically, and that all traces of fat and oil, etc., are thoroughly removed. To remove grease, a caustic soda solution or a caustic potash solution is suitable, the latter being preferable. Acid solutions for cleaning gold, silver, copper, brass and zinc surfaces are being recommended by Trevert as follows:

	Copper	Zinc	Silver	Iron
Water	100	100	100	100
Nitric acid	50	—	10	2 to 3
Sulphuric acid	100	10	—	8 to 12
Hydrochloric acid	2	—	—	2 to 3

192. The plating bath contains principally the salt of the metal which is to be plated out, together with the addition of a solution of high conductivity, so as to reduce the voltage drop. However, other additions have also been found useful, for the following reasons: At moderate current densities a bad deposit is practically always due to the precipitation of a non-metallic solid with the metal, especially of an oxide, hydroxide or basic salt of the metal. Whatever will dissolve the oxide, etc., readily under the conditions of the operation will prevent its deposition and should therefore improve the quality of the deposit. W. D. Bancroft ("Transactions International Electrical Congress," St. Louis, Vol. II, p. 27, and *Transactions* American Electrochemical Society, Vol. VI) shows that a large majority of the more important additions recommended for various plating baths act in the way just described.

193. Securing fine-grained deposits. It seems that a fine-grained deposit is favored by high-current density and potential difference, by acidity and alkalinity and by low temperatures. Solutions containing oxidizing agents appear to yield small crystals while larger crystals are obtained from solutions containing reducing agents.

194. To prevent the formation of "trees" a very small addition of a colloid has been found useful in several cases. In the deposition of lead from a solution of lead-fluosilicate, containing an excess of fluosilicic acid, A. G. Betts found that the formation of trees and the deposition of spongy lead could be completely avoided and the deposition of perfectly solid and dense lead could be assured by the simple addition of a very small amount of gelatine or glue added to the bath. Similar observations have been made with silver and copper. The general rule seems to be that density may be raised to 0.02 to 0.08 amp. per sq. cm. and with moderate circulation of the electrolyte good deposits 1 mm. thick may be obtained.

198. Difficulties in nickel plating. A difficulty in nickel plating was formerly found in the fact that the nickel anodes do not dissolve freely in the nickel-ammonium sulphate solution. Cast nickel anodes are said to dissolve better than rolled nickel anodes. For the same reason it is important to use as large a surface of nickel anodes as possible. This has led to the introduction of corrugated anodes, etc., and it has been recommended to make the nickel anode surface $\frac{3}{2}$ times the surface to be plated. W. D. Bancroft has recently suggested (*Transactions* American Electrochemical Society, Vol. IX, p. 217) that the greater effectiveness of the cast nickel anodes is due to the fact that they contain iron. For this reason they will dissolve better, but iron will also pass into solution, which is a disadvantage. He recommends the use of a pure nickel anode in a nickel-ammonium sulphate solution containing a slight percentage of ammonium chloride or nickel chloride. If this addition is made, the nickel will dissolve as quickly from the anode as it is plated out on the cathode. If iron is to be nickeled it should first receive a coating of copper.

199. Silver plating.* The standard solution for silver plating is the double cyanide of silver and potassium, with silver anodes. As to working on a large scale and the production of the silver cyanide from silver nitrate and potassium cyanide and the production of the double cyanide from silver cyanide and potassium cyanide the reader must be referred to special textbooks. A good silver plating solution is obtained by dissolving 25 g. pure silver cyanide in a solution of 25 g. potassium cyanide in 300 to 500 cu. cm. water and diluting the solution so as to form 1 liter. The best current density is 0.001 to 0.0045 amp. per sq. cm., with about 1 volt at the terminals of the cell. Another prescription for experimental work is to dissolve 3 oz. of silver chloride (rubbed to a thin paste with water) in a solution of 9 to 12 oz. of 98 per cent. potassium cyanide in a gallon of water. A current density of $\frac{1}{10}$ amp. per sq. in. is recommended in the latter case.

200. Gold plating.† The standard solution is the double cyanide of gold and potassium and the problems involved in gold plating are similar in many respects to those of silver plating. In view of the expensive material involved, great care is necessary in details and the reader must be referred to special books on the subject. Gold is generally plated on copper; other metals to be coated with gold first receive a coating of copper; see also (207).

201. Copper plating.‡ A copper sulphate solution, containing free acid, such as is used for electrolytic refining of copper, may be used for copper plating (see 206), but better results are obtained with a cyanide solution. van Horne gives the following formula: to each gallon of water add 5 oz. copper carbonate, 2 oz. potassium carbonate and 10 oz. chemically pure potassium cyanide. Dissolve about nine-tenths of the cyanide of potassium in a portion of the water and add nearly all of the copper carbonate, previously dissolved in a portion of the water; then add the potassium carbonate, also dissolved in water, slowly stirring until thoroughly mixed. Bring the solution to 160 deg. Beaumé, put in a small article and test the solution, adding cyanide or copper or both, until the solution deposits freely and uniformly.

F. Foerster recommends for copper plating a solution made as follows: 20 g. copper acetate are dissolved in 500 cu. cm. water, 20 g. potassium cyanide, 25 g. sodium sulphite crystals and 17 g. sodium carbonate crystals are dissolved in another 500 cu. cm. water. The first solution is then added to the second one and a current density of 0.003 amp. per sq. cm. is used with 3 volts at the terminals of the cell.

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* A voluminous summary of all recipes for electroplating silver on metals is given in a paper by F. C. Frary, *Transact.* Am. Electrochem. Soc., Vol. XXIII, p. 25.

† All recipes for gold plating are collected in the paper by F. C. Frary, *Transact.* Am. Electrochem. Soc., Vol. XXIII, p. 25.

‡ A summary and classification of the different solutions for copper plating is given in a paper by C. W. Bennett, *Transact.* Am. Electrochem. Soc., Vol. XXIII, p. 233.

of a metallic coating from the surface of an article. This is generally carried out as an anodic reaction. The most important industry in this field is the detinning of tin scrap, which has assumed quite considerable dimensions in recent years as a consequence of the enormous growth of the tin-can industry. While formerly only the tin scrap of the tin-can factories (a pure material, consisting of sheet iron, covered with tin) was treated, the treatment of tin cans, tin boxes, etc., which have been in use, has recently been taken up on a commercial scale; since they contain many impurities, these must first be very thoroughly removed (carbonized, etc.).

The object of the electrolytic process is to remove the tin from the iron so as to get both the tin and iron separate and pure. The iron is sold as scrap to open-hearth steel works, etc., and must therefore be absolutely free from tin and in good condition. The process which has been most successful on a very large scale is that of the firm of Theodor Goldschmidt in Essen; it is a secret process and employs the scrap as anode in a solution of caustic soda. Since 1906 detinning with chlorine has entered into competition with electrolytic detinning. Detinning with chlorine may be considered as an electrolytic process only in so far as electrolytic chlorine (see **230**) is used. While the products of electrolytic detinning are tin and iron, those of chlorine detinning are tin tetrachloride and iron. (Karl Goldschmidt, *Electrochem. & Met. Ind.*, Vol. VII, p. 79.)

206. Other stripping processes. A comparatively small, but interesting application of electrolytic stripping is the process of C. F. Burgess for removing from bicycle frames the films of brass which are left there from brazing the joints. A sodium nitrate solution is used for this purpose. (For this and similar processes see C. F. Burgess, *Electrochemical Industry*, Vol. II, p. 8.) As an example of the cathodic removal of a surface coating, the process of C. J. Reed for removing an oxide scale from iron and steel may be mentioned. The iron sheets, rods or wire are treated as cathode in a 27 per cent. solution of sulphuric acid of specific gravity 1.20, with a current density of 0.25 to 0.5 amp. per sq. in. at a temperature of 60° C. Under these conditions the heavy scale on rolled iron rods is removed in from 2 to 3 min. The iron oxide is not reduced to metallic iron, but to a lower state of oxidation and is then dissolved, ferrous sulphate being produced. (*Transactions* American Electrochemical Society, Vol. XI.) Concerning the sharpening of tools by electrolytic etching see Schneckenberg, *Met. & Chem. Eng'ing*, Vol. IX, p 512.

ELECTROLYTIC REFINING OF METALS

207. Fundamental principles. In electrolytic refining of metals the starting material is a highly concentrated alloy and the purpose is to remove the last impurities and to recover not only the principal metal in pure form, but also the foreign metals, especially the precious metals. The impure metal is made the anode and the fundamental principle of the process is that by the electrolytic action the metal to be refined is dissolved from the anode, passes into the electrolyte and is deposited from the electrolyte on the cathode in pure form; the foreign metals (impurities) are intended either to remain back in the anode or anode slime without being dissolved, or if they are dissolved in the electrolyte, they are intended to remain in the electrolyte without being deposited on the cathode. This cannot be satisfactorily accomplished, except with a comparatively pure, high-grade anode; in American practice of copper refining the impure copper anode is generally 98 to 99.5 per cent. pure. The cost of the electrolytic-refining process is covered first by the higher price of the refined metal and secondly by the value of the foreign metals recovered, especially silver and gold.

208. Copper refining. The electrolyte is a copper sulphate solution containing free sulphuric acid. The copper should not exceed 3 per cent. at the most, or 12 per cent. if figured as bluestone. The acid may advantageously be run up to about 13 per cent.* (Usually a very small amount of a soluble chloride, like NaCl, is added to precipitate as chloride

* Figures of the conductivity of mixtures of copper sulphate and sulphuric acid are given by Richardson and Taylor in *Trans.* Amer. Electrochem. Soc., Vol. XX, p. 179.

See also the monograph of T. Ulke on modern electrolytic copper refining. Concerning treatment of the slimes of copper refineries see below under silver refining, also Kern, *Met. & Chem. Eng'ing*, Vol. IX, p. 417. A full description of the Great Falls refinery is given by Burns in *Bulletin* American Inst. Min. Engrs., August, 1913, p. 2011. Concerning the power problem in electrolytic copper refining see papers by Addicks, Longwell, and Newbury, Transact. Amer. Electrochem. Soc., Vol. XXV.

212. Silver refining. The chief commercial problem of silver refining relates to the treatment of the bullion produced by copper refineries, to recover the silver and gold. This bullion may be treated either with the old sulphuric acid parting process or electrolytically by one of the following methods (for a critical comparison see F. D. Easterbrooks, *Transactions* American Electrochemical Society, Vol. VIII, p. 125). In the electrolytic methods the electrolyte is a silver nitrate solution.*

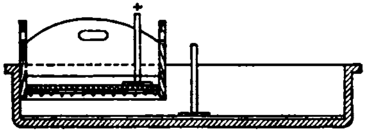

Fig. 7.—Balbach Cell.

213. Balbach process. The cross-section of a tank is shown in Fig. 7. The cathode is made of ½-in. Acheson graphite slabs fitted to the bottom. Two silver contact pieces rest respectively on the bullion to be parted and the graphite slabs. Bullion cast in thin square slabs is contained in a cloth case which is supported on a wooden frame suspended over the tank. The gold slimes accumulate on the under side of the bullion, between it and the cathode, increasing the resistance as the operation continues. Each tank has a cathode surface of 8 sq. ft., and a current density of 20 to 25 amp. per sq. ft. is used. The voltage averages 3.8 per tank, and an average ampere-hour efficiency of 93 per cent. is obtained on a continued run, while occasionally an efficiency of 98 per cent. is secured. The energy required is 31.5 watt-hr. per oz. of fine silver produced. At 20 amp. per sq. ft. about 32 per cent. of the daily output of each tank is held permanently in stock in electrolyte and contacts. (For a description of the Balbach refinery see *Electrochemical Industry*, Vol. II, p. 302.) Thum's modification of the Balbach process, as employed on the Raritan Copper Works, is described by Easterbrooks in *Electrochem. & Met. Ind.*, Vol. VI, p. 277.

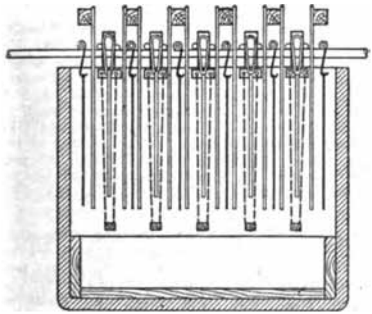

Fig. 8.—Moebius Cell.

214. Moebius process. The cross-section of a tank is shown in Fig. 8. They are arranged in units of 6 placed end to end, each unit being provided with apparatus for raising the boxes containing the deposited silver together with the anodes and cathodes, and with arrangements for imparting a reciprocating motion to the wooden scrapers. There is no system of circulating the electrolyte, but the scrapers moving back and forth agitate it. The anodes are contained in a cloth frame which holds the gold slimes, and the silver is brushed off from the silver cathodes by the wooden scrapers, and drops into a box with hinged bottom. It is removed by raising the boxes above the top of the tanks and emptying them into a tray placed beneath. This operation requires ½ hr. per day per unit. Each tank has a cathode surface of about 16.5 sq. ft., and a current density of 20 to 25 amp. per sq. ft. is used. The voltage

* See also Kern, *Met. & Chem. Eng'ing*, Vol. IX, p. 443.

tails of electrolysis as carried out in England are not known; see, however, E. Guenther's "Darstellung des Zinks auf Elektrolytischem Wege." The latest advance* of the Siemens & Halske Co. in this field is the use of manganese peroxide anodes. The power consumption is 3.4 kw-hr. per kilogram Zn.

220. Iron refining. The **Burgess process** employs a solution of ferrous and ammonium sulphates with a cathodic current density of 6 to 10 amp. per sq. ft. and a slightly smaller anodic current density. The e.m.f. for each cell is slightly under 1 volt; the temperature of the electrolyte is about 30 deg. cent.; the anodes consist of ordinary grades of wrought iron and steel; the starting sheets for the cathode are of thin sheet-iron, previously cleaned of rust (*Electrochemical Industry*, Vol. II, p. 183). See also E. F. Kern, *Transactions*. Am. Electrochem. Soc., Vol. XIII.

As an electrolytic iron-refining process and as a plating operation may be considered the process of Cowper-Coles† for the production of iron sheets and tubes of nearly pure iron from anodes of pig iron. The electrolyte is a concentrated solution of ferrous chloride with addition agents.

221. Tin refining. According to the **Claus process** raw tin is electrolyzed in a 10 per cent. sodium sulphide solution at a temperature of more than 80 deg. cent. with a current density of 0.5 amp. per sq. dm. at a voltage at the electrodes below 0.2 volt. Pure tin plates or plates coated with pure tin must be used as cathodes. The anodes contain at least 90 per cent. tin: no circulation of electrolyte. Before introducing new tin anodes into the cell, it is necessary to dissolve in the electrolyte about 1 per cent. of its weight of sulphur, preferably in form of flowers of sulphur (O. Steiner, *Electrochemical and Metallurgical Industry*, Vol. V, p. 309).

222. Bismuth refining. The electrolyte is bismuth chloride containing free hydrochloric acid (7 per cent. Bi and 9 to 10 per cent. HCl). The cathodic current density is 20 amp. per sq. ft., the anodic current density is three times this amount, the voltage at the electrodes is 1.2. Silver and gold remain at the anode, but traces of the silver pass into the bismuth deposit. The anodes contain over 90 per cent. Bi, besides lead, silver, etc. The product is 99.8 per cent. pure, the chief impurity being silver. The arrangement of the cell is the same as in the Balbach silver-refining process. (A. Mohn, *Electrochemical and Metallurgical Industry*, Vol. V, p. 314.)

223. Cadmium refining. A cadmium sulphate solution containing free acid is electrolysed with a current density of 0.005 to 0.02 amp. per sq. cm. (F. Mylius and R. Funk, *Zeit, f. Anorgan. Chemie*, Vol. 13, p. 157.)

224. Miscellaneous refining processes. Cobalt is stated to be deposited from its sulphate and chloride solutions with the same ease and under the same conditions as nickel. Concerning **thallium** see F. Foerster "*Zeit, f. Anorg. Chemie*," Vol. 15, p. 71. Concerning **chromium** see M. Le Blanc's "Production of Chromium," (English translation by J. W. Richards), also Carveth and Mott, and Carveth and Curry, *Jour. Physical Chemistry*, Vol. IX, pp. 231 and 353, Le Blanc, *Transactions* of the American Electrochemical Society, Vol. IX, p. 315.

PRODUCTION OF HYDROGEN AND OXYGEN GASES BY ELECTROLYSIS OF WATER

225. General theory. In the electrolytic decomposition of water, as carried out on an industrial scale for the production of oxygen and hydrogen gases, instead of pure water which has too low an electric conductivity, either a 20 per cent. solution of sulphuric acid or a 15 per cent. solution of caustic soda is used as electrolyte, these concentrations corresponding to maximum conductivity. If sulphuric acid is used, the cathodic reaction is the dicharge of hydrogen ions and the setting free of hydrogen gas, while the anodic reaction may be written

$$SO_4'' + H_2O = H_2SO_4 + O, \tag{35}$$

so that oxygen gas is set free and sulphuric acid is reformed. The quantity of sulphuric acid, therefore, remains constant and only water disappears.

* Engelhardt. *Met. & Chem. Eng'ing*, Vol. XI, p. 43.
† Palmaer and Brinell. *Met. & Chem; Eng'ing*, Vol. XI, p. 197.

first partial reaction consumes energy, hence it requires that a certain voltage be impressed on the cell from the outside. The second partial reaction evolves energy. Hence the total reaction requires energy equal to the difference of the energies of the two partial reactions. The voltage at the terminals of the whole is less than that required for the first partial reaction alone.

Newer mercury cathode cells are the Whiting cell and* the Wilderman cell.† The advantages of mercury cathode cells are high purity and high concentration of caustic soda with reduction of evaporation charges, and high ampere-hour efficiency. The drawbacks are comparatively high voltage and the first cost of the mercury.

231. Fused-lead-cathode process. While in the mercury-cathode cell an aqueous solution of sodium chloride is electrolysed, the fused-lead-cathode process (C. E. Acker) employs an electrolyte of fused sodium chloride. The sodium alloys with the fused lead. This alloy is carried off and decomposed in another vessel by means of a jet of steam. The principle is exactly analogous to the mercury-cathode process (C. E. Acker, *Transactions* American Electrochemical Society, Vol. I, p. 165). The process is no longer in commercial operation.

232. In the Glocken process or bell-process or gravity-process the anode is contained in a bell-formed non-conducting receptacle, open at the bottom and thereby in connection with the outside cathode compartment surrounding the bell. By force of gravity the anodic and cathodic products are held automatically separate and prevented from mixing and are continually carried off. Fresh saturated NaCl solution is continually supplied to the anode compartment (bell) and passes downward and prevents the OH ions from reaching the anode (O. Steiner, *Electrochemical and Metallurgical Industry*, Vol. V, p. 171).

233. In the Billiter-Leykam cell‡ the bell process has been modified by placing the cathodes (hooded to collect the hydrogen) immediately underneath the bell jar, and not around its sides.

234. In the diaphragm processes§ which are the oldest ones and of which there are quite a number, the electrolytic cell is divided into an anode compartment and a cathode compartment by means of a porous diaphragm which prevents the mechanical mixing of the two solutions. If the chloride solution is supplied to the cathode compartment, the solution cannot be highly saturated with caustic without trouble being produced by the OH ions passing to the anode. The only large industrial process in which this arrangement is used is the Griesheim Elektron process‖ used in Germany.

In most **other diaphragm cells** saturated sodium chloride solution is introduced into the anode compartment so as to flow through the diaphragm toward the cathode and counteract the tendency of the OH ions to pass to the anode. This is the case, for instance, in the cells of LeSueur, McDonald and others. A comparatively very small cathode compartment of special construction is the feature of the Hargreaves-Bird cell. This principle is carried still further in the Townsend cell, in which the cathode compartment contains no electrolyte whatever, but liquid kerosene. The caustic as soon as formed is absorbed in the kerosene and carried off. (C. P. Townsend, *Transactions* American Electrochemical Society, Vol. VII, p. 63; L. Baekeland, *Electrochemical and Metallurgical Industry*, Vol. V, p. 209 and Vol. VII, p. 313.)

Almost all diaphragm cells use vertical diaphragms. An exception is the Billiter-Siemens & Halske cell¶ in which horizontal diaphragms are used.

235. Data on alkali-chlorine cells. Allmand ("Principles of Applied Electrochemistry," p. 383) gives the following comparative table of electrochemical data of different alkali-chlorine cells, which holds for those conditions under which the cell in question is normally worked. Concerning

* *Transactions* Amer. Electrochem. Soc., Vol. XVII, p. 327.
† *Met. & Chem. Eng'ing*, Vol. XI, p. 628.
‡ *Met & Chem. Eng'ing*, Vol. XI, p. 20.
§ Theory by Guye, *Jour. Chim. Phys.*, Vol. I, pp. 121 and 212, Vol. II, p. 79, and Vol. V, p. 398.
‖ Lepsius. *Chem. Zeit.*, Vol. XXXIII, p. 299.
¶ *Met. & Chem. Eng'ing*, Vol. XI, p. 19.

cathodic products must be kept separate, the reverse requirement must be fulfilled for the electrolytic production of hypochlorites (bleaching liquors) by electrolysis of sodium chloride. Sodium hypochlorite is the result of the reaction of chlorine on caustic soda. To obtain the hypochlorite in the electrolytic cell itself, the electrodes are placed near together and the electrolyte is maintained in steady motion in order to mix the anodic and cathodic products together. For a description of commercial cells for the production of bleaching liquor see W. H. Walker, *Electrochemicol Industry*, Vol. I, p. 439; Engelhardt and Abel, "Hypochlorite and Elektrische Bleiche," 2 volumes; Allmand, "Applied Electrochemistry," pp. 318 335. Concerning cost of operation see Engelhardt, *Met. & Chem. Eng'ing*, Vol. IX, p. 489.

Allmand's table (Par. 239) gives typical results yielded by different electrolysers. They cannot be very closely compared, owing to varying conditions, but give an idea of the relative capabilities of the different types.

Concerning the Digby hypochlorite cell see *Met. & Chem. Eng'ing*, Vol. IX, p. 328.

241. Chlorate. The production of chlorate by electrolysis of sodium chloride requires interaction between caustic soda and chlorine under the conditions of a moderately high temperature, above 40 deg. cent. and an absence of reducing conditions. For the latter purpose the addition of chromate has been found especially useful. No diaphragms are used in modern chlorate cells (see the German monograph by Kershaw and Huth; also Allmand, Applied Electrochemistry, pp. 335–341). As to the use of electrolytically produced acid and alkali (obtained by electrolysis of a solution of chlorate or perchlorate of sodium) for producing bichloric phosphate fertilizers see Palmaer, *Met. & Chem. Eng'ing*, Vol. X, p. 581.

ELECTROLYSIS OF CHLORIDES OF COPPER, NICKEL AND ZINC

242. Reduction of copper-nickel matte. Besides the electrolysis of alkaline chlorides, which is now carried out on a very large industrial scale in the numerous processes, sketched above, chloride electrolysis has also been attempted in the metallurgy of copper, nickel and zinc. (Concerning the early work of Hoepfner in this field see Wm. Koehler, *Electrochemical*

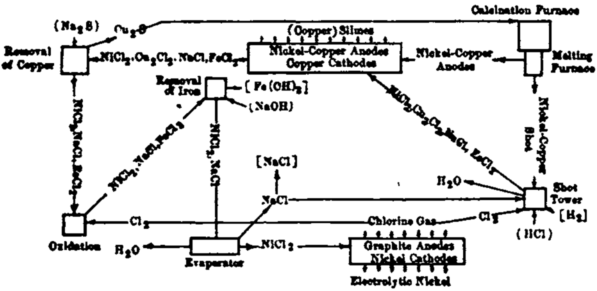

Fig. 9.—Separation of nickel and copper.

Industry, Vol. I, pp. 540, 568.) Success has been attained in this field by D. H. Browne for **separation of the nickel and copper from copper-nickel matte,** the scheme of the process being indicated in Fig. 9. The matte is roasted and melted and one-half of the fused copper-nickel is poured into anode form, the other half is poured into water, thus giving copper-nickel shot of a weight equal to that of the anodes. The anodes are placed in the nickel-copper chloride bath; the copper-nickel shot is brought into the shot tower in which the electrolyte for the copper-depositing baths is made. In these baths pure copper is deposited on the cathodes, nearly all the copper being separated from the nickel in solution. The small amount of copper remaining in solution is removed by means of sodium sulphide. The solution which is now a mixture of $NiCl_2$, NaCl, and a small amount of $FeCl_2$

the most important electrochemical industry. In the processes of Hall and Héroult the electrolyte is a fused solution of alumina (as solute) in the double fluoride of aluminium and sodium (as solvent). Carbon anodes are used, while the melted aluminium metal in the bottom of the pot forms the cathode. The temperature is 900 deg. cent. The alumina is decomposed by the current and fresh alumina is added at intervals to the bath. According to J. W. Richards the production of 1 kg. of aluminium requires 22 kw-hr. Aluminium is used for the manufacture of various utensils, for all purposes where lightness is an advantage, and especially for electric conductors as a substitute for copper. J. W. Richards' "Aluminium" is the standard book on this metal: concerning the theory of the process a different view is defended in the book by Minet, translated by L. Waldo.* According to the U. S. Geological Survey, the production of aluminium in the United States was 61,281 lb. in 1890; 920,000 lb. in 1895; 7,150,000 lb. in 1900; and 11,347,000 in 1905. It is estimated that the output in 1906 was 30 per cent. greater than the output in 1905, but a much greater rate of increase is expected in the future.

247. Properties of aluminium cells. The property of aluminium electrodes to let electricity pass in one direction (when the aluminium electrode is cathode), but not in the other, is made use of in **electrolytic rectifiers.** A. Nodon ("Transactions of the International Electrical Congress," St. Louis, 1904, Vol. I, p. 510) employs a neutral solution of ammonium phosphate in water as the electrolyte, with aluminium as one electrode and the other electrode of lead or polished steel. C. F. Burgess and Carl Hambuechen (*Transactions* American Electrochemical Society, Vol. I, p. 147) use a fused electrolyte of molten sodium nitrate with an aluminium and an iron electrode. If two aluminium electrodes are used, the system represents an **electrolytic condenser** (C. I. Zimmerman, *Transactions* of the American Electrochemical Society, Vol. VII, p. 309). This valve effect of the aluminium electrode is also made use of in the **electrolytic lightning-arrester** (see R. P. Jackson, *Electrical Journal*, August, 1907).

248. Metallic sodium is produced on a large scale by the **Castner process** from a fused NaOH electrolyte at a temperature not more than 10 or 15 deg. cent. above the melting point (which is at 308 deg. cent.). A gauze or screen is provided between the electrodes and a superposed dome for collecting the metallic sodium.

249. The Ashcroft process produces **sodium** from common salt in a double cell of the following construction. In the first half of the cell fused sodium chloride is electrolyzed with a carbon anode (at which chlorine is liberated) and a fused lead cathode (which absorbs the sodium). The same fused sodium-lead alloy forms the anode in the second half of the cell, fused NaOH being the electrolyte and the cathodes consisting of iron or nickel. In this second half of the cell sodium passes from the sodium-lead alloy into the bath and is deposited at the cathode, the fused bath remaining of constant composition. The first half of the process is in principle analogous to the Acker process, the second half to the Castner process, but with the exception that as much NaOH is formed back at the fused sodium-lead anode as is decomposed. The total result of the process is given by the simple equation $NaCl = Na + Cl$ (*Electrochemical and Metallurgical Industry*, Vol. IV, p. 218). (A good summary of various sodium processes is given by C. F. Carrier, Jr., in *Electrochemical and Metallurgical Industry*, Vol. IV, pp. 442 and 475; also *Met. & Chem. Eng'ing*, Vol. VIII, p. 253.) The yearly production of sodium in the world (1906) is about 3,500 tons, of which 1,500 tons are used for making cyanide, 1,500 for peroxide and 500 are sold as metal.

250. Magnesium is produced by electrolysis from a fused dehydrated bath of carnalite, *i.e.*, a double chloride of potassium and magnesium or from a fused bath of magnesium chloride (Tucker and Jouard, Transact. Amer. Electrochem. Soc., Vol. XVII, p. 249).

251. Calcium is made by a process of the Allgemeine Elektricitats Gesellschaft by electrolysis of fused calcium chloride, the cathode being continually and slowly raised during process of electrolysis so that its end always just touches the surface of the bath (J. H. Goodwin, *Electro-*

* See also Neumann and Oesen, *Met. & Chem. Eng'ing*, Vol. VIII, p. 185; Clacher, Vol. IX, p. 146.

Lovejoy, Birkeland and Eyde, Schoenherr (Badische Company) and Pauling, all of which use electric discharges through air to produce a very high temperature. The object of the spark or arc is simply to produce the very high temperature required for the combination of the nitrogen with oxygen, which would go on in the same way if the same high temperature was produced by some other means. The gas mixture of air and nitrogen oxides thus produced is then treated with water or with alkaline solution (caustic soda, lime water, etc.) to give dilute nitric acid, nitrates, or a mixture of nitrates and nitrites.

The higher the temperature, the greater is the content of nitric oxide produced in the air and the quicker is the transformation. This is the reason why the electric arc is so effective. Besides the necessity of producing a high temperature, the second chief requirement is to remove the nitrogen oxide formed as quickly as possible from the high temperature zone and to cool it down as rapidly as possible; the reason is that with decreasing temperatures the opposite reaction takes place and the nitric oxide dissociates into nitrogen and oxygen, so that if the cooling of the mixture of air and nitric oxide is too slow the latter will break up into its constituents. Haber has shown, however, that at low temperatures the formation of nitrogen oxide by means of electric discharges cannot be considered as a purely thermal phenomenon; there seems to be a specific electric effect superposed upon it. At the temperature used in the commercial processes the thermal theory sketched above seems to hold strictly true.*

259. In the Bradley-Lovejoy process† mechanical means (rotation of a wheel carrying one set of electrodes which continually pass along an opposite and stationary set of electrodes) are employed to make and break continuously sparks (6,900 sparks per sec.) in the space through which the air is passed. While this process, which was tried for some years at Niagara Falls without attaining final commercial success, represents the era of the spark furnace, the desire to get larger units led to the construction of arc furnaces. The different types differ essentially in the way by which the produced gas mixture is quickly removed from the gas zone.

260. In the Birkeland-Eyde process‡ the arc is deviated magnetically by means of a single-phase magnet field, until the arc breaks; then a new arc is formed, etc. The Birkeland-Eyde process has been in successful commercial operation since 1905 in Norway (electric energy being very cheap at the plant, 0.094 cent per kw-hr.).

261. The Schoenherr furnace. The Badische Company used successfully for a time the Schoenherr furnace,§ the characteristic feature of which is the use of a very long alternating-current arc around which the air moves in a helical path. This plant has been taken over by the Birkeland-Eyde interests which now use exclusively the Birkeland-Eyde furnace as it has a higher efficiency in larger units.

262. Pauling process. Two plants in Tyrol and in France employ the Pauling process,‖ using electric discharges quite similar to those obtained in a horn lightning arrestor. The results obtained in these three commercial processes were given in 1909 as follows (no later data being available):

	Grams HNO_3 per kw-hr.	Concentration in per cent. NO
Schönherr	75	2.5
Birkeland-Eyde	70	2
Pauling	60	1 to 1.5

* For a concise summary of the thermodynamical principles of the problem see, for instance, *Mineral Industry*, Vol. XIX, p. 58; also Guye, *Electrochem. & Met. Ind.*, Vol. IV, p. 136.

† *Electrochem. Ind.*, Vol. I, pp. 20 and 100.

‡ *Electrochem. Ind.*, Vol. II, p. 399; Vol. IV, pp. 295 and 360; Vol. VII, pp. 304, 305; *Met. & Chem. Eng'ing*, Vol. IX, pp. 340, 364, 436, 545; Vol. X, p. 617

§ *Electrochem. & Met. Ind.*, Vol. VII, p. 245; *Met. & Chem. Eng'ing*, Vol. IX, p. 73.

‖ *Electrochem. & Met. Ind.*, Vol. VII, p. 430; *Met. & Chem. Eng'ing.*, Vol. IX, pp. 99 and 196. Concerning an experimental plant in North Carolina see *Met. & Chem. Eng'ing*, Vol. VIII, p. 555.

nvestigate the Zinc Resources of British Columbia" (Canadian Government publication, 1906, pp. 82 to 118) and in C. G. Gunther's book on "Electromagnetic Ore Separation." See also Ruhoff, *Met. & Chem. Eng'ing*, Vol. X, p. 278.

266. Electrostatic ore separators. The action of electrostatic separators depends on the difference in electric conductivity of the constituents of the ore mixture. According to the conductivity, the electrostatic charge acquired by the different constituents from the same source of electric charge in the same time is different. If the mixture consists of a finely crushed non-conductor and a finely crushed conductor and is brought in contact with a charged surface, the latter will receive a charge while the former remains uncharged. Electrostatic repulsions of the charged particles from the charged surface will then result, while the uncharged particles are not repelled. (See paper by Blake in *Electrochemical and Metallurgical Industry*, Vol. III, p. 181; MacGregor, *Transact.* Am. Electrochem. Soc., Vol. XVIII, p. 267, and Vol. XXIV; Wentworth, *Met. & Chem. Eng'ing*, Vol. X, p. 167.)

267. Dust precipitation by electrostatic means. The Cottrell process* is based on the old familiar phenomenon of the "electric wind." If a metallic needle point is placed opposite a flat metallic plate and the needle is connected to one pole and the plate to the other pole of a high-voltage direct-current supply line, electricity streams out of the needle point and charges the gas molecules in the space between needle and plate. The gas molecules thus receive an electric charge of the same sign as the needle point, hence opposite to the sign of the charge of the plate. They are, therefore, attracted by the plate and move toward it. Now if the space between the needle point and the plate is filled with a gas or fume in which particles of dust, etc., are suspended, these dust particles will be immediately charged with electricity and will, therefore, move toward the plate, stick to it and give up their charges. The speed of movement of the particles is proportional to their charge and to the electrostatic field intensity in the space between point and plate. Cottrell uses this principle for the precipitation of dust particles from smelter fumes, etc. He employs ordinary commercial high-voltage alternating-current and converts it into intermittent direct-current by means of a specially designed synchronous converter. This intermittent direct-current is directly used for charging the system of electrodes (needles and plates) in the flues which carry the gas under treatment. Instead of using needle points he twists asbestos filaments or mica scales with wires. The electricity passes from the wires by surface leakage over the asbestos or mica, and the fine filaments of the asbestos or edges of the mica provide the required (very fine) discharge points. The process is in successful use in smelters,† cement plants,‡ etc.

268. Smoke prevention. The same principle has been proposed for the electric precipitation of smoke (A. F. Nesbit, Elec. Rev., Oct. 31, 1914, p. 877).

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269. One of the best all-around books in English on industrial electrochemistry is Allmand's Principles of Applied Electrochemistry. Other general books are N. Monroe Hopkins, Experimental Electrochemistry; W. G. McMillan and W. R. Cooper, A Treatise on Electro-metallurgy; F. Mollwo Perkin, Applied Electrochemistry; M. de Kay Thompson, Applied Electrochemistry.

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SECTION 20

BATTERIES

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CONTENTS

(*Numbers refer to Paragraphs*)

the copper sulphate in contact with the copper plate of a Daniell or gravity cell, or the slightly soluble mercurous-sulphate paste of the standard Clark or Weston cell.

(b) A chemical compound is present at the negative plate, which is capable of furnishing negative ions to the solution because of its metal constituent possessing different valencies. Examples are the manganese peroxide of the Leclanché or dry cell, and the chromic acid of the bichromate cell. It is of advantage that such depolarizers be relatively insoluble, in order that they do not come in contact with the zinc electrode and thereby suffer reduction.

8. Measurement of internal resistance and polarization. The true internal resistance of a cell is obtained from the formula

$$r = \frac{(E - E_p) - V}{I} \qquad \text{(ohms)} \qquad (1)$$

in which E is the total e.m.f. of the cell on open circuit, E_p is the opposing polarization e.m.f. and V is the voltage at the cell terminals. If immediately after breaking the current, the cell voltage is determined by the condenser-ballistic galvanometer method, or otherwise, then $E_p = E - V$.

Upon open circuit, after the delivery of current, the opposing e.m.f. of polarization decreases, at first rapidly and then more slowly, owing to the gradual diffusion of the polarizing substances. The curves, Fig. 1 are typical of a dry cell. The heavy curve shows the gradual drop in voltage, the cell being closed through a constant resistance, while the dotted curve (read in the opposite direction) shows the voltage recovery, with time, after the current ceases. The vertical portion of the recovery curve represents the voltage drop due to internal resistance, the further recovery being due to the gradual equalization of concentrations throughout the electrolyte, or in the pores of the electrodes.

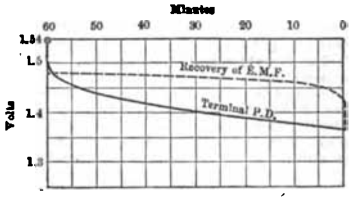

FIG. 1.—Polarization recovery.

9. Local action. In all practical forms of battery, the fundamental reactions are somewhat departed from. Local action takes place, resulting from impurities on one or both the electrodes; this action is of the nature of an elementary short-circuited cell. For example, a zinc electrode always contains impurities such as copper, iron and carbon. Zinc is dissolved, hydrogen gas comes off at the point of impurity, and current flows between the impurity and the point where the zinc enters into solution. This action is reduced by **amalgamating** the surface of the zinc with mercury; this forms a solution of zinc, uniformly covering the surface, and greatly reduces the local action.

10. Electrochemical theory. Two methods may be employed in the theoretical consideration of primary battery phenomena. One, the general thermodynamic method, the other, a mechanical method resulting from the osmotic-pressure theory of solutions. The e.m.f. of a reversible cell may be calculated from the relation

$$E = \frac{JH}{nq_o} + T\frac{dE}{dT} \qquad \text{(volts)} \qquad (2)$$

Where J = mechanical equivalent of heat; H = heat of formation of resultant chemical compound in calories; q_o = charge in C.G.S. units of 1 g. ion, *i.e.*, 9.654 units; n = valency; T = absolute temperature. The first quantity of the right side of the equation is the controlling one, the second usually having a small value. If a cell has a zero temperature coefficient, the e.m.f. can be directly calculated from the heat of formation of the resultant chemical compound of the reaction. The second term may be either positive or negative. The above equation is deduced on the assumption that the cell is reversible, but the voltage of any cell may be closely approximated by its use.

cup and is in a saturated solution of copper sulphate containing excess crystals. The zinc (usually amalgamated) is in the porous cup, which contains sulphuric acid and zinc sulphate solution. The e.m.f. of the cell depends on the concentration of the zinc sulphate in the porous pot, the maximum initial value being about 1.14 volts. The cell may be set up with zinc sulphate solution only in the porous cup in which case the e.m.f. is approximately 1.07 volts and has a very small temperature coefficient. The chemical reaction is $Zn+CuSO_4=ZnSO_4+Cu$. The cell is not adapted to stand on open circuit. When placed out of service the liquids should be poured out and the porous cup should be thoroughly washed in running water until all the zinc sulphate is removed, otherwise the cup will crack on drying.

19. Gravity battery. This cell is the usual modification of the Daniell cell, and is shown in Fig. 3. The porous pot is omitted and gravity is depended upon to keep the heavier copper sulphate solution in the bottom of the cell. The zinc is frequently cast in the form of a "crowfoot" and hangs from the edge of the jar. The copper electrode is made of two or three strips of sheet copper, riveted together and spread out in the bottom of the jar. A rubber-covered wire is fastened to the copper and leads upward out of the cell. Copper-sulphate crystals are placed in the bottom of the jar and zinc sulphate solution is added to cover the zinc. The solution should be poured in carefully, so as not to bring copper sulphate solution in contact with the zinc, as copper would be immediately precipitated on the zinc.

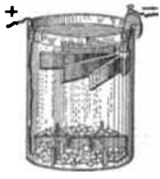

FIG. 3.—Gravity cell.

20. Care of gravity battery. The cell should be kept on closed circuit in order to prevent copper from diffusing upward and precipitating upon the zinc. The edge of the jar should be coated with paraffin to prevent creepage of the zinc sulphate solution. As the top solution becomes saturated with zinc sulphate some of it should be drawn off and carefully replaced with water The copper sulphate solution must not be stirred up. Evaporation may be reduced by covering the solution with a thin layer of mineral oil. If a heavy copper precipitate is present on the zinc, it should be scraped off. A sharp dividing line should be maintained between the two solutions. This can be noted by color difference. At the top should be a light solution, while the copper sulphate is very dark blue. For each ampere hour, the following amounts of materials are theoretically used up or formed—0.042 oz. copper deposited, 0.043 oz. zinc is dissolved, and 0.164 oz. copper sulphate used up. Local action will require at least a 10 per cent. greater amount of zinc and copper sulphate. Note that the increased copper weight should be credited to the cost of upkeep.

21. Bunsen or Grove cell. In the Bunsen cell the zinc plate is in a sulphuric acid solution, while the negative plate is a carbon rod immersed in strong nitric acid, contained in a porous cup. The Grove cell differs from the Bunsen cell only in the use of platinum instead of the carbon. The e.m.f. of this type of cell is about 1.9 to 2 volts and the internal resistance quite low. The cell is adapted for laboratory purposes and can be used for heavy currents. It must not be allowed to stand on open circuit for any considerable time, and must be set up freshly each time it is used.

Vapors of nitric peroxide are given off from the cell and provision must be made for their removal. The chemical reaction of the cell is presented by the equation $Zn+H_2SO_4+2HNO_3=ZnSO_4+2H_2O+2NO_2$.

22. Chromic-acid cell. This cell is in wide use for laboratory purposes. It may be used as a single-fluid cell but the porous-cup form is preferable. The Grenet or plunger type is shown in Fig. 4. Two carbon plates are immersed in a solution of potassium or sodium bichromate, sulphuric acid and water. Potassium permanganate is a fairly satisfactory equivalent to the chromic-acid salt. The zinc plate is between the two carbons when lowered for use. The usual solution is made up as follows: water, 12 lb. concentrated sulphuric acid, 2½ lb. and potassium bichromate, 1 lb. Potassium bichromate gives rise to insoluble crystals of chrome alum and the sodium salt is preferable. Chromic acid, on account of its great solubility is to be preferred over either of the above salts, and the quantity used need be but two-thirds of the weight of either of the salts, required for the same of salammoniac. The e.m.f. is about 1.5 volts but the terminal voltage drops rapidly with high currents. The cell is suitable for open-circuit or closed-circuit work, if large currents are used intermittently and for short periods of time. The continuous current demand on closed circuit must not exceed a few hundredths of an ampere, as otherwise the terminal voltage is too greatly reduced by polarization. The chemical reaction is $Zn + 2NH_4Cl + 2MnO_2 = ZnCl_2 + 2NH_3 + H_2O + Mn_2O_3$. The dry battery, which is a modification of the Leclanché cell, has largely replaced the latter in practical use.

26. Edison Lalande. The usual form of this cell comprises a plate of compressed copper oxide on either side of which is a zinc plate with ribs. These ribs serve to hold the plate together until it is worn out. The copper-oxide plate is superficially reduced to cover it with a very thin layer of metallic copper for conductivity. The electrolyte is caustic soda solution covered with a layer of mineral oil to prevent evaporation and the formation of sodium carbonate from the carbon dioxide of the air. The construction of these cells is shown in Fig. 8. The chemical reaction is $Zn + 2NaOH + CuO = Na_2ZnO_2 + H_2O + Cu$. The e.m.f. of the cell is 0.95 volts and the terminal voltage drops to less than two-thirds of this value when furnishing heavy currents. Its internal resistance is low. It is adapted for both closed and open-circuit work and does not depreciate materially, excepting from the using up of the chemicals corresponding to the ampere-hour output. These cells are available in sizes from 100 to 600 amp-hr. On account of the low voltage, the initial cost of a battery of these cells is relatively high.

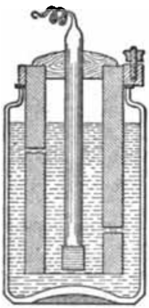

FIG. 7.—Leclanché cell.

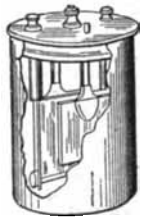

FIG. 8.—Edison-Lalande cell.

27. Carbon cells. A great deal of effort has been expended to develop a cell which would permit the conversion of the chemical energy of coal and the oxygen of the air directly into electric energy. The difficulties at the present time seem insurmountable on account of the high temperature which must obtain in order for the carbon to enter into a suitable reaction, and because the CO_2 necessarily formed, unites with the fused caustic soda electrolyte, which has been proposed. The difficulties in the way of an oxygen electrode are also great.

28. Standard cells. The **Clark cell** comprises an electrode of mercury, containing metallic zinc, an electrolyte of zinc sulphate and a depolarizing electrode of metallic mercury, covered with a paste of difficultly soluble mercurous sulphate. The chemical reaction is $Zn + Hg_2SO_4 = ZnSO_4 + 2Hg$. In the **Weston cell**, cadmium is substituted for the zinc. Very elaborate preparation of all the materials used in these cells is imperative, and the reader is referred to the extensive literature on this subject. The variation of the e.m.f. with temperature of the practical forms of these cells is given in Sec. 3. These cells are not adapted for closed-circuit work, although they quickly recover their voltage after an appreciable discharge.

DRY CELLS

29. Definition. The only "dry battery" in commercial use is a modification of the Leclanché cell, in which the sal ammoniac solution is held by capillary action in a porous medium separating the zinc from the opposite electrode also in the pores of the carbon-depolarizer electrode.

39. Service tests. The committee on dry cell tests of the Am. El. Chem. Society (Transactions 1912) has recomended the tests described in Par. 40 to 42.

40. For telephone work. Connect 3 cells in series through a resistance of 20 ohms for a period of 2 min. during each hour until the terminal voltage falls to 0.93 volt per cell at the end of the 2-min. period. The tests are to continue 24 hr. per day and 7 days per week, and the number of days elapsing until the above limiting voltage is reached is to be noted.

41. For gas-engine ignition. Connect 6 cells in series through 16 ohms resistance for two periods of 1 hr. each during each day, 7 days per week. The first discharge may be made during the morning, and the second, late in the afternoon. At the end of each twelfth of the above discharges, shunt the 16-ohm resistance with a 0.5-ohm resistance connected to an ammeter and note the current. The test is considered complete when the current shunted through the ammeter falls below 4 amp., and the total number of hours of actual discharge to this limiting value of 4 amp. is noted.

42. For flash-lamp service. Discharge the battery through a resistance of 4 ohms for each cell connected in series for a period of 5 min. once each day, and determine the total number of minutes of actual discharge, the terminal voltage of the last discharge being limited to 0.75 volt per cell.

STORAGE BATTERIES

43. Definitions. Cells which are reversible to a high degree, *i.e.*, those in which the chemical conditions after discharge are brought back to the original condition simply by causing current to flow in the opposite direction, or "charge," may be used as storage batteries. Storage batteries are sometimes termed **electric accumulators.**

44. Reversibility. In all the practical forms of storage batteries, both the electrode materials and the products of the chemical reaction are relatively insoluble. The form of the electrodes is practically unchanged with use, or at least it changes but slightly. Many of the cells in which the reaction products are soluble and which are ordinarily used as primary batteries can be used as storage batteries. For example, the Daniell or gravity cell and also the Edison-Lalande cell are reversible to a high degree, but have practical disadvantages contributing against their use as storage batteries.

45. Classification. The storage battery which is in widest commercial use, for various purposes, is the lead-sulphuric acid type. The only other type which is of any prominence is the nickel-iron-potash battery, apparently first proposed by Darrieus, then by Jungner and developed in commercial form by Edison. The use of cadmium instead of iron as a negative plate, the battery otherwise being quite similar to the Edison, is due to Hubbell and his battery is in extensive use for miner's lamps.

46. Positive and negative plates. The positive terminal or pole of a battery is that one from which the current flows into the external circuit. In storage battery practice, a positive plate is one which is connected to the positive pole, and the negative plate, the one which is connected to the negative pole. It should be specially noted that this is the reverse of primary-battery terminology. The U. S. Patent Office has attempted to avoid confusion in this regard by insisting on the use of the terms, **"positive-pole plate"** and **"negative-pole plate,"** but this has not come into general use.

47. The e.m.f. or open-circuit voltage of any storage cell depends wholly upon its chemical constituents and not in any way upon the number or total area of its plates. It varies further with the strength of the solution, or electrolyte, and its temperature, and to a minor extent, upon the state of charge of the plates. Upon charge, the terminal voltage of the cell rises, and, upon discharge, it falls, due to the internal resistance and to a number of more or less obscure causes, such as polarisation, acid-concentration effects, etc.

48. The capacity of a cell with a definite type and thickness of plate is in proportion to the plate area. The size of a cell is usually stated in terms of its ampere-hour capacity at a standard temperature of 70 deg. fahr., but it is necessary, also, to state the discharge rate, as the capacity of all practical forms of batteries is lower with increasing discharge rates.

49. Battery voltage. The voltage of a battery is that of each cell multiplied by the number of cells connected in series.

55. The variation of voltage is approximated by the following formula, due to Streintz:

$$E = 1.850 + 0.917(G - g) \qquad \text{(volts)} \qquad (7)$$

in which E = e.m.f. in volts; G = specific gravity of electrolyte, and g = specific gravity of water at the cell temperature.

56. Test or reference electrode. It is often desirable to determine the relative performance of the positive and negative plate groups in a cell and this may be done by taking the voltage between either group and a reference electrode of zinc, spongy lead or, preferably, cadmium.

57. A typical discharge curve for a stationary type of cell is shown in Fig. 9, also the curves for both positive and negative groups with reference to cadmium. Curve (1) shows the cell voltage, curve (2) the voltage of the positive group and cadmium, while curve (3) represents the voltage for the negative group and cadmium. Fig. 10 shows the corresponding curves for charge.

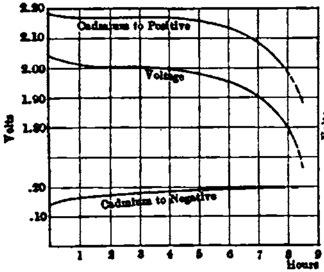

FIG. 9.—Discharge curves.

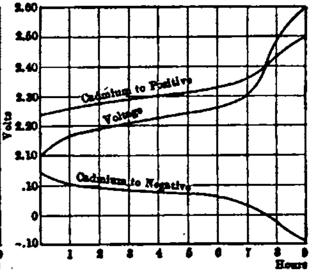

FIG. 10.—Charge curves.

58. Cadmium tests. The cell voltage is the difference between the positive-cadmium and the negative-cadmium voltages. In Fig. 9 the discharge curves are continued in dotted lines and, the greater portion of the final voltage drop occurring with the positives, show that the capacity of the cell, in this instance, is limited by the positive group. This is a desirable condition, as most negatives suffer from overdischarge more than do the positives.

59. Lead battery plates are classified thus: Planté plates (Par. 60) and pasted plates (Par. 62).

60. Planté plates comprise a mass of lead, usually of flat form with a highly developed surface. The increased surface is obtained by casting a cellular structure, or by scoring or cutting a blank of heavy sheet lead. The active material is electrochemically formed as a coherent layer of lead peroxide at the expense of a film of the underlying lead. Such plates are always formed as positives, but Planté negative plates are obtained from the positives by connecting them as negatives in a cell, and charging whereby the active material is reduced to sponge lead.

61. The original Planté process of formation consists of charging the plates alternately in opposite directions; each successive reversal under proper conditions of temperature, strength of electrolyte and current increases the capacity of the plates. This method is extremely wasteful of current and requires a long time; it has been abandoned in favor of accelerated forming processes which consist of making the plate to be formed an anode in an electrolyte of dilute sulphuric acid containing a small amount of nitric, perchloric or other acid which dissolves lead. The current density, straighter in service than other Planté types and that it shows a minimum of buckling. No centre web is employed, an open type of construction being adopted.

70. Centre-web positives. Figs. 12 and 13 show Planté positives made from a sheet-lead blank, the surface being increased by plowing leaves in the first

Fig. 11.—Tudor positive and section.

Fig. 12.—Willard "plowed" plate.

instance, and by "**spinning**" with rotating circular discs in the latter. A section of the latter plate is shown in Fig. 14.

71. Manchester positive. Fig. 15 shows a Manchester positive, comprising a casting of lead antimony with a number of round holes symmetrically spaced. Into these holes are inserted spiral coils of corrugated lead ribbon. The plate as a whole is electrochemically formed, but the frame

Fig. 13.—Gould "spun" plate.

Fig. 14.—Section of Gould "spun" plate.

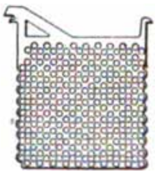

Fig. 15.—Manchester positive.

work is but slightly corroded. This makes a very rugged plate. It will not show as good a life in possible number of cycles of charge and discharge as the pure-lead Planté plates, but this is largely counterbalanced by its rigidity. The plate is, however, much more sensitive to overcharge than are the other Planté plates.

density of the electrolyte varies with its acid content, and the change in density may be used as a measure of the state of charge of the battery, if the initial and final specific gravities are known.

79. The quantity of electrolyte required for 100 amp-hr. discharge is calculated from the following formula.

$$G_o = \frac{1290 - 10.53d}{D - d} \qquad \text{(oz.)} \qquad (8)$$

in which G_o = number of ounces of electrolyte per 100 amp-hr. of discharge; D = per cent. of H_2SO_4 in the electrolyte at the beginning of discharge; and d = per cent. of H_2SO_4 at the end of discharge. For a capacity G other than 100 amp-hr. multiply G_o by $G \div 100$.

When the value of G_o for 100 amp-hr. and either the initial or final density of the electrolyte are known, then that density, which is unknown, can be determined from the following:

$$D = \frac{1290 + d(G_o - 10.53)}{G_o} \qquad (9)$$

and

$$d = \frac{1290 - G_o D}{10.53 - G_o} \qquad (10)$$

80. The change in acid strength is not immediate; it lags behind the values determined in Par. 79 on account of the fact that time is required for the strong acid to diffuse into the plate on discharge, and for the strong acid to diffuse out of the pores of the active material on charge.

FIG. 20.—Hydrometer.

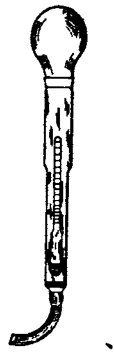

FIG. 21.—Syringe hydrometer.

81. Separation. It is essential that plates of opposite polarity be kept from coming in contact with each other. This is insured by the use of ribbed perforated sheets of hard rubber, glass spacing tubes or, more frequently, wood **separators.** The wood used is selected for a minimum content of such constituents as would be injurious to the plates and it is usually subjected to a treatment to reduce such constituents still further.

82. Lead burning of joints. The use of solder must be avoided in storage-battery construction. Joints are made by lead burning, by which is meant the melting together of the lead parts by a hydrogen flame. This flame deoxidizes the melted lead, and the two parts readily flux together.

ELECTROLYTE AND WATER

83. The electrolyte used in lead storage batteries is a solution of sulphuric acid and water. The sulphuric-acid content determines the density of the solution, *i.e.*, its specific gravity (sp. gr.)or the ratio of its weight to that of an equal volume of water.

84. Hydrometer. The specific gravity of electrolyte is practically determined by the use of an hydrometer which comprises a weighted glass bulb with a graduated stem. In strong acid the stem protrudes further above the surface of the solution, and the point at which the top of the meniscus touches the scale is read off directly in degrees of specific gravity.

With stationary types of cells there is usually space enough between plates or at the end of the tank to float a flat bulb hydrometer directly in the acid of the cell. This type of hydrometer is illustrated in Fig. 20.

85. Syringe hydrometer. With vehicle and other types of batteries with small separation between plates, a convenient method to determine the acid density is to employ a syringe hydrometer as illustrated in Fig. 21; the hydrometer floats within the enlarged portion of the glass barrel when acid is sucked into it by means of the rubber bulb.

given				
1100	1.43	1.122	1.00	0.91
1200	1.33	0.900	0.73	0.62
1300	1.35	1.000	0.79	0.43
1400	1.89	1.425	1.05	0.82

91. Freezing point of electrolyte. The freezing point of the electrolyte of fully charged batteries is quite low; however, the electrolyte of partly or fully discharged batteries will freeze at low temperatures. If batteries are to be subjected to such temperatures, it should be seen to that they are fully charged. The freezing point of sulphuric acid solutions is given in the following table:

Sp. gr.	Temp. (deg. Fahr.)	Sp. gr.	Temp. (deg. Fahr.)
1.060	25	1.220	−31
1.080	22	1.240	−51
1.100	18	1.260	−75
1.120	14	1.280	−90
1.140	8	1.300	−95
1.160	2	1.320	−80
1.180	−6		
1.200	−16		

92. New electrolyte. The presence of impurities in a cell is objectionable (Par. 97). In acid used for the first filling of cells they should not exceed the limits cited in Par. 93.

93. Maximum allowable impurities in electrolyte for first filling (initial charge).

Color	Colorless
Suspended matter	Trace
Platinum	Trace
Antimony and arsenic	Trace
Manganese	0.0025 per cent.
Iron	0.005 per cent.
Copper	0.0025 per cent.
Nitrogen in any form	Trace
Chlorine	0.001 per cent.
Organic matter	None

94. Maximum allowable impurities in water used for replacing evaporation. In the operation of a battery, the electrolyte loses water by evaporation, also some water is electrolytically decomposed. Water must be added to the cells, and any impurities it might contain would be cumulative. The maximum limits of impurities in water for storage-battery purposes are given in the following table:

Color	Colorless
Suspended matter	Trace
Total solids	10 parts per 100,000
Calcium and magnesium oxides	4 parts per 100,000
Iron	0.05 parts per 100,000
Ammonia as NH_4	0.8 parts per 100,000
Organic matter	0.1 parts per 100,000
Nitrates as NO_3	1.0 parts per 100,000
Nitrates as NO_2	0.5 parts per 100,000
Chlorine	1.0 parts per 100,000

silver nitrate. If the solution becomes opalescent, the electrolyte should be examined carefully for chlorine content. A great excess of chlorine will be indicated by the test solution becoming curdy.

TESTING

101. Preliminary. Before starting a test on a lead-acid type of storage battery, see that it is fully charged and in good condition. The acid should be pure and its strength adjusted to that which is recommended by the maker as standard for the type. If the battery is new, insure that it is fully developed by taking several preliminary discharges; the capacity of a battery increases very considerably with the first few cycles of charge and discharge. Before starting tests for capacity or efficiency, continue the charge at the normal or 8-hr. current rate for a stationary type of battery, or at the "finishing" rate (usually about one-half of the normal rate) for pasted plate batteries, until neither cell voltage nor acid density show a further increase for four 15-min. intervals, which will indicate that the battery is fully charged.

102. Capacity tests. Since the capacity depends on the rate of discharge, it will be advisable, with stationary types of batteries, to obtain test discharges at several different rates; in particular, those most nearly approximating the desired service conditions. Nearly all the makes of storage batteries will perform the higher discharge rate if they will give full capacity at the normal or 8-hr. rate. In conducting the usual tests, the charges should preferably take place at the normal rate. When the discharge is started, the current should be maintained as steady as possible and should continue until the cell voltage has reached its limiting value. Voltage readings should be taken at stated intervals and the strength of acid, temperatures and possibly also cadmium readings should be taken at the same time. The same readings should be taken on the subsequent charge. It is advisable to plot these readings, as any discrepancies will then be apparent. The ampere-hour capacity of the cell will be the average amperes multiplied by the time of discharge in hours. The watt-hour capacity will be the ampere-hours multiplied by the average voltage of discharge, provided the current is maintained reasonably steady.

103. Characteristic performance. A complete series of tests as outlined in Par. **102**, carefully plotted, will give the battery characteristics. With a set of these curves, the performance of a battery can be quite definitely determined. It is of little value, from an engineering standpoint, to know the internal resistance of a cell, except for highly special applications, as the drop in voltage due to polarization, usually greatly exceeds the resistance drop. The expression of "**virtual internal resistance**," which is an attempt to include polarisation effects is also of no value, as it contains no time factor, and the time the discharge is to last is of extreme importance.

104. An approximate way of determining the internal resistance of a cell is to proceed as follows: momentarily interrupt the current and note the instantaneous increase in cell voltage, preferably by the condenser, ballistic galvanometer method. The difference between the terminal voltages with and without the current flow is the resistance drop; dividing this difference by the current will give the approximate value of the internal resistance. Values determined by the wheatstone bridge method with alternating current will be in error on account of the capacity effect which any electrode shows in an electrolyte.

105. Efficiency tests. The efficiency of a storage battery is the ratio of watt-hours of discharge to watt-hours of charge and should be determined as the mean of several charges and discharges, as there is no absolutely definite point to terminate either the charge or discharge. The condition to be met is simply that the battery must have received sufficient charge each time, to insure full capacity on the succeeding discharge. The efficiency should be taken as the ratio of the total watt-hours of discharge to the total watt-hours of charge, for all the charges and discharges. For efficiency tests, the end point of charge should be taken as the point when both positives and negatives are gassing uniformly, the voltage showing the same value for two read-which otherwise would cause internal short-circuits. The separators are kept from floating by pieces of glass called **separator hold-downs.** The cells are set in a layer of sand contained in a wood sand tray thoroughly coated with asphaltum paint, and the sand trays are mounted on glass insulators. The use of porcelain insulators is to be avoided, as the glaze is attacked by acid spray and the insulating properties are lost. Glass sand trays with integral insulating feet are often used instead of the wood trays and insulators. They are not satisfactory with the larger sizes on account of liability to breakage.

110. Lead-lined tank construction. Plates 15½ in.×15½ in. and larger are always mounted in lead-lined tanks, the construction being shown in Fig. 25. The wood tanks are preferably of long-leaf yellow pine, with dove-tail joints and dowels and without metal fastenings. The tanks should be painted both inside and outside with three coats of acid-resisting paint, and lined with 4-lb. sheet lead, the lining projecting outside the wood tank in order to prevent acid falling onto the tank. Tanks should have liberal mud space to take the accumulation of sediment. The sediment space should exceed one-third of the length of the plate. The tanks should be supported on glass insulators, the oil-filled type with a protecting cover being preferred. Lead foot-

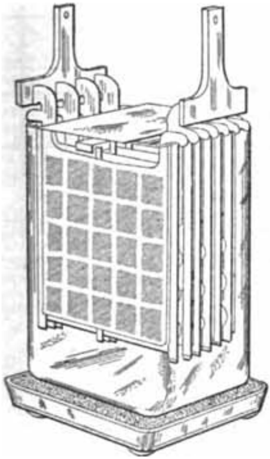

Fig. 24.—Cell in glass jar.

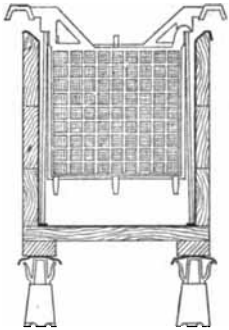

Fig. 25.—Cell in lead-lined tank.

ings are placed in the bottom of the tanks, upon which rest the glass support plates. The support plates are about ¾ in. thick, and have the upper edges, which support the plate lugs, ground smooth. The plates are lead-burned to bus bars of extruded lead and wood separators with dowels are used to space the plates, as with the glass-jar cells. A few installations of large cells have been made in special acid-proof stoneware tanks, but this construction has not come into general use.

111. Erection. Glass-jar cells are mounted on wood stringers, or two tier racks if space is limited, these being thoroughly coated with acid-resisting paint. The insulators for lead-lined tanks usually rest upon acid-resisting tile, the tiles being brought to a level by supporting them on pillars of sulphur-sand cement. These piers are made by supporting the tile on a ball of stiff cement and pouring melted sulphur, into which sand has been stirred. Another method of insulator support is to use heavy earthenware truncated cones in place of the sulphur piers.

harge at the normal rate, may be as high as 2.65 volts with the cell at 70 eg. Fahr., and as low as 2.45 volts. All commercial lead contains a small ercentage of impurities such as copper, antimony, etc., and these are evenually deposited from the positives, with their proceeding corrosion, onto he negative-plate surfaces. The result of these deposits is generally to educe the final charge voltage. If a positive-plate grid contains antimony, he effect is quite marked. Antimony, artificially introduced into a cell, vill produce this effect.

114. The point of discharge termination is determined arbitrarily, he main condition being that the cell voltage drops with increasing rapidity, oward the end. The capacity decreases with increasing discharge rates, as shown in the curves of Fig. 27, and the initial, average, and final voltages are also indicated. The decrease in capacity, as previously stated, results rom lack of time for acid to diffuse into the active material.

115. Voltage variations on intermittent charges and discharges. Stationary types of lead batteries are capable of charging and discharging at high rates for short intervals, with a relatively small variation of voltage. The curves of Fig. 28 show voltages at the end of charge and discharge for the times indicated on the different curves. These curves are of importance in determining the variation of line voltage with a "floating battery," or that amount of work necessary to be done by a booster generator in series with a battery, in order to maintain a constant line voltage.

116. Variation of capacity with temperature. The rate of diffusion of acid into the pores of the plates varies markedly with temperature, and, in consequence, there is a marked decrease in capacity with lower temperatures. Temperature coefficients for different rates of discharge are as shown in the curve of Fig. 29.

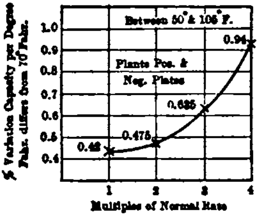

FIG. 29.—Temperature coefficients.

117. Nominal battery ratings. Frequently a stationary battery is referred to as having a kilowatt-hour capacity. By this is meant the 8-hr. or normal ampere-hour capacity multiplied by the number of cells and by the open-circuit voltage per cell which is approximately 2.1 volts.

ELECTRIC VEHICLE BATTERIES

118. Adaptable types. Pasted plates are universally used in vehicle batteries at the present time, although there is no reason why a battery with Planté positives and pasted negatives should not be successful on account of its greater capability to withstand "boosting" charges. By a boosting charge is meant a partial charge at a high current rate, such a charge taking place at the noon hour or other rest period after the battery is partly discharged. The Planté positive, even with a pasted negative, may be charged at enormously high rates without the injurious heating which develops in the Edison battery.

If in a particular service, the capability of a battery to withstand boosting at high rates is of importance, this combination should receive consideration.

The prime reason for the use of pasted plates is their relative lightness, since a reduction in weight of battery results in a reduced current consumption for the vehicle and a reduction in the expense of tire upkeep. For these reasons, battery-plate life is often deliberately sacrificed by using thin plates and a small separation between plates. Small separation makes it necessary to employ strong acid and this reduces the life of the separators as well as the life of the plates. There is already a strong tendency toward the use of thicker separators and a reduced acid strength.

Size of Jar 6.125 in. wide, 4.25 in. long, outside				
Type of plate	Weight per cell (lb.)	Capacity at 6-hr. disch. rate (amp. hr.)	List price per cell	Average life (amp-hr.)
'hick	34½	155	$16.70	77,500
Medium	33¾	171	17.75	71,800
Thin	35	189	19.00	71,000
Extra thin	37	204	20.10	61,200

Size of jar 6.125 in. wide, 8 in. long, outside				
Type of plate	Weight per cell (lb.)	Capacity at 6-hr. disch. rate (amp. hr.)	List price per cell	Average life (amp-hr.)
Thick	64	309.0	$30.00	154,000
Medium	65½	343.0	32.20	144,000
Thin	65½	378.0	34.95	143,000
Extra thin*	67½	382.5	35.10	115,000

124. Separators. The plates are insulated from each other by thin ,eets of corrugated wood veneer, grooved on one side, the wood used being ther naturally free from such organic substances as would injure the plates, else treated to remove such impurities. These veneers are usually kept vay from the positive plate by inserting a thin sheet of perforated hard ıbber. The smooth side of the veneer is placed against the negative ate. The life of these wood separators is unfavorably influenced by very rong acid also by an excessive amount of overcharge. If batteries are 'operly operated, ıe separators will st as long as will ıe plates of a thin-ate battery, that , 12 to 15 months commercial ser-ice and 18 to 24 ıonths in pleasure-ehicle service.

Thick plates will enerally have a nger life than the 'ood separators, so ıat, in order to ob-in the best possible fe of the plates, the parators will re-uire renewal. If

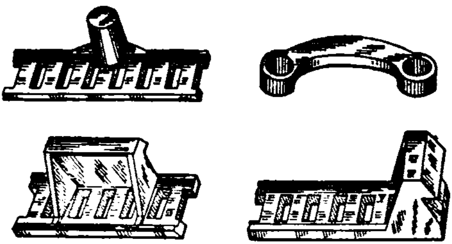

FIG. 33.—Vehicle type straps and connector.

ıe separators and the plates are to give approximately equal lives, sufficient pace should be provided in the jars to take all the sediment which will be hrown off in the life of the plates, *i.e.*, high-bridge jars should be used. therwise the space should be ample to take the sediment which will be de-osited during the interval of separator renewals.

125. The straps to which the plates are burned are of several types, shown in Fig. 33. The pillar-post strap, used with connector links, is

* Length of standard jar for this size is 7¾ in.

discharge is great. In extreme cases, acid of 1.300 sp. gr. at full charge is used, and only sufficient volume employed to give a final acid density of 1.100. A better life of plates and separators will result, however, if a wide enough separation between plates is used to permit a full charge density of 1.260 to 1.280 sp. gr.

128. Crates. The method of assembling vehicle cells into crates is shown in Fig. 34. The crates are of hard wood, painted thoroughly with asphaltum acid-resisting paint or else soaked in hot paraffin oil, then subsequently dipped into melted paraffin. The practice of fastening crate terminals onto the crates is to be thoroughly condemned, as when the crates become acid-soaked, there is current leakage between them, and the positive terminal corrodes seriously. Crate ends are charred from this cause, and the current leakage is of a magnitude not to be neglected.

129. Performance of thin-plate batteries. The variation of capacity of a thin-plate vehicle-type battery in wide commercial use, is shown in

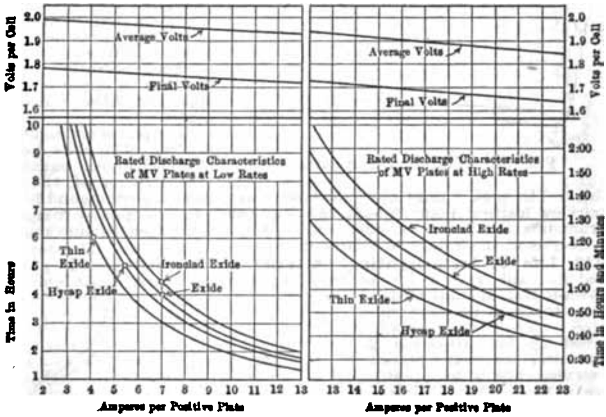

Fig. 36.—Exide plate characteristics.

Fig. 35 and the average and final voltages are also given. The Electric Storage Battery Co. has devised an ingenious chart showing the characteristics of their "Exide" batteries which is reproduced in Fig. 36.

TRAIN-LIGHTING BATTERIES

130. Capacity. A special type of battery has been developed for the lighting of steam railroad trains. The standard battery comprises 16 cells of 300 amp-hr. rated capacity, and this size is used in most cases for coaches, parlor cars, and sleeping cars. For dining cars, 32 cells are frequently used. Batteries of smaller capacity are often used for lighting baggage and postal cars.

131. These batteries are charged either from an outside source at terminal yards, or, especially where the cars run over several different lines, are operated in conjunction with an automatically controlled axle-driven generator. The "head end system," with a steam-driven generator in the baggage car is sometimes used, though it is not so popular as formerly. (See Railway Train Lighting, Sec. 22.)

132. Design. Batteries for train lighting have been standardised, the construction being shown in Fig. 37. The cells are mounted in pairs in

Plate grids are also usually provided with reinforcing diagonal members for the same purpose. Fig. 38 shows a standard battery design for motor starting and lighting.

136. The voltage characteristics of these batteries, as furnished by several manufacturers, is shown in Fig. 39.

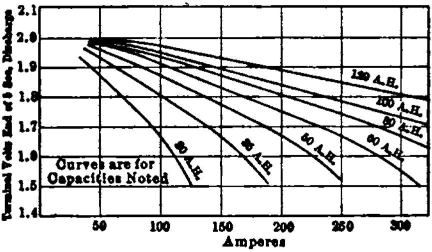

Fig. 39.—Motor starting battery characteristics.

137. Batteries for ignition alone. The current required for ignition rarely exceeds an average value of from ½ to 1 amp. For this reason, batteries for ignition alone usually have thick plate elements, the discharge rates being so low that the full plate thickness is efficiently used. Standard batteries for this service are 4 and 6 volts, that is, two and three cells.

BATTERY ROOMS

138. General rules. It is desirable to install stationary batteries in rooms which have good ventilation and are well lighted. Direct sunlight should not, however, be permitted to fall on the cells; it is well, therefore, to coat windows with an opalescent paint, in order to avoid this possibility and also to cause the illumination of the entire room to be more equally diffused. Where natural illumination is not possible or convenient, a liberal number of electric lamps should be provided. Open flames and fires in stoves must not be permitted, as the cells give off hydrogen and oxygen on overcharge and the mixture of these gases, if sufficiently concentrated, is explosive.

139. Temperature. A battery room should be maintained at as nearly 70 deg. as possible. Higher temperatures than 95 deg. to 100 deg. Fahr., excepting during rare intervals, must be avoided. Low temperatures temporarily reduce the battery capacity, but do no injury.

140. Cleanliness of location. Batteries should not be installed adjacent to an ice plant, or to a stable, as ammonia gas is absorbed with great avidity by the electrolyte and eventually, crystals of ammonium sulphate collecting on the containing tank, may cause the electrolyte to syphon off by capillary action. The capacity of negative plates is reduced by the presence of ammonia. Corrosive gases or vapors from other manufacturing processes should also be avoided. Iron ore dust is also objectionable.

141. Ventilation. If large batteries are to be installed in the immediate vicinity of dwellings, forced ventilation may have to be provided, during the completion of charge, by means of an exhaust fan. The acid vapors may be removed from the exhaust by sucking it through several layers of bronze screen or thin perforated sheets of lead. Exhaust ventilation is much preferable to direct, as air currents are more uniform and there are fewer eddies. The acid spray in the first method does not so readily precipitate upon the tanks and insulators.

142. Protection to iron work and walls. There should be a minimum of exposed piping and iron work in a battery room, especially near the floor.

batteries, the losses of the preceding methods are avoided by the use of automatic regulating boosters (Par. 150) or end cells with end-cell switches (Par. 158).

148. Counter-e.m.f. cells. These are simply cells with unformed plates. When current flows through such cells, they oppose the main battery voltage by approximately 2.8 volts for each counter-e.m.f. cell in series. They are so connected in a circuit that current always flows through them in the same direction, as otherwise they would gradually attain a considerable capacity.

149. Shunt charging booster. This consists of a generator, usually motor-driven, whose field is excited from the line; actually, therefore, the designation is misleading. A variable resistance in series with the field permits the adjustment of the booster voltage to the desired value. These boosters are connected as shown in Figs. 47 and 48.

150. Automatic regulating booster. The charge and discharge of a battery may be made responsive to the variations of any desired means by placing a motor-driven generator in series with the battery, the field of the generator being excited in accordance with such variations. Automatic boosters usually regulate for constant current or for constant voltage. Current regulation is the more frequent application. Regulating boosters are usually driven at practically constant speed. They are used when rapid variations of battery charge and discharge are required.

151. Entz booster. Mailloux proposed the use of two opposing field coils on the booster generator, one a shunt field excited from the line voltage, the other carrying the total current. The Entz modification of this scheme, formerly in wide use, is shown in Fig. 40, in which the coil A carries the current from the generator, B carries the external load, while the shunt coil C, excited at line voltage, carries a practically constant current opposed to A and B. The coils are so determined that the resultant booster field is zero when both the outside load and the generator load have a certain definite value. Any increase in the outside load then causes a resultant field, and consequently a resultant booster voltage, in the direction forcing the battery to discharge. Any portion of the increased load falling on the generator would tend still further to increase the booster field and result in additional battery discharge. The resultant booster voltage would be in the opposite direction if the outside load decreased and the battery would be forced to charge. Regulation tending toward constant generator current, therefore, results from this scheme. A practical defect of the Entz booster is that, the field being the resultant of two opposing fields, the field structure must carry much more than the normal amount of winding and a highly special machine results.

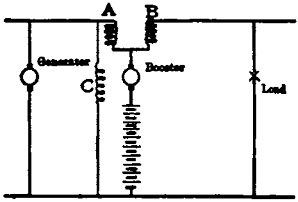

FIG. 40.—Entz booster.

152. Separately-excited booster. The modern boosters have fields of normal dimensions with a single winding excited from a separate machine for this purpose. The excitation schemes in practical use are of two types described below.

153. Carbon-pile regulator. This regulator is shown diagrammatically in Fig. 41 in which two piles of carbon discs are under but a slight compression when the lever arm is in the horizontal position. The lever arm is operated by a solenoid plunger whose coil carries the current to be regulated. The pull of the solenoid is balanced by a spring whose tension is such as to equal the solenoid for normal average current. The bottoms of these two piles are connected, one to the positive and the other to the negative of the battery, and the two tops of the piles connected together. One terminal of the booster field is connected to the junction of the two piles, the other to the middle point of the battery. With the two piles under equal compression, no current flows through the booster field. An increase of current from the main generator causes the solenoid to compress cuits, such as result from hoists, elevator operation, etc., are taken off the opposite side of the booster and are subjected to the battery voltage variation. If the average value of the variable load is less than the difference between the maximum current and the average load, it may be possible to reduce greatly the booster capacity by so connecting it as to realize constant current.

157. Electrical position of booster regulator. Where a portion of the station load is steady and another portion variable, the regulating coil should in general be so placed as to be affected by the variable load only, if this is conveniently possible. This can be done by grouping the constant and the variable loads separately, the coil then being placed between the two groups of circuits. The position indicated will result in closer regulation, since all the practical regulating schemes provide that the current to be regulated shall not depart from its average value by more than a given percentage. This rule holds for both constant current and differential boosters.

158. End-cell switches. An end-cell switch is a device for cutting in or cutting out cells of a series and thereby compensating for battery voltage variation. The contacts of the smaller size switches are usually arranged in the arc of a circle, while with larger sizes the contacts are arranged in a straight row and a heavy laminated copper brush is moved over these contacts by means of a motor-driven worm. In switching from one point to the next, the circuit must not be opened, and the blade must not touch two adjacent contact points, as this would short-circuit a cell having its terminals connected to these points. End-cell switches are therefore provided with an auxiliary contact, either on the moving blade as shown in *B*, Fig. 44, or, in some instances, fixed adjacent to each main contact. The main and auxiliary contacts are joined by a resistance as shown at *C*, but otherwise insulated from each other. The auxiliary contact touches one of the switch points, while the main contact touches the adjacent point. The circuit is, therefore, not interrupted, being completed through the resistance, *C*, which has too low a value to affect the line voltage appreciably. Its resistance, however, is sufficiently great to prevent short-circuiting the cells connected across the two points. The larger sizes of end-cell switches are motor-driven, and are very elaborately designed. The reader is referred to the literature of the various manufacturing companies for full particulars of these switches.

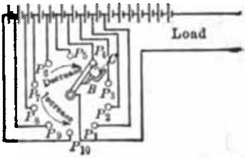

FIG. 44.—End-cell switch.

159. Load-limit devices. It is sometimes desirable to limit the load on the battery. This may be accomplished by providing an adjustable stop to limit the travel of the lever arm of the carbon-pile regulator, and thus limit the amount of current which will flow through the booster field. This, in turn, will limit the amount of battery charge and discharge. An equivalent device for the same purpose can be applied to the Hubbard booster.

160. Average adjuster. It is often desirable to limit the work which a battery does, to taking simply those heavy variations of current which persist for short times, and to allow the main generator to follow the load averaged over relatively long intervals. A device which accomplishes this object is furnished by the Electric Storage Battery Co., and its design is dependent upon the following principle: the armature of a small motor is connected to the adjusting screw which controls the tension of the spring of the carbon pile regulator, through a suitable train of reducing gears. The armature of this motor carries a practically constant current, as it is connected across the line in series with a fixed resistance. The field of the motor is connected across the terminals of the booster. The effect of this arrangement is to permit the battery to absorb momentary fluctuations, while the main generator current follows the load averaged over a relatively longer interval.

OPERATING EQUIPMENT

161. Pilot cells. The specific gravity of the electrolyte of a cell in which the acid level is kept constant by adding water to replace evaporation, is of the power-house. It is necessary to provide a reverse-current circuit-breaker in circuit with the generator.

166. Load-regulating batteries. Batteries may be installed to absorb momentary fluctuations above or below the average load, or any desired percentage of these fluctuations. In this connection it is usual practice to employ an automatic regulating booster (Par. 149) to force the battery to charge and discharge in accordance with the load variations. The number of cells usually installed is equal to the line voltage divided by 2.08, and the size of the battery is generally determined by the condition that frequently recurring discharges should not exceed twice the 1-hr. discharge rate of the battery. Under these conditions, the main battery voltage will not fall below 1.6 volts per cell nor exceed 2.6 volts per cell under regular operating conditions. A limiting voltage of 2.65 volts per cell must, however, be available to complete the regular charge of the battery and to give it the necessary overcharge which occasionally should take place. The booster must, therefore, have a voltage range equal to approximately 0.48 volts times the number of cells, for regulation service. Provision must be made either by increasing the speed of the booster, or else by forcing the booster field to reach the extreme voltage (for booster and generator together) of 2.65 volts per cell in order to give the battery its periodic overcharge. Fig. 46 is a diagram of connections, showing how batteries are applied for this purpose. Regulating battery plants are installed in connection with generators, motor-generator sets or rotary converters, supplying railroad, rolling-mill, elevator and other widely varying loads.

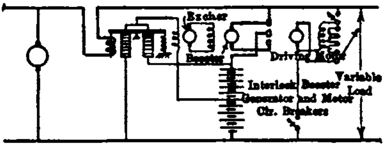

Fig. 46.—Regulating battery.

167. Alternating-current regulation. If there is a reversible means of converting alternating to direct current on an alternating-current source of supply, and it is desired to equalize the load variations on the latter, the battery may be made to do this by exciting the booster field in accordance with these variations. The lever of the carbon-pile regulator (Par. 153) would then be subjected to a pull in proportion to the load in watts, or the power component of the load. A solenoid coil carrying the current only will not effect the desired result unless the power-factor remains constant.

Another method of securing equalization of alternating-current variations is to rectify the secondary current from series transformers in the line in such a way that the output of the rectifier is proportional to the power component of the load. The latter may then be the excitation of the c.e.m.f. exciter of the Hubbard booster. The literature of the Gould and Electric Storage Battery Companies should be consulted for details of this method.

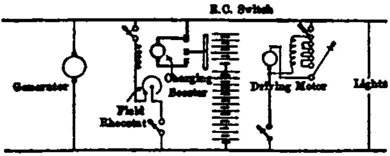

Fig. 47.—Peak load battery.

168. Peak-load batteries. If a battery is to supply a discharge of relatively long duration and at constant voltage, it is usual to effect the voltage regulation by means of an end-cell switch. A diagram of connections for a direct-current two-wire system is shown in Fig. 47. The charging booster is employed for the purpose of adding to the line voltage a sufficient amount to complete the charge of all the cells of the battery. Plants of this nature are used to supply hotel and residence lighting and motor circuits, but are infrequently used for regular operation with large plants, except for emergency reserve.

in regular operating practice, and the end-cell switches are usually installed in pairs for the sake of limiting the amount of current to be carried by a single contact. Provision is not made in the majority of cases for floating the battery on the bus during charge, for the reason that a greater number of end-cell points would be required, and because of the heavy expense of the copper runs to the additional number of end cells. The capacity of a battery for stand-by service is frequently determined by the requirement that it should carry the maximum station peak for a period of 5 or 6 min., and that the usual 150 cells will maintain a voltage of about 115 volts per side during this period.

172. Batteries for telephone exchanges. The batteries of the larger offices are either 11-cell or 22-cell installations, and are floated directly across the power circuit without any special regulating means. The capacity of these batteries is usually such that they will carry the entire station load for a period of 24 hr. or longer. The internal resistance of the batteries is extremely low, owing to the relatively large size of the battery. A low internal battery resistance is especially desirable for telephone service, in order to eliminate the possiblity of "cross talk" (Sec. 21). It is desirable, with these batteries, to select a type that will permit completion of charge at relatively low rates in order to avoid excessive voltages and resultant interference with relay operation and lamp signals.

Planté type batteries are usually used for the purpose on account of their long life. Pure-lead Planté negative plates show high voltages on the completion of overcharge, especially when new, and this fact should receive consideration.

The loads on telephone-office power plants in business districts usually show decided morning and afternoon peaks, and it is usual to operate the charging generator in parallel with the battery during the periods of higher load. The battery alone usually carries the load excepting from, say, 9 A.M. to 4 P.M. in the typical exchange in business districts.

173. Residence and farm lighting plants. A great number of these plants are in service, and they vary in elaboration from a simple battery without voltage regulation (the battery being taken off the lighting service when charging) to

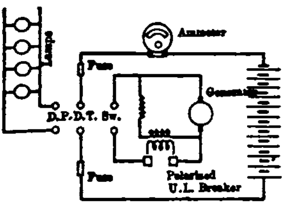

Fig. 49.—Farm lighting plant without voltage regulation.

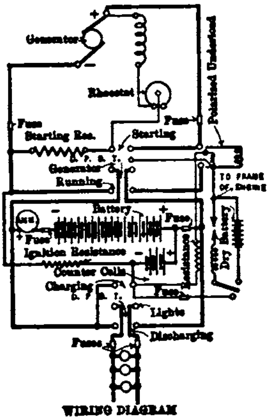

Fig. 50.—Lighting plant with voltage regulation.

the more complete plants previously described. The usual low-voltage plants are 8 and 16 cells, *i.e.*, furnishing 15 and 30 volt lamps. The small plants frequently use vehicle or motor starting and lighting batteries, as these are cheaper for the same capacity and may be readily shipped to a service station for repairs when necessary. The couple-types (Par. 107) of stationary batteries are also frequently used. The regular stationary types will give longer and somewhat more reliable service. Diagrams of connection are given in Figs. 49 and 50, the former without voltage regulation while, in the latter, voltage regulation is effected by counter-e.m.f. cells.

ceive a periodic overcharge at intervals of at least once a week if the attery is called on for heavy service, or once every 2 weeks if the service light. The overcharge is simply a continuation of the regular charge ntil the battery voltage at constant current input has remained constant nd also until the acid density, corrected for temperature, has reached a aximum value as indicated by three successive acid-density determinations, t half-hourly intervals, having the same value.

If any cell or cells are late in gassing or become warm during charge, or if he specific gravity of the electrolyte is markedly lower than in the remaining cells, they should be investigated for short-circuits. Short-circuits will lso be made evident if any cell falls materially behind the others in voltage n discharge. An excessive amount of charge should be avoided, as the resultant gassing will throw off some of the active material, especially from the ositive plates.

182. Removal of separators. If for any reason it is necessary to remove wood separators from a cell, they should be kept covered with water. If llowed to dry out they will shrink, also the resulting concentration of acid n the wood will ruin them. Wood separators which have been in acid for everal months will have so little strength that they cannot be handled without danger of breaking. New separators should be kept damp to prevent heir shrinkage.

183. Evaporation of the electrolyte should be replaced by adding pure water. Keep the level of the electrolyte well above the tops of the plates. Do not add acid to the electrolyte unless it is clearly established hat the removal of possible short-circuits and the subsequent overcharges will not restore the density of the electrolyte. Both water and electrolyte should be pure. It is preferable to add water before an overcharge; as the gassing will serve thoroughly to stir up the acid and equalize any differences in specific gravity between the tops and bottoms of the cells.

184. Operating temperatures. It is best not to allow the temperature of a battery to exceed 100 deg. Fahr.; a temperature above 105 deg. should positively be avoided.

185. It is well to note the color of the plates from time to time and to see that the colors of the plates in different cells are uniform.

186. If the battery is low in capacity, the relative condition of the positive and negative plates should be determined by taking voltage readings between both the positive and negative groups and a cadmium test electrode. This should be done toward the end of the discharge and will determine which of the groups are at fault.

187. If any cell shows low voltage or low acid-density by reason of short-circuits, it should be separately charged after the short-circuits have been removed. In large installations a **milker set** is usually provided for this purpose. This comprises a motor-generator supplying energy at from 3 to 6 volts. Another method is to cut-out the cell on discharge and replace it in the series on charge.

188. The strength of the acid to be used in various types of cells should be that prescribed by the manufacturer. It will depend entirely upon the battery design. The usual practice is to use electrolyte of 1.210 sp. gr. with stationary types of cells, while with vehicle types and with motor-starting and lighting batteries, maximum densities of 1.300 sp. gr. are sometimes used.

189. Be sure that sediment does not accumulate to such an extent as to touch the bottoms of the plates, as this would cause internal short-circuits in the cells. Separators must be kept in place and in good order. The entire battery should be kept clean and free from dirt. Condensed moisture or acid vapors should be wiped off from time to time, and the insulation kept dry. Raw linseed oil should be applied to the wood of lead-lined tanks as occasion demands.

190. Charging rates. The recommendations of the various manufacturers differ widely as to the proper charging current values. The following found necessary thus to interrupt the charging current, the number of ampere-hours of initial charge must be increased.

(e) The initial or developing charge is to be considered complete only when both positives and negatives are gassing uniformly in all the cells, and when there has been no increase in voltage or specific gravity of electrolyte (the latter corrected for temperature) for a period of 5 or 6 hr. The battery should then be open circuited for an hour or so and, subsequently, the current applied again; in this charge, the cells should begin to gas from both positives and negatives within a minute or two.

(f) The battery should not be allowed to discharge until it has been fully developed as above. The color of the positives should be a very deep brown, and the negatives a light lead color.

194. Placing batteries out of commission. If a battery is not to be used for several months it should receive a very thorough charge before allowing it to stand idle. It is desirable, though not absolutely necessary, to give it a freshening charge of an hour or so once a month. If glass-jar batteries are to be left over winter and low temperatures will be met, it may be necessary to remove the acid, see Par. **100**.

If a battery is to remain out of service an indefinitely long time, it will be advisable to remove the acid. Before doing this, it should be given a thorough overcharge. If the plates are to remain in the cells, syphon off the acid and remove the wood separators. Watch cells carefully and when the negatives become hot sprinkle with water. If the plates are to be removed from the cells, keep the positives apart and simply let them dry out. Do not rinse in water. The negative plates must be carefully kept apart, and sprinkled with water as soon as they become hot.

DEPRECIATION AND MAINTENANCE OF LEAD STORAGE BATTERIES

STATIONARY BATTERIES

195. General considerations. As with generating machinery, obsolescence, due principally to changes in service requirements, is the important factor of depreciation. A stationary battery may be maintained indefinitely by replacing worn out parts, but a renewal of tanks or the replacement of a battery room floor is a considerable item of expense. In these events it will frequently be advisable to reconsider the entire installation. Many floating batteries on interurban lines have given ten to twelve years of service with a single renewal of positive plates. The same result has often been obtained with regulating batteries.

196. Actual maintenance costs. A case of five large railway regulating batteries which are called upon daily excepting Sundays, for peak discharges each morning and afternoon, the ampere-hours of discharge aggregating quite approximately the equivalent of one 8-hr. discharge per day, may be cited. A blanket contract to furnish and install all the maintenance material required to maintain the five batteries in efficient operating condition for a second term of 10 years was entered into, the contractor undertaking to do this for approximately 8 per cent. per annum of the initial cost of the installation. The foregoing are among the hardest-worked batteries installed in the United States. Stand-by batteries can be maintained for a period of 10 to 15 years at within 3 per cent. per annum of the cost of installation.

197. Life of plates. Planté positive plates in regulating or line batteries will have lives of from 4 to 6 or more years if they are in hard service, and should last longer in light service. Planté negative plates should outlast two sets of positives within a period of 12 to 14 years. Paste positives in stand-by service show every indication of being good for 10 years of service, negatives being good for a somewhat longer period. The scrap lead of plates, to be replaced, has a considerable value and the cost of plate replacements should be credited with this value. Manufacturers will usually guarantee a minimum life of plates if they know the service conditions.

198. Life of tanks. Glass jars are good until broken and a few jars, especially with the larger sizes, will break from time to time outside of accidental causes. This breakage is usually a consequence of imperfect vercharge of these batteries requires that water be added frequently, if this is not carefully done the insulation of the tanks is injured. Over-rge also results in a greater deposition of sediment from positive plates a shortening of their lives.

209. Frequency of cleaning. Train-lighting batteries which are perly charged can be kept in operating condition for 3 years without ng opened up for cleaning. After cleaning the first time such batteries ould be cleaned at intervals of 2 years. With many railroads the actice is to make the first cleaning 2 years after placing in service, with bsequent intervals of 1 year between cleanings.

ALKALINE STORAGE BATTERIES

210. Classification. There are but two practical types of alkaline storage tteries in commercial use: one is the Hubbell, used in the miners' lamps of e Portable Electric Safety Light Co.; the other is the Edison storage battery.

211. The Hubbell battery differs from the Edison in principle, only in sing a negative plate of cadmium instead of the iron of the Edison battery. ubbell apparently was the first to use nickel threads incorporated in the ickel-oxide active material, and this is one of the essential steps in the pro-uction of a practicable battery plate with this active material. The nickel xide of the original Edison battery, contained flake graphite to increase the onductivity; the graphite was seriously affected by electrolyte action, and hese plates were short lived. In the present type of Edison battery, flake ickel replaces the graphite of the earlier type. In December, 1914, the first ew of these batteries had completed 5 years of service.

212. Theory of the Edison battery. The active materials of the Edison battery consist of nickel peroxide for the positive plate and finely divided iron for the negative plate. The electrolyte is a 21 per cent. solution of potassium hydrate in water to which is added a small amount of lithium hydrate. To overcome the passivity of iron a certain amount of mercury is incorporated with the iron of the negative plate; a suitable compound is also incorporated with the nickel hydrate which is the salt from which the nickel peroxide is electrolytically formed. The nickel oxide is a relatively poor electrical conductor and, for this reason, layers of flake nickel are added in the mass to increase its conductivity. Catalysis plays a large rôle in the action of the Edison battery. A complete and correct theory of these reactions has probably not yet been given. Essentially, however, it is the following:

$$8OH + 3Fe = Fe_3O_4 + 4H_2O \qquad \text{(Negative Plate)} \qquad (11)$$

$$8K + 6NiO_2 = 3Ni_2O_4 + 4K_2O \qquad \text{(Positive Plate)} \qquad (12)$$

$$8KOH + 6NiO_2 + 3Fe = Fe_3O_4 + 2Ni_3O_4 + 8KOH \qquad \text{(Both Plates)} \qquad (13)$$

or,

$$6NiO_2 + 3Fe = Fe_3O_4 + 2Ni_3O_4 \qquad (14)$$

The above formula, read from left to right, indicates discharge; read in the reverse direction, it indicates charge.

Both the iron and nickel oxides probably do not exist as such, in the electrolyte, but are hydrated. In the charge of the battery, potassium is not deposited, and there are none but concentration changes in the electrolyte in the pores of the active materials. There is no appreciable change in electrolyte density from the charged to discharged state of the Edison battery. At the latter end of charge a higher oxide of nickel is formed, which is unstable on standing. This oxide decomposes to NiO_2 with time. A freshly charged Edison battery shows a higher voltage on discharge than one which has been standing.

213. Positive-plate construction. The positive plate consists of a nickel-plated steel frame into which are pressed perforated tubes filled with alternate layers of nickel hydrate and metallic nickel in very thin flakes. The tube is formed from a thin sheet of steel, nickel plated and perforated, and has a spirally lapped joint. The active material is tamped into the tubes, nickel hydrate and nickel flake being fed alternately and the tubes when

214. Data, Edison Cel

Type of cell	B-2	B-4	B-6	A-4	A-5	A-6	A-8	A-10
No. positive plates	2	4	6	4	5	6	8	10
No. negative plates	3	5	7	5	6	7	9	11
Weight (lb. per cell)	4.6	7.4	11.0	13.3	16.8	19.0	27.0	34.0
Capacity (amp.-hr.)	40	80	120	150	187.5	225	300	375
Charge amp. for 7 hr.	7.5	15	22.5	30	37.5	45	60	75
Discharge amp. for 5 hr.	7.5	15	22.5	30	37.5	45	60	75
Avg. volt per cell discharge at above rate	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Amp.-hr. efficiency	82	82	82	82	82	82	82	82
Watt-hr. efficiency	60	60	60	60	60	60	60	60
Watt-hr. per lb. of cell	10.4	13.0	13.7	13.3	13.4	14.1	13.1	13.2

boxes are assembled in the grid and subjected to pressure to weld the joints and to corrugate their surfaces. The iron is precipitated as a chemical compound and the nickel hydrate and this iron compound are converted electrolytically to nickel peroxide and metallic iron respectively, in the forming of plates.

216. The assembly of the cell is shown in Fig. 53. The plates are supported on hard-rubber spacing and insulating pieces. The lugs of the plates are punched and are mounted upon a steel pin with a terminal post. The ends of the pins are threaded and the plates, separated by washers, are held together by steel nuts. The elements are contained in a nickel-plated sheet-steel case, the walls of which are corrugated to add stiffness and also to assist in cooling the cells in action. The cover also is of

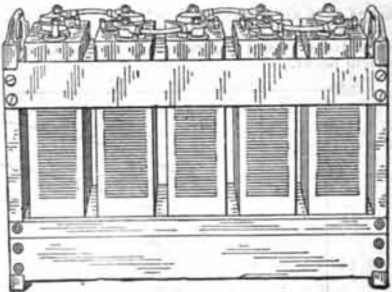

Fig. 54.—Crate mounting.

sheet steel with three openings; two for the terminal bushings, which are provided with stuffing boxes, and the third for the gas vent and for the filling of the cell with water.

The cells are assembled in wood crates as shown in Fig. 54, usually with the bottom left open to secure a circulation of air sufficient to keep the cells cool.

With the Edison battery the discharge rate which has been taken as the normal or standard, is that which would discharge the battery in 5 hr.

The numerals of the type designations indicate the number of positive plates in a cell, and each positive plate of the vehicle size is capable of giving 7.5 amp. for 5 hr.

217. Charge and discharge curves. The characteristic normal charge and discharge curves for an Edison battery are given in Fig. 55. It will be noted that the average voltage on discharge is approximately 1.2 volts; the initial open-circuit voltage is approximately 1.5

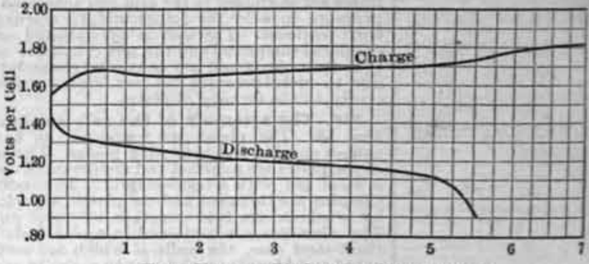

FIG. 55.—Normal charge and discharge curves.

charge. If an Edison cell is known to have been considerably discharged it is always well to continue the charging current for the full 7-hr. period, as the battery is not injured by overcharge unless the temperature passes a critical point.

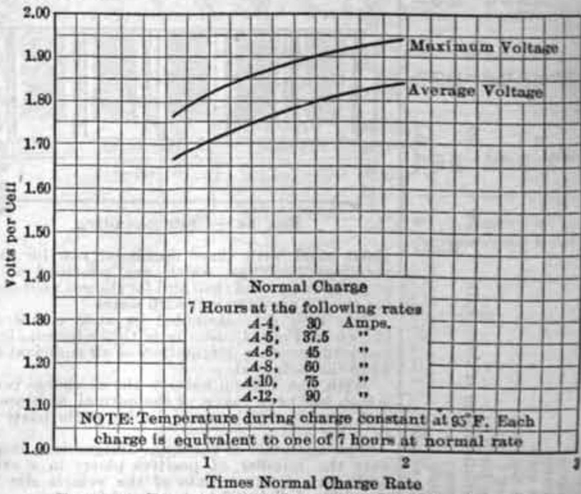

FIG. 56.—Temperature influence on charging voltage.

218. Charging curves. Maximum and average voltages of charge as influenced by charging rate, are shown in Fig. 56. In these curves, the cell is presumed to have a constant temperature of 95 deg. Fahr. and the duration of charge is 7 hr. The voltage on charge decreases considerably with increasing temperatures.

219. Characteristic discharging curves. Characteristic discharge curves for Edison type "*A*" cells are given in Fig. 57. It will be noted that the ampere-hour capacity of an Edison cell does not suffer very greatly with increasing discharge rates, if the terminal voltage be carried low enough. For practical purposes, however, the last portion of the discharge at high rates would have no value because of its great falling off from the open-circuit voltage.

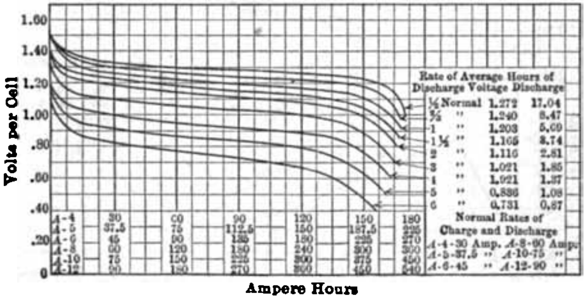

FIG. 57.—Typical discharge curves, type "*A*" cells.

220. Standing discharged. No injury is done to the Edison battery if it is completely discharged and allowed to stand in this condition. This is one of the principal distinguishing features of the Edison battery. The cell, however, loses in capacity by standing as shown in Fig. 58, and is most easily brought back to its condition of full capacity by giving it a very considerable overcharge. The usual practice is to ship the Edison battery in a discharged condition, and it requires several cycles of charge and discharge to bring it to its full capacity.

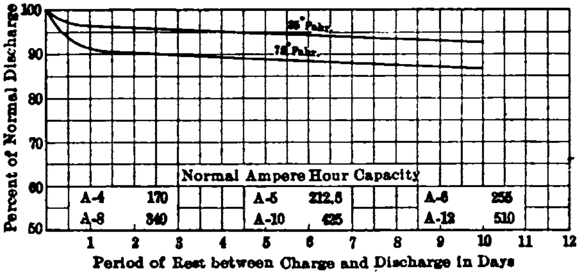

FIG. 58.—Loss of capacity.

221. Overcharge. The Edison battery is not injured by overcharging unless its temperature exceeds 105 to 110 deg. Fahr. High temperatures seriously affect the capacity and life of Edison negative plates, and the manufacturer's guarantee does not hold for overheating from this cause. A continuance of overcharge increases the capacity on the subsequent discharge, but this increase in capacity is obtained at the expense of efficiency. The effect of continued charge is shown in Fig. 59.

222. Effect of temperature. There is a marked falling off in capacity of the Edison battery with low temperature, especially at high discharge suitable neutral or test electrolyte for an Edison battery is a nickel-oxide tube, such as those used in the standard positive plates.

225. Application. The "*B*" type cells are used for ignition and lighting of gasoline motor cars; they are not commercially used for motor starting on account of the high internal resistance. The vehicle-type cells are used for electric vehicle propulsion, storage battery street cars, mining locomotives and industrial trucks; they are not used for load regulation on account of the heavy drop in voltage at high discharge rates, this factor also limiting their use in other power applications.

226. Operation. The life of the Edison battery is guaranteed under certain restrictions as to its operation. The operating instructions of the Edison Storage Battery Co. should be carefully followed if the battery company is to be held to its guarantee. A temperature of 115 deg. Fahr. should not be exceeded under any circumstances, as high temperatures will seriously injure the negative plates.

227. Initial or first charge. Edison batteries are usually shipped in a discharged condition. Before placing them in service they should receive a continued charge at the normal or 5-hr. rate, for a period of 12 hr. or more.

228. Regular charge. If the battery has received a complete discharge, the charge should be started at the normal rate and continued for a period of 7 hr., or until each cell, under normal temperature conditions, has reached a voltage of at least 1.8 volts per cell. The ampere-hours of charge should exceed the ampere-hours of discharge by approximately 40 per cent., and the battery should receive in addition, an overcharge of several hours at the end of each month of service.

229. Replacing evaporation. The electrolyte must be kept well above the plates by adding water whenever necessary, to maintain the level. Always use distilled water for this purpose.

230. The outside of the cells and the trays must be kept clean and dry. Dampness under certain conditions will cause the containers to pit under electrolytic action.

231. Standing idle. If an Edison battery is to be placed out of commission it need not receive any special attention, other than to see that the electrolyte is brought to the proper level. The battery can stand either charged or discharged equally well. To obtain the full capacity, however, after a long period of standing it is necessary to overcharge the battery.

232. Life of Edison battery. A log of a life test as published by the Edison Storage Battery Co. is shown in Fig. 60, the statement is made that the conditions of the test are harder than would normally be met in service. The battery is more durable than the vehicle types of lead battery. It is doubtful if it approaches the durability of the heavy Planté types of lead cells.

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SECTION 21

TELEPHONY, TELEGRAPHY AND RADIOTELEGRAPHY

BY

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CONTENTS

(*Numbers refer to Paragraphs*)

TELEPHONY AND TELEGRAPHY

RADIOTELEGRAPHY

TELEPHONY AND TELEGRAPHY

BY

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DEFINITIONS

1. The scope of this section is confined to the needs of electrical eng neers who encounter telephone or telegraph problems only in the sense of a adjunct to a major operation, or subsidiary to the main work in han Therefore the section deals exclusively with those applications of telepho and telegraphy which may be termed **private-line systems**, as found in co nection with steam and electric railways, transmission and distribution sy tems, industrial plants, etc.

2. Telephone systems may be classified, according to their commerci uses, as follows:

Telephone Systems
- *Public*
  - *Exchange*
  - *Toll*
- *Private*

3. Public telephone systems are those operated for commercial prof under some fixed schedule of tariffs or rates. Such systems must serve a who apply, and are usually subject to some form of regulation as to rates an service by the public authorities. Any public system might be broadl defined as a common carrier of intelligence or communication.

4. Telegraph systems may be classified, according to their uses, as fo lows:

Telegraph Systems
- *Public*
- *Fire Alarm*
- *Police*
- *Private*

5. Public telegraph systems may be defined in general the same public telephone systems, in Par. **3**, with the exception that the mode communication of course is different.

6. Private telephone and telegraph systems are those operated auxiliaries to some other form of business or enterprise (Par. **1**), but not d rectly for commercial profit. Private systems are sometimes interconnect with public systems, and in other cases are completely isolated. Any priva system which is operated under especially hazardous conditions, such long parallel exposure under a high-tension transmission line or close pro imity to a single-phase traction system, should be connected to a publ system, if at all, only through elaborate protective apparatus designed reduce to an absolute minimum the probability that dangerous potentials currents will penetrate beyond the protection to any part of the public syste

7. Private systems may be classified, according to their uses, as follow

Private Systems
- *Train Dispatching*
- *Load Dispatching*
- *Line Patrol*
- *General communication*
- *Intercommunicating*

ystems, or in large transmission and distribution systems, in connection with the centralised control of the distribution system by one or more load dispatchers.

10. Line patrol systems are used in connection with the patrol of transmission lines, to enable patrolmen to communicate quickly with headquarters; they are used also by the U. S. Life-Saving Service.

11. Private systems for general communication have numerous and extensive applications on steam and electric railways, and in connection with central stations, transmission and distribution systems, etc.

12. Intercommunicating systems are designed for isolated local service, usually without attendance, in factories, mills, shops, residences, etc.

STANDARD TELEPHONE INSTRUMENTS

13. Speech is transmitted electrically by means of three supplementary elements, termed the transmitter, the line, and the receiver. The sound waves of the voice impinge upon the diaphragm of the transmitter and cause it to vibrate in substantial synchronism with the impressed disturbance. The diaphragm forms part of an electromechanism which establishes in the line circuit an alternating current of variable frequency, amplitude and wave form, but substantially proportional at any instant to the pitch, intensity and quality, respectively, of the impressed sound. The line current in its passage over the line suffers both loss of intensity, or attenuation, and change of wave shape, or distortion. If not too greatly enfeebled or distorted by its passage over the line, the transmitted energy enters the receiver and is there converted again into sound waves, approaching in pitch, intensity and quality the impressed sound waves at the transmitter. The receiver is an electromechanism whose function is the reverse of that performed by the transmitter.

The alternating line current, in certain instances, is superimposed on a continuous current, the resultant being a pulsating current. The two currents are separable either by means of a transformer, known in telephony as a repeating coil, or by a combination of reactance (choke) coils and condensers.

14. Transmitters of the variable-resistance, granular-carbon type are almost universally employed. This type consists essentially of two parallel circular electrodes, usually of carbon, one of which is attached to the diaphragm, the other being rigidly mounted. Between the electrodes is a loose mass of finely granulated carbon. Vibration of the diaphragm causes simultaneous variations of pressure on the granular carbon, with accompanying changes in total resistance from electrode to electrode; the resistance decreases with increase of pressure, and *vice versa*.

15. High-resistance transmitters, having about 30 to 60 ohms average resistance, are ordinarily employed for both common-battery and local-battery (magneto) sets. High resistance is particularly desirable in common-battery sets, with central energy supply; it also has the advantage, in local-battery sets, of being economical in energy consumption.

16. Low-resistance transmitters, having about 10 to 15 ohms average resistance, are used in special service (local battery) where the transmission requirements are severe, such as railway train dispatching. Special low-resistance transmitters intended to operate from 110-volt direct-current lighting circuits are used in connection with loud-speaking telephones for announcing trains, paging guests in hotels, etc.

17. Solid-back transmitter. Fig. 1 shows a cross-section of what is commonly known as the White or solid-back transmitter. In this, P is the bridge mounted securely at its ends on the front, F. The diaphragm, D, is of aluminium, with its edges enclosed in a soft rubber ring, *e*, and is held in place by two damping springs, *f*. W is a heavy block of brass, hollowed out to receive the rear electrode, B, which is of carbon secured to the face of a metallic disc, *a*. E is the front electrode, also of carbon, carried on the head of a metal stud, *b*. This electrode is clamped to the diaphragm by means of a

19. Induction coils, when used, form a portion of the transmitting circuit and perform the function of a step-up transformer, in order to transmit to the line impulses or waves of higher potential than those produced in the transmitter circuit. Induction coils are always used with local-battery sets, but not with all makes of common-battery sets (see Fig. 10). It is very important to use the particular type and construction of induction coil which is designed for the transmitter with which it is associated; a different type may operate with fair satisfaction, but not with maximum efficiency.

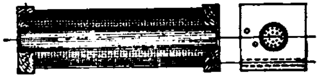


Fig. 3.—Cross-section and end view of induction coil.

The general construction of induction coils is shown in Fig. 3. The core consists of a bundle of small iron wires; some manufacturers employ annealed Norway iron. One manufacturer recommends a ratio of primary to secondary turns, for local-battery sets, of one to four. The secondary is usually wound over the primary. Primary resistances vary from a fraction of an ohm up to about 10 ohms; secondary resistances range from about 20 to 150 ohms. Primary windings range in size from No. 18 to 26 A.W.G. and secondary windings from No. 26 to 36. The diameter of the iron core is usually 0.25 in. minimum.

20. Receivers consist essentially of three elementary parts, a permanent horse-shoe magnet, a sheet-iron diaphragm assembled in front of the magnet poles, and a winding on the polar extremity of each leg of the magnet. The normal tension on the diaphragm varies in synchronism with the current traversing the winding; thus when the winding is energized by voice currents, the diaphragm sets up corresponding voice sounds. Such an instrument is also reversible and may be used as a transmitter of the electromagnetic type; it is not efficient, however, and is used for this purpose only in emergencies, for example when the transmitter battery supply fails, to communicate with the switchboard operator. A modern telephone receiver is shown in Fig. 4. The working parts of this receiver are composed of two bar magnets clamped together by screws passing through an iron tail block, *b*, at one end and through a brass block, *c*, at the end nearest the magnet coils. The magnet unit, in one type, is welded to avoid the presence of joints. The pole pieces are clamped between the magnet ends and the brass block and on their outer ends carry the two coils. The block engages a shoulder in the hard rubber shell and is secured in place by screws, thus holding the working parts securely within the shell. The diaphragm is clamped between the ear piece and the main body of the shell. The terminals of the coils are led to the binding posts, *aa*, to facilitate connecting the receiver in the external circuit. The cord covering is secured to the tail block, *b*, so as to relieve the cord terminals from strain. A type similar in design but differing in that the diaphragm, coils and magnets are all mounted on a separate metallic frame, independently of the enclosing shell, has the advantage that breakage of the shell does not necessarily destroy the adjustment of the instrument.

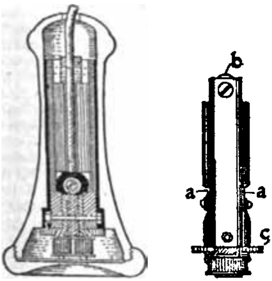


Fig. 4.—Cross-section of receiver and side view of magnets.

Bipolar receivers are also made in the so-called "watch-case" type. This type is attached to a head band and almost universally employed with operators' sets for switchboard service.

type is arranged to revolve in the magnetic field produced by permanent

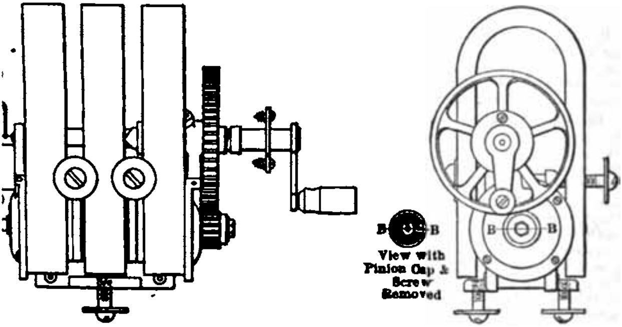


FIG. 6.—Magneto generator.

ıgnets, being driven through light spur gears increasing the speed in ratio of
out 5 to 1. Therefore when the crank is revolved at 200 rev. per min.,
e frequency will be about 17 cycles per sec.; probably the average fre-
ency is between 10 and 15 cycles.

The **series type**, for series sets (Par. 25), must be provided with an auto-
atic short-circuiting device to remove it from circuit when not in use. The
unt or **bridging type**, for bridging sets (Par. 24), must be provided with
automatic circuit-opening device to disconnect it from circuit when not in
e. These automatic switches are
erated by the shaft which carries the
nerator handle and large spur gear.
g. 7 shows the circuit of a bridging
nerator; the shaft *b* is so arranged
at it will advance against a coiled
ring and engage the spring *c* before
tating the spur gear, thus closing the
rcuit between the terminals *aa*. In
e make of generator, a device is also
ovided to separately short-circuit
e generator armature when out of
e, in order to protect it from light-
ng or excessive foreign potentials.

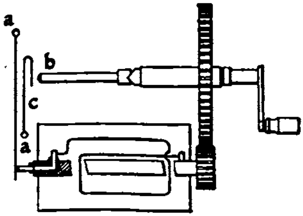


FIG. 7.—Diagram of magneto generator connections.

**27. Magneto generator windings
ıd ratings.** The output of these
nerators, owing to their small size
d high internal impedance, is very
nited. The lower the internal impedance and the larger the magnetic flux
rough the armature, the greater will be the output for a given size and
eed. The windings vary in resistance, in different sizes and makes, from
out 100 to 500 ohms, with several thousand turns. The best grade of
agnet steel (Sec. 4), with maximum retentivity and minimum aging,
ould be used. Generators for light service are usually equipped with
ree magnets, and are known as the 3-bar type; four bars are used for me-
ium service and five for heavy service. The generated effective e.m.f. at
o load and 1,000 r.p.m. (armature speed, giving 16.7 cycles per sec.)

each other, and connected to the instrument terminals through the contacts of the hook switch, the latter being closed only when the receiver is off the hook, as shown in Fig. 9. The ringer and the generator are connected in series with each other, and stand normally connected to the instrument

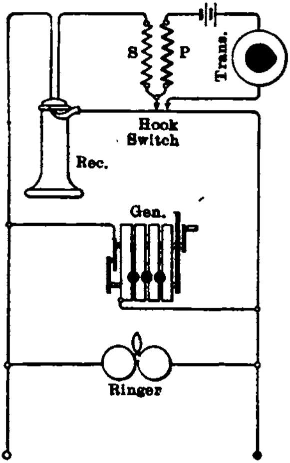


FIG. 8.—Circuit diagram of typical bridging telephone set.

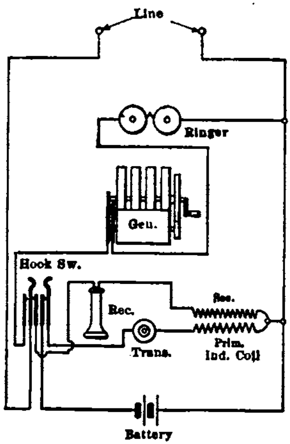


FIG. 9.—Circuit diagram of typical series telephone set (Stromberg-Carlson).

terminals when the receiver is on the hook, but are disconnected when the receiver is in use. The generator is short-circuited except when in action.

38. Common-battery bridging sets are illustrated in Figs. 10 to 13. The simplest type of circuit appears in Fig. 10. The transmitter current is obtained over the line circuit from the central battery at the switchboard.

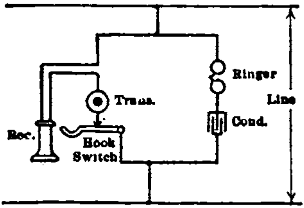


FIG. 10.—Circuit diagram of typical common-battery bridging set without induction coil.

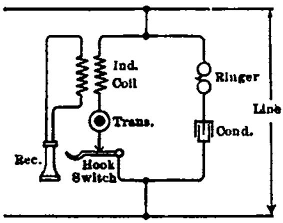


FIG. 11.—Circuit diagram of typical common-battery bridging set with induction coil.

Receivers of the permanent-magnet or polarized type must be properly poled, so that the transmitter current will strengthen their magnets instead of weakening them. Continuous-current receivers (Par. 22) are sometimes used in this type of set.

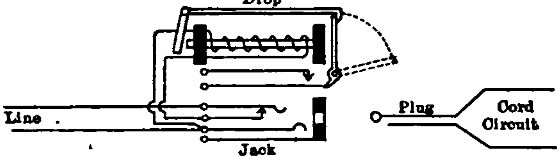


FIG. 14.—Circuit diagram of line jack and drop in non-multiple magneto switchboard.

are made in some cases with a restoring coil which serves to return the shutter to normal position when the operator answers the call by inserting a plug in the answering jack (Par. 43); in other cases the drop and the answering jack

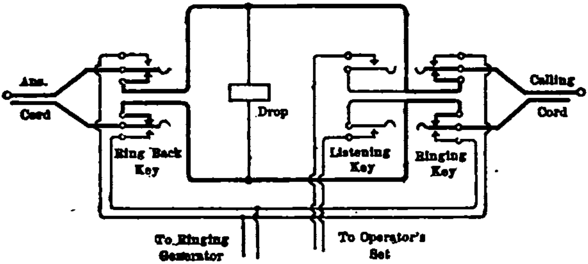


FIG. 15.—Circuit diagram of cord-circuit in non-multiple magneto switchboard; single clearing-out drop.

are mounted together and so arranged that the plug restores the shutter mechanically when the plug enters the jack. The terminus of the line circuit is usually wired as indicated in Fig. 14. Drops are wound of various resistances from 80 ohms to 1,000 or 1,200 ohms; a resistance of 500 to 600 ohms is very commonly used.

43. Switchboard line jacks for non-multiple magneto boards are usually of the type illustrated in Fig. 14. The drop is disconnected from one side of the line by the insertion of the plug in the jack. The night-alarm contacts are shown just below the drop winding.

44. The wiring of a cord circuit with ringing keys, listening key and single supervisory drop is given in Fig. 15. The wires of the through talking circuit are shown in heavy lines. There is some disadvantage in having but one supervisory drop, since it is not possible for the operator to predetermine which line is signalling for attention. This difficulty is overcome in the cord circuit which appears in Fig. 16 (keys not shown), inasmuch as

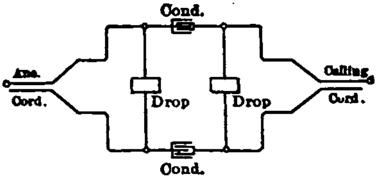


FIG. 16.—Circuit diagram of cord-circuit with double clearing-out drops, for double supervision.

in position between the main frame and the board, for the purpose of enabling any answering jack to be associated with any set of multiple jacks.

50. Switchboard wiring is usually in cable, and the style of cable is commonly referred to as **switchboard cable.** This type of cable is made from various sizes of tinned annealed copper wire (Sec. 4), ranging from No. 18 to 24 A.W.G. The insulation, where the cable is for use in dry places, usually consists of two wrappings of silk and one of cotton; the conductors are twisted into pairs or triples, then a wrapping of paper is applied over all, next a wrapping of thin metal tape (lead, antimony and tin), and finally an outside cotton braid saturated with beeswax. The insulation of the individual wires is sometimes varied, using one silk wrapping and one cotton wrapping, or one silk and two cotton, or two silk and two cotton. These cables are laid up in round, oval or flat cross-sections as desired, in twisted pairs or triples, ranging from 6 pairs to 100 pairs; 5, 10, 15, 20, 25, 30, 40, 50 and 100 pairs are approximately standard sizes. A code color scheme is employed in the cotton covering of individual wires, for the purpose of identifying the pairs and facilitating splices and connections; the manufacturers' bulletins give the codes employed.

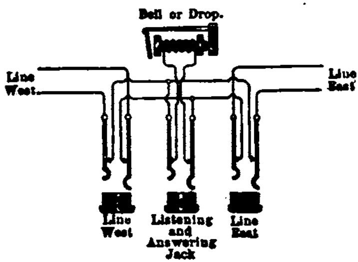


FIG. 18.—Circuit diagram of cut-in station or looping bridge.

Wool-insulated cable is now generally employed in place of pot-head wire (rubber insulated) for connecting underground or aerial cable terminals with the main frame, and in places where there might be trouble with ordinary cotton insulation on account of moisture.

Lead-covered interior cable, insulated with double silk and single cotton saturated with beeswax, is very useful for interior wiring in moist or damp places. It is standard in sizes of 5 to 40 pairs, by steps of 5, and 50, 60, 75, 100, 120, 150 and 200 pairs, of No. 22 A.W.G. tinned annealed copper.

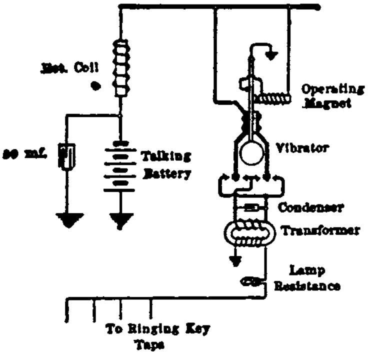


FIG. 19.—Circuits of vibrating pole changer for supplying ringing current from a battery source.

Twisted pairs should be used invariably for all **talking circuits** in order to avoid cross-talk. The length of one complete twist should not exceed 4 or 5 in.

51. Wiring of a through line is shown in Fig. 18. The middle jack is so wired that the operator can listen to determine whether the line is busy before attempting to use it. Code ringing must be employed on a through line connected in this manner. This style of jack wiring is termed a **cut-in station** or **looping bridge.** It can also be arranged with keys instead of jacks, and mounted in a special cabinet if desired.

52. Ringing energy can be obtained in three ways: (a) from a ringing dynamotor (Sec. 9) supplied on the primary side from a lighting or motor circuit, or from a storage battery (in common-battery installations); (b) from a hand generator (Par. 26) mounted in the switchboard; (c) from a one type of cord circuit, complete with ringing and listening keys; this type employs a repeating coil, and is used by the Western Electric Co. in non-multiple boards. The lamp signals are termed supervisory signals,

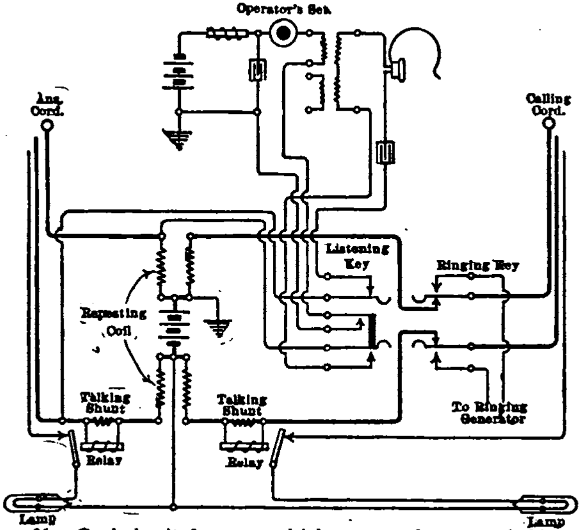


FIG. 21.—Cord circuit for non-multiple common-battery switchboard.

and will be lighted whenever the receiver hook at the line station is depressed. The method of operation is obvious from the figure. Combination cord circuits are those specially wired for the purpose of connecting common-battery lines with local-battery lines.

57. Retardation and repeating coils are quite similar in general construction, but differ in their windings. The principal types of simple impedance or retardation coils are shown in Figs. 22 to 24. Soft Norway iron wire is commonly used in core construction; the **toroidal coil** in Fig. 24 is

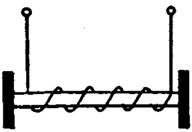


FIG. 22.—Impedance coil with open magnetic circuit.

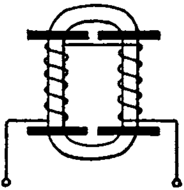


FIG. 23.—Impedance coil with closed magnetic circuit.

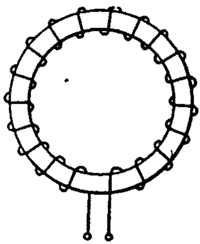


FIG. 24.—Torroidal type of impedance coil.

usually constructed with very fine iron wire covered with a very thin insulation of cellulose or enamel to reduce the eddy-current losses. The desired properties of the iron are high permeability, high resistivity and low hysteresis loss. Enamel insulation for the electrical windings is the most economical frequency, while the impedance coils tend to suppress the corresponding ripples of current in the battery circuit. In large installations, especially with large batteries (of very small internal impedance), the condenser is not required.

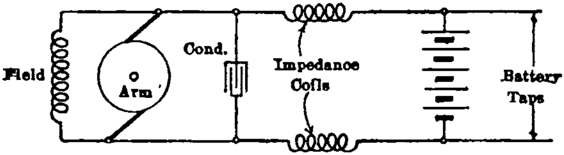


FIG. 26.—Method of suppressing battery noise caused by generator or motor operation.

AUTOMATIC SWITCHBOARDS

64. Fundamental features. There are two general types of automatic systems, the **full automatic** (Par. 65 to 72) and the **semi-automatic** (Par. 73 to 75). The former type performs all switching operations by means of automatic mechanisms under the control of the selector dials or calling devices at the telephone stations; the latter type requires switchboard operators, as in the manual system, but the automatic switching mechanism is under their direction, in the place of using dials at the instruments.

65. Numerous systems have been invented and reduced to commercial practice, including the Strowger, the Lattig-Goodrum, the Lorimer, the Bullard-Rorty and the Clark systems. These systems are all complicated when viewed in their entirety, and cannot be described in the space here permitted. The following description, Par. 66 to 72, covers the **Strowger system** (Automatic Electric Co.) as developed for small installations not exceeding 100 lines.

66. Telephone sets for automatic service are equipped with **calling devices**, one of which is shown attached to a desk stand in Fig. 27. The circuit diagram of this set is given in Fig. 28. The calling device consists of a dial with eleven holes, ten of which numbered with the ten digits, consecutively from 1 to 0. In order to call line No. 73, for example, the person calling first removes the receiver from the hook and then, placing his finger in the seventh hole, pulls the dial around until his finger engages the stop, which causes seven impulses (which are really interruptions of a steady current) to pass over the line to the switchboard; he then places his finger in the third hole and repeats the operation, whereupon the automatic switching mechanisms connect the calling line with line No. 73 and ring the station. When someone answers at station No. 73, the ringing current is automatically cut off and the talking circuits are clear.

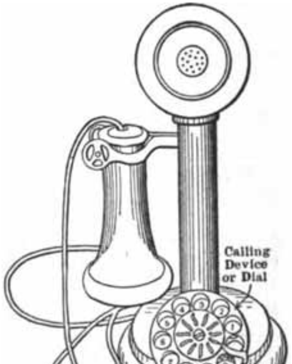


FIG. 27.—Desk stand equipped with calling device or dial for automatic (Strowger) service.

The mechanism of the calling device is shown in Fig. 29. The dial winds a spring which drives an interrupter, consisting of a fibre cam engaging the impulse springs; a tiny ball governor is attached, which insures uniform speed. The line circuit is normally closed (when the receiver is off the hook) and an impulse, so-called, is really a brief interruption of the line current.

switch to the second position, and thus opens the circuit of the vertical magnet and closes the circuit of the rotary magnet. These details are made clearer in Fig. 32.

The second set of impulses actuates the rotary magnet and rotates the shaft until the wipers rest on the corresponding set of contacts, which would be the third set in the seventh vertical row, in the case of a call for line No. 73. When the second set of impulses ceases, the private magnet moves the side switch again, and closes the ringing circuit on the called line; ringing continues at short periodic intervals until the receiver at the called station is removed from the hook, upon which the direct current through the back bridge relay operates the same and in turn the ringing cut-off relay. The circuits are then clear for through communication.

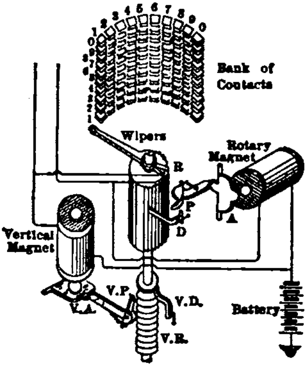
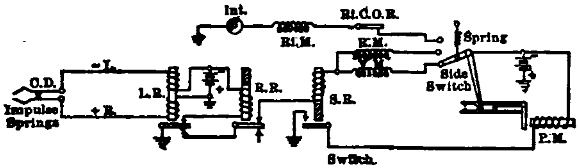


FIG. 31.—Connector switch.

When the receiver at the calling station is returned to the hook, the slow-acting release relay (Fig. 32) is de-energized by the line relay and thus rereleases the double-dog (Fig. 30) and the wiper shaft returns to normal, clearing the connection. The off-normal switch serves to keep open the circuit of the release magnet unless the wiper shaft is in action or use.

For the sake of simplicity certain details have been omitted, but the essential principles have been emphasized as fully as space will permit. The busy test, which is not shown, is so arranged that a call for a busy line will not be completed, and the usual busy signal will be communicated to the calling line. For further details see the references below* and the Bibliography (Par. 263).



C.D.—Calling device.
L.R.—Line relay
R.R.—Release relay.
S.R.—Series relay.
INT.—Interrupter (ringing).
Ri.M.—Magnet for ringing-cut-off relay.
Ri.C.O.R.—Ringing-cut-off relay.
P.M.—Private magnet.

FIG. 32.—Details of connector circuit.

70. Mounting. Line switches are usually mounted in groups of 100 each. The necessary connectors for a group of 100 lines are mounted with

* Campbell, W. L. "A Study of Multi-office Automatic Switchboard Telephone Systems;" *Trans.* A. I. E. E., Vol. XXVII, 1908, p. 503–541.
Campbell, W. L. "A Modern Automatic Telephone Apparatus;" *Trans.* A. I. E. E., Vol. XXIX, 1910, p. 55–84.
Smith, A. B. and Campbell, W. L. "Automatic Telephony;" McGraw-Hill Book Co., Inc., New York, 1914.

75. Trunking between automatic and manual switchboards can be readily provided by means of appropriate apparatus, and is extensively employed. For details of such trunking in exchange systems see the Bibliography (Par. 263).

INTERCOMMUNICATING SYSTEMS

76. Intercommunicating systems comprise relatively compact private telephone systems, in most cases without any switchboard or operating attendants, for the purpose of internal communication in factories, industrial plants, stores, offices, hospitals, residences, apartment buildings, etc.

77. Equipment. Each station is equipped with a telephone set and a switching device mounted in a small box or cabinet. For each station there is a telephone line or circuit extending to all other stations, and so arranged that by depressing the appropriate switching key or button in the switching cabinet at any other station, connection can be established with this particular line; at the home station there is also a calling signal or bell (or buzzer), and an answering key arranged to connect the home telephone set with the line. Thus for a 10-line system there will be 10 keys or buttons in each switching cabinet and 10 talking circuits in a small cable multipled to all 10 cabinets; in addition to the 10 line-circuits there is another pair for supplying the talking current (common battery) to each station, and still another pair for supplying ringing current to each station. Direct-current is usually employed for ringing, and dry batteries are used for both ringing and talking.

The keys or buttons are usually so arranged that when depressed as far as possible, the ringing current is sent out on the line; when released, the key automatically returns to an intermediate position, where it is held by a lock or detent, and thereupon the ringing connection is broken and the talking circuit completed. The several keys in any individual switching cabinet are usually so arranged or interlocked, that the depression of one key automatically releases or restores all the others.

78. The operation is very simple. In order to call station No. 7 from station No. 3, the No. 7 button at station No. 3 is depressed as far as possible and held there a moment before releasing it, and meanwhile the bell connected to line No. 7, which is at station No. 7, responds. At station No. 7, the home button is depressed and the receiver taken from the hook, thus establishing communication. The ringing connection on the home button can be omitted, since it is obviously unnecessary.

79. Other equipment combinations can be arranged readily, including master stations for switching, with annunciator; one-way stations for inward calls only; non-selective code-ringing party lines, etc. The manufacturers offer many varieties of equipment for such combinations, which are readily understood from their bulletins.

80. The line capacity of standard equipments varies somewhat among the different manufacturers, but not to any great extent. One manufacturer offers complete units equipped for 6, 12, 22 or 32 stations; another offers sets for 11, 21 or 31 stations; another, 6, 12, 16, 20 or 24 stations, etc. These equipments are usually made in several styles, for desk mounting, wall mounting, or the flush wall type.

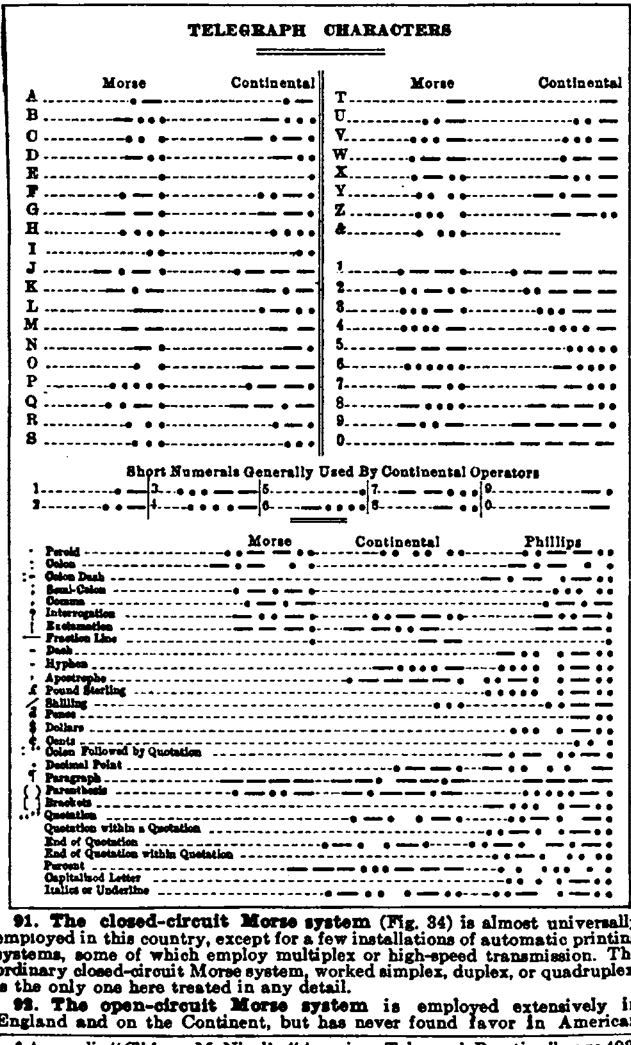
PHANTOM CIRCUITS

81. Two types of phantom circuits are in use, one derived by means of repeating coils, the other by bridged impedance coils. Both types are illustrated in theory in Fig. 33, all circuits being metallic.

82. The repeating-coil type of phantom circuit is shown in theory in Fig. 33, at the left of the diagram, where *RC* are repeating coils tapped at the centres of the line-side windings for the derived or phantom circuit.

83. The impedance-coil type of plantom circuit also appears in Fig. 33, at the right, where *IC* are retardation or impedance coils tapped at the centres of their windings for the derived or phantom circuit. This type is especially suitable for station circuits, where it is possible to economise in line wire by connecting the more distant stations to a phantom circuit. In this case grounded signalling cannot be employed. The side circuits should be subtantially alike in all particulars, including length.

90. Morse and Continental Alphabets.*



91. The closed-circuit Morse system (Fig. 34) is almost universally employed in this country, except for a few installations of automatic printing systems, some of which employ multiplex or high-speed transmission. The ordinary closed-circuit Morse system, worked simplex, duplex, or quadruplex, is the only one here treated in any detail.

92. The open-circuit Morse system is employed extensively in England and on the Continent, but has never found favor in American

* Appendix "*C*" from McNicol's, "American Telegraph Practice," page 492.

98. The operating currents required in closed-circuit Morse working vary according to the system of working and the sensitiveness of the relays. The usual current with 150-ohm relays, line-circuit closed, is about 0.040 to 0.050 amp.; with 35-ohm relays, 0.060 to 0.075 amp.; for 20-ohm pony relays, about 0.100 amp.; for local sounders, 0.100 to 0.250 amp.

99. The polar duplex is illustrated in theory in Fig. 35, which shows but one terminal of the line, since the other is identical. The polar relay, as its name indicates, is polarised, and responds to currents in one direction but not the other. In order that the armature may be under a slight normal attraction when no signals are passing, it is given a slight bias, or so adjusted that it is nearer one pole-piece, than the other. The polar relay, being differentially wound, is neutral to outgoing currents from the home key, if the artificial and the real line-circuits are electrically balanced. When the distant key is closed the line current in the upper limb of the polar relay becomes (theoretically, with a perfectly insulated line) double that in the lower limb and actuates the local sounder; if the home key is next closed, the relay is not affected. If the home key is closed, while the distant key is normal, the home relay will also be unaffected, as can be seen from consideration of the relative strengths and directions of the currents in the two limbs.

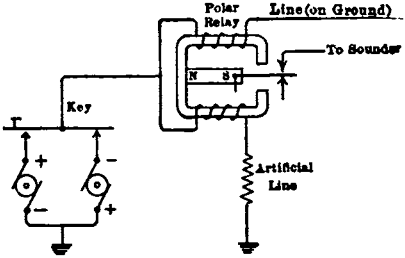


FIG. 35.—Theory of differential polar duplex.

100. The bridge duplex is shown theoretically in Fig. 36, where R_1R_2 are two equal resistances, or equal windings of an impedance coil. The relay is a plain non-polarised type. The compensating resistance should be equal to the internal resistance of the battery, in order not to upset the adjustment of the artificial line.

101. The bridge polar duplex* is similar to Fig. 36, except that the battery and key are displaced by the generators and key in Fig. 35, and a polar relay is required.

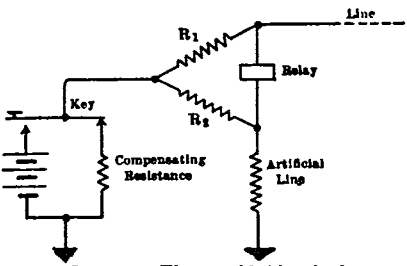


FIG. 36.—Theory of bridge duplex.

102. The bridge quadruplex of the Western Union type developed by Athearn† is shown in theory in Fig. 37. The function of the holding coil H on the neutral relay is to hold down the armature of the relay during reversals on the polar side. The extra current condenser $E.C.$ has a capacitance of about 0.25 mf. and is in series with a 20-ohm resistor. The impedance coils U have a total resistance of 1,000 ohms, or 500 ohms per side. The operating currents are about 0.020 amp. for the polar side and 0.060 for the neutral or common side. This type of quad is very efficient and less subject to interference from inductive disturbances on the line than the differential quad.

* *Telegraph and Telephone Age*, Dec. 1, 1912, p. 802 and Dec. 16, 1912, p. 835.

† *Telegraph and Telephone Age*, Mar. 16, 1911, p. 226: also see issue of Nov. 1, 1910, p. 722.

105. The artificial line must be adjustable, both in resistance and capacitance, in order to establish readily a balance with the real line. When adjusting for a balance the distant battery or generator should be cut out, and a connection made to ground in its place, through an equivalent resistance.

106. Single-line repeaters designed to repeat signals from one Morse circuit to another, with single working, are of various types, including the Milliken, Toye, Weiny-Phillips, Ghegan, Atkinson, Neilson, Horton, d'Humy and others. Only one of these types will be shown; for descriptions of others see the references in Par. 263. Every repeater embraces, for each line, a receiving relay, a transmitter and a holding device; these elements, in duplicate, are common to every type. The principal differences among the various types relate to the form of holding device.

107. The Milliken single-line repeater is shown in Fig. 39, where *RR'* are the main-line relays, *TT'* are the transmitters, and *EM*, *EM'* are the extra magnets or holding devices. When the circuit opens on the west, relay *R* is released, opening the local circuit of transmitter *T* and in turn discon-

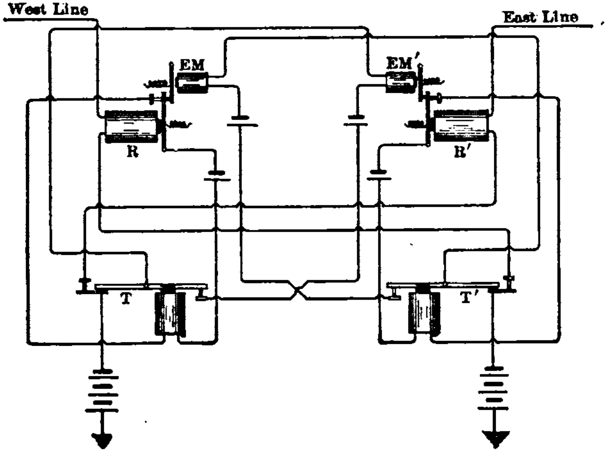


Fig. 39.—Circuits of the Milliken single-line repeater.

necting the battery of the line east; simultaneously the magnet *EM'* is released and its armature falls back on the armature of relay *R'*, holding it closed and thus protecting the transmitter *T'*. The other operations will be evident from this description and the circuits in Fig. 39.

108. Duplex and quadruplex repeaters* are very simple, it being necessary only to place the pole-changer of the east line under control of the polar relay on the west line, and the transmitter (common side) of the east line under control of the neutral relay on the west line, with corresponding connections for working from east to west.

109. Half-set repeaters consist of one relay and one transmitter for connecting a duplexed line with a single line, or one side of a quad with a single line.

110. The phantoplex is a system for superimposing an alternating-current telegraph on an ordinary single, duplex or quadruplex circuit.† It

* "Western Union Bridge Duplex." *Telegraph and Telephone Age;* Jan. 16, 1913, p. 54; Feb. 1, 1913, p. 84.

† McNicol, D. "American Telegraph Practice;" McGraw-Hill Book Co., Inc., New York, 1913; Chap. XIX.

the half-set in Fig. 43. The 2-mf. condensers cc perform the sam
30-ohm coils ee are for the purpose of shunting to groun
pulses passing through the condensers cc, which otherw
through the telephone circuit and result in cross-writing b
morse legs.

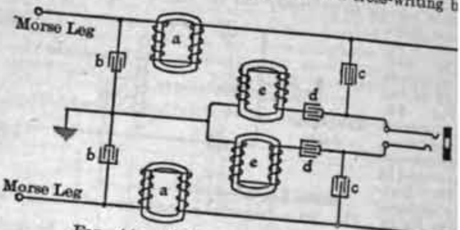


FIG. 44.—Full composite set for metallic circu

118. Duplex working through composite sets require of a dummy composite set in the artificial line at each term establish a balance with the sets in the main line. It is also nect a grounded shunt condenser and serial impedance coil b changing transmitter and the polar relay, in order to furn sharpness of the impulses when transmitting morse.

119. Composite ringers. It is not permissible to signal telephone circuits with the usual 16-cycle ringing current, sin the morse relays. A high-frequency ringing system is in use with relatively weak currents and does not interfere wit morse transmission.*

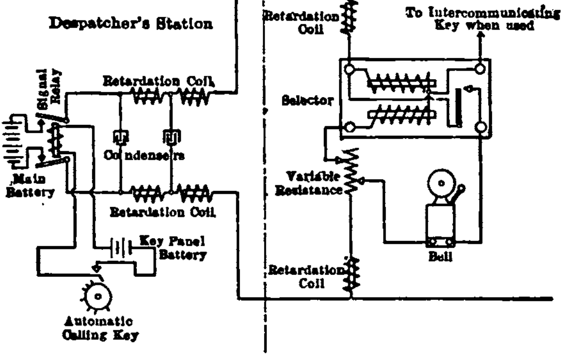
DISPATCHING AND PATROL SYSTEM

120. Train dispatching systems on steam railroads operated by Morse telegraph exclusively, but the telephone superseded the telegraph during the last 6 or 8 years. I tems on electric interurban railways have been operate almost without exception since the earliest days of such sys dispatching system comprises in brief a master sending station, with means for selectively signalling all other s circuit, and a plurality of way stations equipped primaril Dispatching systems vary in detail, but nearly all embrace t mental features.† Dispatching equipment is manufactu all of the leading makers of telephone equipment, and the system are too extensive to reproduce here. Only the l will be described.

121. The Kellogg selective signalling system for train shown in theory in Fig. 45. Normally the battery circuits automatic calling-key s operated by clockwork, there being for calling each station. The particular key shown will send a impulses to line represented by 3–1–2–1. The object of the r and condensers at the dispatcher's station is to make the sign

* Kissel, N. C. "The Composite Ringer;" *Telegraph and* May 1, 1910, p. 318.

† Brown, G. "Some Recent Developments in Railway Tele Amer. Inst. of Elec. Eng., 1911, Vol. XXX, p. 1007.
Clapp, M. H. "A Comparison of the Telephone with the Means of Communication in Steam Railroad Operation;" *Pr* Mar., 1914.



IG. 45.—Theoretical circuit of Kellogg selective signalling system using Gill selector, for train dispatching.

fect on voice currents, and also has an adjustable resistance designed to jualize the line currents in all the selectors to about 0.008 amp. each. A **ill selector** is employed at each station, which is so arranged that a com-nation of impulses, with intermediate tervals, will rotate a wheel and at a rtain point in its travel close a local bell rcuit. The bell may be operated by cal battery or from the main line, and ıe dispatcher receives a signal in his own ceiver which gives a positive indication ıat the bell is ringing. The dispatcher ın also prolong the ringing as long as he esires, by means of a special key.

122. Way-station dispatching sets e usually wired in a special manner ited to the peculiar needs of such ser-ice. The circuit of the Kellogg booster" set is shown in Fig. 46. This a bridging set arranged with a push-utton for closing the transmitter battery rcuit and shunting the receiver when ılking. The adjustable 150-ohm re-ırdation coil is for the purpose of grad-g the shunt talking impedance so that l stations on the line will hear equally ell when several are listening simulta-eously; the highest impedance should be t the station nearest the dispatcher, nd the lowest impedance at the last ation. Obviously the operator can sten without closing the transmitter cir-ıit, which is a great advantage. When ıe push-button or self-restoring key is epressed, the local battery circuit is osed and the 3.5-ohm adjustable impedance is shunted around the receiver nd the 150-ohm coil, so that the outgoing transmission is materially

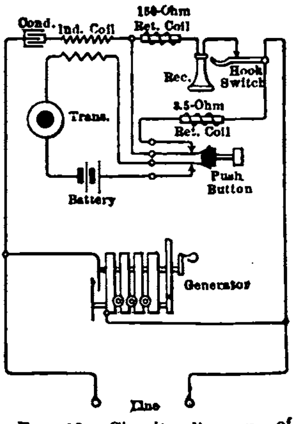


FIG. 46.—Circuit diagram of Kellogg booster set for train dis-patching.

units, in response to changes in the system demand. The telephone
ipment for such service is not as a whole distinguished by any unusual
adical features, and needs no further elaboration. It is quite essential,
lectric trunk line operation, to provide ready communication between the
n dispatchers and the load dispatcher.

34. Patrol systems may be defined as embracing telephone lines
ending along routes covered by patrolmen or inspectors, provided with
ans at intervals of ¼ mile or so for connecting portable sets and estab-
ing temporary communication with headquarters. In the place of
table sets, there may be booths or boxes at fixed locations, with telephones
rein. Patrol systems are in use along railroad rights of way and along the
tes of transmission and distribution lines. In the case of high-tension
s, it is desirable where possible to have the telephone line on separate
es or supports at some distance away; this not only reduces the induction
the telephone line, but also renders it safer and tends to make it more
endable in emergencies, when it is most needed.

FIRE AND POLICE ALARM SYSTEMS

135. Fire alarm systems consist essentially of signal boxes distributed
er the area to be protected, a series line circuit looping through the boxes,

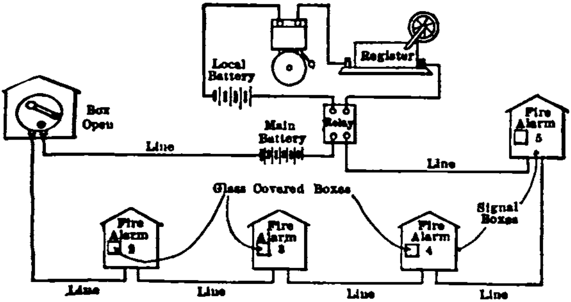


FIG. 47.—Elements of a small fire-alarm system.

and a central station at the engine house or fire headquarters where signals
rom the boxes will be registered as received and the alarm given. The simple
elements of such a system are shown in Fig. 47. Lack of space prevents
more than brief description of
the characteristic details; fur-
ther information should be
sought in the references given
in the bibliography, Par. 263.

136. The line circuit is
normally closed, as shown in
Fig. 48. If an alarm is turned
in at signal box 12, the circuit
will be interrupted once, then
after a pause, twice, this signal
being repeated each time the
wheel revolves; and each time
the line relay R becomes de-energised, the bell relay B causes the bell to be
struck once.

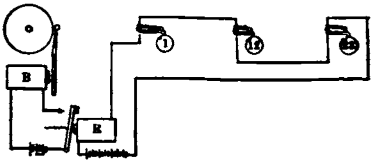


FIG. 48.—Elementary line circuit.

137. Non-interfering box. If two or more alarms should be turned in
simultaneously on the same line, they would interfere with each other and

147. Aerial and underground lead-covered paper-insulated cable
(Western Electric Co.)

No. of pairs	No. 22 A.W.G.			No. 19 A.W.G.		
	Thickness of sheath (in.)	Approx. weight per ft. (lb.)	Convenient no. of feet on reel	Thickness of sheath (in.)	Approx. weight per ft. (lb.)	Convenient no. of feet on reel
5	1/16	0.530	2500	1/16	0.640	2500
10	1/16	0.640	2500	1/16	0.850	2500
15	1/16	0.745	2500	1/16	0.970	2500
20	1/16	0.849	2500	1/16	1.138	2000
25	1/16	0.970	2500	1/16	1.264	2000
30	1/16	1.019	2500	1/16	1.390	1500
40	1/16	1.189	2000	1/16	1.643	1500
50	1/16	1.319	2000	3/32	1.995	1500
55	1/16	1.370	1500	3/32	2.130	1200
60	1/16	1.449	1500	3/32	2.220	1200
75	1/16	1.645	1500	3/32	2.584	1200
90	1/16	1.831	1500	3/32	2.810	1200
100	3/32	2.120	1500	1/8	3.738	1000
110	3/32	2.250	1200	1/8	3.949	1000
120	3/32	2.480	1200	1/8	4.221	1000
150	3/32	2.740	1200	1/8	4.865	1000
180	3/32	3.039	1200	1/8	5.439	1000
200	1/8	4.058	1000	1/8	5.808	800
220	1/8	4.257	1000	1/8	6.168	800
240	1/8	4.474	1000	1/8	6.594	800
300	1/8	5.163	800	1/8	7.587	700
330	1/8	5.460	800			
360	1/8	5.853	800			
400	1/8	6.212	700			
440	1/8	6.654	700			
480	1/8	6.920	700			
500	1/8	7.360	500			

These cables have the following constants per mile:

	No. 22	No. 19
Average mutual capacity (mf.)	0.070	0.074
Average grounded capacity (mf.)	0.105	0.111
Insulation resistance (megohm-miles)	500	500

Lead-antimony alloy (Par. 146) is employed for the sheaths. There is but one application of paper insulation; this is so laid on, however, as to provide two thicknesses of paper over each conductor.

148. Aerial lead-covered paper-insulated cable, is made in sizes from 5 to 400 pairs of No. 22 A.W.G. with either double or single wrapping of paper, and pure lead sheaths. Such cable has a mutual capacitance of 0.08 mf. and a grounded capacitance of 0.12 mf. per mile, with a minimum insulation resistance of 500 megohm-miles. On account of the higher capacitance it is somewhat more compact and lighter than No. 22 cable of 0.070 mf. per mile.

149. Composite cable is the term applied to cable which is made up of pairs of more than one gage or diameter, as for example, No. 22, No. 19 and No. 14 A.W.G. Such an arrangement is often economical for trunk cables where several different transmission requirements must be met.

150. Phantom circuits in cable are made possible by twisting together two similar metallic pairs, constituting a "**quad,**" and laying up such quads in reversed helical layers, after the manner of an ordinary cable. This method is not economical in the use of space within the sheath, however, and it is customary to add as many single pairs as space will permit.

151. Electrolysis of lead cable sheaths from stray or foreign currents is covered as a whole by the article in Sec. 16 by Prof. Gans.

158. Ground wires from arresters to earth form a most important link in the system of protection. The conductor should be not smaller than No. 14 A.W.G. and should pass by the nearest accessible route to a substantial ground plate, rod, or coil, or to a water pipe; **gas pipes should never be used** for this purpose. Too much care cannot be given to securing good electrical connection with the earth, with means of a substantial and reliable character.

When a wrought-iron or steel water pipe (service connection) is not available, a fairly efficient earth connection can be made by driving an iron or steel pipe or rod into the ground, in a moist location, to a depth of 5 or 6 ft. See Hayden, J. L. R. "Notes on the Resistance of Gas-pipe Grounds;" *Trans.* A. I. E. E., 1907, Vol. XXVI, p. 1209.

159. Heat coils or sneak-current arresters are, in reality, fuses of special construction, designed to overcome the unreliability of ordinary fuses for very small currents. For example, a heat coil can be constructed to operate on a current of 0.2 amp. in 30 sec., or a variety of other ratings. This device comprises a small winding of fine wire, which develops sufficient heat to melt a small piece of fusible metal and release a spring which grounds the line circuit; the resistance of the winding usually amounts to several ohms, at least. The function of heat coils is to protect telephone apparatus wound with fine wire (relays, drops, etc.), such that injury might result from foreign currents insufficient to blow the fuses. The proper location for the heat coils is between the protectors and the apparatus.

160. Protective or insulating transformers are employed to protect telephone sets, switchboards or terminals connected to lines which are exposed in a hazardous manner to high-tension high-energy transmission lines, such as those erected on the same poles or structures with a transmission circuit. An insulating transformer of this character* made by one of the leading manufacturers is built to withstand a 25,000-volt test between windings for 1 min., and requires a magnetizing current equal to about half the current taken by a 1,000-ohm polarized bell. The transformer is mounted in a weatherproof case for out-door mounting; the casing should always be thoroughly grounded. It should be observed that such transformers introduce additional losses in both transmission and ringing, which should be taken into account in arranging circuit layouts.

161. Special protectors are usually employed with these insulating transformers, located between the line and the transformer. The protector consists of extra long fuses in the line circuit, with spark-gaps bridged to ground; sometimes the fuses are so mounted as to be integral with an air-break disconnecting switch. See Sec. 11.

162. Insulating stools are often used in conjunction with telephones connected to hazardously exposed lines, as in the case of patrol circuits on transmission lines, so that the attendants may be thoroughly insulated from earth while telephoning. An ordinary four-legged hardwood stool, with the legs inserted in inverted porcelain line insulators, will serve very well. **Insulating mats** are sometimes used, in dry interior locations, in place of stools, but in general are not as efficacious.

163. Extra insulation of telephone sets used in connection with hazardously exposed lines is very desirable. Exposed terminals or connections and uninsulated exposed parts should be particularly avoided in selecting equipment for such service. The hook switch should also be very thoroughly insulated.

CROSS-TALK AND INDUCTIVE DISTURBANCES

164. Induction between parallel aerial wires is due to a combination of electrostatic and electromagnetic induction. Such induction is the cause not only of cross-talk between parallel aerial telephone circuits, but also the inductive disturbances in aerial telephone lines situated in parallel exposure to aerial distribution circuits (Sec. 12) or high-tension transmission circuits (Sec. 11). The general means of eliminating such induction is by interchanging or transposing the wires of each circuit at suitable locations, in accordance with a predetermined system. In severe cases it is necessary to resort to further measures of protection. The subject has been treated at

*"Insulating Transformer for Telephone Lines;" *Telephony*, June 5, 1909, Vol. XVII, p. 666.

169. Phantom transpositions make it necessary to modify the details in Fig. 50 quite materially; changes are necessary at one-half the total number of transposition poles and only the "A" poles remain as they were. An 8-mile section, arranged for phantom circuits, is given in Fig. 51. It is also feasible to transpose pairs 5–6 and 15–16 to make a fifth phantom circuit.

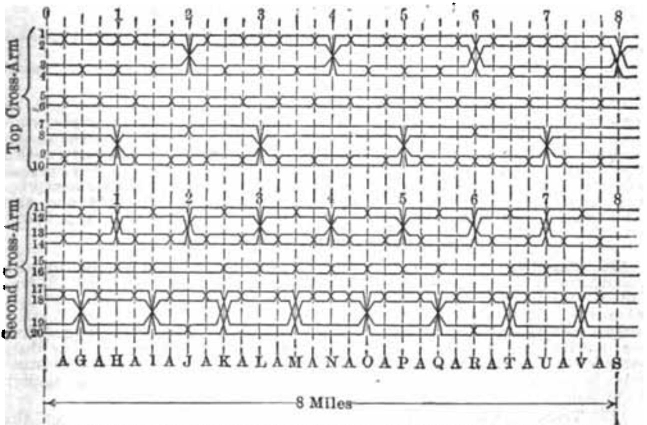


Fig. 51.—Eight-mile transposition section for twenty wires with phantom circuits.

170. Balancing coils, Fig. 52, are sometimes employed to improve the balance of metallic circuits and diminish the intensity of inductive interferences from high-energy circuits. Such coils interfere, however, with phantom, composite or simplex operation, unless installed in the drop side or leg.

171. Drainage coils, Fig. 53, are useful in preventing excessive rise of potential on telephone lines from heavy inductive disturbances caused by parallel high-tension high-energy circuits. The installation of these coils at intervals along the circuit establishes local circuits through earth for the flow of induced currents and thus prevents the cumulative rise of potential which otherwise might occur.

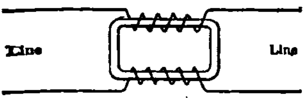


Fig. 52.—Balancing coil for metallic circuit.

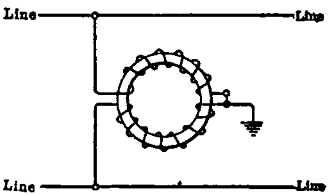


Fig. 53.—Drainage coil for metallic circuit.

172. Inductive disturbances may be minimized by proper arrangement of phase wires, as indicated in the specifications forming part of the report of the Committee on Overhead Line Construction, N. E. L. A., 1911. The phase wires constituting any individual circuit should be grouped as close to each other as feasible. Series circuits should be laid out on the closed-loop system (Sec. 12) and the lamps should be inserted alternately in each side of the loop, to maintain electrostatic balance.

where ϵ is the base of Naperian logarithms, β is the attenuation constant and α is the wave-length constant. In a line of length l, the total attenuation is

$$\epsilon^{-\beta l - j\alpha l} = \epsilon^{-\beta l}(\cos \alpha l - j \sin \alpha l) \tag{3}$$

The quantity $\epsilon^{-\beta l}$ is the numerical magnitude of the attenuation and the quantity within the bracket is the directive or vector portion; the latter has always a numerical magnitude of unity, and is merely a unit vector expressed in terms of complex imaginary quantities. It follows that when two dissimilar lines give equal transmission,

$$\beta_1 l_1 = \beta_2 l_2 \tag{4}$$

182. The attentuation constant is given by the expression

$$\beta = \sqrt{\tfrac{1}{2}[\sqrt{(R^2+\omega^2L^2)\,(G^2+\omega^2C^2)} + (RG-\omega^2LC)]} \tag{5}$$

where R is the effective resistance in ohms per mile, L is the effective inductance in henries per mile, G is the effective leakage conductance in mhos per mile, C is the effective capacitance in farads per mile, and $\omega = 2\pi f$, where f is the frequency in cycles per sec.

183. The wave-length constant is given by a similar expression, which is

$$\alpha = \sqrt{\tfrac{1}{2}[\sqrt{(R^2+\omega^2L^2)\,(G^2+\omega^2C^2)} - (RG-\omega^2LC)]} \tag{6}$$

where the symbols have the same meaning as in the preceding paragraph.

184. The wave length is $\lambda = 2\pi/\alpha$, where λ is the length of one complete wave, α is the wave-length constant and $\pi = 3.1416$. If the line constants are taken per mile, as customary, λ will be in miles.

185. The velocity of propagation is $V = f\lambda$, where V = the velocity, λ is the wave length and f is the frequency. If λ is in mile units, V will be in miles per sec.

186. The KR law, which is strictly applicable only to cables, can be obtained by substituting $L=0$ and $G=0$ in Eq. 5. This will give $\beta = \sqrt{RC\omega/2}$. Therefore two dissimilar cables, neglecting the dielectric losses, will give equal transmission when

$$\frac{l_1}{l_2} = \sqrt{\frac{R_2C_2}{R_1C_1}} \tag{7}$$

where l_1 and l_2 are the respective lengths, R_1 and R_2 the respective resistances per mile and C_1 and C_2 the respective capacitances per mile. The term *KR* law comes from the use of the symbol K for capacitance; it might also be called the *CR* law.

187. The line impedance at the sending end is given by the formula

$$Z = \sqrt{\frac{R+j\omega L}{G+j\omega C}} \tag{8}$$

The **surge impedance** is equal to $\sqrt{R/G}$. For example the line impedance of 9 A.W.G. open copper metallic circuit at 800 cycles is about 690 ohms; for No. 9 copper clad, of 47 per cent. conductivity, it is about 830 ohms; and for a sample of No. 9 A.W.G. iron it was 1,640 ohms.

188. Wave reflection, or reflection loss, occurs at the junction of dissimilar impedances, such as the junction of open-wire line and cable, or more particularly at the junction of a loaded circuit with a non-loaded circuit.

189. Transmission tests are usually made under talking conditions by comparing one instrument with another, or one line circuit with another, and introducing extra cable in the more efficient circuit until the two are alike in talking volume as nearly as can be determined. The amount of extra cable measures the loss, which is expressed in so-called **cable equivalent.** For this work it is very convenient to have a portable artificial cable.

190. Artificial cable for transmission tests can be made in very compact portable form. A 32-mile artificial cable, equivalent to 32 miles of No. 19 A.W.G. metallic copper cable, 88 ohms loop resistance and 0.054 mf. (at 800 cycles per sec.) mutual electrostatic capacity, is a convenient size; the whole cable is subdivided into two 1-mile, one 2-mile, one 4-mile, one 8-mile and one 16-mile sections.

192. Table of transmission equivalents

Type of circuit			Constants of circuit per mile of loop (2 wires)			Transmission equivalent	
Gage No. A.W.G.	Construction	Physical pairs or phantoms	Resistance (ohms)	Capacity (mf.)	Insulation (megohms)	Miles equivalent to 1 mile of No. 19 A.W.G. standard cable	Reciprocal
19	Dry-core paper cable	Pairs	88	0.060	500	1.00	1.00
22	Dry-core paper cable	Pairs	176	0.083	500	0.60	1.66
22	Dry-core paper cable	Phantoms	88	......	.....	0.68	1.48
22	Dry-core paper cable	Pairs	176	0.070	500	0.65	1.53
22	Dry-core paper cable	Phantoms	88	......	.....	0.74	1.36
19	Dry-core paper cable	Pairs	88	0.074	500	0.90	1.11
19	Dry-core paper cable	Phantoms	44	......	.....	1.01	0.99
16	Dry-core paper cable	Pairs	44	0.074	500	1.28	0.78
16	Dry-core paper cable	Phantoms	22	......	.....	1.43	0.70
14	Dry-core paper cable	Pairs	27	0.074	500	1.61	0.62
14	Dry-core paper cable	Phantoms	13	......	.....	1.82	0.55
13	Dry-core paper cable	Pairs	22	0.074	500	1.82	0.55
13	Dry-core paper cable	Phantoms	11	......	.....	2.04	0.49
10	Dry-core paper cable	Pairs	11	0.074	500	2.55	0.39
10	Dry-core paper cable	Phantoms	5.5	......	.....	2.85	0.35
19	Submarine (impregnated paper)	Pairs	88	......	500	0.53	1.9
3 No. 22	Submarine (rubber)	Pairs	59	......	.....	0.63	1.6
16	Submarine (impregnated paper)	Pairs	44	......	500	0.71	1.4
22	Swbd. cable (cotton and silk)	Pairs	176	......	100	0.45	2.2
19	Swbd. cable (cotton and silk)	Pairs	88	......	100	0.59	1.7
19	Swbd. cable (wool)	Pairs	88	......	100	0.67	1.5

TELEGRAPH TRANSMISSION

199. The theory of telegraph transmission has been developed from a number of standpoints. Herbert* has treated it empirically for English (open-circuit) practice, while Kennelly† has handled it from the purely analytical standpoint, regarding morse impulses as nearly the equivalent of a low uniform frequency (Par. 89). The author has applied the leakage theory to uniform open-wire lines, for American practice, with results given in Par. **202**. None of these theories is perhaps satisfactory from the standpoint of every type or condition of line met in practice, but collectively they form a fairly reliable guide.

200. The leakage theory as applied to uniform aerial (low-capacitance) lines, derived from the theory of the distribution of continuous currents in the steady state, has been extensively studied by the author,‡ and appears to be applicable to open-wire lines of the closed-circuit type, if there are no considerable lengths of cable in circuit.

201. Commercial operative limits of transmission, with given line resistances and an assumed leakage conductance of 4 micromhos per mile, have been tabulated in Par. **202**, under the further assumptions next stated: single working, 150-ohm main-line relays, 300 ohms total resistance at each terminal, and a ratio of releasing to operating current equal to 0.75; differential polar duplex, 800-ohm polar relays, and a 300 ohm protective resistor at each terminal; differential quadruplex, 400-ohm polar relays, 800-ohm neutral relays, an e.m.f. of 90 volts on the short (polar) side, ratio of long to short voltages equal to 3.5 and a 600-ohm protective resistor at each terminal.

202. Table of commercial operative limits, with closed-circuit single, duplex and quadruplex Morse working

(Based on a leakage conductance of 4 micromhos per mile)

Resistance per mile (ohms)	Maximum permissible length of line§ (miles)		
	Duplex (two sides)	Simplex or single	Quadruplex (four sides)
2	783	597	531
3	658	510	442
4	580	450	386
6	485	376	313
8	425	331	268
10	384	299	236
15	318	248	186
20	278	217	156
25	250	195	135
30	229	179	120
40	200	156	98.7
50	180	140	84.3

203. The KR law of transmission as developed by Herbert (see footnote of Par. 199) can be stated as follows:

$$W = \frac{A}{KR} \tag{9}$$

where W is the maximum commercial speed in words per min., K is the total capacitance and R is the total resistance of the line; A is a constant having a value of 10,000,000 for open-wire lines of iron, 12,000,000 for open-

* Herbert, T. E. "Telegraphy;" Whittaker and Co., London, 1906, Chap. XVII.

† Kennelly, A. E. "The Application of Hyperbolic Functions to Electrical Engineering Problems;" The University of London Press, 1912.

‡ Fowle, F. F. "Telegraph Transmission;" *Trans.* A. I. E. E., Vol. XXX, 1911, pp. 1683 to 1741: A Study of Telegraphic Transmission, *Telephone Engineer*, Vol. IV, Oct., 1910, p. 171, continued to Vol. VI, July, 1911, p. 49.

§ No intermediate stations.

Length in ft.	Circumference (in.)									
	Class A		Class B		Class C		Class D	Class E	Class F	Class G
	Top	6 ft. from butt	Top	6 ft. from butt	Top	6 ft. from butt	Top	Top	Top	Top
20	....	.....	....	.....	....	.....	......	......	15.5	12.5
22	....	.....	....	.....	....	.....	......	15.5	15.5	12.5
25	....	.....	22	32	18.8	30	18.8	17.3	15.5	12.5
30	24	40	22	36	18.8	33	18.8	18.8	18.8	......
35	24	43	22	38	18.8	36	18.8	18.8	18.8	......
40	24	47	22	43	18.8	40	18.8	18.8	18.8	......
50	24	53	22	50	18.8	46	22.0	22.0	18.8	......

Class A poles are used in lines carrying 50 to 80 wires; Class B poles for 40-wire lines; Class C poles for 20-wire lines; Class E for 10-wire lines; Classes F and G for light farmer lines and bracket lines. For properties of timber, see Sec. 4.

210. Pole setting. The depth of poles in the ground should be as follows, for ordinary soil or for solid rock.

Length of pole (ft.)	Depth in the ground		Length of pole (ft.)	Depth in the ground	
	Earth (ft.)	Rock (ft.)		Earth (ft.)	Rock (ft.)
20	4.0	3.0	50	7.0	4.5
25	5.0	3.0	55	7.5	5.0
30	5.5	3.5	60	8.0	5.0
35	6.0	4.0	65	8.5	6.0
40	6.0	4.0	70	9.0	6.0
45	6.5	4.5	75	9.5	6.0

211. Reinforced concrete poles have been used to a very limited extent, largely on an experimental basis. They are not in sufficient use to warrant any considerable description here; see Still, A. "Over-head Electric Power Transmission," New York, 1913. Coombs, R. D and Slocum, C. L. "Reinforced Concrete Poles;" Universal Portland Cement Co., 1910.

212. Preservative treatment of poles to prevent decay, especially below the ground line, is constantly becoming more common. Among the preservatives employed are creosote, carbolineum avenarius, creolin, spirittine, coal

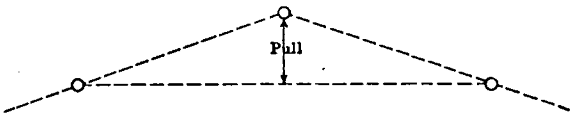


FIG. 55.—Measurement of "pull" on pole-line curve or turn.

tar, zinc chloride and others. There are three methods of treatment, closed-tank process (treating entire pole), open-tank process and brush treatment. The open-tank method, for treating the butts (only) with coal-tar creosote, is recommended as superior to the brush treatment. See publications of the Forest Service, U. S. Dept. of Agriculture, Washington, D. C.

213. Spans. On level straight sections the spans should be about as follows: 40-wire lines, 130 ft.; 20-wire lines, 130 to 150 ft.; 10-wire lines, 150 shown in Figs. 57 and 58; in some cases it is desirable also to guy from the top of pole 1 to the butt of pole 2, and from the top of pole 4 to the butt of pole 3. Back-braces are required on cross-arms on corner poles.

221. Guy strand consists of a galvanized seven-wire strand (or concentric-lay cable) and is usually obtainable in four standard sizes having an ultimate tensile strength of 4,000 lb., 6,000 lb., 10,000 lb. and 16,000 lb., respectively.

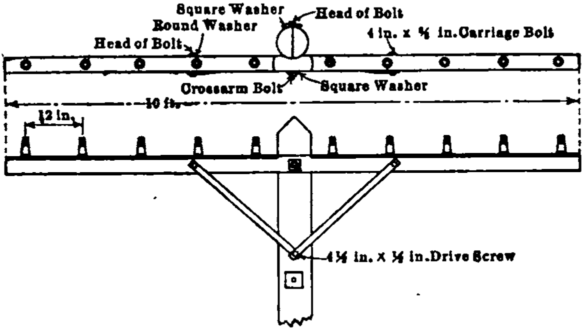
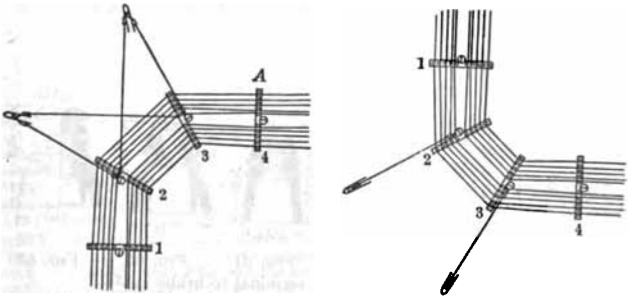


Fig. 56.—Standard pole top and cross arm.

222. Wire used in aerial construction ranges in size from No. 8 B.W.G. (435 lb. per mile) to No. 14 S.W.G. (102 lb. per mile) in hard-drawn copper and from No. 6 B.W.G. (573 lb. per mile) to No. 14 B.W.G. (96 lb. per mile) in galvanized annealed iron and steel. The independent telephone companies employ No. 6 to No. 12 A.W.G. copper, while the Bell companies have



Figs. 57 and 58.—Methods of guying at a corner.

standardized No. 8 B.W.G. and No. 12 and No. 14 S.W.G. copper. For the properties of wire see Sec. 4.

Insulated open wire is usually covered with two cotton braids saturated with weather-proof compound; this is known as ordinary weather-proof wire. Twisted pairs are insulated with a covering of rubber compound and a braid over each conductor. For weights of insulated wire see Sec. 12 and Sec. 13.

226. Test connectors are usually installed at intervals along a pole line, in order to provide facilities for opening the lines for test without cutting the wires. A pole thus equipped with test connectors is termed a **test pole.** The location of test poles is varied in different installations to suit convenience.

227. Line insulators are ordinarily made of glass, in one of the patterns shown in Figs. 61 to 63. Porcelain is used to a limited extent in place of glass, especially to secure the high insulation necessary on loaded circuits, but is more expensive. Porcelain is used to a much greater extent in Europe than in this country.

228. Sag table for hard-drawn bare copper line wire consisting of No. 12 S.W.G. (0.104 in. diam.) is as follows. The sags are given in inches.

Temp. (deg. fahr.)	Length of span (ft.)								
	75	100	115	130	150	175	200	250	300
−30	1.0	2.0	2.5	3.5	4.5	6.0	8.0	14.0	22.0
−10	1.5	2.5	3.0	4.0	5.0	7.0	9.0	16.0	26.0
+10	1.5	3.0	3.5	4.5	6.0	8.0	11.0	19.0	30.0
30	2.0	3.5	4.0	5.5	7.0	10.0	12.0	21.0	33.0
60	2.5	4.5	5.5	7.0	9.0	12.0	16.0	27.0	43.0
80	3.0	5.5	7.0	8.5	11.5	15.0	19.0	31.0	49.0
100	4.5	7.0	9.0	11.0	14.0	18.0	23.0	36.0	55.0

The sags for No. 14 S.W.G. (0.080 in. diam.) hard-drawn bare copper under like conditions, should be at least 2 in. greater than the above values for No. 12.

229. Transpositions are made by means of special line insulators known as transposition insulators. These insulators are made sometimes in one piece with double grooves, and sometimes in two pieces, with one groove in each.

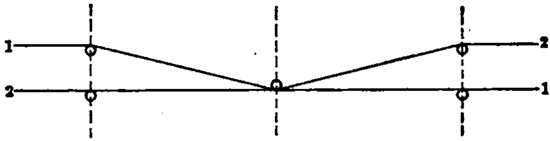


Fig. 64.—Plan view of single-pin transposition.

In modern practice the single-pin transposition is used very extensively (Fig. 64); an alternative method is the use of a two-pin upright iron bracket mounted on the cross-arm so that one wire passes over the arm and one beneath.

230. Phantom transpositions are made by means of upright iron brackets attached to the cross-arms; these brackets may support either transposition insulators or standard insulators, as designed.

231. Stresses in pole lines and wire spans are covered in Sec. 11 and Sec. 12.* In territories subject to sleet storms, the maximum stresses occur with combined sleet and wind loads. The maximum load sometimes assumed in calculating pole and wire stresses is that due to an ice coating ⅜ in. thick combined with a wind velocity of 50 miles per hr. Sleet frequently accumulates to a greater thickness, however; assumptions of 0.5 in. to 0.75 in. have been made in some cases.

* Also see Report of Committee on Overhead Line Construction; N. E. L. A., 1911, 1912, 1913 and 1914.

Thomas, P. H. "Sag Calculations for Suspended Wires;" *Trans.* A. I. E. E., Vol. XXX, 1911, p. 2229.

Still, A. "Overhead Electric Power Transmission;" McGraw-Hill Book Company, Inc., New York, 1913.

239. Cable rings (galvanized) attached to the messenger are now extensively employed for supporting the cable. Rings should be spaced from 15 to 20 in. apart.

240. Continuous cable lengths in aerial construction are limited by the amount of cable which can be pulled into place in one operation without injury. Except with very small cables, the continuous lengths do not ordinarily exceed 1,000 to 1,200 ft.

241. Cable splices. A straight splice is shown in Fig. 66. The conductors are twisted together in pig-tail fashion and folded back so that a

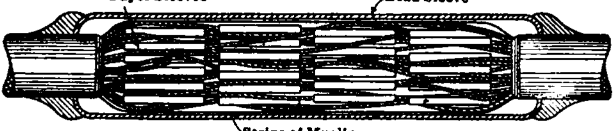


FIG. 66.—Cable splice.

paper tube or sleeve may be slipped over the joint to insulate it. These individual joints are staggered as shown in Fig. 66 and the whole is covered with a lead sleeve made water-tight by means of wiped joints. A number of forms of patented construction for such joints are also on the market.

242. Twisted pairs in rings, the latter supported from a messenger (perhaps carrying a cable also), constitute a form of construction now extensively used in reaching drops from a cable terminal or box.

243. The messenger should be bonded to the cable and grounded as a means of protection against foreign currents and lightning.

244. Grounds may be made by means of a coil of messenger or guy strand buried in coke, at a depth of 5 to 6 ft. in the ground, or by means of an iron pipe (about 6 to 8 ft. long and 1.5 in. diam.) driven into the ground. The first method is preferable. See Par. 158.

245. Underground conduit construction consists of a system of ducts laid from 2 to 4 ft. below ground, with intercepting manholes at intervals of 300 to 700 ft. (Fig. 68).

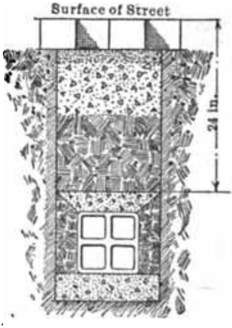


FIG. 67.—Section of four-duct underground conduit, showing cover.

246. Ducts are made of vitrified clay tile, creosoted wood, concrete, impregnated fibre, or iron pipe. The material most used is vitrified tile; this is made in both single duct and multiple duct, the latter including two-duct, three-duct, four-duct, six-duct, and nine-duct combinations in one piece The length of a single piece of duct is from 1.5 ft. to 3 ft., and the duct opening about 2¼, 3⅜ or 3⅞ in. in diameter.

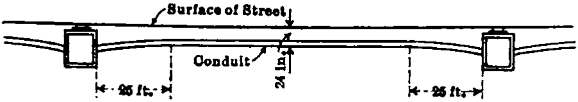


FIG. 68.—Section of underground conduit showing method of grading for drainage of ducts.

247. Standard conduit construction consists of some one of the above mentioned materials laid in a properly graded trench on a bed of Portland cement concrete and covered with an envelope on the top and sides, of the

258. The location of a ground usually requires the use of the Varley loop test or the Murray loop test, next described.

259. The Varley loop test, Fig. 70, is frequently employed. When the bridge is balanced,

$$R_x = \frac{R_1R_0 - R_2R}{R_1 + R_2} \qquad \text{(ohms)} \qquad (10)$$

$$R_0 = R_x + R_y + R_c \qquad \text{(ohms)} \qquad (11)$$

Equation (10) expresses the resistance of the grounded conductor from the bridge to the fault and (11) expresses the loop resistance of both conductors. Assuming the conductors to be uniform, it is a simple matter to calculate the distance to the fault. If desired, the resistance R can be connected in series with the other conductor, and in that case the formula given above (Eq.

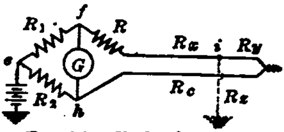


Fig. 70.—Varley loop test.

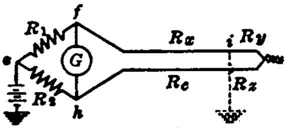


Fig. 71.—Murray loop test.

10) no longer holds true, and instead becomes, $R_x = R_1(R + R_0)/(R_1 + R_2)$. This test is especially useful because it is not affected by the resistance of the fault.

260. The Murray loop test, Fig. 71, is quite similar to the Varley test. The resistance of the defective conductor from the bridge to the fault is given by this formula, assuming the bridge to be balanced.

$$R_x = \frac{R_1R_0}{R_1 + R_2} \qquad \text{(ohms)} \qquad (12)$$

261. Insulation resistance comes under the class of high-resistance measurements (Sec. 3). A simple method in extensive use for measuring insulation resistance is the so-called **voltmeter method,** Fig. 72. The insulation resistance in megohm-miles is

$$R = lr_v\left(\frac{E}{V} - 1\right)10^{-6} \qquad (13)$$

where E = potential in volts of the battery; V = voltmeter reading when connected to line: r_v = voltmeter resistance in ohms; l = length of line in miles. See discussion of this method, and a modification of it, by the author in the *Electrical World*, Feb. 6, 1904 and Mar. 9, 1912. The reciprocal of insulation resistance is termed leakance, and is a conductance expressible in mhos or micromhos.

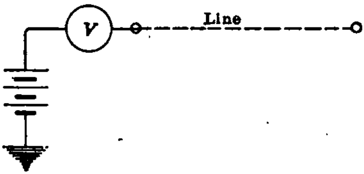


Fig. 72.—Voltmeter test for insulation resistance.

262. Quantitative measurements of telephone or telegraph circuits to determine resistance, inductance, reactance, capacitance and leakance, either to continuous or alternating currents, are covered as a whole in Sec. 3.

BIBLIOGRAPHY

263. General literature on telephony and telegraphy. The following treatises, text-books, periodicals and society transactions are given for the convenience of those who desire more detailed or specialized information.

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Miller, K. B.—"American Telephone Practice." McGraw-Hill Book Co., Inc., New York, 1905.

forth until the energy is consumed either in the form of heat in the circuit itself, or through radiation of electrical waves. The number of times the charge surges back and forth before it is dissipated and the discharge across the spark gap ceases depends on the equivalent resistance of the various sources of energy loss in the circuit.

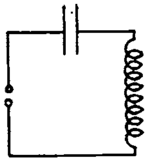

FIG. 73.—Closed oscillatory circuit.

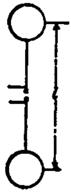

FIG. 74.—Hertzian oscillator.

265. Damped oscillations. Gradually decreasing oscillations of this kind are called damped oscillations and obey the law that each succeeding amplitude is a given fraction of the one before it. The constant difference between the natural logarithms of the successive amplitudes is known as the **logarithmic decrement.**

266. Spark. In the simplest form of sending set, the spark is placed directly in the antenna (see Figs. 74 and 78), but in order to use any except the smallest power (since the antenna capacity is in all ordinary cases small), a high voltage must be applied to the antenna. This necessitates the use of a long spark, which in turn introduces a high resistance into the antenna circuit, thus limiting the antenna current obtainable.

267. Coupled circuits. In order to get rid of this objectionable spark resistance, it is customary to excite the antenna circuit by means of a step-up transformer either inductively connected (Fig. 75) or directly connected (Fig. 76), the antenna circuit and the closed circuit containing the spark-gap

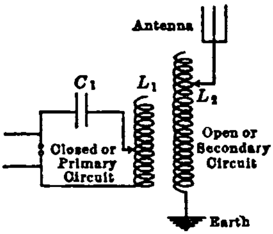

FIG. 75.—Inductive coupling.

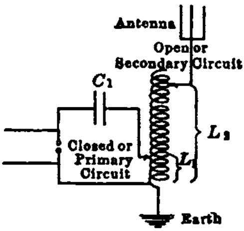

FIG. 76.—Direct coupling.

being tuned to resonance. Two circuits are in resonance, or the electric charges oscillate with the same frequency, when the product of the inductance and capacity in one circuit is equal to the product of the inductance and capacity in the other. A certain portion of the energy oscillating in the antenna is returned and is lost in the spark circuit; that is, the presence of the spark circuit is equivalent to a definite resistance introduced in the antenna. The amount of this equivalent resistance can be regulated by varying the mutual inductance between the antenna and spark circuit.

The fact that the spark length and the capacity in the spark circuit can be varied, provided the conditions of resonance are maintained, makes the double-circuit sending system far more flexible and capable of producing much higher currents in the antenna than the simple system shown in Fig. 78. The only disadvantage of the double-circuit system is that in general parallel wires separated by spreaders and supported by two masts. Fig. 80 is an umbrella antenna. This consists of a system of wires supported on a single tower and held in position by insulated guys. Another type is the platform antenna which is the one used in the high-power Naval station at Arlington, Va. In this, the antenna is supported by three towers and may consist either of a system of wires supported on spreaders, or simply of a triangular network of wires between the towers. All of these forms of antenna in practical use are subject to various modifications which cannot be entered into here. The effective height of the antenna is measured to the geometric centre of capacity of the wire system, if the ground is perfect (salt water) and there are no elevated masses of metal (steel supporting towers) close to the antenna. In land stations the actual effective height is from 50 to 90 per cent. of the measured height. That the height may be made as great as possible, it is desirable to increase the capacity of the upper portion, and to diminish the capacity of the leading-down wires, keeping them bunched together and using only enough to supply proper conductivity.

271. The amount of energy which can be introduced into an antenna (Eq. 14) is proportional to its capacity, the square of its maximum voltage, and the number of times it is charged per sec.; *i.e.*, the spark frequency. The voltage is limited by the insulation and on shipboard should not exceed 70,000 volts maximum. The fact that the energy for a given voltage is proportional to the spark frequency shows the great advantage of making the latter large, and explains why 60-cycle apparatus will not deliver a large amount of energy.

272. Antenna capacity required per kilowatt of antenna energy

Maximum antenna potential	1,000 sparks per sec.	120 sparks per sec.
50,000 (volts)	0.0008 (mf. per kw.)	0.0067 (mf. per kw.)
71,000	0.0004	0.0033
100,000	0.0002	0.0017

273. Energy in antenna of 0.001 microfarad capacity at 50,000 volts maximum potential*

Sparks per second	Kilowatts	Antenna current†
120	0.15	5.0 amp.
240	0.30	7.1 amp.
500	0.625	10.2 amp.
1,000	1.25	14.3 amp.

274. Capacity required per kw. at 1,000 sparks per sec. and various voltages

Volts, (max.)	Mf. per kw.	Volts, (max.)	Mf. per kw.
14,500	0.010	25,000	0.003
17,700	0.006	31,400	0.002
22,400	0.004		

275. Wave length. If no inductance coil is introduced into the antenna, it oscillates with a period corresponding to the distributed inductance and capacity of the antenna wires, and the wave length produced is called the fundamental wave length of the antenna. If it is desired to increase this wave length, inductance coils are placed in series between the antenna and the earth, and if it is desired to decrease it, a condenser is placed between the antenna and the earth. In the case of the excitation of the antenna by the closed circuit, it is of course necessary to have a certain amount of inductance in the antenna for the purpose of coupling.

276. Radiation resistance. The process of radiation withdraws energy from the antenna and it is customary to speak of radiation resistance,

* *Journal* of the Washington Academy; 1911, Vol. I, p. 5.

† Antenna resistance assumed to be 6 ohms.

coupled. The coupling is defined as $K = M/\sqrt{L_1L_2}$. In the case of close coupling, owing to the mutual reactions between the circuits, oscillations of two wave lengths are produced in each circuit, even though the two circuits singly are tuned to resonance with each other. As the coupling is loosened, the two wave lengths approach each other and eventually merge. It was formerly customary to employ close coupling, but modern practice finds that the greatest range is attained with a coupling loose enough to cause the antenna to radiate waves of a single frequency.

230. Types of spark gap. For small sets the simple **sphere gap** such as commonly seen on induction coils is sometimes used, but for larger powers either a **rotary gap** or the so-called **quenched gap** is commonly employed.

231. The rotary gap (Fig. 81) usually consists of two stationary electrodes with a rotating disc provided with projecting metal spokes or knobs which form the movable electrodes. The disc is usually attached to the shaft of the alternator and insulated from it, and is so adjusted that the maximum potential in the circuit is reached just before the movable electrodes come opposite the stationary electrodes. This ensures the regular passage of the spark, and the rapid motion produces sufficient cooling to prevent the formation of an arc. When used with a 500-cycle alternator, a pure musical note of 1,000 vibrations per sec. is produced in the receiving telephones. This high-pitched musical note is particularly advantageous in telephonic reception, being easily read through the atmospheric disturbances.

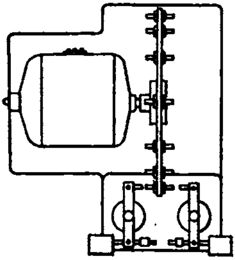

FIG. 81.—Rotary spark gap.

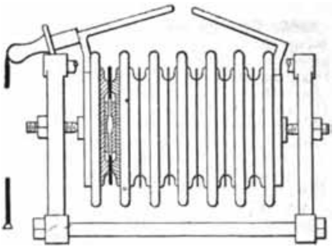

FIG. 82.—Quenched spark gap.

232. The quenched gap (Fig. 82) consists of a number of plates insulated from each other and separated by spaces of a fraction of a millimeter. It is in reality a number of gaps in series. On account of the spark being divided up into many parts in close proximity to large surfaces of metal, the cooling is very rapid. This, in addition to the rapid flow of energy from the closed circuit into the antenna, causes the spark to go out after four or five complete oscillations, and before a sufficient time has elapsed for any of the energy transferred to the antenna to return to the closed circuit. By adjusting the mutual inductance between the two circuits it is possible to make this quenching take place at the exact moment when practically all the energy is in the antenna. The fact that no energy can flow back into the closed circuit does away with the complicated reactions of ordinary double-circuit sending, and ensures that the radiated oscillations shall be of only one wave length. This gap is slightly more efficient in transferring energy to the antenna than the rotary gap.

233. Antenna ground connections. The outward and inward movement of the lines of electric force during the oscillations in the antenna give rise to earth currents. These earth currents are most intense in the immediate neighborhood of the antenna, and if the earth is a poor conductor a large waste of energy ensues. To guard against this loss, a radiating network of wire is placed beneath and around the antenna. In the case of a flat-top antenna, the radius of this wire net should not be less than the length of the horizontal portion of the antenna. In addition, if ground water is generally employed in the better types of apparatus are various kinds of rectifying contacts and vacuum detectors.

289. Contact rectifiers. The rectifiers most frequently consist of a contact between a fine wire and some variety of mineral. Among the minerals frequently used are iron pyrites, galena, silicon, and molybdenite. In other forms, two crystals are used in contact, such as zinkite with chalcopyrite or bornite, or silicon with metallic arsenic.

The exact nature of the action of the contact rectifiers is not known. They behave in general like high resistance thermoelements (though it is certain that they are not thermoelements in the ordinary sense), the rectified current pulses produced by each wave-train being very approximately proportional to the square of the oscillatory current passing through the detector.

For detecting the direct-current pulses, **head telephones** of from 1,000 to 3,000 ohms resistance are ordinarily used. These are placed in shunt across the stopping condenser K (Fig. 83) of from 0.01 to 0.02 mf., which permits the oscillatory currents to pass freely through it but stores up the direct-current pulses and discharges them through the telephone. If the spark at the sending station is regular, the sound produced in the telephone is a pure musical note. As a rough method of measuring the strength of signal, a resistance box is frequently placed across the telephones and the resistance reduced until the signals just remain audible. The relative strength of the telephone current at various times can thus be determined from the law of shunts. For laboratory purposes a galvanometer is frequently used in place of the telephones.

TRANSMISSION OF WAVES FROM THE SENDING TO THE RECEIVING ANTENNAS

290. Day transmission.—The radiation from a radiotelegraphic antenna may be conceived to consist of lines of electrostatic force with their ends terminating in positive and negative electric charges at the earth's surface somewhat as shown in Fig. 87. At moderate distances the strength of the electric field is represented by Eq. 16. For distances of more than 100 miles, over sea water, and for still shorter distances over land, an absorption of energy appears which modifies the results of Eq. 16. This absorption is due in part, at least, to the resistance of the earth to the passage of the positive and negative electric charges at the base of the electrical wave. At great distances the bottom of the wave is so much retarded that the wave front becomes bent forward. When brought into this position the electric field can be divided into two components, one at right angles to the earth's surface and the other parallel to it. The latter produces oscillatory earth currents which, while they withdraw energy rapidly from the wave, make possible the reception of signals by means of long horizontal antennas, only a few feet above the ground. Experiments by the U. S. Navy Department extending up to a distance of 2,000 miles have given results for flat-top antennas which may be represented by the following empirical formula*

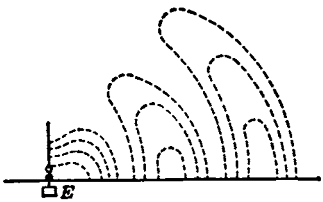

Fig. 87.—Earthed electric waves.

$$I_R = 377 \frac{h_1 h_2 I_s}{\lambda d R \sqrt{1+\frac{\delta_1}{\delta_2}}} \epsilon^{-\frac{0.0015d}{\sqrt{\lambda}}} \qquad \text{(amp.)} \qquad (20)$$

where I_R represents the current in the receiving antenna, I_s the current in the sending antenna, R the receiving resistance, d the distance, λ the wave length, and $h_1 h_2$ the height to the centre of capacity of the sending and

* Austin L. W. Bulletin Bureau of Standards, Vol. VII, p. 362 (reprint 159), 1911, and Vol XI, p. 69 (Reprint 226), 1914.

fluctuations. At times night signals between two stations will be no stronger than those observed in the day time, while at other times sending sets of very moderate power and efficiency have been known to transmit signals several thousand miles. During the colder months of the year, night transmission can be depended upon to be considerably superior to day, with a fair degree of regularity. The cause of the increased night range is not definitely known. It has been thought by some authorities that it is due to a clearing up of the absorption supposed to exist in the upper atmosphere caused by the shorter light waves, and possibly cathode rays from the sun. Another explanation is that the absorption is fairly constant and that the increased received energy is due to reflection from the upper conducting layers of the atmosphere. This last view is supported by certain interference phenomena which cannot be entered into here, and by the fact that the abnormally strong night signals appear to pass over land almost as freely as over salt water, although the absorption in the day time is many times greater over land. That the normal energy is at times augmented in long-range night communication is shown by the fact that in many cases the received signals are stronger than would be expected from the geometric diminution of intensity with the distance, leaving absorption entirely out of account. It must also not be forgotten in this particular that observations show that the day condition is the stable one while the longer ranges covered at night show the irregularities which might be expected to come from irregular conditions of reflection.

UNDAMPED OSCILLATIONS

295. Advantages of undamped oscillations. It has already been said (Par. 264) that the oscillations produced from the electric spark form damped wave trains with intervals between in which no energy is given off. If, instead of supplying energy merely at the beginning of the wave train, a constant source of supply can be obtained, the oscillations will continue indefinitely and with equal amplitude. The use of such undamped oscillations in radio communication has a number of advantages; first, if the energy is divided among a great number of waves of equal amplitude, instead of being concentrated in a few wave trains, the maximum voltages required for a given amount of power are very much less than in the case of damped waves, and consequently the insulation of the apparatus is much less difficult, ard much larger amounts of energy can be sent out from moderate sized antennas. Second, undamped oscillations allow a greater sharpness of tuning and enable a looseness of coupling to be used at the receiving station between the antenna and secondary which greatly reduces the danger of interference and disturbance from atmospheric discharges. Third, and most important of all, observations indicate that undamped oscillations in passing over the surface of the earth fall off in intensity less rapidly at great distances than the damped oscillations from the spark.

296. Production of undamped oscillations. The most obvious way of producing undamped oscillations is by means of high frequency generators. Three types of such machines have been built; the Fessenden-Alexanderson, the Goldschmidt, and the Arco. The first has been used successfully with small powers, and the last two have been constructed with a capacity of more than 100 kw. and are in successful use in communication between Germany and America. For descriptions of these machines the reader is referred to Zenneck's "Lehrbuch der drahtlosen Telegraphie."

THE ELECTRIC ARC WAVE GENERATOR

297. The arc method of producing oscillations was discovered by Elihu Thomson in 1892 and has been developed by V. Poulsen, R. A. Fessenden and others. In this method a circuit containing suitable inductance and capacity is placed around the arc as shown in Fig. 88. Choke coils and resistance are placed in the main dynamo circuit to control the voltage and to prevent the oscillations from running back into the dynamo. When the shunt condenser circuit is closed around the arc a part of the current flows into the condenser thus robbing the arc of a portion of its current. But since the arc has the characteristic that the potential across the arc increases as the current decreases, this decrease in current increases the potential difference and the condenser continues to charge. At the next instant, however, the condenser commences to discharge, increasing the direct arc current until it is entirely discharged. Then the process repeats itself. For the

301. The Fessenden heterodyne. In the heterodyne method of receiving, an ordinary receiving set is used, as shown in Fig. 91. The heterodyne proper is a piece of auxiliary apparatus consisting of a small arc circuit coupled to the antenna and so tuned to the incoming waves as to produce beat tones in the detector and its telephone. By slightly shifting the frequency of the heterodyne any desired tone can be produced in the receiver proper which makes it particularly efficient in working through interference and atmospheric disturbances. It has also the property of increasing somewhat the sensitiveness of the detector. The heterodyne is also used with spark oscillations but in this case a musical note is not generally obtained.

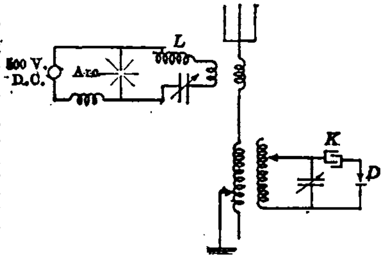

Fig. 91.—Heterodyne circuit.

302. Vacuum detectors. Hot-filament vacuum detectors were first invented by Prof. Fleming. The modern oscillating types, of which the DeForest ultra audion, the von Lieben and the Marconi tubes are examples, all operate on the same principle, differing only in arrangement of electrodes, voltage employed, etc. The DeForest ultra-audion is shown diagrammatically in Fig. 92. It consists of a highly evacuated glass bulb containing a filament F heated to incandescence by a storage battery of 6 volts, A, an intermediate grid electrode G, and a plate electrode P. The secondary receiving circuit LC is connected through a small variable stopping condenser C′ of a few ten-thousandths microfarad to P and G. The incoming oscillations produce disturbances in the electron flow in the tube which are heard as audible sounds in the telephone T. When the condenser C is small and the inductance L large, instability is automatically set up in the electron flow and continuous oscillations take place in the secondary circuit. The strength of these oscillations is increased by a variable bridging condenser C″. Then, as in the case of the heterodyne, if the local oscillations are slightly detuned from the incoming continuous oscillations, musical beat tones are produced which are heard in the telephone and by means of which the incoming signals may be read. The presence of the oscillations in the local circuit may be ascertained by touching with the finger any metallic portion of the circuit between the inductance of the secondary circuit and the stopping condenser. If oscillations are present a sound is heard in the telephones. For receiving spark signals the ultra-audion may be used either oscillating or non-oscillating. In both cases it is far more sensitive than the crystal detectors, especially when oscillating. In this case however the muscial tone of the spark is not clear.

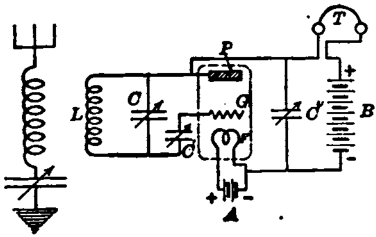

Fig. 92.—Deforrest ultra audion vacuum detectors.

The Audion Ampliphone. The audion ampliphone consists of two or three audions connected in cascade through small transformers by which the strength of signal in any detector may be increased from 20 to 150 times.

THE WIRELESS TELEPHONE

303. General principles. As long as continuous oscillations either from the high frequency machine or from the electric arc are of the same intensity,

308. The theories* of the directive radiation of the bent antenna have been much discussed and the different authorities are not yet in entire agreement on the subject. Low horizontal antennas several hundred feet long and only a few feet above the earth have been tried by a number of experimenters and have recently been brought into prominence by the work of F. Kiebitz.† These antennas usually have the receiving apparatus in the middle while the ends are either free or connected to earth through condensers (Fig. 95). They receive remarkably well in the direction of their length, while at right angles to this direction the energy received is very feeble. Dr. Kiebitz has also had some success in using these antennas for sending, but at the present writing it seems doubtful whether they will in practice be made to take the place of the elevated forms already described.

309. The directive antennas of Bellini and Tosi differ from those already mentioned. They are based on the fact that a nearly closed oscillating system (Fig. 96) radiates and receives more powerfully in its plane than at right angles. These inventors have very ingeniously made use of two such antennas at right angles to each other (Fig. 97). Each of the antennas contains a primary of a double transformer, the coils lying at right angles to each other. Inside the primaries a single secondary can be rotated so as to receive different amounts of energy from the two primaries. By noting the position of the secondary at which the signals are strongest, the direction of the sending station can be determined within two or three degrees. The same system of antennas can be used for sending if the rotating coil be connected to a suitable spark gap and condenser. By placing the moving coil in the proper position signals can be sent out in any plane desired.

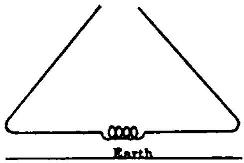

FIG. 96.—Directive antenna (nearly closed type).

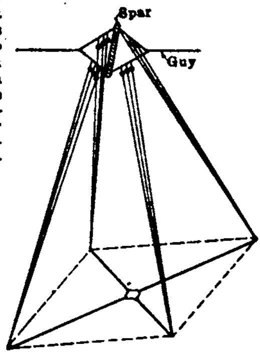

FIG. 97.—Bellini Tosi directive antenna.

The Bellini-Tosi system has proved itself valuable in permitting ships to determine the direction of sending stations erected along the coast for the purpose of aiding navigation in time of fog. According to the international regulations, stations used for this purpose must operate with small power and very short wave lengths so as not to interfere with other radiotelegraphic work.

310. Telefunken compass. Another system intended to assist in navigation has been developed by the Telefunken Company of Berlin and is called the Telefunken Compass. In this, the directive stations are fixed shore stations and the receiving is done on an ordinary ship's antenna. The sending station has a set of thirty-two bent antennas (Fig. 98) extending radially from it. The sending circuit is connected to each of these in turn by means of a rotating contact. When contact is made with the antenna sending in a certain definite direction, say due North, a special signal differing from the others is produced and sent out also from a non-directive antenna. The mariner desiring to know his direction from the sending station starts a

* Fleming, J. "Electric Wave Telegraphy," p. 651.
Zenneck, J. "Lehrbuch der drahtlosen Telegrahpie," p. 427.

† Kiebitz, F. "Jahrbuch der drahtlosen Telegraphie," Vol. V, p. 360, 1912 and Vol. VI, p. 1, 1912.

milliwattmeter which indicates by a maximum deflection when the wave meter is brought into resonance with the high-frequency circuit under examination. The variable capacity in the wave meter usually consists of a semi-circular plate air condenser which is varied until the point of resonance is obtained. Fig. 100 shows a so-called **resonance curve** giving the relation between the hot-wire milliwattmeter deflection and the degrees on the condenser. As was mentioned in Par. **267,** when the wave meter is in resonance with the circuit under examination the product of the inductance and capacity in the wave meter circuit is equal to the product of the inductance and capacity in the other. The wave lengths corresponding to various wave meter readings are either engraved on the condenser scale or given in a table.

313. Formula for wave length. Since the time of oscillation of the charge is

$$T = 2\pi\sqrt{LC} \qquad \text{(sec.)} \qquad (21)$$

and $v = n\lambda$ and $T = 1/n$, then the wave length is

$$\lambda = v2\pi\sqrt{LC} \quad \text{or}$$

$$\lambda = 1.885\sqrt{LC}.\times 10^{9} \qquad \text{(meters)} \qquad (22)$$

where v is the velocity of light, L the inductance and C the capacity, all expressed in electromagnetic units. In place of the milliammeter a thermo-element and galvanometer or some other indicating device is sometimes used to indicate the current strength in the wave meter.

In order that the wave meter may be used for exciting receiving and other circuits at definite wave lengths, it is often connected to a buzzer circuit shown in Fig. 101. When the current from the cell s flowing through the inductance of the wave meter is broken at the vibrator of the buzzer B, the induced electromotive force charges the condenser of the wave meter. This charge oscillates back and forth through the inductance and condenser until the energy is dissipated in heat or radiation. As there is little resistance in the wave meter circuit the oscillations produced in this way are very feebly damped. If greater damping is desired, fine-wire resistance is introduced into the circuit at r. In order to eliminate the disturbing effects of the buzzer spark, a condenser K, of a few tenths of a microfarad, is placed around the coil of the buzzer. As the intensity of the oscillatory current in the wave meter depends on the magnitude of the direct current through the buzzer, this last should be of low resistance, about two or three ohms. Where great steadiness of high frequency current is desired for measurement purposes, the small high-pitch buzzers manufactured by the Eriksson Telephone Co., have proved especially satisfactory.

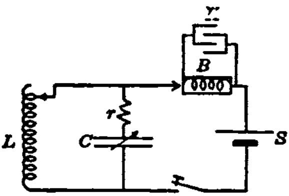

FIG. 101.—Buzzer-driven wave meter.

314. Measurement of logarithmic decrement. This measurement is of great importance since it makes possible the determination of the equivalent resistance of the circuits under consideration, and also gives information concerning the lengths of the wave trains. The value of the sum of the decrements of two circuits may be obtained from their resonance curve (Fig. 100).

According to the theory of coupled circuits,*

$$\delta_1 + \delta_2 = \pi\frac{C_m - C}{C_m}\sqrt{\frac{I^2}{I_m^2 - I^2}} \qquad (23)$$

where δ_1 is the decrement of the unknown circuit, δ_2 that of the wave meter, C_m the reading of the wave meter condenser for resonance, and C any other condenser setting. I_m is the corresponding current in the wave meter for resonance and I for the setting C. If great accuracy in the determination is not desired, the formula becomes much simplified if instead of plotting a com-

* Fleming, J. "Principles of Electric Wave Telegraphy," p. 212.

Spark length (in cm.)	Spark voltage	Spark length (in cm.)	Spark voltage
0.1	4,700	1	31,300
0.2	8,100	1.5	40,300
0.3	11,400	2	47,400
0.4	14,500	2.5	53,000
0.5	17,500	3	57,500
0.6	20,400	3.5	61,100
0.7	23,250	4	64,200
0.8	26,100	4.5	67,200
0.9	28,800	5	69,800

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819. For the complete theory of radiotelegraphy the reader is referred to the following:

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ZENNECK, J.—"Text-book of Wireless Telegraphy"—Translated from the German by A. E. Seeleg. McGraw-Hill Book Company, Inc., New York, 1915.

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ROBISON, S. S., Commander, U. S. N.—"Manual of Wireless Telegraphy for Naval Electricians," 1913.

PIERCE, G. W.—"Principles of Wireless Telegraphy." McGraw-Hill Book Company, Inc., New York, 1910.

International regulations are agreed to by the leading governments of the world and **Federal regulations** of the U. S. A., are published as a bulletin of the Radio service, Department of Commerce, July, 1914.

SECTION 22

MISCELLANEOUS APPLICATIONS OF ELECTRICITY

CONTENTS

(*Numbers refer to Paragraphs*)

(a) Use a dry coat, a dry rope, a dry stick or board, or any other *dry non-conductor* to move either the victim or the wire, so as to break the electrical contact. Beware of using metal or any moist material. The victim's loose clothing, if dry, may be used to pull him away; do not touch the soles or heels of his shoes while he remains in contact—the nails are dangerous.

(b) If the body must be touched by your hands, be sure to cover them with rubber gloves, mackintosh, rubber sheeting or dry cloth; or stand on a dry board or on some other dry insulating surface. If possible, use only *one* hand.

If the victim is conducting the current to ground, and is convulsively clutching the live conductor, it may be easier to shut off the current by lifting him than by laying him on the ground and trying to break his grasp.

(c) Open the nearest switch, if that is the quickest way to break the circuit.

(d) If necessary to cut a live wire, use an ax or a hatchet with a dry wooden handle, or properly insulated pliers.

II.—SEND FOR THE NEAREST DOCTOR

This should be done without a moment's delay, as soon as the accident occurs, and while the victim is being removed from the conductor.

III.—ATTEND INSTANTLY TO VICTIM'S BREATHING

(a) As soon as the victim is clear of the live conductor, quickly feel with your finger in his mouth and throat and remove any foreign body (tobacco, false teeth, etc.). Then begin artificial respiration at once. Do not stop to loosen the patient's clothing; *every moment of delay is serious.*

Fig. 1.—Inspiration; pressure off.

(b) Lay the subject on his belly, with arms extended as straight forward as possible, and with face to one side, so that the nose and mouth are free for breathing (see Fig. 1). Let an assistant draw forward the subject's tongue.

If possible, avoid so laying the subject that any burned places are pressed upon.

Do not permit bystanders to crowd about and shut off fresh air.

(c) Kneel straddling the subject's thighs and facing his head; put the palms of your hands on the loins (on the muscles of the small of the back), with thumbs nearly touching each other, and with fingers spread over the lowest ribs (see Fig. 1).

Fig. 2.—Expiration; pressure on.

(d) With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the subject (see Fig. 2). This operation, which should take from two to three seconds, *must not be violent*—internal organs may be injured. The lower part of the chest and also the abdomen are thus compressed, and air is forced out of the lungs.

(e) Now *immediately* swing backward so as to remove the pressure, but leave your hands in place, thus returning to the position shown in Fig. 1

and the reversing mechanism. It is so constructed that inspiration ceases when the entering gas encounters sufficient resistance to cause the mechanism to reverse and expiration to begin. This reversal is intended to result from the resistance due to completely filled organs of respiration.

Records of cases in which the pulmotor has been used are not convincing that it is superior to or even the peer of the Schaefer method, properly applied. It is claimed that two factors interfere with its successful use. In the first place, as the reversal of respiratory flow is controlled automatically, there is no assurance that inspiration may not be changed to expiration too soon, as the result of obstructions in the air passages which act upon the reversing mechanism before a complete ventilation has taken place. It is possible to overcome this defect by manually controlling the operating mechanism and thus extending the inspiration to the proper limit. The second factor is observed in connection with expiration by suction. The finer bronchioles are provided with no cartilages to stiffen them, and when air is sucked from the trachea and from the larger bronchi, these bronchioles are likely to close before air can be drawn through them from the alveoli. Furthermore, during the process of suction, the walls of the bronchioles and alveoli may collapse and stick together, rendering the subsequent inspiration more difficult, and further decreasing the ventilation. The escape of air into the stomach has been observed to cause movements of the thorax which closely simulate respiration, while actually no air enters or leaves the bronchial tree.

9. Pharyngeal insufflation* is a method of mechanically applied artificial respiration which has been recommended by the Commission on Resuscitation as a satisfactory supplement to the prone-pressure (Schaefer) method in cases of suspended respiration. Inspiratory air enters through a tube inserted in the pharynx, and so constructed as to conform to the human anatomy in order to prevent the escape of air through the mouth and nasal passages. An oxygen tank or a pair of foot bellows supplies the necessary pressure, and reversals of respiration are controlled by the operation of a respiratory valve, which can be conveniently held and operated with one hand. This valve is essentially a three-way cock which, when the valve is in one position, will furnish communication between the source of pressure and the pharyngeal tube, and when in another position, will allow a free expiration to the atmosphere while the pressure lead is shut. In case a specially constructed pharyngeal tube is not available, it is possible to use a close-fitting mask, provided with a tube for connection to the valve. Air is prevented from entering the stomach by placing a heavy weight upon the abdomen; this may be reinforced by a belt, though a belt alone should not be depended upon. A weight upon the abdomen may likewise render good service to a failing circulation by increase of blood pressure. In cases where it is found impracticable to use weights, the air may be drained from the stomach through a tube which furnishes communication between the stomach and the outside air. This stomach tube passes through the pharyngeal tube, but interferes in no way with the process of insufflation. This machine is light and can be constructed at relatively small expense.

10. Current tolerance of the human body. It was announced many years ago by Tesla, Elihu Thompson and D'Arsonval, that alternating currents of high frequency produced little sensation when passed through the human body, compared with alternating currents of low frequency and equal strength. Tests have been made to determine the "tolerance current" of various individuals at several frequencies. The tolerance current was arbitrarily assumed as the limiting current strength which the subject could take through his arms and body, without marked discomfort or distress.

It was found that for each individual, there is a marked increase of current strength which may be tolerated, as the frequency is increased from 11,000 to 100,000 cycles per sec. A man can tolerate only about 30 milliamperes at 11,000 cycles per sec. but can tolerate nearly half an ampere at 100,000 cycles per sec.† Although the tolerance current was found to increase

* See *Journal of American Medical Association*, 1913, Vol. LX, p. 1407.

† Kennelly, A. E. and Alexanderson, E. F. W. "The Physiological Tolerance of Alternating-current Strengths;" *Electrical World*, 1910, Vol. LVI, page 154.

Diff. in temp. Deg. Fahr.	Ratio K_1	Diff. in temp. Deg. Fahr.	Ratio K_1	Diff. in temp. Deg. Fahr.	Ratio K_1
10	1.15	160	1.61	310	2.34
20	1.18	170	1.65	320	2.40
30	1.20	180	1.68	330	2.47
40	1.23	190	1.73	340	2.54
50	1.25	200	1.78	350	2.60
60	1.27	210	1.82	360	2.68
70	1.32	220	1.86	370	2.77
80	1.35	230	1.90	380	2.84
90	1.38	240	1.95	390	2.93
100	1.40	250	2.00	400	3.02
110	1.44	260	2.05	410	3.10
120	1.47	270	2.10	420	3.20
130	1.50	280	2.16	430	3.30
140	1.54	290	2.21	440	3.40
150	1.57	300	2.27	450	3.50

17. Convection. Heat transfer from a body by convection is a form of conduction in which the heat is absorbed and carried away by the surrounding medium, which is in motion. Convected heat is mainly influenced by the following conditions: (a) the velocity of the passing air; (b) the extent of the friction between the body and the air, due to the surface condition; (c) the temperature difference between the air and the heated surface; (d) the location of the heated surface, whether at the top, bottom or side of the body.

18. Conduction of heat is simply the transference of heat through matter without visible molecular motion. Conduction of heat is comparable to the transmission of electric current through a conductor, under the following assumptions: (a) that the temperature difference is similar to the difference of potential; (b) that thermal resistance is similar to electric resistance. With these assumptions, the thermal resistance may be expressed as follows:

$$\frac{L}{\lambda_t A} \tag{3}$$

Where L is the length of path, A is the cross-section and λ_t the thermal conductivity. For a table of thermal conductivities of various substances, see Sec. 4. The flow of heat which a given temperature difference will establish through a given thermal resistance equals the difference in temperature divided by the thermal resistance.

19. Resistors. One of the essential qualifications necessary in heating apparatus is that the operation of the electric heater be as rapid as possible. In this manner the losses are reduced and appliances of the highest efficiency and lowest operating cost are obtained. New resistance materials available in recent years have aided this development materially, in the respect that the alloys can be rated much higher, and thus answer the requirements of good, high-duty resistors.

These requirements may be stated as follows: (a) no oxidation; (b) high melting point; (c) high specific resistance; (d) low temperature coefficient of resistance; (e) no deterioration or aging due to repeated heating and cooling; (f) uniformity of cross-section; (g) freedom from impurities.

20. The resistors most widely used at the present time by manufacturers of heating devices, are comprised of nickel-chromium alloys (Sec. 4). These not only satisfy the requirements of withstanding oxidation and high specific resistance, but can be operated safely at high temperatures and without danger of burning out the unit. The German silver resistors become brittle after repeated heating and cooling. Copper-nickel is still used for low-temperature work. The materials of nickel steel oxidize in the open air, and are only used when protected by special cements or enamels.

26. Heat Given off by the Human Body

	Authority	B.t.u. per hr.		Authority	B.t.u per hr.
Infant	Rubner	63	Child 6 years	Barrel	240
Adult at rest	Rubner	380	Man 29 years of age in atmosphere whose temp. is 31 deg. Fahr.	Barrel	610
Adult at medium hard work	Rubner	470	Same, temp. 68 deg. Fahr	Barrel	440
Adult at medium hard work	Rubner	550	Man, 59 years	Barrel	510
Adult in old age	Rubner	360	Woman, 32 years	Barrel	480

Petten Kofer states that the mean heat radiated from an adult at 70 deg. Fahr. is 400 B.t.u. per hr., and 200 B.t.u. from a child.

27. Advantages of electric heating. The general advantages gained by electric heating are as follows: (a) the elimination of explosion and fire risk; (b) the absence of smoke and fumes; (c) the ease of variation, exact duplication and control of temperature; (d) the localization of heat where desired. These advantages result in a reduction of insurance rates, better working conditions, and a superior product.

28. Cost of operating heating devices. The cost depends entirely on two variables each of which has a wide range; first, the unit cost of energy, which is determined by local conditions; second, the efficiency of the apparatus, which depends upon its design.

The following results are given as the comparative charges for gas and electric cooking:

	Elec. per kw-hr.	Gas per 1,000 cu. ft.
R. Borlase Matthews; Oct. 6, 1911; *Elec. Rev.*, London	$0.033	$1.00
W. R. Cooper; Inst. of Elec. Eng., Nov. 26, 1908	0.03	1.00
Heating Committee; Ass'n. of Edison Illum. Co. (Sept., '07)	0.025	1.00
James I. Ayer; N. E. L. A. Report, May, 1904	0.0227	1.00

29. A general rule for cooking is to allow one-third kw-hr. per person per meal. The following table shows the result of comparative experiments on the cost of electric cooking for three persons extending over a period of three months, by W. R. Cooper, Institution of Electrical Engineers, September 25, 1908.

Period 1901	Kw-hr.	
	For one month	Per day
March 22–April 22	67.04	2.24
May 1–May 31	63.55	2.19
June 1–June 30	66.31	2.21

30. Equipment of Hotel Moserboben.* Boiler for soups and meats, a potato steamer and table range. Boiler—3 heats, 3 kw. capacity, 15 gal., boil water in 30 min. Potato steamer—1 kw. capacity, 10 gal., water jacket, 5 qt. water, boil water in 10 min. Table Range—4 plates, 12 in. diam., each 1.5 kw., 4 plates 8½ in. diam., each 1 kw., total 11.2 kw. Large range—8 plates—2 roasting ovens, 3 kw. each, total 16.2 kw.

* Electric Cooking and Heating in Hotels, *Electrician*, July 19, 1907.

	cu. in.	bread	min.	Energy used
Gas	6400	8	58	31 cu. ft. gas
Electricity	6137	9	52	0.92 kw-hr.

The United States Navy has adopted electric heating devices for cooking and baking on war-ships, finding that they are cheaper to operate, occupy less space, are cleaner, and give better results.

34. Industrial heating. In industrial trades, due to the large consumption of electricity, manufacturers can obtain a very favorable rate for electricity. In many industries it has been found cheaper to operate an isolated plant, using a dual system of exhaust steam and electric heating. The exhaust steam is used for low-temperature heating and electricity for high temperatures. In these isolated plants the cost per kw-hr. depends upon the load factor and the uses of exhaust steam, and varies from a minimum of less than 1 cent to approximately 2½ cents.

The following trades are using electrically heated devices on a large scale to advantage: hatting, laundry, newspaper, printing and publishing, candy, clothing, buttons and celluloid, paper-box, shoes, furniture, handkerchiefs, gloves, tin-can manufacturing, branding and many leather goods industries.

In many cases, even where the electricity charges are high, it has been proven that the total cost of production is cheaper by using electrically heated devices as compared with gas. The better working conditions, absence of exhaust gases, and control of temperature, have raised the efficiency of the workman and the machine, resulting in fewer products scrapped, and also, including rejected and accepted products, more articles produced per day.

35. Laundry Appliances

	Watts
Flat irons, 6 & 7 lb.	500
Flat irons, 9 lb.	600
Sleeve and yoke ironer	1,300
Combined hand ironer	
Sleeve ironers—10 in.	1,080
Sleeve ironers—15 in.	1,620
Wrist band ironer	500
Band ironer, 4½ in. shoe	520
Band ironer, 6 in. shoe	680
Body ironers–12 in. roll	1,140
Body ironers–24 in. roll	2,260
Drop board ironer–12 in	2,050
Drop board ironer–18 in	3,080
C–C ironers	1,650 to 3,860
Collar & cuff press	1,600
2-loop conv. D.R. (68½ in. × 100 in. × 82½ in.)	13,000
6-loop conv. D.R. (122½ in. × 100 in. × 82½ in.)	23,500
Dry rooms for cu. ft.	40
(From Troy Laundry Machine Co.)	

36. Tailoring Appliances

	Watts
Narrow iron—15 lb.	700
Wide iron	800
Machine iron	770

* Gray, Harold. "Electric Heating as applied to Cooking Appliances," *Electrical Review*, London, Feb. 10, 1911.

Linotype pots	600
Monotype pots	1300
Matrix beds	2500
1-qt. glue pots	300
4-qt. glue pots	500
Back rounders	200
Press heads—embossing	
Matrix scorchers	
Glue cookers—25 gal	1000
Sweating plate—14 in. × 14 in.	1200
Sweating plate—18 in. × 25 in.	3200
Wax kettle—20 in. dia., 17 in. Deep	3710
Wax stripping table—28 in. × 34 in.	6100
Composition kettle	4000
Finisher's tool heater	550
Palette-elect. heads—3 in. × 10 in.	235
Bench lever stamp	1650
Felt burners	110

43. Shoe Machinery

	Watts
Shoe warmer	60
Relasting irons	50
Stamping machine	500
Shoe ironing tools	200
Treeing machines	......

ELECTRIC WELDING

BY OTIS ALLEN KENYON

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44. There are three distinct processes of electric welding. (a) the incandescent process; (b) the carbon arc process; (c) the metallic arc process.

THOMPSON PROCESS

45. Temperature distribution. In making welds it is important that the temperature distribution over the face of the joint should be as uniform as possible. Alternating current assists in meeting these requirements as, on account of skin effect, the current density is greater near the surface than at the center, which tends to maintain an even temperature throughout the joint in spite of the radiation from the surface. On account of the necessity for uniform temperature distribution, it is impracticable to butt weld two pieces of different areas, as the smaller one will become much hotter than the large one. For this same reason it is also impractical to butt-weld large surfaces, as the current will not distribute itself uniformly over the section.

46. The incandescent process (known as the Thompson process) is primarily suited for manufacturing process where more or less standard welds are made. The principle of this process consists in connecting the joint to be welded in a low-potential alternating-current circuit and applying a definite mechanical pressure to the joint while the metal is at the welding temperature. The heating energy may be taken from any alternating-current system. The welding machine itself consists of suitable clamps for holding the pieces to be joined, and a means of applying pressure. The clamps, together with the joint, close the secondary circuit of a transformer, and these terminals are usually water cooled. Fig. 3 gives the average

48. Power and Energy Absorbed in Electric Welding.—Professor Thomson's Process

Iron and steel					Brass					Copper			
Area sq. in.	Watts in primary of welders	Time sec.	H.p. applied to generator	Kilo ft.-lb.	Area sq. in.	Watts in primary of welder	Time sec.	H.p. applied to generator	Kilo ft.-lb.	Area sq. in.	Watts in primary of welders	Time sec.	H.p. applie… to gen… ator
0.5	8,550	33	14.4	260	0.25	7,500	17	12.6	117	0.125	6,000	8	10.0
1.0	16,700	45	28.0	692	0.50	13,500	22	22.6	281	0.25	14,000	11	23.4
1.5	23,500	55	39.4	1,191	0.75	19,000	29	31.8	508	0.375	19,000	13	31.8
2.0	29,000	65	48.6	1,738	1.00	25,000	33	42.0	760	0.500	25,000	16	42.0
2.5	34,000	70	57.0	2,194	1.25	31,000	38	52.0	1087	0.625	31,000	18	51.9
3.0	39,000	78	65.4	2,804	1.50	36,000	42	60.3	1390	0.75	36,500	21	61.2
3.5	44,000	85	73.7	3,447	1.75	40,000	45	67.0	1659	0.875	43,000	22	72.9
4.0	50,000	90	83.8	4,148	2.00	44,000	48	73.7	1947	1.000	49,000	23	82.1

NOTE.—The stock should be clamped in the machine so as to fulfil the following relations: Iron and steel: $l =$ … $l = 3d$; copper: $l = 4d$, wherein l is the distance between the inside face of the clamps and d the diameter of the … welded.

CARBON-ARC PROCESS

49. Characteristics of Carbon Welding Arc
(C. B. Auel, Amer., Mach., Mar. 16, 1911)

Arc length. (in.)	E.m.f. across arc and carbon (volts)	Current (amp.)	Length carbo…
6	101	300	1×6.5
5	98	350	
4	93	400	
3	86	605	
2	80	750	

57. The arc can also be used for filling blow holes in castings. The casting must first be heated to a dull red color in order to prevent the production of harmful stresses, then the arc is applied either by connecting one side of the circuit to the casting, or by deflecting against the casting, with a magnet, an arc formed between two carbons, the metal used to fill the holes being introduced in the arc.

METALLIC-ARC PROCESS

58. The metallic-arc (Slavianoff) process was developed to avoid the introduction of carbon into the weld. In this process there is substituted for the carbon electrode an iron or steel pencil, which is melted by the arc and serves to fill the space between the pieces to be welded. The composition of the welding pencil is an important factor in determining the success of a weld. At present it is impossible to give specific information on this subject because those who have investigated it do not choose to reveal their results. However, the practice of those most successful, seems to be the employment of a commercially pure iron to which small percentages of other metals have been added, according to the character of the metal to be welded.

59. Refractory-flux coating. This process did not come into commercial use until the value of refractory-flux coatings on the welding pencil was discovered by Kjellberg in Sweden. In accordance with Kjellberg's invention the electrode or welding pencil is dipped in a paste containing suitable fluxing materials and a refractory base, and this mixture is then allowed to dry upon the electrode. The composition of welding fluxes is even more important than that of the pencils. Indeed in many cases it is possible to use commercially pure iron pencils and to insert the alloying metals in the flux. The composition of fluxes, like that of welding pencils, is jealously guarded by those who have investigated the subject.

The **advantages** of the refractory coating are: First, it applies the flux to the weld at a rate which adjusts itself perfectly to that of the melting of the welding pencil. Second, when welding overhead, it forms a tiny crucible which holds a small quantity of molten iron on the end of the pencil and allows the "pinch effect" (Sec. 19) of the current to squeese the molten iron upward and into the weld.

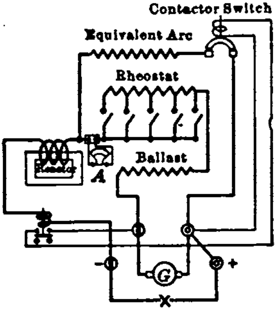

Fig. 7.—Metallic-arc controller for constant-potential generator. (The Elec. Weld. Co.)

60. Equipment. The metallic arc is short, varying from less than 0.125 in. to 0.187 in. and requires a pressure between 15 and 30 volts. The current depends upon the character of the work, varying from 50 amp. for light work to 170 amp. for very heavy work. The arc being short and of low voltage is very sensitive to changes in length; therefore it is desirable to design a welding circuit for a constant-current characteristic. In practice constant-potential generators of from 60 to 100 volts or more are used, the difference between the arc voltage and generator voltage being absorbed in rheostats. A single arc may be operated from a constant-current generator and the rheostats eliminated. However, if the generator is to furnish energy over a wide range of currents, rheostats must be provided for shunting the windings. Very recently there has been developed a constant-current machine, equipped with relays, which permits the operation of several arcs in series. This machine, as at present designed, meets the requirements of metallic-electrode welding and allows the adjustment of current from 60 amp. to 160 amp. without the use of heavy-current rheostats. When a constant-potential generator is used for welding (Fig. 7), any number of welders up to the capacity of the machine may draw energy from it. However, on account of the necessity of maintaining a suitable arc, it is necessary to connect a **ballast resistance** in series with each arc, In comparing arc-welding costs with oxy-acetlyene-welding costs, the cost of electric energy is balanced against that of oxygen and acetylene.

63. Advantages. The extreme localization of heat in the metallic-arc process is an enormous advantage, especially where large masses of metal are concerned, as it minimizes stresses due to expansion and contraction with the practical result that preheating need not be resorted to nor must the joints be more open at one end than at the other to allow for expansion, as is the case with hot-flame and carbon-arc processes. Another advantage of the metallic arc is that the operator uses only one hand for welding, leaving the other free to manipulate a glass screen. This he holds before his face when the arc is on, and lowers each time the arc breaks in order that he may examine the work and closely control its quality.

64. Strength of weld. Experience shows that with a metallic arc, welds can be made in which the strength of the joint is the same as that of the metal itself and even greater. However, on account of inferior work that has been done by unskilled welders, engineers are inclined to avoid arc welding except in cases where it can be subjected to test before putting it into service. If some method of inspection could be developed whereby the quality of a finished joint could be determined without damaging it, welding would undoubtedly displace riveting in a great many structures, and thus an enormous saving in labor and materials be accomplished.

65. Porosity test. Wherever the character of a joint is suitable, its porousness may be tested by applying kerosene to one side. Kerosene will penetrate a porous joint that is so tight that water under high pressure could not penetrate it. In this way the soundness of welds may be tested and a really unsound weld will reveal itself under a few minutes' application of kerosene.

66. Literature. The May, 1913, *Bulletin* of the New York Public Library gives a list of works relating to electric welding, covering the period between 1786 and 1912, inclusive, comprising several hundred articles and books in English and foreign languages, as well as references to the most important patents.

ELECTRICAL EQUIPMENT FOR GAS AUTOMOBILES

BY JOHN C. BOGLE

Engineer, McMeen and Miller; Associate, Amer. Inst. Elec. Engineers

BATTERIES

67. Type adaptable to requirements. It is standard practice to employ the pasted-plate lead cell for gas-car service. The advantageous features of this type of cell are: economy of space and reduction of weight, together with a low internal resistance and the possibilities of discharge at a high rate for a short interval. The last-mentioned advantage obtains in the case of battery systems which include provisions for electric starting.

The battery should be of rigid construction, capable of withstanding the severe vibration to which it will be subjected in service. The outer box should be of excellent workmanship. It has been thought desirable, in some cases, to fill the space between the outer box and the inner jar with some yielding plastic or compound. Jars are constructed of hard rubber having relatively high tensile strength and some flexibility.

Plates are designed for least possible internal resistance and for maximum product of life and capacity. Separators of wood or hard rubber are usually inserted between adjacent plates; these should be perforated or otherwise so constructed that they will interpose no appreciable increase in internal resistance.

68. Methods employed in charging. If the battery system serves merely for ignition and car lighting, it is usual practice to charge the cells independent of the car equipment. If the car equipment includes electric starting devices, the battery will receive its charge from a direct-current generator in the car. Charging on removal from the car must be attended with precautions observed in connection with any battery (see Sec. 20). In addition, however, separate precautions should be observed in case the battery is to be left out of service for any considerable length of time. Under

74. Battery discharge rate during cranking. From the curve of Fig. 10,* it will be seen that if a battery is discharged at the 20-min. rate, an amp-hr. capacity will be realised with an approximate value only 30 per cent. of that obtained at the normal 8-hr. discharge rate. This means that a battery with a normal rating of 120 amp-hr. will furnish only 36 amp-hr. if allowed to discharge completely in 20 min., and the current will be in the neighborhood of 110 amp. if maintained uniform throughout this period. Compare this figure with the result of a test, shown in Par. 76.

75. The ampere "draw" during the cranking period depends upon the operative voltage, the engine dimensions, the degree of compression, the number of cylinders, the friction, and upon certain exigencies such, for example, as obstruction in any part of the starting mechanism. The "draw" with 6-volt systems will usually be about 80 amp. for the lighter cars, and will not greatly exceed 140 amp. for the heaviest. Some 6-cylinder pleasure cars draw as high currents at starting as large 4-cylinder trucks. The proper value of ampere draw can only be determined accurately as the result of exhaustive tests, which take into consideration all possible rigors to which the equipment may be subjected in service.

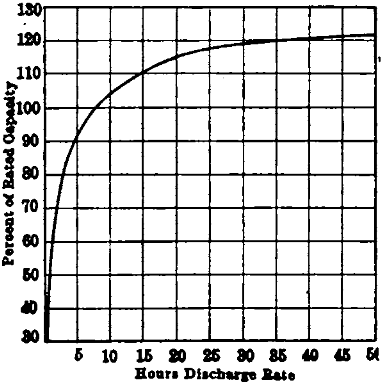

FIG. 10.—Variation of amp-hr. capacity with different discharge rates.

76. Typical starting-test data.† Commercial starter turning dead engine of Model 36-B, Buick. A 6-volt, 120-amp-hr. (on 10-amp. discharge rate) battery was used. Car had been run about 2,000 miles, and engine was warm at time of test.

Time	Volts per cell	Ampere draw	Rev. per min.	Specific gravity
3:00 P.M.	2.00	95	120	1300
3:05 P.M.	1.99	91	116	1295
3:10 P M.	1.96	95	116	1280
3:15 P.M.	1.93	97	116	1280
3:20 P.M.	1.88	102	112	1275
3:25 P.M.	1.84	103	112	1270
3:30 P.M.	1.80	105	112	1265
3:35 P.M.	1.72	110	112	1255
3:38 P.M.	1.52	110	100	1250
3:39 P.M	Stopped			

77. Battery requirements for starting service. A rough rule for battery requirements may be stated, namely: that the capacity of the battery in ampere-hours shall be numerically equal to the ampere draw necessary to turn the engine after it has once been started. This figure is suggestive of the S. A. E. rating for batteries (Par. 72).

78. The momentary discharge rate at the instant of starting is dependent on the **breakaway torque** of the engine, which consists chiefly of

* *The Automobile*, Feb. 6, 1913; page 421.
† Vesta Accumulator Co., April, 1914.

One of the first automatic controllers was the so-called speed governor. This was in reality a centrifugally operated clutch connecting the generator element with the engine driving it, and so arranged that at the higher speeds the fly-balls would relieve the frictional adhesion between parallel surfaces, and the slippage, thus automatically adjusted, would maintain a constant generator speed and potential. The speed governor is in disfavor at the time of this writing (March, 1915), due to its rapid depreciation in service.

Another class of charging controllers includes those employing a vibratory contact, connected as a recurrent shunt on the generator field rheostat; in other systems, the vibrator has been used to shunt the magnetic circuit or to oppose to the main field flux the counter magnetomotive force of a differential winding; any of these methods operates by varying the effective flux threading the armature.

The present tendency seems to be toward a reduction of the number of moving parts. There are several starters on the market which limit the charging current either by a differential field compounding or a correctly

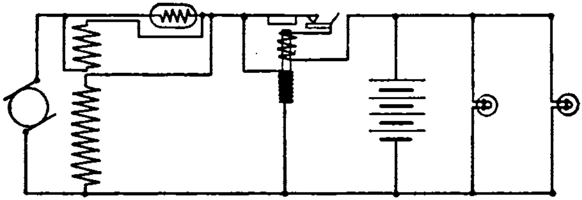

Fig. 11.—Typical charging controller and automatic cut-out.

gaged armature reaction. A starter of this class is illustrated in Fig. 11. Here a ballast coil or series resistance of iron wire is inserted in one of the leads from the generator. The shunt field is connected outside the ballast coil, and a differential field is shunted across the ballast coil. The effect of the differential compounding is to limit the field strength and the charging current.

83. Constant charging current vs. constant potential. If constant charging current is maintained, the generator voltage will have to increase slowly as the charge progresses, in order to overcome the rising e.m.f. of the battery. The resultant variation of generator voltage is objectionable, however, because it shortens the life of the lamps; it is not considered practicable to employ a lamp regulator such as may be found in train-lighting systems (Par. 298), because of the added complexity.

If constant generator voltage is maintained, the battery charge will be a tapering one, since the battery e.m.f. ranges from 1.7 volts per cell at com plete discharge to 2.2 volts per cell at full charge. Necessarily the charging current will be excessive when the battery is exhausted; the discharge may be excessive at times, also, and the combined effects are likely to shorten the life of the cells.

84. Grounded and ungrounded systems. The wiring of electric apparatus on gas cars should be as simple as possible in order not to confuse the operator who is presumed to be unversed in electric circuits. To carry this idea further, some manufacturers utilize the metal framework of the car as a ground return. Though the simplicity of this arrangement presents an obvious advantage, the difficulty of maintaining a multiplicity of ground connections militates against such practice in the judgement of some manufacturers who prefer the use of the two-wire system.

85. Single-unit, two-unit, and three-unit systems. As in all rapidly developing arts, competition allows no standardisation of operating method. In order that each system may have distinctive design, the manufacturers of starters approach a common objective from widely differing directions. One point of differentiation lies in the number of rotational unit equipped with two commutators; these commutators are connected in series for charging and in parallel when the machine is operating as a motor.

The wiring connections of a typical single-unit system are shown in Fig. 13.

The mechanical construction of the several units should be such as to demand little or no attention from the operator. Easy access should be afforded for repairs.

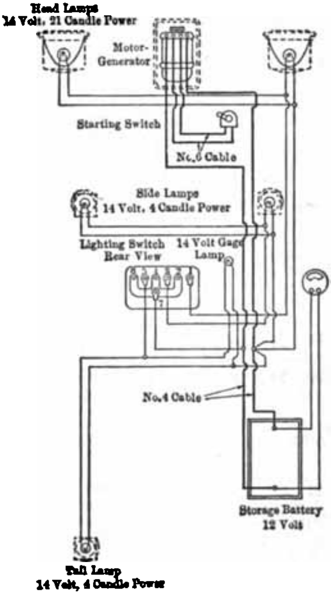

FIG. 13.—Single-unit, two-wire, 12-volt system.

LIGHTING

86. Reflectors are of many shapes, and perform the same function as the backing of any ordinary headlight. It is essential for efficient use that they focus properly, and that the beam have proper alignment with the direction of car motion. Some lamps are provided with a mechanism by which the bulb may be either advanced or retracted until the proper focus is obtained. Proper alignment is secured by focusing the ray to a pencil beam and then aligning the lamp by resetting the props. A focusing lamp is shown in Fig. 14.

In some cities a "glare ordinance" restricts the use of blinding rays from head lamps. This difficulty has been overcome by the use of translucent screens, by an auxiliary lamp of smaller size located in the same reflector, by interposed obstructions to the beam, and by backing the bulb with a small shroud of low reflecting power.

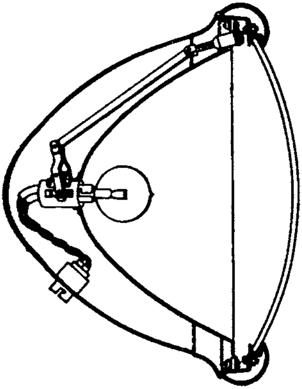

FIG. 14.—Focusing lamp.

87. Wiring for lighting systems must be installed with a view toward permanence of insulation and contact. Oil will depreciate rubber insulation, hence automobile wire is cloth-covered. If a grounded or a one-wire system is used, care must be taken to secure a perfect and lasting ground on the metal frame of the car. It should be remembered that the carrying capacity of wire for a given candle-power must be considerably higher than is found in standard 110-volt systems of distribution. Simplicity in the arrangement of leads is essential, for repairs are likely to be made by operators absolutely uninformed regarding the simplest electrical circuits.

Lamps are usually controlled from a multi-point switch located within easy reach of the operator. Ordinances of certain cities demand that the

The spark variation may be accomplished manually, or, by means of a governing apparatus, the process may be made automatic. This relieves the operator of the care and attention bestowed on the spark lever, and, in addition, accurately determines the proper position of the spark for all engine speeds.

93. Low-tension (make-and-break) system. The spark may be made within the cylinder by the action of a spring which breaks the contact made by a device driven from a cam mechanism which is positively connected to the engine. The circuit leading to the terminals of this contact include either a battery or a low-tension magneto in series with a simple reactance. The sparking action is simply the inductive kick of the reactance coil when a steady current temporarily flowing through it is suddenly broken. The size of the spark depends upon the value of current built up in the reactance during the time of contact; this current value varies with the engine speed. At high engine speeds a reduced intensity of spark is thus realized, and a heavier spark is obtained at the lower speeds, which is desirable.

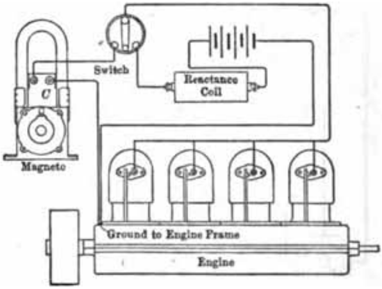

Fig. 15.—Low-tension (make-and-break) system.

The timing of ignition is secured by the adjustment of the cam or cams. Fig. 15 shows the arrangement of a low-tension system of ignition, offering a choice of magneto or battery and coil at the will of the operator. In the former case, the magneto, as here shown, embodies all the reactance necessary. An arrangement of this nature provides an auxiliary source of energy, whereby, if starting with ignition supplied from a magneto is insufficient at the low cranking speed, ignition may temporarily be supplied from the battery.

94. Multiple-vibrator system. Where more than one cylinder is used it is possible, by supplying duplicate ignition units (a separate unit for each cylinder), to secure firing which is approximately synchronous. In Fig. 16 may be seen four separate induction coils, each supplied with its own vibrator. The primary circuit of each one of these coils is completed by a contact maker, which at the proper time (here indicated by the position of a cam), closes the primary circuit of the coil corresponding to the cylinder which is to be fired, and, by the action of a vibrator, causes a spark in that cylinder. Synchronized ignition for four or more cylinders with this method, can be only approximate at best. It is impossible so to attune the vibrators that they will respond equally to the action of the timer. The time lag, mentioned in Par. 91, may vary for each of the several cylinder equipments. The effect of this is improperly timed firing, and the smoothness and economy of the engine as a whole is greatly reduced. It is due to these difficulties that multiple-vibrator ignition is losing in favor, and is being rapidly replaced by several other systems.

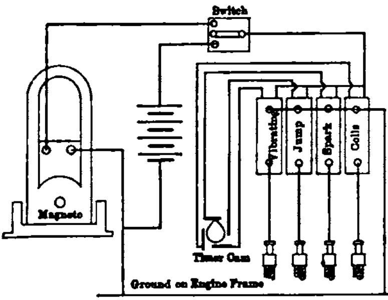

Fig. 16.—Multiple-vibrator system.

convert a multiple-vibrato system into one more nearl synchronous. Essentially consists of a single vibrato connected in that primar lead from the battery whic is common to all coils. I addition, certain features c refinement have been adde which ordinarily do not ap pear in the separate vibrato of the multiple-vibrator sys tems. In Fig. 17 a maste vibrator is shown connecte to a four-coil ignition ar rangement. A master vibra tor can be installed in an accessible place in the ca and may be connected, wit few changes, to an existin multiple-vibrator system however, all vibrators on th individual coils must b short-circuited. The sourc of energy, as in the multiple vibrator system, may be either a battery or a low-ten sion magneto.

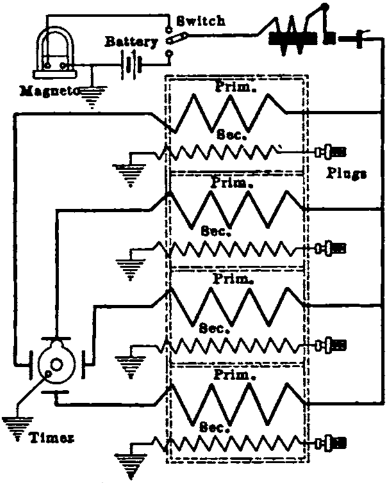

FIG. 17.—Connections of master vibrator.

96. Single coil with distributor. In many of the modern types of car ignition is accomplished by means of a single coil whose secondary is connected successively to the spark plugs of all cylinders by means of a device which is known as a **distributor**. The required energy may be supplied from a high-tension magneto or a battery and coil.

The high-tension magneto may be of several designs, each maker claiming certain advantages for his own method. In one type (Fig. 18), current is first generated at a low voltage, and then led out to the primary of a coil. From the secondary of this coil, high-tension current is brought back to the distributor which is mounted on the magneto and connected with the magneto shaft through suitable gearing. The primary circuit is normally closed through the armature of the magneto and the coil. This circuit is opened by a contact breaker, also located on the magneto. Leads extend from the distributor to the spark plugs of the various cylinders. Another type of high-tension magneto contains the induction coil as an integral part of the armature. The armature thus carries

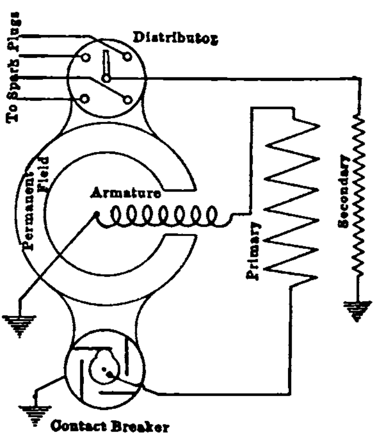

FIG. 18.—High tension magneto with separate induction coil.

two coils, one of few turns and one of many turns. The former or primary winding includes in its circuit the contact breaker, and the secondary winding is led to the distributor which is located on the magneto. High-tension magnetos are coupled positively to the engine in order that the proper relation may be preserved between magneto and engine.

Where a battery is used with the single-coil distributor system, it is usual practice to employ what is known as a **single-spark contact maker and breaker.** Such a device is shown diagramatically in Fig. 19. It will be seen that in this system the circuit is closed for a certain definite percentage of each revolution of the timer. As the engine speed increases, this duration of contact will be preceptibly shortened, consequently the primary current will build up to a smaller value, and when this current is broken, the resultant spark will be smaller, even though the speed of break is reasonably constant for all speeds. A refinement which has been added to this system, is an automatic regulator for securing the same length of break at all except the very slowest speeds. It is argued in favor of this kind of battery ignition, that a quick break, properly timed, results in a rapid combustion of the gas and the greatest pressure upon the piston at the beginning of the power stroke.

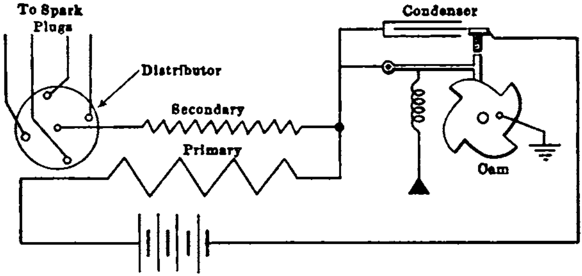

FIG. 19.—Single-spark system of battery ignition.

97. Battery versus magneto. Prior to the advent of recent improvements in battery starting and lighting systems, the magneto system of ignition was decidedly in public favor. But the very rapid adoption of battery starting and lighting systems has resulted in considerable controversy over the relative merits of battery and magneto ignition systems. The most important advantage claimed for the magneto was reliability; it also consumes but a small portion of the engine output, never becomes exhausted and never requires recharging as batteries do. The last-named advantages disappear in large degree when the magneto system is compared with the modern battery ignition systems in which the batteries are under charge almost continuously while the engine is in operation. It is also claimed that the magneto is less likely to suffer complete failure than a battery which may become short-circuited and give out completely. On the other hand, battery ignition produces greater spark intensity at the lower engine speeds than the magneto system, and certain experts have claimed that this feature makes the battery system decidedly superior. Another advantage which is claimed for battery ignition is the increased range of spark adjustment (Par. 92).

THAWING WATER PIPES

BY H. B. GEAR, A.B., M.E.

Engineer of Distribution, Commonwealth Edison Company, Member, American Institute of Electrical Engineers

98. Advantages of electrical method. The thawing of frozen water pipes by the use of electrical energy has become quite common in the northern

100. Another method of thawing pipes, using a small amount of energy, is shown in Fig. 21. With this scheme a piece of rubber-covered wire is thrust into the end of the pipe and a current of about 20 amp. slowly melts the ice. A disc of insulating material centres the wire and prevents it from making contact with the pipe. This method is only applicable where the pipe is straight and where the end is accessible.

101. Power capacity required. In thawing ordinary house services which are not over 1[illegible] in. in diameter, it has been found that a transformer capacity of about 30 kw. is ample to start water flowing in from 15 to 30 min. Where standard transformers are used, the connection shown in Fig. 22 has been quite generally employed; this affords about 55 volts and from 350 to 500 amp. Standard transformers may be safely overloaded 50 per cent or more for 15 min. during the cold weather in which this kind of work is done.

The thawing of a 6-in. (15.24 cm.) main, 1,700 ft. (518 m.) in length in the East River at New York required the use of 750 kw. for 36 hr. In this case the pipe was laid in the bed of the river and was surrounded by salt water having a temperature of about 30 deg. Fahr. It was very difficult to raise the temperature sufficiently to thaw the ice inside, as the heat was carried away so rapidly by the moving water around the pipe. The accompanying table gives data on the amount of current and the length of time required to thaw frozen water pipes by electricity. ("Proceedings of American Water Works Association," 1912. *Eng. and Cont'g*, Feb. 12, 1913.)

Size pipe (iron)*, in.	Length, ft.	Volts	Amperes	Time required to thaw, min.
[illegible]	40	50	300	8
[illegible]	100	55	135	10
[illegible]	250	50	400	20
1	250	50	500	20
				Hours
1	700	55	175	5
4	1,300	55	260	3
10	800	62	400	2

* To thaw out lead pipe, the current must be increased 50 per cent.

MARINE APPLICATIONS OF ELECTRICITY

BY H. A. HORNOR, B.A.

Fellow, American Institute of Electrical Engineers, Member, Illuminating Engineer Society, Member, American Electro-chemical Society

MERCHANT MARINE PRACTICE

102. Rules for installations. In general the electrical construction on merchant vessels must comply with the requirements of the classification society under the rules of which the vessel is constructed. Such societies are established in all the large maritime countries. The American Bureau of Shipping and Lloyd's Register of British and Foreign Shipping are the societies under which most of the merchant vessels of this country are built. In addition, the Navigation Laws of the U. S., and the Pilot Rules, issued by the Department of Commerce, must be carefully followed. For certain inland vessels, especially those plying to and from New York City, the National Board of Fire Underwriters specify and inspect the installation. To cover detail requirements and special operating features the vessel owner also provides a general specification both for use in obtaining a price as well as for an instrument of guarantee. These rules and specifications give a wide latitude to the engineer, and in many cases the finished installation more than covers the requirements. This is due to rapid advance in the art.

103. Lighting circuits. The distribution of energy is the same as in a two-wire system on land. Feeders are led from the switchboard to distribution cabinets, and branch leads are thence distributed to groups of

111. Searchlights. This apparatus, because of the comparatively large current consumed, is considered as furnishing part of the power load. The searchlight is served through a separate switch on the main switchboard, and the arc voltage is adjusted by an external variable resistance. Provision is made on the switchboard whereby the voltage of the searchlight feeder may be observed by use of the generator voltmeter. The searchlight may be managed from the pilot house by either direct hand control or remote electric control. In order to insure against the ill effects of radio-telegraph induction it is necessary that exposed leads to searchlights be either encased in pipe or wrapped with wire. In both cases the outer steel covering must be well grounded to the hull of the vessel. Searchlights are useful in picking up buoys in harbor channels and, in some trades, are very necessary for loading and unloading at night. For freight vessels or for passenger and freight vessels of 4,000 tons carrying capacity or over, the searchlight should not be less than 18 in. in diameter.

112. Electric radiators. For certain service, such as the coastwise traffic of the Pacific coast, electric air heaters find a suitable application. Where the temperature varies but a few degrees, as in this instance, passenger steamers can thus be comfortably heated without exceeding proper temperatures. For attractiveness some vessels carry luminous radiators in the staterooms and lounging rooms, and tubular air heaters in the passageways and in the rooms less frequented. These appliances must be designed to undergo hard service, must be properly fused, arranged for mounting on bulkheads, and should be sufficiently guarded to prevent inflammable materials from being cast upon them.

113. Engine telegraph system. For the maneuvering directions between the pilot house and bridge and the engine room, mechanical signals are employed. This system consists generally of transmitters, located one in the pilot house and one on the bridge, connected by low-brass wire and triple-link chain passing over brass pulleys to a receiver in the engine room. A reply system assures that the signal has been properly received. Occasionally an electrical attachment is made from the engine-room receiver to the reversing shaft of the engine whereby a false signal may be immediately made known. The transmitter dials are electrically illuminated. Various models to suit the propelling machinery are manufactured.

114. Miscellaneous mechanical telegraph and bell pulls. Other telegraphs for the purpose of docking the ship, steering, indicating the rudder angle, and for adjusting the mooring lines, are exactly similar to the engine telegraph instruments except that the dial orders are suitably changed. As an emergency precaution mechanical bell-pulls are installed near the engine telegraphs, connecting with a gong and a jingle bell in the engine room. As an auxiliary to any means for operating the main steam-whistle valve, mechanical pulls are located on the bridge and in the pilot house.

115. Telephone speaking tubes and call-bell system. The law requires that for vessels in which the distance from the pilot house to the engine room is greater than 150 ft. a telephone must be installed in addition to, or in place of, the voice tube. For shorter distances speaking tubes are used giving communication between important places in the vessel. It is compulsory to install either a speaking tube or a telephone between the wireless room and the bridge. Other points of communication are merely for convenience and differ with the desires of the owner. In both passenger and freight vessels, annunciators are located in the main pantry and push buttons are installed in all staterooms, messrooms, saloons, etc. In living quarters remote from the bridge and not provided with watchmen on continuous duty, alarm gongs are installed; these are actuated by a push button located in the pilot house. This is a requirement of law.

116. Fire-alarm system. All vessels are not equipped with such a system, and the systems that have hitherto been installed have not proven altogether satisfactory. Such systems usually consist of electrical contacts which are closed by the melting of a fuse of soft metal, and merely indicate the presence of fire. Two systems are on the market to-day which more nearly approach satisfactory service. In one of these not only is warning of the exact location of the fire given, but live steam is admitted to the origin of the fire by means of a direct lead of pipe.

117. Submarine signals. Large cast-brass bells, rung either by electric, air or wave power, are submerged beneath the lightships that beacon the be run in parallel, others preferring that each feeder be provided with a double-throw switch and that separate bus bars be provided for each generator. This is more a question of operation than one of engineering, but with the conditions as described in Par. 121 it would seem more desirable to keep the generators on separate bus bars, should no electrician be carried.

124. Conduit and moulding. The special requirement for any marine installation is that the conductors be so protected that grounds will seldom occur and that the water-tightness of the vessel will not be impaired. All of the above cited rules require a heavy insulation of rubber and furthermore require that the completed installation must show approximately one megohn of insulation resistance. Beyond these rules the owner usually specifies the highest quality of wire upon the market. As it is customary to use enamel-lined conduits, double-braided wire is installed in conduits and single-braided wire in mouldings. In a combined conduit and moulding installation, conduits are run on exposed decks, in cargo holds, machinery spaces, galleys, pantrys, crew's quarters, etc. Water-tight junction boxes for branch connections and steam-tight fixtures are used on such lines. In the living quarters, mouldings matching the woodwork are provided, all connections being carefully made and laid in the moulding. When conductors pass through steel beams or bulkheads the hole is bushed with hard rubber. When conduits pass through water-tight decks or bulkheads a brass stuffing tube is fitted at the bulkhead; this tube is packed with red lead and flax, forming a water-tight joint.

125. Flexible cables and conduit. Flexible cables with or without a lead covering are sometimes used in lieu of mouldings. The flexible cables are strapped on the structure, have the advantage of being readily overhauled, and, if the insulation is properly selected, reduce the amount of inflammable material.

126. Steel braided armored cables. There is at present on the American market a design of steel-armored cable similar to that used for some time past in foreign countries. This material supersedes both conduits and mouldings, as the lead-covered steel-armored cable is perfectly water-tight and sufficiently protected for exposed spaces; the armored cable without a lead sheath is applicable for living spaces where it may be safely run behind panel work or in decorative mouldings. As mentioned above, this type of installation besides having the important characteristic of reducing grounds to a minimum also makes a perfectly safe installation for heavy wireless telegraph outfits. The only change necessary in fittings is that stuffing tubes must be added to the water-tight branch junction boxes.

NAVAL PRACTICE

127. Lighting system. All governments strive to obtain for their naval vessels the very latest and best developments of the art. This desire precludes standardisation to any great extent. The methods of distributing light, the type of lighting fixtures, and the problems of illumination are all being carefully studied; advances in the art are rapidly adopted. In general the fixtures are heavier than in ordinary practice, and the materials, as specified, are more closely inspected. In the United States Navy, the standard lamp is rated at 123 volts, and metallic-filament lamps are now in service. Arc lamps are no longer used, having been superseded by the 250-watt tungsten lamp.

128. Motor system. Motors and their controlling equipments are elaborately specified, tested and inspected by the United States Government. Copies of these specifications as well as all apparatus and material furnished the United States Government may be procured upon application to the Navy Bureau concerned. Within recent years the motor load on a battleship has very greatly increased both in capacity and importance. This augmentation has caused some governments to increase the generator voltage to 220, still retaining direct current. Such auxiliaries as the anchor windlass, requiring 300 rated horse-power, and the steering gear which requires approximately a like amount, illustrate the above statement.

Avery, W. G.—"Marine Electric Generating Plant, Distribution and Interior Communication." *International Marine Engineering*, Vol. XVI, p. 265, 1911.

Hornor, H. A.—"The Electrical Equipment of the Modern Battleship." *The Journal of the Franklin Institute* of Pa., 1913.

APPLICATIONS OF ELECTRICITY IN THE UNITED STATES ARMY

BY EDWARD D. ARDERY

Captain, Corps of Engineers, United States Army

134. General applications. Aside from the usual applications to illumination and the operation of machinery, electrical energy is employed in the Army for communication, operation of searchlights, maneuvering seacoast guns, operating ammunition hoists, blasting, exploding mines and firing guns.

135. Energy supply. A central generating plant would be the most economical arrangement, but might be paralyzed by a single well-directed shot. To provide for such an emergency, a reserve supply is necessary. Where reserve energy supply is not already provided for in other ways at seacoast forts, it is current practice to install 25-kw. gasoline generating sets in or near the batteries. Commercial supply also is used when available. On account of the development of the gasoline sets, the use of storage batteries in fortifications is being discontinued; these batteries were formerly required for supplying the telautographs, but are now employed only in connection with the telephone systems.

136. General specifications for power plants in fortifications. The National Coast-Defense Board, in 1906, recommended: (a) that the electrical energy used for fortification and defense purposes be furnished by an adequate steam-driven, direct-current central power plant, all machinery to conform in type to approved commercial standards; (b) that each battery or group of batteries be equipped with gas-driven or oil-driven direct-current generators, installed as a reserve to the central plant; (c) that the energy supply of searchlights be provided by self-contained units unless the searchlights are in close proximity to the central plant; (d) that the torpedo casemates be supplied with energy from independent sources for submarine-mine purposes; this arrangement should constitute an integral part of the submarine-mine defense; (e) that alternating current energy, when essential, should be obtained from the direct-current distribution system, using for the purpose a suitable converter; if, however, it is found more economical, this energy may be obtained from a separate alternator; (f) that the central-station output, when not needed for fortification service, may be used for garrison purposes, provided that the latter load does not require too large an increase in the size and number of units; (g) that, should the garrison service require an alternating-current distribution system, the energy should be supplied from the central plant, either through a suitable converter or from alternators installed for this special purpose in the central station; (h) that uniformity of types and accessories should be adhered to as closely as possible.

137. Protection of distribution. Considerations of economy, efficiency, and protection against hostile fire require that the greater part of the electrical communications be either subterranean or submarine. Conductors are sometimes laid underground in trenches roofed with plank for protection. Such conductors should be lead-covered and armored, the armor being served with a jute yarn in some cases. Lead-covered, unarmored cable, without jute on the lead covering, is suitable for conduit construction.

138. Wiring specifications. The wiring rules formulated by a Board on Standardization of Wiring for Seacoast Batteries are as follows: (a) conduits should not be employed for local distribution in emplacements where their use can be avoided; (b) all wires leading out from the emplacepart in the transmission of information, orders, etc. The telegraph is of less importance, and is used in the same manner as in commercial practice.

145. Buzzer. This apparatus consists of an interrupter and an induction coil supplied with energy from a few dry cells. In operation the buzzer is used as a transmitter for the purpose of signaling; the frequency of the current is such as to produce a high note in a telephone receiver at the far end of the signaling circuit. Leaks, bad connections, and high resistances, any one of which would cripple a system employing Morse instruments, merely affect the loudness of the signals in the receiver. Each transmitting station is equipped with a telegraph key and a telephone transmitter, and may be used either for telegraph or telephone communication.

146. Wireless telegraphy (radio) is readily adaptable to military purposes, and for ordinary distances can take the place of the telegraph, making it particularly useful in field operations. In Alaska, on account of the frozen soil, satisfactory grounds are sometimes difficult to obtain. The Signal Corps has developed portable radio sets that may be transported on mules, on a wagon, or on an aeroplane. High frequency, quenched-spark circuits are used. Both silicon and perikon detectors are employed. The generator of the pack set is driven by hand, but a storage battery can be used. The wagon set is larger and of higher efficiency than the pack set. For aeroplanes the generator is operated by a friction drive from the engine. In the absence of a ground connection, a counterpoise is used. Receiving is rendered difficult on account of the noise of the engine.

147. Handling of guns. For enabling seacoast guns to be traversed by power, motors are attached to some of the gun carriages. When, at drill, the guns on disappearing carriages are tripped into battery without being subsequently fired, the retracting to the loading position may be done by motors. Retracting motors can also be arranged to elevate or depress the muzzle of the guns when being aimed.

148. Firing of seacoast guns may be accomplished electrically or by pulling a lanyard. To guard against accidents in electrical firing, there are usually three breaks in the circuit. Two are closed automatically: one when the breech-block is properly locked, and the second when the gun has moved properly into battery; the third is a contact which is manually closed at the firing pistol or switch when all is in readiness. Energy may be supplied from dry cells or an electric exploder.

149. Ammunition hoists are used for raising projectiles from the magazine level to the loading-platform level of some of the larger guns; these hoists consist of endless sprocket chains, with carrier arms attached, operated by electric motors. To avoid accidents, the motors cannot normally be reversed, but the projectiles can be lowered by hand. The powder charges may be handled on similar hoists.

150. The velocity of a projectile is measured by firing it through two targets *t*, Fig. 23, separated by a known distance. An electric circuit is broken at each target, and the elapsed time between breaks is determined with a Le Boulengé Chronograph (*b*, *d*, *r*). The velocity of gun recoil can be similarly determined.

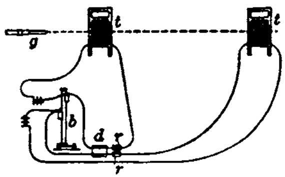

Fig. 23.—Velocity recorder.*

151. Targets. The face of the self-scoring target for rifle practice is divided into segments of armor plate, which the rifle bullet cannot penetrate. Held against the backs of these sections by springs are one or more spindles. A bullet striking a segment causes the spindle or spindles abutting against that segment to jump backward, closing an electrical contact; this causes a number representing the value of the hit to appear in a corresponding place on a miniature-target annunciator at the firing point. Dry cells furnish the energy required for operation. Each segment has a separate circuit, but with a common return.

152. Electrical caps, or fuses (Fig. 24) contain fulminate of mercury, with a platinum bridge, *p*, imbedded in the fulminate; heating the bridge by passage of an electric current through it causes the ignition. Caps stored

* Lissak, O. M. "Ordnance and Gunnery;" New York, Wiley and Sons, 1908.

lery School, 1912.

ELECTRICITY AND PLANT GROWTH

By JOHN E. NEWMAN

General Manager, The Agricultural Electric Discharge Co., Ltd.

155. General. In the eighteenth century a Scotchman subjected myrtles to the discharge from a frictional machine and reported that they were benefitted. Since his time there have been many experiments, but they may all be divided into two main classes, as follows: (a) those aiming to influence the plant by changes in the atmospheric electrification; and (b) those in which currents are passed through the soil about the plants. The records of these experiments show that, generally speaking, where artificial discharges of electricity to the air over the plants take place, favorable results have been recorded; where the method has been that of passing currents through the soil, the results are contradictory.

156. The first systematic experiments on any important scale are those of the late Prof. Lemstrom, of Helsingfors University, Finland, who carried out experiments on a field scale in Finland, France, Germany and in England (at Durham University). In the course of his trials, he experimented with almost all the common vegetables and cereals as well as with strawberries and raspberries. His method was to suspend a network of fine iron wires, spaced about 4 ft. apart, 16 in. above the plants to be electrified. These wires were provided with points like barbed wire, and had to be raised as the plants grew. While the results showed a definite increase, from 20 per cent. to 45 per cent. in the case of most crops, the method is impracticable for work on a large scale. The close network of wires about 1 ft. above the crop and the numerous posts necessary, seriously interfere with the ordinary cultivation of the ground and make horse or steam cultivation impossible. Nor can an influence machine be considered practical from an engineering standpoint.

157. In the Evesham experiments, commenced in 1906 (and still being carried on) by the writer, in cooperation with Mr. R. Bomford and Sir Oliver Lodge, the following arrangements were adopted and have been followed essentially in subsequent installations in different parts of the world, including the plant now being worked by the Department of Agriculture at Washington. Over the area to be electrified is erected a wire network consisting of thin galvanised steel or bronze wire run at an average height of 15 ft. above ground (this being assumed as that clearance which would allow a loaded harvesting wagon to pass underneath), the wires being 10 ft. apart and carried as span wires between stout telegraph wire, on insulators mounted on posts planted 71 yd. apart in parallel rows 102 yd. apart. Thus 21 poles will do for 20 acres, or roughly a pole to an acre.

158. The potential at which the network is charged varies from 50,000 to 75,000 volts. This corresponds to the potential at which the network is actually charged by an average thunderstorm, and at this pressure the discharge on a quiet day is distinctly audible. What we have is practically a leaky condenser, with the air as the dielectric; and this condenser must be kept charged.

159. Source of energy. The current to charge the network is provided by an induction coil, the negative high-tension pole of which is earthed and the positive high-tension pole connected to the network through from 3 to 5 **Lodge valves** in series. The valves will allow positive electricity to pass through them in one direction only, and negative electricity to pass through them only in the other direction. Any value of direct-current voltage up to 250 may be employed, or alternating current may be used, with some decrease in efficiency.

160. A motor-driven mercury gas break, able to run about 1,000 hr. without being cleaned out, is used; it is equipped, when necessary, with an automatic hydrogen generator.

161. The power absorbed by the coil when charging a network of 25 acres is about 300 to 500 watts, and the small break motor and ventilating fan motor absorb another 100 watts.

162. The best length and time of application of the current is

where V is the true wind velocity and v is the actual velocity of the cup centres in the anemometer. See *Electrical World*, Vol. LVI, Oct. 27, 1910, pp. 995 to 1000. As a rule, the measured or indicated velocity is the one implied in discussions of velocity and pressure.

167. Wind movement is recorded in miles, and is virtually the integration of the instantaneous velocities for a given period or the total distance a given particle of air would move in that time. Tables of wind movement per day or per month have been prepared and published for various localities; many of these can be found in the government publications. Such information is very essential to any careful study or forecast of the probable performance of a windmill in any specific locality.

Wind pressure and its relation to wind velocity is a subject which has received much study by many investigators. The Weather Bureau formula is

$$P = 0.004\left(\frac{B}{30}\right)V^2 \qquad \text{(lb. per sq. ft.)} \qquad (6)$$

where B is the barometer reading in inches of mercury and V is the indicated velocity in miles per hr.

168. Available work in air currents. The total aerostatic head of a moving gas, at any given point, is the sum of the pressure head and the velocity head. Since the aerostatic gradient changes but slightly between areas of high and low pressure, it is sensibly constant in passing any given locality. Therefore the total available work stored in the moving gas is represented by the velocity head, or energy of momentum.

169. Windmill characteristics are shown in Figs. 26 and 27, plotted from the test data on a 16-ft. aermotor (steel mill) taken from Par. 172. It is obvious from Fig. 26 that both the speed and the load torque increase

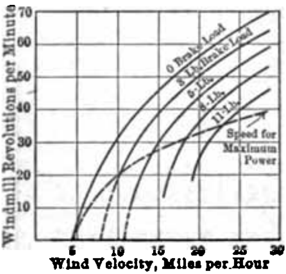

FIG. 26.—Speed curves of 16-ft. Aermotor.

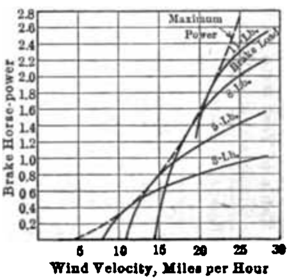

FIG. 27.—Power curves of 16-ft. Aermotor.

with the wind velocity, for maximum output; this is made even clearer by the maximum power curve in Fig. 27. Maximum output therefore requires that the load on the mill, under variable wind velocities, shall have the characteristic of increasing torque with rising speed, in a certain definite manner for any given mill.

170. Efficiency. The 12-ft. aermotor (Par. 172) in a 9-mile wind, at maximum power, had an efficiency of 26 per cent.; this value was computed from the basis of the total wind area of the wheel (12-ft. circle). In a 14-mile wind the efficiency was 23 per cent. Maximum efficiency always occurs with maximum power or output.

171. Windmill governors. Practically all forms of vertical mills are equipped with a form of device which throws them partially or wholly out of the wind, when the wind velocity exceeds a certain value. The effect is to prevent excessive or dangerous speeds in high winds or gales.

led him to the conclusion that steel wheels are superior to wooden wheels, also that curved sails are superior to flat sails. Furthermore, a relatively small number of large sails will give higher efficiency than a large number of small sails, of equal total area. Steel mills are commonly employed except along the seacoast or in very damp climates, where corrosion is likely to give more than ordinary trouble.

174. Example of useful work performed in a given period. Based on the records of mean wind movement at Dodge, Kansas, from 1889 to 1893, Murphy estimated (Water Supply and Irrigation Paper No. 42, Part II, page 118) that steel mills (aermotor) would give the following performances.

Size of mill	Horse-power-hours per month		
	Mean	Maximum (April)	Minimum (November)
12-foot........	338	461	245
16-foot........	488	671	351

175. Height of tower. The mill should always be placed well above surrounding objects such as trees or buildings, at least 30 ft. On account of competition, the tower weights are kept as low as possible and for this reason steel towers sometimes lack stiffness; wooden towers are usually less objectionable in this respect. It is almost always economical to place the mill at an elevation of 50 ft. or more above the ground, not only to avoid obstacles to free wind movement, but also because wind velocities are known to increase somewhat with the elevation.

176. Generators for windmill electric plants are referred to in Sec. 8, Par. **166** and **169**. A shunt-wound machine, with variable-speed drive, requires an automatic regulator for maintaining constant voltage. The differential type of winding, applied to a machine for charging storage batteries, tends inherently to regulate for constant output with variable-speed drive.

177. Automatic battery switch. In order to connect the generator to the storage battery when the speed and the terminal voltage are sufficiently high, and to disconnect the generator when the speed and the voltage fall too low for charging, an automatic switch is employed whose functions are controlled by the terminal voltage of the generator.

178. Storage-battery reserve. The necessary reserve capacity in the storage battery, for any given installation, can be determined only by a careful study of the records of wind movement at the place in question. If the periods of calm occur frequently and last for any considerable time, it will pay to consider a gasolene engine for stand-by instead of the extra battery capacity required.

179. Data on Cost and Capacity of Windmill Electric Plants
(A. V. Abbott)

Diam. of wheel (ft.)	Horse-power in 16-mile wind	Total cost of installation	Required capacity of battery (amp-hr.)	Watt-hours delivered per day from battery*
12	0.21	$249	5	280
16	0.41	415	10	551
20	0.79	606	32	1,762
30	2.40	1,344	103	5,640
40	4.42	2,000	190	10,390
50	6.88	3,190	294	16,170
60	10.00	4,179	427	23,500

* Assumed dynamo efficiency, 50 per cent.; battery efficiency, 45 per cent.; assumed daily charge, 8 hr.; wind velocity, 16 miles per hr., for 8 hr. per day.

becomes a dark blue mobile liquid with highly magnetic properties. The chemical formula is O_3 and the molecular weight 48; the critical pressure is 125 atmospheres and the critical temperature, −103 deg. cent. It is an endothermic compound and the heat of formation is nearly 33,380 g-cal. per mole. At ordinary temperatures it is relatively stable but it decomposes in contact with organic, or in general, oxidisable matter, and spontaneously at 260 deg. cent. It is practically insoluble in water, 1.5 to 10 mg. per liter being the limits of solution at temperatures of from 2 deg. to 28 deg. cent., according to Maufang.

184. Formation. Ozone may be formed in various ways, which are: (a) by chemical action; (b) by electrolysis; (c) by the electrostatic field; (d) by ultraviolet rays; (e) by the radioactive elements; (f) by incandescent solids: (g) and by the evaporation of water. Only the production by the electrostatic field has been developed commercially. The theory of this method is not fully understood but it is probable that ionisation by collision takes place, with consequent dissociation of the oxygen which on recombination furnishes aggregates of ions consisting of molecules with an attached extra atom. Within working limits, in commercial ozone generators, the production is roughly proportionate to the electrostatic intensity above a certain critical value, and with alternating currents, to the frequency employed.

185. Chemical analysis. Treadwell and Anneler, in 1905, checked all previous results and finally established the correctness of the method of chemical analysis which is now in general use. This depends on the following reactions:

$$2KI + O_3 + H_2O = 2KOH + I_2 + O_2 \qquad (7)$$

$$2Na_2S_2O_3 + I_2 + 2KOH + H_2SO_4 = Na_2S_4O_6 + 2NaI + K_2SO_4 + 2H_2O \qquad (8)$$

In practice these reduce to the following volumetric equation:

$$1{,}000 \text{ c.c. } N/10Na_2S_2O_3 = O_3/20 = 48/20 = 2.4 \text{ gm. } O_3 \qquad (9)$$

The sample of ozonised air of measured volume is drawn through a neutral solution of KI and titrated with $Na_2S_2O_3$ or it may be collected in a calibrated flask and shaken with the neutral KI solution. The mixture of KI and I_2 is acidified with an equivalent of H_2SO_4 before the titration. It is customary to denote the amount of ozone in terms of gm. per cu. m. of air and to reduce the readings to spt.

186. Ozone generators have been made in various forms. The essential principle in all cases is the juxtaposition of two or more discharging surfaces so as to form a condenser with an air gap which may or may not be furnished with a dielectric element. The discharging surfaces may be smooth or armed with points, and if smooth they may be flat or curved. Ozonators without dielectrics generally possess rotating electrodes, so that they are in relative motion in order to avert sparking which favors the formation of nitrogen oxides and the destruction of ozone already formed. The great majority of successful ozone generators have smooth electrodes and dielectrics, and are divisible into two types, the cylindrical and the plate.

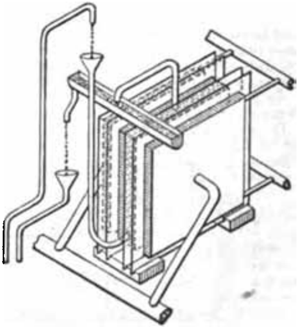

FIG. 28.—Plate ozonator.

187. A typical form of plate ozoniser is shown in Figs. 28 and 29. The two outer plates are pierced at the centre, and the ozonised air is aspirated through tubes inserted in the holes. The air enters at the peripheries of the plates and passes through the field to the centre. Cooling is effected by means of flat rectangular water boxes in contact with the two outer plates, and with a similar box in contact with and between the two inner plates. The two outer boxes are earthed; the inner box is insulated and forms and removed by allowing the water to fall through the air a distance sufficient to ensure against wasteful electrical leakage. The whole structure is commonly contained in a glass retaining case into which suitable dry air is introduced. The advantage of this type of ozonator is that as the field is produced between the two glass plates, the labor necessary to keep the machine clean is nominal. The disadvantages are as follows: difficulty of assembling and taking apart, high potential required, complexity of the cooling system, large space occupied and danger of shut down of the whole system through the failure of one unit.

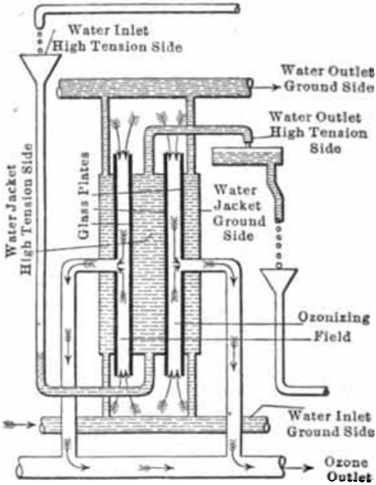

FIG. 29.—Plate ozonator.

188. Operating voltages. Commercial ozonators are commonly operated on voltages ranging from 5,000 to 20,000 and at frequencies of from 50 to 500 cycles per sec., and are used in connection with transformers. Special high-frequency generators are generally furnished in all but the smallest installations, for the capacity of an ozone generator is almost proportional to the frequency employed.

189. Refrigeration of air supply. An essential to successful and economical ozonizing is dry dense air and consequently most installations, excepting very small ones, include a means for refrigerating the air. It has been found in practice that air cooled to about zero Centigrade possesses the requisite dryness, and that further cooling is uneconomical because, though the yield of the ozonator is increased, this is secured only at the expense of relatively greater cost for refrigeration.

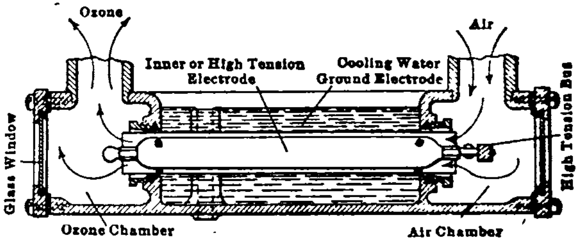

FIG. 30.—Tubular ozonator.

190. Tubular ozonisers. A representative tubular unit is shown in Figs. 30 and 31. This consists of a cast-iron frame with two closed bulkheads connected together by the ozone tubes in much the same way as in a water in water which forms the ground element, while the inner high-potential elements are connected to the circuit by means of suitable contacts on a bus bar which is carried into the air header through insulating bushings. The air is introduced into the rear header and passes through the tubes to the front, whence it passes into the ozone collecting pipe. This machine requires cleaning from time to time, but the operation is simple and quickly performed. The door of the ozone header is removed, the inner electrodes are drawn out and the tubes are cleaned with a swab.

The advantages of the tubular ozoniser are compactness, relatively low voltage (about one-half that of the plate machine), readiness with which it may be assembled and taken apart, simplicity of the cooling system, and facility with which one or more units may be inserted or taken out.

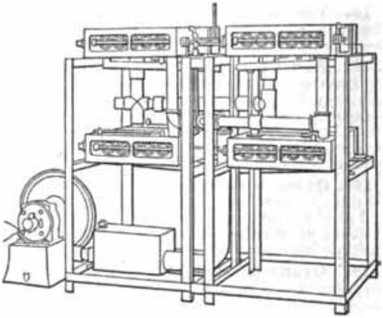

FIG. 31.—Tubular ozonator.

191. Concentrations and yields. For most industrial purposes the concentration should be in the neighborhood of from 1 to 3 g. per cubic meter of air, although in some special cases it may be as high as 5 g. It is rarely found expedient to operate at greater concentrations. The average yield is about 50 g. per kw-hr., and although much higher yields are claimed from time to time for certain types of generators, these have not been attained in commercial operation.

192. Oxidizing effect of ozone. The applications of ozone are dependent upon the fact that it is a powerful oxidizing agent, and that it oxidizes most substances at temperatures far below those at which they are capable of combining with ordinary oxygen.

193. Ventilation. Ozone is used in ventilation chiefly on account of its power of destroying organic odors. It has been shown that it is capable of oxidizing the odors arising from various animal and industrial activities, for instance those of valerianic acid, butyric acid, skatol, indol, decayed foods, fish, tanners' scrap, manure, etc. The causes of distress in vitiated air are heat moisture and crowd odors. It is not believed that the organic excreta causing the latter are poisonous, although admittedly objectionable. Prof. Bass recently has conducted experiments on school children, which have established the fact that the addition of about one part of ozone in a million parts of air determines the difference between tolerable and intolerable conditions, when the air supply is very small.

194. Bactericidal power. It was at one time supposed that on account of the very great bactericidal power of ozone it would prove valuable in disinfecting the air of dwellings and factories, but it has been shown that in breathable concentrations it has little effect on the dry bacteria in the air; this, however, is immaterial, as it is now generally conceded that the dried bacteria in the air are not concerned in its vitiation nor in disease transmission. In suitable concentrations ozone may be used for disinfecting and deodorizing rooms that have become contaminated or infected.

195. Water purifications. The purification of potable water constitutes the most important application of ozone, in point of magnitude, up to the present time. The advantages of the method are the non-poisonous nature of the reagent; its insolubility which ensures against an excess remaining in the water; and the fact that besides rendering the water sterile, it removes all taste and odor which might be due to organic defilement.

moving charged particle, its effective mass should increase with its velocity, but only appreciably when its velocity approaches that of light; a particle moving with the velocity of light would have an infinite mass. This prediction of theory is borne out by experimental results. The ratio of charge to mass for particles whose velocities do not exceed 3×10^{9} cm. per sec. is found to be 1.77×10^{7} in absolute c.g.s. electromagnetic units. Thus the mass of a single β particle is 10^{-27} grams. The β particle is the smallest known mass.

205. The α rays. These are formed of positively charged atoms of helium, carrying a charge double that of the elementary charge carried by the β particles. They are projected with definite velocities from the different radioactive substances, varying from 1.45×10^{9} to 2.22×10^{9} cm. per sec.

206. The γ rays. In addition to the α and β rays, which are formed of charged particles, radioactive substances also emit another type of radiation, the γ rays. According to theory, when a rapidly moving charged particle is accelerated, either positively or negatively, an electromagnetic pulse spreads out from it. It is probable that the γ rays are made up of a succession of these pulses, arising, mainly, from the sudden liberation and sudden stopping of the β particles. There is evidence that the α rays also produce γ rays.

207. The δ rays. When an α particle is ejected from an atom, the residue is negatively charged. It must move in a direction opposite to that of the α particle so that its momentum is equal to that of the particle. The δ rays are formed of the residues of the atoms after expulsion of α particles.

208. Effects produced by the rays. The α, β, and γ rays produce both photographic and ionising effects. To show the former effect, a photographic plate is exposed to a radioactive substance. It is found to be affected just as if it had been exposed to light. The ionising effects are shown by their rendering air a conductor of electricity. The neutral molecules of air are split into positive and negative ions through the action of the rays. When a potential difference is applied, these ions travel in opposite directions, thus setting up an electric current. The photographic effect is caused mainly by the β and γ rays and the ionising effect by the α rays.

The ionising effect is employed to measure the "activity" of a radioactive substance. Metallic uranium is taken as a standard, and by an activity of 100 times, is meant that the substance produces 100 times the effect of an equal weight of metallic uranium in rendering air a conductor of electricity under the same conditions.

209. Radioactive disintegration. The atoms of any radioactive element break down according to the law $N = N_0e^{-\lambda t}$. N_0 is the number of atoms initially present, N the number after a time t has elapsed, and λ is a constant which has a definite value for each radioactive substance. External conditions are found to have no effect on the rate of disintegration. For example, the same value of λ is found whether it be measured at the temperature of liquid air or at the high temperature of an electric furnace. Thus radioactive disintegration is a phenomenon of an altogether different kind from any known chemical change.

210. Radioactive elements. Of the chemical elements that have long been known, only uranium and thorium have marked radioactive properties. There is considerable evidence that rubidium, potassium and sodium are also radioactive, but to a much less degree. In fact it is not improbable that all the elements are radioactive, the rate of disintegration of all but a few of them being too slow for detection. The phenomenon of radioactivity must be regarded as evidence of the instability of the atoms of the elements. The most unstable atoms are those belonging to the most radioactive elements. There is an enormous difference in the rate of disintegration of the different radioactive products. For example, uranium decays to half its initial amount in 5×10^{9} years, while actinium A requires but 0.002 sec. for half of it to disappear.

There are three known series of radioactive elements, the uranium series, the thorium series, and the actinium series; it is not improbable that the last two series, as well as the first, have uranium as their parent. In each of these series, any member arises from the previous one by a radioactive disintegration, accompanied by the expulsion of an α or a β particle, resulting in the formation of an atom of a different kind. In the uranium series is series, the constant λ of the disintegration of uranium itself has a value such that 5×10^9 years elapse before a given amount of uranium decays to half its initial value. Thus millions of years are necessary for the uranium series to come to equilibrium. In most uranium minerals the equilibrium condition is satisfied, so that there is a definite relation between the amounts of uranium and radium contained in them. It is found that the amount of radium associated with 1 g. uranium is 3.4×10^{-7} g.

212. Heating effects. The continual emission of particles projected with high velocities from radioactive substances results in heating effects. The kinetic energy of the particle is transformed into heat. The α particles produce about 90 per cent. of the heating effect; while their velocities are lower than those of the β particles, their mass is so much greater that the kinetic energy of an α particle is many times greater than that of a β particle. One gram of radium in equilibrium with all of its products sets free approximately 118 cal. of heat per hr.

213. Radioactive minerals. The principal source of radium and the other strongly radioactive elements of the uranium and actinium series is the mineral pitchblende, which is an oxide of uranium. From this radium may be separated by chemical processes, its behavior being the same as that of barium from which it is separated by fractional crystallization. Carnotite is another uranium mineral, but of rarer occurrence. The principal source of the elements of the thorium series is monazite sand.

214. Uses of radium. Aside from its great scientific interest, the only important use of radium is as a therapeutic agent. Many cures of cancerous growths have been reported to result from its application.

215. Mesothorium, one of the members of the thorium series, is coming to be employed widely as a therapeutic agent. It has the advantage over radium of being easier to obtain. It is found in the residues left in the manufacture of thorium salts used in making Welsbach gas mantles. But it is far less permanent than radium. While 2,000 years must elapse for a given amount of radium to decay to half its amount, a given amount of mesothorium is reduced one-half in less than 6 years.

216. Determination of physical constants. The study of radioactive phenomena has resulted in the most reliable determination that we have of certain important physical constants. Some of these are given in the following table:

The elementary electric charge	1.59×10^{-20}
Number of molecules in 1 c.c. of a gas at 0 deg. Cent. and 760 mm. pressure of mercury	2.7×10^{19}
Mass of the hydrogen atom	1.65×10^{-24} g.
Number of atoms of hydrogen in 1 g.	6.0×10^{23}

217. Bibliography.

RUTHERFORD.—"The Radioactive Substances and Their Radiations." New York, G. P. Putnam's Sons, 1914.

THE ELECTRON THEORY

218. The electron. The electron theory is built upon the observed wide distribution of electrons or corpuscles and their capability of accounting for many otherwise unexplained phenomena. Electrons are identical with the beta particles; the latter term is used to denote them when they appear accompanying radioactive disintegration. Electrons appear also under the name of cathode particles, when they are projected from the negative electrode, or cathode, by an electric discharge through a gas at low pressure. Ultra-violet light falling upon the surface of a metal sets electrons free; they are also liberated from incandescent solids. Whatever their origin, all electrons appear to be identical in nature. Their velocity of projection depends upon the circumstances under which they appear, but the ratio of their charge to their mass is the same for all except for the highest velocities of projection; this ratio diminishes with increase of velocity according to the same law in every case. The conclusion is forced upon us that the electron is the one common constituent of all matter. We cannot go so far as to say that matter is built up wholly of electrons, for some means has to be found for holding the electrons together against their mutual repulsion. For this purpose, positive electricity is assumed, but our knowledge of this is meagre compared to our knowledge of negative electricity. The electron may be regarded either as a particle of matter charged with negative electricity, or as a particle of electricity endowed with mass in virtue of its motion.

219. Interpretation of electric phenomena in terms of the electron theory. In a conductor, in addition to the electrons contained in the atoms, which, in part, form the atoms, it is assumed that there are free electrons which pursue zigzag paths among the atoms. When the conductor is all at one potential there is no more tendency for these free electrons to travel in one direction than in any other. But when a difference of potential is applied to the conductor there is a force acting on the electrons driving them in a direction opposite the force, since they are negatively charged. Thus there is a drift of electrons in one direction, and this drift constitutes the electric current. An electric current, therefore, is to be regarded as a flow of electrons. In a perfect insulator, there are no free electrons but only those contained in the atoms. Thus there can be no continuous flow of electrons, *i.e.*, an electric current, in an insulator, under a constant electric force. When an electric field is applied to an insulator, the electrons inside the atoms move from their normal equilibrium positions until the forces of the external electric field balance the forces on the electrons arising from the atoms. There is thus a momentary flow of electrons inside the atoms and this constitutes the displacement or dielectric current. The displacement of the electrons from their normal position inside the atoms under the influence of an external electric force constitutes the polarization of the insulator.

220. Thermoelectric effects. The free electrons inside a conductor may be considered as moving about exactly as the molecules of a gas. They thus exert a pressure corresponding to the pressure of a gas on its enclosure. This electronic pressure varies for different metals so that if two different metals are in contact there will be a greater pressure of electrons on one side of the junction than on the other. Suppose now that we have a closed circuit consisting of two different metals, with, therefore, two junctions. Let the two junctions be at different temperatures. As in the case of gas pressure, the higher the temperature the greater the pressure. So there will be a greater pressure driving the electrons from, say, metal A to metal B at junction 1, than from A to B at junction 2. There will thus be a steady flow of electrons around the circuit, constituting the thermoelectric current.

221. Magnetic effects on the electric current. An electron in motion constitutes an element of an electric current. So that if a magnetic field is applied, there will be a force acting on the electrons in a direction perpendicular to both the direction of motion of the electron and the magnetic field, and proportional to the sine of the angle between them. Suppose now that in a metal plate there is an electric current from left to right, and therefore a flow of electrons from right to left. Let the plate be placed in a uniform magnetic field perpendicular to it, the electrons will then be acted upon by forces in a direction perpendicular to their motion, and they will therefore traverse shorter distances measured in the direction of their drift between collisions with the atoms of the metal, and thus the resistance of the metal will apparently be increased. This effect, which is observed in all metals, is especially marked in bismuth, and is made use of in measuring magnetic fields; the increase of resistance of bismuth is a measure of the strength of magnetic field.

222. Hall effect. If, in the case just considered (Par. **221**), the ends of a wire be joined to two points at the ends of a line on the plate, which line is perpendicular to the direction of the current, a current will flow through this branch circuit when the magnetic field is applied. This is the "Hall effect," and may be explained by the bending of the paths of the electrons by the magnetic field which drives them through the branch circuit. According to this view, the Hall effect should have the same sign for all metals, *i.e.*, with the primary current kept in the same direction and the magnetic field in the same direction, the secondary current through the branch circuit should flow which is itself affected by the magnetic field.

223. Magnetism. In order to account for the magnetic properties of bodies it has been found necessary to consider the electrons contained in the atoms. We may consider the atoms as containing electrons circulating in closed orbits. It is a fundamental theorem in electromagnetism that a small closed current is equivalent, as far as its external effects are concerned, to a magnetic particle perpendicular to the plane of the current. An electron circulating in a closed orbit is equivalent to a current flowing in a closed circuit. So that if each atom contains a single circulating electron, it will be itself a magnet, *i.e.*, it will have a resultant magnetic moment. But it is necessary to suppose that the atoms contain many electrons, and so it may happen that the magnetic moments of the different circulating electrons will neutralise each other, in which case the atom will have no resultant magnetic moment. When this is the case, the theory shows that the effect of an external magnetic field is to modify slightly the electronic orbits in such a way as to make the atoms exhibit a diamagnetic property. On the other hand, the magnetic moments of the different electrons may not neutralise themselves so that the atoms have a résultant magnetic moment. In this case the atoms show a paramagnetic property. The effect of the external magnetic field is to orient the atoms in the same sense, and the substance as a whole becomes magnetised.

224. Electrons in optical theory. The electron theory has had its greatest triumphs in the field of optics. Let us consider first the part electrons play in the emission of light. According to our present view, light waves are of an electromagnetic nature. There is no difference between a train of light waves and a train of electromagnetic waves produced electrically except in wave length. The limitation as to the dimensions of the apparatus used in producing electric waves leaves a wide interval between the longest light or heat waves and the shortest electric waves. An electron circulating in an atom in a circular path is a generator for electromagnetic waves. The known order of magnitude of atomic size, and the known value of the charge and the mass of the electron enable us to calculate the wave lengths of the light so generated. The result is something of the order of magnitude of the known wave lengths of visible light. This in itself is an important result as it is the only mechanism known which leads to estimates of this magnitude.

When an incandescent gas is placed in a magnetic field it was discovered by Zeeman that some of the spectral lines become split up into a number of components. One frequent case is that of the splitting up of a single line into two or three components, depending upon whether the magnetic field is along the line of sight or perpendicular to it. This is accounted for by the change in the electron orbits produced by the magnetic force. An electron in motion behaves just as an element of a linear current; so in a magnetic field there is a force upon the electron at right angles to the motion and to the magnetic field. This force has the opposite direction for an electron moving in the opposite direction. The electrons circulating in one direction inside the atoms will thus have the radii of their orbits increased, and those circulating in the opposite direction, diminished. The frequency of the light emitted depends upon the radius of the orbit. Thus a spectral line, which corresponds to a definite frequency when no magnetic field is applied, splits up into two or three lines in a magnetic field. In addition, it is found that the two outer components are circularly polarised in opposite directions, which is what this theory demands. The distance between the spectral lines may be measured, and from this the ratio of charge to mass may be deduced. The results of this wholly independent method of determining the ratio of charge to mass, are so close to the values obtained for the cathode particles and the beta particles from radioactive substances, that there is little doubt but that the centres of light emissions are electrons—the same as the cathode and beta particles.

225. Bibliography.
Lorentz: "The Theory of Electrons;" Leipsic. B. G. Teubner, 1904.

Richardson: "The Electron Theory of Matter;" New York, G. P. Putnam's Sons, 1914.

226. Discovery. In December, 1895, William Conrad Roentgen, then Professor of Physics at the University of Wurtsburg, announced that while experimenting with the vacuum tubes of Lenard, he had discovered a new form of radiation which he called X-ray, because its exact nature was unknown.

227. Properties. These rays differ from the cathode rays previously discovered by Lenard in having greater penetration and in not being deflected by magnets.

Roentgen found that these rays would pass through materials opaque to ordinary light and set up fluorescence in crystals of barium platinum cyanide. He found that they could not be sensibly refracted or reflected by any materials available; that they were not deflected by a magnetic field; that they penetrated different materials in a ratio approximately inversely proportional to the atomic weights, and that they acted like light on the silver salts used in photography.

228. Transparency of Various Substances to X-rays

(Batelli and Garbasso)

Material	Specific gravity, water = 1	Transparency, water = 1	Material	Specific gravity, water = 1	Transparency, water = 1
Solids:			Zinc	7.20	0.0116
Pinewood	0.56	2.21	Iron	7.87	0.101
Walnut	0.66	1.50	Nickel	8.67	0.095
Paraffin	0.874	1.12	Brass	8.70	0.093
Rubber	0.93	1.10	Cadmium	0.69	0.090
Wax	0.97	1.10	Copper	8.96	0.084
Stearine	0.97	0.94	Bismuth	9.82	0.075
Cardboard		0.80	Silver	10.5	0.070
Ebonite	1.14	0.80	Lead	11.38	0.055
Woolcloth		0.76	Palladium	11.3	0.053
Celluloid		0.76	Mercury	13.59	0.044
Whalebone		0.74	Gold	19.36	0.030
Silk		0.74	Platinum	22.07	0.020
Cotton		0.70			
Charcoal		0.63	Liquids:		
Starch		0.63	Ether	0.713	1.37
Sugar	1.61	0.60	Petroleum	0.836	1.37
Bone	1.9	0.56	Alcohol	0.793	1.22
Magnesium	1.74	0.50	Amylalcohol		1.20
Coke		0.48	Olive oil	0.915	1.12
Glue		0.48	Benzol	0.868	1.00
Sulphur	1.98	0.47	Water	1.0	1.00
Lead ointment		0.40	Hydrochloric acid	1.240	0.86
Aluminum	2.67	0.38	Glycerine	1.260	0.76
Talcum	2.6	0.35	Bisulphate of car-		
Glass	2.6	0.34	bon	1.293	0.74
Chalk	2.7	0.33	Nitric acid	1.420	0.70
Antimony	6.7	0.126	Chloroform	1.525	0.60
Tin	7.28	0.118	Sulphuric acid	1.841	0.50

229. Secondary rays. Roentgen showed that rays similar in all respects to X-rays but of comparatively small quantity were set up in most materials when X-rays passed through them.

230. Characteristic rays. J. J. Thompson has shown that when X-rays strike metallic plates such as copper, silver, lead, etc., new rays are set up at the metal surfaces, having penetrating properties peculiar to the metal the tube. The operation of this tube is radically different from that of the tubes which are dependent upon gaseous ions.

Earlier attempts to produce tubes operating on this principle were made by Wehnelt and Lillienfeld.

237. The electrical generating apparatus must be capable of maintaining a potential difference of 60 to 80 kilovolts across the terminals of the tube. For ordinary fluorscopy 2 or 3 milliamperes will suffice, but for rapid Roentgenographic work as much as 100 milliamperes may be used. The induction coil with interrupter is still in common use. For powerful discharges needed in short radiographic exposures, electrolytic interrupters of the Wehnelt or Caldwell type are preferred. For Roentgenoscopy and for therapeutic uses, mechanical interrupters of the vibrating type, rotary breaks or the mercury-jet interrupters are better. (See Sec. 6.) The so-called "interrupterless" machine consists of a high-tension transformer operated in connection with a synchronous rotary rectifier which transmits the peaks of the high-tension secondary discharge to the terminals of the machine always in the same direction. For operation with direct current the rotary rectifier is usually mounted on an extension of the shaft of a rotary converter which supplies the alternating current to primary of transformer. With alternating-current supply the high-tension rectifier is rotated by a small synchronous motor.

Influence machines or so-called electrostatic machines of the Holts and Wimshurst type may be used, but these are not so reliable or so powerful as induction coil or transformer with rectifiers.

238. Measurement. It is customary to measure the current passing through the tube, with an ordinary milliampere meter of d'Arsonval type mounted on an insulating support and having one terminal connected to the metal case. The potential difference across tube terminals is estimated by length of equivalent spark gap. Electrostatic voltmeters may be used for this purpose. There are several more or less commonly used empirical units for both quantity and penetrating quality of X-rays.

239. Penetrometers. There are several of these which depend upon the relative degree of transmission of the ray by two dissimilar metals such as aluminum and silver, the silver being especially pervious to the softer rays. The Benoist penetrometer consists of a series of steps of aluminum of varying thickness arranged around a thin disc of pure silver. Reading is made by observing what thickness of aluminum absorbs the same amount of X-rays as the thin disc of silver. In the Wehnelt penetrometer the principle is the same but the aluminum is in the form of a wedge. The electroscope and electrometer have long been used as indicators of penetration. The "Qualmeter" of Bauer is an electroscope provided with the empirical scale of Benoist or Wehnelt. It is connected to the negative terminal of the tube.

The measurement of quantity of X-ray is usually made by comparing, with a standard scale, the change in color produced in a chemical test piece which has been exposed to the rays.* Stern in 1903 proposed to use strips of bromide paper for measuring the dose of X-ray; the strips were developed, after exposure, for a standard time in a standard developer and then compared with a color scale. The Kienboeck quantimeter which appeared a few years later is essentially the same device. Sabarand and Noiré use discs coated with barium platinum cyanide which turns darker when exposed to X-rays.

240. Principal uses. The applications of X-rays in medicine and surgery for diagnosis and treatment overshadow all others in importance. Other uses for X-rays are: (a) detection of pearls in pearl-bearing mollusks; (b) customs examination of baggage for detection of smuggled articles; (c) sterilization of tobacco and foodstuffs to prevent hatching of eggs of worms or other parasites; (d) detection of flaws in metals; (e) the sterilisation of testes and ovaries of criminals; (f) distinguishing between real and spurious diamonds, the real diamonds being more nearly transparent than the imitation.

241. Roentgenography. The so-called X-ray photography for medical or surgical diagnosis should not be undertaken by electricians or photographers. The safe interpretation of Roentgen ray shadows is difficult, and

* S. Stern, *Journal of Cutaneous Diseases*, Dec. 26, 1907.

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245. Source of atmospheric electricity. Among the many theories propounded that of Dr. George C. Simpson* appears perhaps most rational. In brief he concludes from laboratory experiments with drops of water in air that when such drops are broken up in smaller drops the water becomes positively and the air negatively charged. This fact used in conjunction with Lenards proof that drops larger than 0.2 in diameter are unstable when falling through air and that drops smaller than 0.2 in diameter attain a velocity less than 18 miles per hr., form the basis for the following brief explanation quoted in Dr. Simpson's words.

"It is exceedingly probable that in all thunderstorms ascending currents greater than 18 miles an hour occur. Such currents are the source of large amounts of water which cannot fall through ascending air. Hence at the top of the current, where the vertical velocity is reduced on account of the lateral motion of the air, there will be an accumulation of water. This water will be in the form of drops which are continually going through the process of growing from small drops into drops large enough to be broken. Every time a drop breaks a separation of electricity takes place, the water receives a positive charge, and the air a corresponding amount of negative ions. The air carries away the negative ions, but leaves the positively charged water behind.

"A given mass of water may be broken up many times before it falls, and in consequence may obtain a high positive charge. When this water finally reaches the ground it is recognised as positively charged rain. The ions which travel along with the air are rapidly absorbed by the cloud particles, and in time the cloud itself may become highly charged with negative electricity. Now, within a highly electrified cloud there must be a rapid combination of the water drops, and from it considerable rain will fall; this rain will be negatively charged, and under suitable conditions both the charges on the rain and the rate of the rainfall will be large.

"A rough quantitative analysis shows that the order of magnitude of the electrical separation which accompanies the breaking of a drop is sufficient to account for the electrical effects observed in the most violent thunderstorms. All the results of the observations of the electricity of rain described above are capable of explanation by theory, which also agrees well with the actual meteorological phenomena observed during thunderstorms."

246. Importance of lightning protection. Statistics show that in this country, between 700 and 800 persons are annually killed by lightning, and about twice as many seriously injured.† The efficiency of lightning rods for farm houses in the middle west can be judged from statistics gathered by Mr. E. W. Kellog§ who concludes that for an equal number of houses rodded and not rodded, the fires due to lightning are approximately 15 times greater with the buildings not rodded than with those which are rodded.

247. Nature of the discharge. Sir Oliver Lodge first suggested that there are at least two distinct kinds of discharges, one of which is relatively quiet and which results from the gradual breaking down of the air between the object struck and the charged cloud and another which is a violent secondary discharge caused by a primary discharge in the vicinity.‡ The first kind follows the well-known laws familiar to the electrical engineers—laws that deal with more or less permanent conditions. The nature of the discharge is governed by the resistance, inductance and capacity of the path. The path itself is almost certain to be the rod on account of the conducting streamers above it. The second kind is more complex, and the laws that it follows are less thoroughly understood. There is no conducting path above the rods because there may have been no potential difference between them

* Proceedings of the Royal Society, Series A, Vol. LXXXII, p. 169.
† Farmers' Bulletin, No. 367, U. S. Dept. of Agriculture.
§ University of Missouri, Bulletin No. 7, Eng. Exp. Station.
‡ Lightning Conduction, published by Whittaker & Co.

ycles is perhaps 50 times as great as that converted to heat in the rod. Whether, however, the energy is radiated or directly converted to heat is not so material. In either case the maximum current in the rod may be enormous and depends upon the frequency of the discharge. With a lightning discharge this may be from 100,000 to perhaps 5,000,000 per sec., in which case the maximum value of the current is from 15,000 to 750,000 amp., t being proportional to the frequency. Steinmetz* has shown that the impedance or total obstruction of the high frequency conductor is about 0.1 ohm per ft. at 100,000 cycles, 0.5 ohm per ft. at 500,000 cycles, 1 ohm per t. at 1,000,000 cycles, and 2.5 ohms per ft. at 5,000,000 cycles. Thus the maximum drop of potential per ft. of lightning rod would be 1,500 volts at 100,000 cycles, 9,000 volts at 250,000 cycles, 37,000 volts at 500,000 cycles, 150,000 volts at 1,000,000 cycles and 1,880,000 volts at 5,000,000 cycles.

250. Relation of frequency to other factors. While in every discharge almost an infinite number of frequencies undoubtedly are represented, it s probable that one is preponderating. Were it permissible to consider that the frequency in the discharge after it reaches the rod is governed only by the electrical constants of the rod, the wave length would be somewhat more than four times the height of the rod. This would mean with an ordinary dwelling, with a rod of say about 50 ft., about 5,000,000 cycles. If on the other hand the effect of the rod is hardly noticeable and the frequency is governed by the distance between cloud and earth, the frequency will be much lower, say 250,000 cycles, with a distance of 2,000 ft. between the cloud and earth.

In the first case the drop in potential per ft. is about 2,000,000 volts, in the second case only 9,000 volts. The first case gives an idea of the conditions of a secondary stroke. It is of very high frequency and may be the result of the discharge of the air immediately surrounding the rod rather than the entire air between cloud and earth. The discharge area is in this case difficult to estimate; it may be quite limited or it may be quite great.

Assuming again an area of 100 ft. square and calculating the voltage and capacity, it is found that the capacity is increased in the same proportion as the voltage is decreased; therefore the charge and maximum vale of the current remains unchanged. The maximum value of the current would be, say 750,000 amp., and the drop per ft. of rod about 2,000,000 volts.

It is evident that only a very small part of such discharge would travel through the conductor, and that the main discharge would jump several feet in the air rather than travel 1 ft. in the conductor. (The drop in potential of 2,000,000 volts per ft. corresponds to 2 ft. striking distance between parallel planes and perhaps 10 ft. distance between projecting masses of metal.)

The second case is approached when a lightning discharge takes place from cloud to rod after a conducting path has been prepared by means of streamers. It is the first, the quiet type of lightning mentioned in the beginning of the paper.

251. Advantage of multiplicity of rod. A single lightning rod may be expected to take care of low frequency discharge from cloud to earth, but is entirely inadequate to cope with a violent secondary discharge, even if it struck the rod instead of the building proper.

One lightning rod, while offering some protection, may be considered, under abnormal conditions, entirely inadequate to cope with the situation. If the buildings were grounded by ten rods the condition would be much improved, and the lightning discharge would probably be confined to the system of rods.

252. Installations. Experience seems to have settled beyond reasonable doubt, that, if properly installed, lightning rods afford considerable protection. A large number of instances might be quoted, but suffice it here to mention only one. Before equipping the buildings of The University of Illinois with rods, three fires were caused by lightning; since that time, though the number of buildings has been greatly increased, there has been no damage from lightning. It should be remembered, however, that a rod faultily installed may make matters worse than would be found where no rods were used. Assume, for instance, that a large building is equipped with a high but broken rod having poor joints or a high resistance to ground, say several hundred ohms, which undoubtedly sometimes is the case. Such a rod could serve the function of equalising the potential between cloud and earth almost

* "Transient Phenomena." McGraw-Hill Book Company, Inc.

as effectively as a good rod, and were there only a sufficient number of them it is conceivable that the neutralization of potential would be so complete as to make a flash discharge practically impossible. A building having one rod only, however, is considered at present. The rod is assumed as projecting considerably above the building. If the electric tension is great, unquestionably streamers are emitted, the air above the rod is made fairly conductive and thus the discharge is invited. The question is then: How can such a rod take care of the discharge? It has been shown how the discharge current frequently is very large and while the ohmic resistance of the rod is practically immaterial as long as it is at all reasonable, it must not approach or exceed the normal value of the impedance. In a rod, say 30 ft. long, the ohmic resistance of even the smallest practicable iron conductor is a fraction of an ohm only and the impedance is perhaps 30 to 75 ohms, depending upon the height and frequency of the discharge. It is easily seen that a poor joint may have many times this resistance; therefore, when the discharge encouraged by the streamers from the defective rod strikes the building it finds the rod entirely inadequate to cope with the situation. The voltage drop in the rod is so great that it is far easier for the current to split up in a number of paths and enter through the building than to confine itself to the rod. An apparent paradox thus exists. The rod should have good joints, should have good ground connection, and should be mechanically secure against breaking; although the shape of the rod, its metal or its general dimensions are rather immaterial.

253. Location. The rods should always be placed outside of the building and it is indeed a question whether the vertical part of the system, that is, the rod proper, should not be some little distance from the wall and possibly even insulated therefrom. They should be placed a considerable distance from gas pipes, stove pipes, water pipes and balconies or places where persons might be during a storm.

254. Material and construction. Lodge's experiments and theory show conclusively that there is no advantage in copper over iron. Copper may have mechanical advantages under certain conditions, for instance in cities where the atmosphere is charged with soot and a variety of fumes. Galvanized iron has the advantage of cheapness, with a possible electrical superiority. While flat conductors have a very slight advantage, it appears too small to be considered seriously. A round wire or a pipe can be handled conveniently, and seems preferable. In the installation of the rods, sharp bends should be avoided as much as possible. There is little or no advantage in using large and expensive copper conductors or cables; a size mechanically satisfactory is likely to serve all electrical purposes. Expensive sharp points offer little advantage over ordinary rather blunt points. The rods may advantageously terminate in a number of points projecting only a short distance above the part to be protected.

255. The ground connection should be of low resistance, and therefore the rods should preferably terminate in moist soil. "Salting" the ground may be an advantage, but experience with such grounds is not sufficient to warrant its adoption unless an occasional inspection is made. In many cases excellent connection can be made by driving a galvanized gas pipe a few feet into the ground. In installing the rod, allowance for expansion and contraction should be made. Gas pipes should not be connected to lightning rods, nor should the rods be placed in too close proximity to them.

256. Precautions. A building having its windows and doors open, affords opportunity for the entrance of air, perhaps ionized air made conductive by a previous discharge. It is, therefore, safer to keep the house closed during a violent storm. It is also well to keep away not only from the rod but from chimneys, kitchen ranges, metal pipes, etc.

The damage by lightning in cities is relatively small, and so far the modern sky scraper, with its vast amount of steel, appears to be lightning proof.

ELECTROSTATIC MACHINES

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257. Classification. There are two fundamental types of electrostatic generators, namely, those in which the e.m.f. is generated by contact of wo unlike substances and those in which it is generated by electric induction; he former are called frictional machines and the latter are called influence nachines.

258. Frictional machines. In a circuit composed of unlike materials here exists a difference of electric potential at the junction of these materials. However, from the law of the conservation of energy, no electricity will flow n the circuit unless energy from an external source is applied thereto. In rictional machines the energy which produces the flow of electricity is supplied by the heat due to mechanical friction.

259. Electrical Series*

(Riess)

Positive	Negative
Fur, human hair..................	Glass, porcelain, wood, metals, rosin, sulphur.
Glass.............................	Zinc—tin amalgam on leather (sure).
Fur, wool, linen, silk, paper, metals	Rosin, sealing wax, sulphur, shellac, amber (sure).
Diamond, topas, thummer-stone, quartz, calcareous spar, mica, polished glass.	Wool, linen, silk, leather.
Glass, silk........................	Metals.

260. Theory of frictional machines. When two unlike bodies are rubbed together, the energy applied is partly stored by the establishment of a dielectric field and partly dissipated as radiated heat. The dielectric field established while the two bodies are in contact causes electricity to flow to the surface of the bodies, a positive charge being collected at one extremity and a negative charge at the other. The energy thus stored, in watt-seconds, is numerically equal to the product of the strength of the dielectric field, in volts, and the quantity of electricity transferred, in coulombs. The energy thus imparted to the dielectric field may be manipulated so as to raise the e.m.f. to a point limited only by the dimensions and insulation of the machine. For instance, in the case of two bodies in contact as at *a*, Fig. 32, the quantity

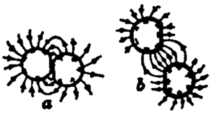

Fig. 32.

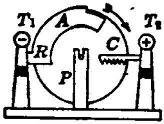

Fig. 33.

of electricity transferred by the dielectric field is $Q = CE$ and the energy thus absorbed is $W = EQ$ where Q is the quantity in coulombs, C is the capacity in farads, E is the potential difference in volts and W is the energy in joules. If the two bodies are separated as at *b*, Fig. 32, the capacity is reduced to C', and since the quantity Q is fixed, the strength of the dielectric field must increase to E' in accordance with the relation $E' = Q/C'$. However, $E'Q = W'$ is greater than W; therefore, it requires mechanical force to separate the bodies.

261. Construction of a laboratory type of friction machine is shown in Fig. 33. A glass plate, P, is rotated in the direction shown by the arrow and the rubbing surface, R, which is made of leather coated with an amalgam (a good amalgam recommended by Kienmayer is 1SN + 1Zn + 2Hg), rubs against the glass plate generating a dielectric field which conveys the negative electricity toward the terminal T_1 and the positive electricity to the opposite

* The substances at the left are each supposed to be rubbed with any one of the substances given at the right and in the same row.

side of plate P. At the comb C the dielectric flux is so dense that the air is rendered conducting and electricity passes between P and T_2. Thus the tendency is for positive electricity to be transferred to T_2 and the negative electricity to T_1. The energy for this transfer of electricity is generated by the friction between R and P, and the potential of the machine depends upon its own dimensions and its insulation.

262. Experiments by Reiss* disclose the relation between e.m.f. and friction. The results are given briefly as follows: a flat metallic cylinder, 1.575 in. (40 mm.) in diameter, covered with leather, was set upon an ebonite plate and drawn by an insulated handle over the surface, the charge being measured with a sine electrometer. The disc was drawn 1.18 in. (3 cm.) in one place; it was then set in another place and drawn 1.18 in. (3 cm.) again and so on, eight times, with the following results:

Number.......	1	2	4	8
Charge........	1	1.45	1.7	1.93

Next the disc was drawn 9.45 in. (24 cm.) without stopping and the same result (1.93) was obtained. It was also found that there was maximum value beyond which the charge was not increased by drawing the disc farther.

263. Influence machines. The second type of machine, based on the principle of electric induction, and commonly known as the influence machine, operates as follows: a conductor thrust into a field of dielectric flux will have an e.m.f. generated in it which will cause a certain quantity of electricity to flow, and store a corresponding amount of energy. Fig. 34 shows two bodies, 1 and 2, connected to a battery B as a source of e.m.f. The e.m.f. establishes a dielectric field between the bodies, drawing energy from the battery and storing it in the electric circuit. The energy stored is $W = C(E/2)$, wherein C is the capacity, and E the e.m.f. of the battery. Now if two bodies, 3 and 4, connected conductively, are inserted into the dielectric field, the capacity C, which is inversely proportional to the length of the dielectric will be increased, and the value of the dielectric flux correspondingly increased, thus drawing more energy from the battery and storing it in the system. Electromotive force will be generated in the bodies 3 and 4 which will tend to start a flow of electricity, and will transfer a quantity of electricity to the outside surface of the plates, sufficient to absorb the increase of energy stored in the system. If while in this position the two bodies are separated by severing the connecting link, the electricity will be unable to return to its state of equilibrium and the energy stored will remain bound. In order to utilise this energy, the bodies must be removed from the electric field of 1 and 2, and, now that each has a field of its own, mechanical energy equal in value to that stored in the bodies will be required to remove them. When the bodies are removed, the capacity of 1 and 2 will return to its original value, and the extra energy called forth for the placing of 3 and 4 in the field will be returned to the battery.

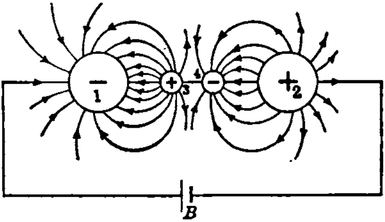

Fig. 34.

264. Excitation of influence machines. The influence machine does not employ a battery to maintain the e.m.f., but is given an initial charge of e.m.f., after which it is self-exciting. It will be noted that in this method a certain amount of electricity is stored in the bodies 3 and 4, and that the

* "Wiedemann Annalen," Bd. I, p. 1052.

value of e.m.f., and therewith the value of the energy can be changed at will by varying the capacity between them; an increase in capacity corresponds to a decrease in energy or motor action and *vice versa*.

265. The Toepler influence machine is shown schematically in Fig. 35; S is a fixed glass plate with two segment-shaped pieces of paper, p_1 and p_2 (called field pieces) fastened on the back (shown dotted); P is a glass plate mounted on an axle and can be rotated by a belt not shown in the sketch; on the plate, P, are mounted a number (8 in the sketch) of tin-foil discs, called carriers, each disc being armed with a small brass button which makes the contact with the various brushes; b_1 and b_2 are called appropriating brushes and are connected with the field plates p_1 and p_2, respectively; n is the neutralising rod and carries a brush at each extremity; c_1 and c_2 are metallic combs connected to the terminals, T_1 and T_2, of the machine. The Toepler machine is very reliable and is self-exciting regardless of weather conditions. By connecting a number of pairs of plates in multiple the load capacity of the machine can be increased.

266. The polarity of the Toepler type of machine is not always the same, depending on how the charges are distributed when it starts. Tests for polarity should be made, where it is of importance. The flame of a Bunsen burner will be attracted by the negative pole.

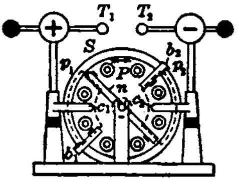

Fig. 35.

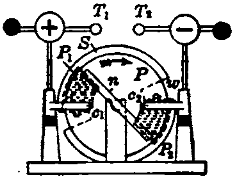

Fig. 36.

267. The Holtz machine is shown schematically in Fig. 36. S is a stationary glass plate on the back side of which are mounted two paper field plates, P_1 and P_2; small blunt tongues project through slots, w, in the glass plate S and nearly touch the rotating plate P. The rotating plate, P, is a plain glass plate covered with a coat of varnish; c_1 and c_2 are metallic combs connected to the terminals, T_1 and T_2. The rod, n, is a neutralising rod and carries a comb at each end.

268. The operation of the Holtz machine is as follows: The terminals T_1 and T_2, are put in contact and the machine started. One of the field plates is given a charge (let P_1 be charged positively). This charge will draw negative electricity to the comb, c_1, which will leak across to the glass plate, P. Passing around to the other side of the machine this negative charge on plate P attracts a positive charge from the plate, P_2, to the other side of the plate, leaving P_2 negative. Now the negative charge on P_2 draws positive electricity from c_2 which neutralises the negative charge and leaves both sides of the plate negatively charged. Upon coming to the other side the positive charges on both sides of the plate draw negative electricity from the field plate, P_1, neutralising the charge on the lower side of P and completing the cycle. The neutraliser, n, serves to keep the machine from reversing its polarity and losing its excitation.

The Holtz machine is sensitive to atmospheric conditions and should be enclosed in a tight compartment for satisfactory results. The compartment can be heated or some moisture-absorbing agent can be used to keep the air dry. The polarity of the machine can be determined by observing the character of the sparks at each pole; at the negative pole the sparks between the comb and the plate are broad and occur in bunches giving a bluish light, while at the positive pole they appear as single points of light.

269. Effect of operation under air pressure. Influence machines can be greatly increased in e.m.f. by enclosing them in an air-tight case and operating them under air pressure. As discussed in Sec. 4, the dielectric three independent swell boxes. As there is no limit to the number of notes or combinations that can be put into operation simultaneously, the automatic player can produce effects that are impossible to the organist. The Tel-Electric system may also be applied to existing organs, and, in every case, the organs may be operated by hand in the usual way without removing the player.

274. Mechanism. The principle upon which the translating mechanism operates is shown in Fig. 37. The brass record, which is perforated with longitudinal slots, is wound from the roll *A* to the roll *M* over the so-called tracker roll *C*. Above the tracker roll there are arranged a number of reading fingers *D*, mounted on a shaft *R* about which they are free to rotate, there being a finger for each magnet on the piano, as well as for the expression magnets. These reading fingers each carry a contact wire *G* embedded in a piece of ivory *E*. Normally the reading fingers rest upon the surface of the brass record and the circuit of the magnet is open at the point *P*. As soon as a perforation passes underneath, the reading finger drops down and closes the circuit through its magnet, and remains closed for a length of time that depends upon the length of the slot. The amount of current in the circuit, that is, the dynamic power of the magnet, depends upon the value of resistance included in the circuit and this is regulated by magnets which cause the comb wire *J* to move up and down over the resistor unit *H*. The magnets all operate on the rotating armature principle. Fig. 38 shows one of the magnets as attached to a key on the pianoforte. The armatures of these magnets are laminated to minimise the retarding effect of eddy currents.

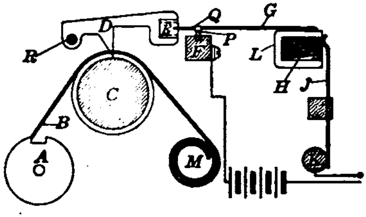

Fig. 37.—Skeleton diagram of the operating mechanism of a Tel-Electric piano player.

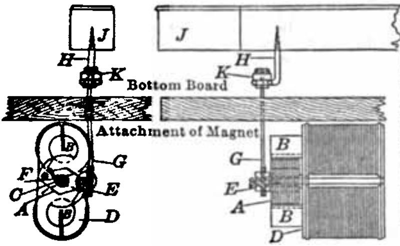

Fig. 38.—Showing attachment of magnets to key in a pianoforte.

275. Combination organ and piano players. Certain combinations are also made whereby the Tel-Electric transmitter operates a piano by means of a piano music roll. By turning over a coupler, the piano is cut out, and the same transmitter operates the organ by means of an organ music roll. With this type of combination, when the organ is coupled to the transmitter, the piano is played entirely automatically by means of the organ music sheet, so it is possible to play very closely organ and piano arrangements, the piano part being played nearly in full on the piano and the orchestral or organ accompaniment played in full on the organ. In this combination, the piano is used manually, similar to any stop in the organ, by means of one of the keyboards.

THE TELEGRAPHONE

BY OTIS ALLEN KENYON

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276. Theory. The telegraphone, which was invented by Valdemar Poulsen, is based upon the peculiar magnetic properties of hard steel which shown in Fig. 39. Assume an endless steel wire to be passed over two revolving drums at a suitable speed. If an electromagnet (Fig. 40) is brought into close proximity to the traveling wire, the wire will be magnetised to a degree corresponding to the strength of the magnet. If the exciting circuit through the magnet is alternately opened and closed the steel wire will become magnetised only during the periods when the circuit is closed and because of the coercive strength of steel the magnetism will remain fixed in the positions where it is received and not equalize itself; that is, the steel wire

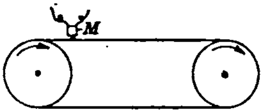

Fig. 39.—Principle of telegraphone.

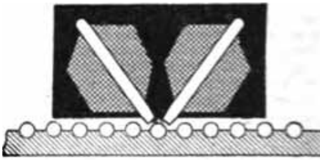

Fig. 40.—Electromagnet for wire recorder.

retains a permanent record of the magnetic fluctuations and if it were passed between the poles of a suitable electromagnet it would be capable of transforming the magnetic variations into electric variations by electromagnetic induction, the energy for which would be supplied entirely by the motor which drives the wire between the poles of the magnet.

277. In the Poulsen telegraphone these principles are utilised by connecting a system similar to that shown in Fig. 39 to telephone instruments. The electric currents produced by speaking into the transmitter (Fig. 41) are used to excite the recording magnet which leaves a permanent magnetic record in steel that is made to travel through the magnetic field. This record can reproduce the sounds that generated it by passing between the poles of a similar magnet that is connected to a telephone receiver as shown

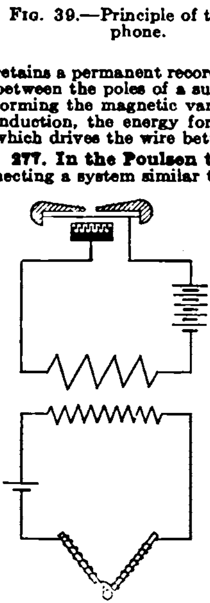

Fig. 41.—Transmitter.

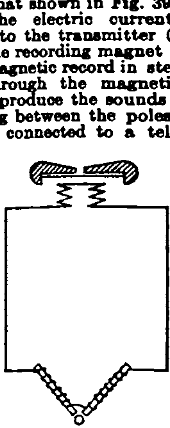

Fig. 42.—Receiver.

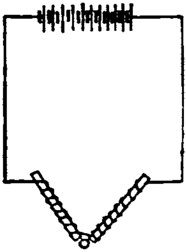

Fig. 43.—Eraser.

in Fig. 42. In order to make it possible to use the same steel over and over again a third magnet (Fig. 43) is provided which is excited with a relatively strong and constant current in the opposite direction to the transmitting magnet. This magnet obliterates all previous records and leaves the steel in condition to receive a new record.

magnet, by means of which the writing is to be performed is used to obliterate a prior magnetic record and also simultaneously magnetise the writing basis, then, during the inscription, the electromagnet is given a polarization opposed to that which it possessed when obliterating. In this way a lively movement of the molecular magnets is obtained at the very moment of forming the writing. The susceptibility seems to increase very much in that magnetic *status nascendi*, and every shade of the writing becomes extremely perceptible. Ordinarily the polarisation of the writing magnet is only a very small fraction of that of the obliterating one. The nearer its polarisation approaches the neutralisation of that of the writing basis, however, the feebler may be the polarisation of the obliterating magnet. The coercive force determines the degree of polarisation which exactly neutralizes the magnetization of the writing basis. It is found that the writing is somewhat weak when the polarisation of the electromagnet during the process of inscription is just equal to that used in the preceding obliteration. In order to polarise the electromagnet, either a constant-current or a permanent magnet may be used.

279. Recorders. There are three distinct forms of recorders which are as follows: (a) the wire recorder; (b) the tape recorder; (c) the disc recorder.

The type of magnet used with the **wire recorder** is shown in Fig. 40, the wire being wound upon grooved drums first in one direction and then in the other. The disc and tape recorders use magnets with straight cores.

In the **tape recorder** the tape is wound up like a ribbon without any intervening substance. There is no perceptible effect from this method of procedure as experience has shown that the magnetism does not traverse the tape but is present only in the uppermost portions near the surface.

The **disc recorder** is constructed somewhat similar to the disc form of phonograph and the electromagnet is provided with a very sharp point.

280. Adaptations. There are many practical uses to which the telegraphone may be adapted and a number of commercial forms have been placed upon the market. These are described in Par. **281** to **286**.

281. Amplification of weak voice currents. In telephone work it sometimes happens that the current impulses received over the line are so weak that they do not furnish sufficient energy to produce records of proper magnetic intensity. However, in such cases the only effect is a diminution in the volume of sound. In an attempt to avoid this effect William A. Rosenbaum patented in 1903 a modified form of magnet for use with Poulsen's apparatus. In this improved construction a permanent magnet is used and a variation in intensity is obtained by varying the distance between the poles of the magnet and the steel record. Fig. 44 shows the principle of the construction. The permanent magnet is mounted upon an iron diaphragm which is vibrated by electric impulses received over the telephone line.

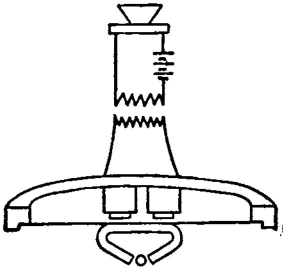

Fig. 44.—Rosenbaum's recorder.

282. A type of telegraphone intended for use in connection with the ordinary telephone is so arranged that it will perform three distinct services: (a) it may be set to record all messages received during the absence of the operator; (b) it may be set to record complete telephone conversations for the purpose of accurate record; (c) it may be set to repeat messages left by the operator. When the telegraphone is set for operation during the absence of the operator it is arranged to start automatically when a call is received and to run for a definite period of time, usually 2 min. It usually begins by sending a buzzing signal which apprises the speaker at the other end of the fact that the telegraphone is in operation, either to receive or transmit a message.

by the pull due to the series winding of a solenoid, acting on a compression rheostat in series with the generator field. Meanwhile, the ampere-hour meter is running in the direction of "charge," and, when the contact-making needle has reached its point of contact, the resistance, *R*, is short-circuited.

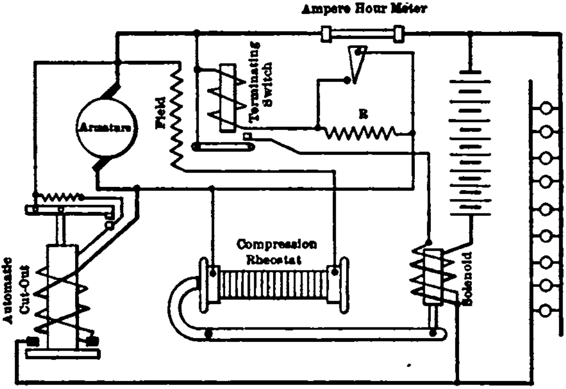

FIG. 45.—Simplified diagram of typical train-lighting system.

By this means, the solenoid of the terminating switch becomes sufficiently energized to close the contact points, thereby energising the potential winding of the solenoid governing the field rheostat. This pull is added to the action of the series winding, and the effect is a sudden reduction in generator voltage by such percentage as the regulator has been adjusted for. The

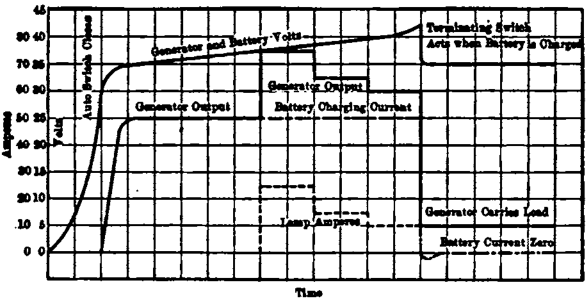

FIG. 46.—Curves illustrating performance of U-S-L-Axle equipment with type S-2 panel, starting from stand-still, with various lamp loads, and finally with battery fully charged.

battery is, by this process, floated on the supply circuit, the generator feeding the lamp load directly. See curves of Fig. 46. In this connection it is usual to employ what is known as a **lamp regulator**, in order that constant voltage may be applied to the lamps under all conditions of normal operation. Such a device consists of a potential solenoid controlling a series rheostat.

303. Telegraphs

	Year		
	1902	1907	1912
Number of companies or systems	25	26	27
Miles of pole line	237,990	239,646	247,528
Miles of single wire	1,318,350	1,577,961	1,814,196
Nautical miles of ocean cable	16,677	46,301	67,676
Number of messages	91,655,287	103,794,076	109,377,698
Number of telegraph offices	27,377	28,110	30,864
Total income	$40,930,038	$51,583,868	$64,762,843

304. Electrical machinery, apparatus and supplies, according to the 1910 Census, had a total value as follows:

Year	Total value
1899	$218,238,277
1904	309,775,089
1909	405,600,727

See Thirteenth Census of the U. S., 1910; Bulletin on Manufactures.

ENGINEERING SPECIFICATIONS AND CONTRACTS

305. Contracts. Since a contract which is good in law embraces for the most part questions which are wholly legal in character, it is beyond the function of an engineering handbook to go into the matter. The advice of competent legal counsel is always advisable in all matters connected with contracts, even though the engineer may have acquired an extensive knowledge of the law of contracts. Such knowledge should never be relied upon as a final guide, but is frequently useful in assisting the engineer to avoid serious mistakes and difficulties. The bibliography appended hereto is recommended as a course of reading for engineers who wish to equip themselves with a general knowledge of the subject.

306. Specifications. An engineering specification is almost always made part of a contract, either by direct embodiment in the contract or by reference. It is therefore essential that such a specification should be clear, direct, definite, conclusive, and legally sound. The art of drawing specifications is acquired necessarily by practice, founded upon a thorough technical knowledge of the subject matter in hand. General rules for guidance have been formulated by numerous authorities and references to a number of these will be found in the appended bibliography. These general rules will usually be found helpful as to the proper or desirable scope of the subject matter in a specification, but it is frequently more helpful to have before one a specification covering similar or identical subject matter which was drawn by a competent engineer. If no other source is available, the specifications used by the U. S. Government are sometimes obtainable through the Supt. of Documents, at Washington, D. C.

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SECTION 23

MECHANICAL SECTION

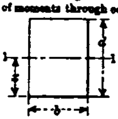
COMPILED FROM STANDARD AUTHORITIES

CONTENTS

(Numbers refer to Paragraphs)

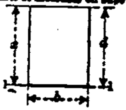
2. Mathematical Properties of Sections.—*Continued*

Rectangle
Axis of moments through center



$$A = bd$$
$$x = \frac{d}{2}$$
$$I_{1-1} = \frac{bd^3}{12}$$
$$S_{1-1} = \frac{bd^2}{6}$$
$$r_{1-1} = \frac{d}{\sqrt{12}} = 0.288675d$$

Rectangle
Axis of moments on base

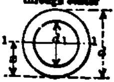


$$A = bd$$
$$x = d$$
$$I_{1-1} = \frac{bd^3}{3}$$
$$S_{1-1} = \frac{bd^2}{3}$$
$$r_{1-1} = \frac{d}{\sqrt{3}} = 0.577350d$$

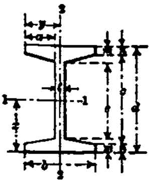
Circle
Axis of moments through center

$$A = \frac{\pi d^2}{4} = 0.785398d^2$$
$$x = \frac{d}{2}$$
$$I_{1-1} = \frac{\pi d^4}{64} = 0.049087d^4$$
$$S_{1-1} = \frac{\pi d^3}{32} = 0.098175d^3$$
$$r_{1-1} = \frac{d}{4}$$

Hollow Circle
Axis of moments through center



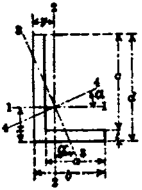
$$A = \frac{\pi(d^2 - d_1^2)}{4} = 0.785398(d^2 - d_1^2)$$
$$x = \frac{d}{2}$$
$$I_{1-1} = \frac{\pi(d^4 - d_1^4)}{64} = 0.049087(d^4 - d_1^4)$$
$$S_{1-1} = \frac{\pi(d^4 - d_1^4)}{32d} = 0.098175\frac{(d^4 - d_1^4)}{d}$$
$$r_{1-1} = \frac{\sqrt{d^2 + d_1^2}}{4}$$



BEAM

$$A = dt + 2a(m+n)$$
$$x = \frac{d}{2}$$
$$y = \frac{b}{2}$$
$$I_{1-1} = \frac{bd^3 - \frac{a}{4(m-n)}(c^4 - e^4)}{12}$$
$$I_{2-2} = \frac{2nb^3 + et^3 + \frac{m-n}{4a}(b^4 - t^4)}{12}$$

UNEQUAL ANGLE



$$A = t(b+c)$$

$$x = \frac{t(b+2c)+c^2}{2(b+c)}$$

$$y = \frac{t(2a+d)+a^2}{2(a+d)}$$

$$\text{Tan } 2\alpha = \frac{t[(2y-t)d(d-2x)+a(2x-t)(b+t-2y)]}{2(I_{1-1}-I_{2-2})}$$

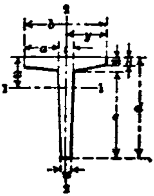
$$I_{1-1} = \frac{t(d-x)^3+bx^3-a(x-t)^3}{3}$$

$$I_{2-2} = \frac{t(b-y)^3+dy^3-c(y-t)^3}{3}$$

$$I_{3-3} = \frac{I_{2-2}\cos^2\alpha - I_{1-1}\sin^2\alpha}{\cos 2\alpha}$$

$$I_{4-4} = \frac{I_{1-1}\cos^2\alpha - I_{2-2}\sin^2\alpha}{\cos 2\alpha}$$

TEE



$$A = \frac{e(t+u)}{2} + mt + a(m+n)$$

$$x = \frac{6an^2+2a(m-n)(m+2n)+3td^2-e(t-u)\ (3d-e)}{6A}$$

$$y = \frac{b}{2}$$

$$I_{1-1} = \frac{e^3(3u+t)+4bm^3-2a(m-n)^3}{12} - A(x-m)^2$$

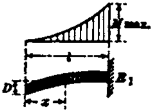
$$I_{2-2} = \frac{nb^3+(m-n)t^3+eu^3}{12} + \frac{a(m-n)[2a^2+(2a+3t)^2]}{36} + \frac{e(t-u)[(t-u)^2+2(t-2u)^2]}{144}$$

BEAMS

3. Moments. The moment of a force with respect to any given point is equal to the product of the force and its perpendicular distance from the point. If the force is expressed in lb. and the distance in in., the moment will be expressed in in-lb.

4. Reaction at supports. In the case of a horizontal beam supported at two or more places, each support reacts against the beam, and the sum of all these reactions is equal to the combined weight of the beam and its loading.

5. Shear. The loads and the reactions of the supports are vertical forces tending to shear or cut the beam across, and the stresses they produce within the beam are, therefore, called shearing stresses. The shearing force at any section is the force with which the part of the beam on one side of the section tends to slide past the part on the opposite side. The shear at each support is equal to the reaction of the support; the shear at any point between the supports is equal to the reaction of the support less the total load between the support and the point; or if the upward reaction is considered



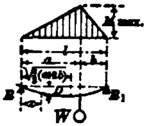
M, distance x $= \frac{Wx^2}{2l}$

M max. at R_1 $= \frac{Wl}{2}$

W max. $= \frac{2fS}{l}$

D max. $= \frac{Wl^3}{8EI}$

III. BEAM SUPPORTED AT ENDS—Concentrated load near one end



R(max. shear if $b>a$) $= \frac{Wb}{l}$

R_1(max. shear if $a>b$) $= \frac{Wa}{l}$

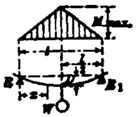
M, distance x $= \frac{Wbx}{l}$

M max. at point of load $= \frac{Wab}{l}$

W max. $= \frac{fSl}{ab}$

D max. $= \frac{Wab(a+2b)\sqrt{3a(a+2b)}}{27EIl}$

IV. BEAM SUPPORTED AT ENDS—Concentrated load at centre



R (max. shear) $= R_1$ $= \frac{W}{2}$

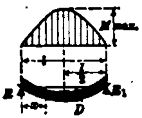
M, distance x $= \frac{Wx}{2}$

M max., at point of load $= \frac{Wl}{4}$

W max. $= \frac{4fs}{l}$

D max. $= \frac{Wl^3}{48EI}$

V. BEAM SUPPORTED AT ENDS—Uniformly distributed load



R(max. shear) $= R_1$ $= \frac{W}{2}$

M, distance x $= \frac{Wx}{2}(1-\frac{x}{l})$

M max. at centre $= \frac{Wl}{8}$

W max. $= \frac{8fs}{l}$

D max. $= \frac{5Wl^3}{384EI}$

allowable for shear, and A is the area of the section in sq. in.

10. Safe unit stresses for steel beams. Steel beams are usually I-beams; however they may be of almost any section demanded by structural conditions. See Par. 9. The allowable unit stresses for general structural work will not usually depart from the following values* expressed in lb. per sq. in.; care, however, should be exercised in the assumption of unit stresses for structures which will be called upon to meet unusual requirements.

Tension, net section, rolled steel	16,000
Direct compression, rolled steel and steel castings	16,000
Bending, on extreme fibres of rolled shapes, built sections, girders, and steel castings	16,000
Bending on extreme fibres of pins	24,000
Shear on shop rivets and pins	12,000
Shear on bolts and field rivets	10,000
Shear—average—on webs of plate girders and rolled beams, gross section	10,000
Bearing pressure on shop rivets and pins	24,000
Bearing on bolts and field rivets	20,000

11. Safe unit stresses for wooden beams. The maximum safe loads, as limited by the allowable shearing stresses along horizontal axes of the beams, or allowable longitudinal shear, should be calculated from the formula

$$\text{Maximum safe load} = \tfrac{2}{3}Af \qquad \text{(lb.)} \qquad (4)$$

where A is the area of the section and f is the allowable working stress in longitudinal shear. These limits should not be exceeded to avoid failure of the beam in the horizontal direction of the grain of the wood. The bending stress should be calculated as shown in Par. 9.

For a full discussion of the theory of longitudinal shear, see Chap. VI of Lanza's "Applied Mechanics." A table of allowable working stresses for structural timber is given in Sec. 4. The proper factor of safety is usually determined by the character or conditions of service.

12. Concrete beams and floor slabs. The arrangement of concrete beams follows the same principles as in structural-steel construction. On short spans, floor cross beams may be omitted, or used only at columns in order to secure lateral stiffness. Beams are usually designed as tee beams, and a part of the floor slab thus comprises part of the beam. The width of the slab considered to act as part of the beam should not exceed five times the slab thickness.

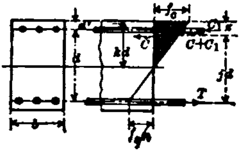
The reinforcement of floor slabs may be of small rods, wires or metal fabric, the latter especially on cross spans. Cross reinforcement of small rods or wires about 2 ft. apart laid parallel to the beam supporting the slab, should be used to prevent cracks, shrinkage, etc. If the length of the slab exceeds one and one-half times its width, the entire load should be carried by transverse reinforcement. The distribution of the load on a rectangular slab supported on four sides and reinforced in both directions may be approximately determined by the formula

$$R = \frac{l^4}{l^4 + b^4} \qquad (5)$$

where R is the ratio of the load, l the length and b the width of the slab. An effective bond should be provided at the junction of the beam and the slab, and if the principal reinforcement of the slab is parallel to the beam, transverse reinforcement should be used extending over the beam and well into the slab.

In the calculation of shear or web reinforcement, concrete may be assumed to carry one-quarter to one-third of the total shear, the remainder being taken

* "Pocket Companion," Carnegie Steel Co., 1913; pp. 126 and 127.



$$z = \frac{\frac{1}{3}k^3d + 2p'nd'\left(k - \frac{d'}{d}\right)}{k^2 + 2p'n\left(k - \frac{d'}{d}\right)}$$

$$f_s = \frac{M}{pjbd^2} = \frac{nf_c(1-k)}{k}$$

$$f_s' = \frac{nf_c\left(k - \frac{d'}{d}\right)}{k}$$

$$f_c = \frac{6M}{bd^2\left[3k - k^2 + \frac{6p'n}{k}\left(k - \frac{d'}{d}\right)\left(1 - \frac{d'}{d}\right)\right]}$$

A' = Area of compressive steel, in sq. in.
p' = Steel ratio for compressive steel.
f'_s = Unit compressive stress in steel, in lb. per sq. in.
C = Total compressive stress in concrete, in lb. per sq. in.
C' = Total compressive stress in steel, in lb. per sq. in.
d' = Depth to centre of compressive steel, in in.
z = Depth to resultant of $C+C'$, in in.

16. Shear and bond in reinforced concrete beams.*

Rectangular Beams	$f_v = \frac{V}{bjd}$	(6)	$f_u = \frac{V}{jd\,\Sigma o}$	(7)
T Beams	$f_v = \frac{V}{b'jd}$	(8)	$f_u = \frac{V}{jd\,\Sigma o}$	(9)

V = Total shear, in lb.; f_v = Unit shearing stress in concrete, in lb. per sq. in.; f_u = Unit bonding stress in concrete, in lb. per sq. in.: Σ_o = Sum of the perimeters of the tension bars.

17. Unit allowable stresses in reinforced-concrete beams. The following working stresses are in current use for reinforcing bars of medium structural steel and good Portland cement and gravel concrete of a 1 : 2 : 4 or 1 : 2½ : 5 mixture:

f_c = unit compressive stress of concrete.........	650 lb. per sq. in.
f_v = unit shearing stress of concrete,	
straight reinforcement...................	30 to 40 lb. per sq. in.
special shear reinforcement..............	60 to 100 lb. per sq. in.
f_u = unit bond stress of concrete,	
smooth rods	60 to 80 lb. per sq. in.
deformed bars..........................	100 to 175 lb. per sq. in.
f_s = unit tensile stress of steel	16,000 lb. per sq. in.
f_b = unit compressive stress of steel............	10,000 lb. per sq. in.

$n = E_s \div E_c = 15$.
for notation, see Par. 13 to 16.

COLUMNS

18. Discussion of column formulas. Due to the tendency to buckling, compression members are assumed to carry bending stresses. Failure of a column may, then, be due to direct compression, to bending or to a combination of both. No rigorous formula has ever been deduced for columns under all conditions of loading. However, several empirical formulas (Par. 21) have proven satisfactory when checked by tests made on full-sized members. All these formulas take into consideration the properties of the section (Par. 1), the allowable unit stress and the ratio of slenderness (Par. 20).

19. Radius of gyration is defined in Par. 1. For purposes of computation it is more convenient to employ the radius of gyration than either the moment of inertia or the section modulus.

* See footnote, Par. 13 and 14.

are produced. In Fig. 1 a column is pictured as carrying a beam supported on a bracket with a load W_1, and also a direct loading W. Selection of the proper column size may be accomplished by repeated trials, using the following formula:

$$f \gtrless \frac{w + w_1}{A} + \frac{Mn}{I} \qquad \text{(lb. per sq. in.)} \qquad (10)$$

where W and W_1 are expressed in lb.; A is the area of the column section in sq. in.; M is the bending moment in in-lb., ($= w_1x$) due to eccentric loading; n is the distance of the extreme fibre from the neutral axis, measured in the direction of bending; and f is the allowable axial unit compression stress, in lb. per sq. in.

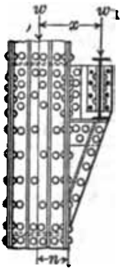


FIG. 1.—Column with eccentric superposed load.

23. Wooden columns.* The safe load tables of wooden columns which follow, based upon the working unit stresses adopted by the American Railway Engineering Association, give the allowable direct compressive loads for square and round columns.

The safe loads of rectangular columns may be found from the safe loads of square columns by direct proportion of areas, using the safe load unit stress of the square column whose side is equal to the least side of the rectangular section.

The following table gives the safe load in lb. per sq. in. of sectional area for ratios of

$$\frac{l}{d} = \frac{\text{effective length of column, in in.}}{\text{least side or diameter, in in.}} \qquad (11)$$

ranging between limits of 15 and 30.

Unit Working Stresses in Lb. per Sq. In.

$\frac{l}{d}$	Longleaf pine, white oak	Douglas fir, Western hemlock	Shortleaf pine, spruce, bald cypress	White pine, tamarack	Red cedar, redwood	Norway pine
	$1{,}300 \times (1 - l/d60)$	$1{,}200 \times (1 - l/d60)$	$1{,}100 \times (1 - l/d60)$	$1{,}000 \times (1 - l/d60)$	$900 \times (1 - l/d60)$	$800 \times (1 - l/d60)$
15	975	900	825	750	675	600
16	953	880	807	733	660	587
17	931	860	788	717	645	573
18	910	840	770	700	630	560
19	888	820	752	683	615	547
20	867	800	733	667	600	533
21	845	780	715	650	585	520
22	823	760	697	633	570	507
23	802	740	678	617	555	493
24	780	720	660	600	540	480
25	758	700	642	583	525	467
26	737	680	623	567	510	553
27	715	660	605	550	495	440
28	693	640	587	533	480	427
29	672	620	568	517	465	413
30	650	600	550	500	450	400

24. Concrete columns may be reinforced by means of longitudinal bars, by bands or hoops, or by both. The general effect of the banding or hooping is to permit the use of somewhat higher working stresses; the value

* "Pocket Companion," Cambria Steel Co., 1913; p. 327.

27. Horse-power of Shafts for Simply Transmitting Power.

$$\text{H.p.} = \frac{D^3R}{50}$$

Diam. of shaft, in.	Rev. per min.								
	1	50	100	150	200	250	300	400	500
$1\frac{3}{16}$	0.0335	1.67	3.35	5.02	6.70	8.37	10.05	13.40	16.74
$1\frac{7}{16}$	0.0594	2.97	5.94	8.91	11.88	14.85	17.82	23.76	29.70
$1\frac{11}{16}$	0.0961	4.81	9.61	14.42	19.22	24.03	28.83	38.44	48.05
$1\frac{15}{16}$	0.1455	7.27	14.55	21.82	29.09	36.37	43.64	58.18	72.73
$2\frac{3}{16}$	0.2094	10.47	20.94	31.40	41.87	52.34	62.80	83.74	104.7
$2\frac{7}{16}$	0.2896	14.48	28.96	43.45	67.93	72.41	86.89	115.9	144.8
$2\frac{11}{16}$	0.3882	19.41	38.82	58.23	77.64	97.05	116.5	155.3	194.1
$2\frac{15}{16}$	0.5069	25.35	50.69	76.04	101.4	126.7	152.1	202.8	253.5
$3\frac{3}{16}$	0.6477	32.39	64.77	97.15	129.5	161.9	194.3	259.1	323.9
$3\frac{7}{16}$	0.8124	40.62	81.24	121.9	162.5	203.1	243.7	324.9	406.2
$3\frac{11}{16}$	1.003	50.14	100.3	150.4	200.6	250.7	300.8	401.1	501.4
$3\frac{15}{16}$	1.221	61.04	122.1	183.1	244.2	305.2	366.2	488.3	610.4
$4\frac{7}{16}$	1.748	87.38	174.8	262.1	349.5	436.9	524.3	699.0	
$4\frac{15}{16}$	2.407	120.4	240.7	361.1	481.5	601.8	722.5	962.9	
$5\frac{1}{2}$	3.328	166.4	332.8	499.1	665.5	831.9	998.2		
6	4.320	216.0	432.0	648.0	864.0	1080.0	1296.0		
$6\frac{1}{2}$	5.493	247.6	549.3	823.9	1099.0	1373.0			
7	6.860	343.0	686.0	1029.0	1372.0	1715.0			
$7\frac{1}{2}$	8.438	421.9	843.8	1266.0	1688.0				
8	10.24	512.0	1024.0	1536.0	2048.0				

GEARING AND CHAIN DRIVE

28. Toothed gearing is used for positive drive between shafts, that is, where the requirements will permit no slippage. There are two styles of teeth, the cycloidal and the involute. The former is used where the distance between centres of driving and driven member can be rigidly maintained. **Cycloidal gears** do not wear so rapidly as involute gears, and are used to transmit energy at rather high speeds. **Involute gears**, on the other hand, do not require so accurate a spacing of centres, although, after wearing for some time, this advantage becomes lessened, and such gearing is no longer insensible to badly adjusted bearings. Involute teeth are thicker at the root than cycloidal gears, and this added strength has considerable weight in the selection of gears for high-torque service. They operate at somewhat lower allowable speeds than cycloidal gears.

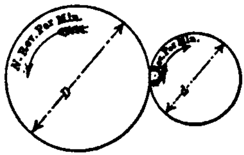


Fig. 2.—$D : d :: n : N$.

29. Gear pitch.* When, as in Fig. 2, two elemental circles may be said to roll one on the other with no slippage, their speeds in rev. per min. are inversely proportional to their diameters. In the case of gearing, the elemental circle just mentioned is known as the **pitch circle**, and the ratio of rotational speeds of a pair of meshed gears follows the relation above expressed. There are two common methods of describing the pitch of gear teeth. **Diametral pitch** is an expression derived by dividing the number of teeth on the gear by the diameter of the pitch circle in in. Thus, an eight-pitch gear has eight teeth per in. of pitch-circle diameter. **Circular**

* Schwamb & Merrill. "Elements of Mechanism," John Wiley & Sons.

ever with ordinary gears it would be exceptional to secure speeds, satisfactory from a standpoint of noise, which would range as high as 1,200 ft. per min. With herring-bone gears running in oil, pitch-line speeds as great as 5,000 ft. per min. have been reached. In the case of rawhide and cloth pinions, operation with a satisfactory minimum of noise can be attained at speeds ranging from 2,000 to 3,000 ft. per min.

32. Maximum Speed of Gearing

(A. Towler, *Engineering*, April 19, 1889, p. 388)

Ordinary cast-iron wheels	(ft. per min.)	1,800
Helical cast-iron wheels		2,400
Mortise cast-iron wheels		2,400
Ordinary cast-steel wheels		2,600
Helical cast-steel wheels		3,000
Special cast-iron machine-cut wheels		3,000
Double herringbone gears in oil *		5,000

33. Horse-power and working loads of cut cast-iron gears.† For significance of symbols, see Par. **30**.

Diametral pitch	Circular pitch	No. of teeth	Speed of pitch line (ft. per min.) 100		200		300		600		900		1200	
			w.l.	h.p.	w.l.	h.p.	w.l.	h.p.	w.l.	h.p.	w.l.	h.p.	w.l.	h.p.
10	0.3142	12	90	0.27	79	0.47	70	0.63	53	0.96	42	1.15	35	1.27
		20	120	0.36	105	0.63	94	0.85	70	1.27	56	1.53	47	1.71
		40	145	0.44	127	0.76	113	1.02	85	1.55	68	1.86	56	2.04
		60	152	0.46	133	0.80	119	1.07	89	1.62	71	1.94	60	2.18
		130	160	0.49	140	0.84	124	1.12	94	1.71	74	2.02	62	2.26
8	0.392	12	113	0.34	98	0.59	87	0.78	66	1.20	52	1.42	44	1.60
		20	150	0.45	130	0.78	116	1.04	87	1.58	70	1.91	58	2.11
		40	180	0.55	158	0.95	141	1.27	105	1.91	84	2.29	70	2.54
		60	190	0.58	165	0.99	148	1.33	110	2.00	88	2.40	74	2.69
		130	200	0.61	174	1.04	155	1.40	115	2.09	92	2.51	77	2.80
4	0.785	12	225	0.68	195	1.17	175	1.58	130	2.36	105	2.86	87	3.16
		20	300	0.91	260	1.56	230	2.08	175	3.18	140	3.82	116	4.22
		40	360	1.09	315	1.89	280	2.52	210	3.82	170	4.64	140	5.09
		60	380	1.15	330	1.98	295	2.68	220	4.00	177	4.83	147	5.35
		130	400	1.21	350	2.10	310	2.79	230	4.18	185	5.05	155	5.64
3	1.047	12	300	0.91	260	1.56	232	2.08	175	3.18	140	3.82	116	4.22
		20	400	1.21	350	2.10	310	2.79	232	4.22	185	5.05	155	5.64
		40	480	1.45	420	2.52	373	3.36	280	5.10	225	6.14	187	6.80
		60	503	1.52	440	2.64	391	3.52	295	5.37	235	6.42	196	7.13
		130	530	1.61	462	2.77	411	3.70	310	5.64	248	6.77	206	7.50
2	1.57	12	450	1.37	390	2.34	350	3.15	260	4.73	209	5.71	174	6.33
		20	600	1.82	520	3.12	467	4.20	350	6.37	280	7.64	232	8.44
		40	720	2.18	630	3.78	560	5.04	420	7.64	348	9.50	280	10.20
		60	760	2.30	663	3.98	592	5.33	442	8.05	355	9.70	295	10.72
		130	795	2.40	695	4.17	619	5.57	462	8.40	370	10.10	309	11.23
1½	2.09	12	595	1.80	520	3.12	462	4.16	348	6.34	278	7.59	230	8.37
		20	800	2.42	700	4.20	620	5.58	466	8.47	372	10.15	310	11.28
		40	963	2.92	840	5.04	750	6.75	560	10.20	450	12.28	372	13.52
		60	1010	3.06	880	5.28	780	7.03	585	10.65	470	12.82	390	14.20
		130	1060	3.21	925	5.55	820	7.38	617	11.22	493	13.44	410	14.90

* This figure was supplied in 1913 by Mr. W. C. Bates, Engineer of the Faucus Machine Co.

† Data Book 125, Link-Belt Co., New York, 1914, p. 106.

36. Horse-power Transmitted by Belts*

Pulley Running at 100 Rev. per Min.

Diameter of pulley (in.)	Width of belt															
	2 in.	3 in.	4 in.	5 in.		6 in.		8 in.		10 in.		12 in.	14 in.	16 in.	18 in.	20 in.
	S	S	S	S	D	S	D	S	D	S	D	D	D	D	D	D
	4 ply	4 ply	4 ply	4 ply	6 ply	4 ply	6 ply	4 ply	6 ply	4 ply	6 ply	6 ply	8 ply	8 ply	8 ply	8 ply
6	0.29	0.43	0.57	0.71	1.3											
8	0.38	0.57	0.76	0.95	1.7	1.1	2.1									
10	0.48	0.71	0.95	1.2	2.2	1.4	2.6	2.1	4.2							
12	0.57	0.86	1.1	1.4	2.6	1.7	3.1	2.5	5.0	3.1	6.3					
14	0.67	1.0	1.3	1.7	3.1	2.0	3.7	2.9	5.9	3.7	7.3	11.0				
16	0.76	1.1	1.5	1.9	3.5	2.3	4.2	3.4	6.7	4.2	8.4	12.6	14.7			
18	0.86	1.3	1.7	2.1	3.9	2.6	4.7	3.8	7.5	4.7	9.4	14.1	16.5	18.8		
20	0.95	1.4	1.9	2.4	4.4	2.9	5.2	4.2	8.4	5.2	10.5	15.7	18.3	21.0	23.6	
22	1.0	1.6	2.1	2.6	4.8	3.1	5.8	4.6	9.2	5.8	11.5	17.3	20.2	23.0	25.9	28.8
24	1.1	1.7	2.3	2.9	5.2	3.4	6.3	5.0	10.0	6.3	12.6	18.8	22.0	25.1	28.3	31.4
26	1.2	1.9	2.5	3.1	5.7	3.7	6.8	5.4	10.9	6.8	13.6	20.4	23.8	27.2	30.6	34.1
28	1.3	2.0	2.7	3.3	6.1	4.0	7.3	5.9	11.7	7.3	14.7	22.0	25.7	29.3	33.0	36.7
30	1.4	2.1	2.9	3.6	6.5	4.3	7.9	6.3	12.6	7.9	15.7	23.6	27.5	31.4	35.3	39.3
32	1.5	2.3	3.0	3.8	7.0	4.6	8.4	6.7	13.4	8.4	16.8	25.1	29.3	33.5	37.7	41.9
34	1.6	2.4	3.2	4.0	7.4	4.9	8.9	7.1	14.2	8.9	17.8	26.7	31.2	35.6	40.1	44.5
36	1.7	2.6	3.4	4.3	7.9	5.1	9.4	7.5	15.1	9.4	18.8	28.3	33.0	37.7	42.4	47.1
38	.....	.....	3.6	4.5	8.3	5.4	10.0	8.0	15.9	10.0	19.9	29.9	34.8	39.8	44.8	49.8
40	.....	.....	3.8	4.8	8.7	5.7	10.5	8.4	16.8	10.5	20.9	31.4	36.6	41.9	47.1	52.4
42	.....	.....	4.0	5.0	9.2	6.0	11.0	8.8	17.6	11.0	22.0	33.0	38.5	44.0	49.5	55.0
44	.....	.....	4.2	5.2	9.6	6.3	11.5	9.2	18.4	11.5	23.0	34.6	40.3	46.1	51.8	57.6
46	.....	.....	4.4	5.5	10.0	6.6	12.0	9.6	19.3	12.0	24.1	36.1	42.1	48.2	54.2	60.2
48	.....	.....	4.6	5.7	10.5	6.9	12.6	10.1	20.1	12.6	25.1	37.7	44.0	50.3	56.6	62.9
50	.....	.....	.....	6.0	10.9	7.1	13.1	10.5	20.9	13.1	26.2	39.3	45.8	52.4	58.9	65.5
60	.....	.....	.....	7.1	13.1	8.6	15.7	12.6	25.1	15.7	31.0	47.1	55.0	62.8	70.7	78.6
72	.....	.....	.....	.....	.....	10.3	18.9	15.1	30.2	18.9	37.7	56.6	66.0	75.4	84.8	94.3
84	.....	.....	.....	.....	.....	.....	.....	17.6	35.2	22.0	44.0	66.0	77.0	88.0	99.0	110.0

* Link-Belt Co., Data Book, No. 125, 1914.

S and *D* refer to thickness of leather belting; 4 ply, 6 ply, and 8 ply refer to thickness of cotton or rubber belting. 5
min. is the limiting speed for iron pulleys. A good belt speed is 3,500 ft. per min. If possible, use pulleys listed below

(**American**) **system**, one rope is used; this is wrapped around the sheaves the desired number of times, and then carried over from the last groove of one sheave to the first groove of the other by a guide pulley which, at the same time, maintains a constant tension in the rope. It is clearly seen that while the latter system is the more flexible and easily installed of the two, the results of a single breakage would be much more serious.

The angle of the groove should be about as shown in Figs. 5 and 6, which illustrate the grooves used for manila, hemp, or cotton ropes on the driving sheaves of both the English system and the American. For economical wear the pulleys should be not less than forty times the diameter of the rope.

The horse-power which can be transmitted by ropes at various speeds is the subject of much controversy, some engineers imposing loads greater by 35 or 40 per cent. than the recommendations of others. The data offered

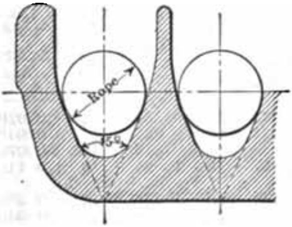


FIG. 5.—Standard groove of English system.

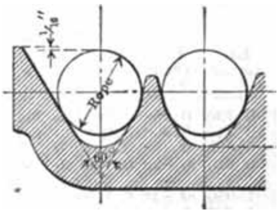


FIG. 6.—Standard groove of American system.

in Par. 42 represent conservative practice. Lanza* and the Link-Belt Co.† in their tables advocate values considerably higher, while J. J. Flather‡ is even more conservative than the accompanying authority.

42. Horse-power of Transmission Rope at Various Speeds**

Diam. of rope	Speed of the rope in ft. per min.											Smallest diam. of pulley in in.
	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	6,000	7,000	8,000	
½	1.45	1.9	2.3	2.7	3.0	3.2	3.4	3.4	3.1	2.2	0	20
⅝	2.3	3.2	3.6	4.2	4.6	5.0	5.3	5.3	4.9	3.4	0	25
¾	3.3	4.3	5.2	5.8	6.7	7.2	7.7	7.7	7.1	4.9	0	30
⅞	4.5	5.9	7.0	8.2	9.1	9.8	10.8	10.7	9.3	6.9	0	36
1	5.8	7.7	9.2	10.7	11.9	12.8	13.6	13.7	12.5	8.8	0	42
1¼	9.2	12.1	14.3	16.8	18.6	20.0	21.2	21.4	19.5	13.8	0	54
1½	13.1	17.4	20.7	23.1	26.8	28.8	30.6	30.8	28.2	19.8	0	60
1¾	18.0	23.7	28.2	32.8	36.4	39.2	41.5	41.8	37.4	27.6	0	72
2	23.1	30.8	36.8	42.8	47.6	51.2	54.4	54.8	50.0	35.2	0	84

* Lanza, G. "Notes on Friction," J. S. Cushing & Co., Boston.
† Data Book, No. 125, Link-Belt Co., New York, 1914.
‡ Flather, J. J. "Rope Driving," John Wiley & Sons, New York, 1895.
** Hunt, C. W. "Manila Rope," Cat. 054, C. W. Hunt Co., New York.

EXTRA STRONG PIPE

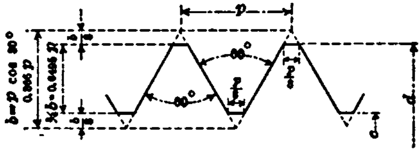
Size (in.)	Diameter (in.) External	Diameter (in.) Internal	Thickness (in.)	Weight per ft. (lb.) Plain ends
1/8	0.405	0.215	0.095	0.314
1/4	0.540	0.302	0.119	0.535
3/8	0.675	0.423	0.126	0.738
1/2	0.840	0.546	0.147	1.087
3/4	1.050	0.742	0.154	1.473
1	1.315	0.957	0.179	2.171
1 1/4	1.660	1.278	0.191	2.996
1 1/2	1.900	1.500	0.200	3.631
2	2.375	1.939	0.218	5.022
2 1/2	2.875	2.323	0.276	7.661
3	3.500	2.900	0.300	10.252
3 1/2	4.000	3.364	0.318	12.505
4	4.500	3.826	0.337	14.983
4 1/2	5.000	4.290	0.355	17.611
5	5.563	4.813	0.375	20.778
6	6.625	5.761	0.432	28.573
7	7.625	6.625	0.500	38.048
8	8.625	7.625	0.500	43.388
9	9.625	8.625	0.500	48.728
10	10.750	9.750	0.500	54.735
11	11.750	10.750	0.500	60.075
12	12.750	11.750	0.500	65.415
13	14.000	13.000	0.500	72.091
14	15.000	14.000	0.500	77.431
15	16.000	15.000	0.500	82.771

DOUBLE EXTRA STRONG PIPE

Size (in.)	Diameters (in.) External	Diameters (in.) Internal	Thickness (in.)	Weight per ft. (lb.) Plain ends
1/2	0.840	0.252	0.294	1.714
3/4	1.050	0.434	0.308	2.440
1	1.315	0.599	0.358	3.659
1 1/4	1.660	0.896	0.382	5.214
1 1/2	1.900	1.100	0.400	6.408
2	2.375	1.503	0.436	9.029
2 1/2	2.875	1.771	0.552	13.695
3	3.500	2.300	0.600	18.583
3 1/2	4.000	2.728	0.636	22.850
4	4.500	3.152	0.674	27.541
4 1/2	5.000	3.580	0.710	32.530
5	5.563	4.063	0.750	38.552
6	6.625	4.897	0.864	53.160
7	7.625	5.875	0.875	63.079
8	8.625	6.875	0.875	72.424

Taper of pipe threads is 3/4 in. diameter per ft. length. Report Com. Pipe and Threads, A. S. M. E., Nov., 1886.

45. Screw Threads
(United States Standard)



Diameter		Area		No. of threads per in.	Diameter		Area		No. of threads per in.
Total d (in.)	Net c (in.)	Total dia., d (sq. in.)	Net dia., c (sq. in.)		Total d (in.)	Net c (in.)	Total dia., d (sq. in.)	Net dia., c (sq. in.)	
¼	0.185	0.049	0.027	20	2½	2.175	4.909	3.716	4
⅜	0.294	0.110	0.068	16	2⅝	2.300	5.412	4.156	4
½	0.400	0.196	0.126	13	2¾	2.425	5.940	4.619	4
⅝	0.507	0.307	0.202	11	2⅞	2.550	6.492	5.108	4
¾	0.620	0.442	0.302	10					
⅞	0.731	0.601	0.419	9	3	2.629	7.069	5.428	3½
					3¼	2.879	8.296	6.509	3¼
1	0.838	0.785	0.551	8	3½	3.100	9.621	7.549	3¼
1⅛	0.939	0.994	0.693	7	3¾	3.317	11.045	8.641	3
1¼	1.064	1.227	0.890	7					
1⅜	1.158	1.485	1.054	6	4	3.567	12.566	9.993	3
1½	1.283	1.767	1.294	6	4¼	3.798	14.186	11.330	2⅞
1⅝	1.389	2.074	1.515	5½	4½	4.028	15.904	12.741	2¾
1¾	1.490	2.405	1.744	5	4¾	4.255	17.721	14.221	2⅝
1⅞	1.615	2.761	2.049	5					
					5	4.480	19.635	15.766	2½
2	1.711	3.142	2.300	4½	5¼	4.730	21.648	17.574	2½
2⅛	1.836	3.547	2.649	4½	5½	4.953	23.758	19.268	2⅜
2¼	1.961	3.976	3.021	4½	5¾	5.203	25.967	21.262	2⅜
2⅜	2.086	4.430	3.419	4½	6	5.423	28.274	23.095	2¼

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SECTION 24

STANDARDIZATION RULES OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

APPROVED BY THE BOARD OF DIRECTORS, JUNE 28, 1916.

CONTENTS

(*Numbers refer to Paragraphs*)

14. Non-sinusoidal quantities. Quantities that cannot be represented by vectors of constant length in a plane. The following definitions of phase, active component, reactive component, etc., are not in general applicable thereto. Certain "equivalent" values, as defined below, may, however, be used in many instances, for the purpose of approximate representation and calculation.

15. Crest-factor or peak-factor. The ratio of the crest or maximum value to the r.m.s. value. The crest factor of a sine-wave is $\sqrt{2}$.

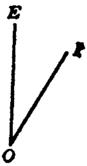
16. Form factor. The ratio of the r.m.s. to the algebraic mean ordinate taken over a half-cycle beginning with the zero value. If the wave passes through zero more than twice during a single cycle, that zero shall be taken which gives the largest algebraic mean for the succeeding half-cycle. The form factor of a sine wave is 1.11.

17. The distortion factor of a wave. The ratio of the r.m.s. value of the first derivative of the wave with respect to time, to the r.m.s. value of the first derivative of the equivalent sine-wave.

18. Equivalent sine-wave. A sine-wave which has the same frequency and the same r.m.s. value as the actual wave.

***19. Phase difference: lead and lag.** When corresponding cyclic values of two sinusoidal alternating quantities of the same frequency occur at different instants, the two quantities are said to differ in phase by the angle between their nearest corresponding values, *e.g.*, the phase angle between their nearest corresponding values; *e.g.*, the phase angle between their nearest ascending zeros or between their nearest positive maxima. That quantity whose maximum value occurs first in time is said to lead the other, and the latter is said to lag behind the former.

***20. Counter-clockwise convention.** It is recommended that in any vector diagram, the leading vector be drawn counter-clockwise with respect to the lagging vector,† as in the accompanying diagram, where *OI* represents the vector of a current in a simple alternating-current circuit, lagging behind the vector *OE* of impressed e.m.f.



***21. The active or in-phase component** of the current in a circuit is that component which is in phase with the voltage across the circuit; similarly the active component of the voltage across a circuit is that component which is in phase with the current. The use of the term *energy component* for this quantity is disapproved.

***22. Reactive or quadrature component of the current in a circuit.** That component which is in quadrature with the voltage across the circuit; similarly, the reactive component of the voltage across the circuit is that component which is in quadrature with the current. The use of the term *wattless component* for this quantity is disapproved.

***23. Reactive factor.** The sine of the angular phase difference between voltage and current; *i.e.*, the ratio of the reactive current or voltage to the total current or voltage.

***24. Reactive volt-amperes.** The product of the reactive component of the voltage by the total current, or of the reactive component of the current by the total voltage.

***25. Non-inductive load and inductive load.** A *non-inductive* load is a load in which the current is in phase with the voltage across the load. An *inductive* load is a load in which the current lags behind the voltage across the load. A *condensive* or *anti-inductive* load is one in which the current leads the voltage across the load.

26. Power in an Alternating-current circuit. The average value of the products of the coincident instantaneous values of the current and voltage for a complete cycle, as indicated by a wattmeter.

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* NOTE.—Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see Par. 11 and 12).

† See Publication 12 of the International Electrotechnical Commission (Report of Turin Meeting, Sept., 1911, p. 78).

60. Diversity factor. The ratio of the sum of the maximum power demands of the subdivisions of any system or parts of a system to the maximum demand of the whole system or of the part of the system under consideration, measured at the point of supply.

61. Connected load. The combined continuous rating of all the receiving apparatus on consumers' premises, connected to the system or part of the system under consideration.

62. The saturation factor of a machine. The ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. Unless otherwise specified, the saturation factor of a machine refers to the no-load excitation required at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

63. The percentage saturation of a machine at any excitation may be found from its saturation curve of generated voltage as ordinates, against excitation as abscissas, by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in percentage, is the percentage of saturation and is independent of the scales selected for excitation and voltage. This ratio, as a fraction, is equal to the reciprocal of the saturation factor at the same excitation, deducted from unity; or, if f be the saturation factor and p the percentage of saturation,

$$p = 100\left(1 - \frac{1}{f}\right)$$

64. Magnetic degree. The 360th part of the angle subtended, at the axis of a machine, by a pair of its field poles. One **mechanical degree** is thus equal to as many magnetic degrees as there are pairs of poles in the machine.

65. The variation in prime movers which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360 deg.

66. The variation in alternators or alternating-current circuits in general, is the maximum angular displacement, expressed in electrical degrees (1 cycle = 360 deg.) of corresponding ordinates of the voltage wave and of a wave of absolutely constant frequency equal to the average frequency of the alternator or circuit in question, and may be due to the variation of the prime mover.

67. Relations of variations in prime mover and alternator. If p is the number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct connected, and pn times the variation of the prime mover if rigidly connected thereto in such a manner that the angular speed of the alternator is n times that of the prime mover.

68. The pulsation in prime movers, or in the alternator connected thereto. The ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

80. Capacity. The two different senses in which this word is used sometimes lead to ambiguity. It is therefore recommended that whenever such ambiguity is likely to arise, the descriptive term *power capacity* or *current capacity* be used, when referring to the power or current which a device can safely carry, and that the term "*Capacitance*" be used when referring to the electrostatic capacity of a device.

81. Resistor. A device, heretofore commonly known as a resistance, used for the operation, protection, or control of a circuit or circuits. See Par. 740.

Phase displacement	θ, φ	degree or radian	°
Frequency	f	cycle per second	~
Angular velocity	ω	radians per second	
Velocity of rotation	n	revolutions per second	rev. per sec.
Number of conductors or turns	N	convolutions or turns of wire	
Temperature	T, t, θ	degree centigrade	°C
Energy in general	U or W	joule, watt-hour	
Mechanical work	W or A	joule, watt-hour	
Efficiency	η	per cent.	
Length	l	centimeter	cm.
Mass	m	gram	g.
Time	t	second	sec.
Acceleration due to gravity	g	centimeter per second per second	cm. per sec. per sec.
Standard acceleration due to gravity (at about 45 deg. latitude and sea level) equals 980.665*	g_0	centimeter per second per second	cm. per sec. per sec.

91. E_m, I_m and P_m should be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values (see Par. **10**) and P for the average value of the power, or the active power. These distinctions are not necessary in dealing with continuous-current circuits. In print, vector quantities should be represented by bold-face capitals.

CLASSIFICATION OF MACHINERY

100. The machinery under consideration in these rules may be classified in various ways, these various classifications overlapping or interlocking in considerable degree. Briefly, they are direct-current or alternating-current, rotating or stationary. Under rotating apparatus there are two principal classifications: *First*, according to the function of the machines; motors, generators, boosters, motor-generators, dynamotors, double-current generators, converters and phase advancers; *Second*, according to the type of construction or principle of operation; commutating, synchronous, induction, unipolar, rectifying. Obviously, some of these machines could be rationally included in either classification, *e.g.*, motor-generators and rectifying machines.

In the following, self-evident definitions have, for the most part, been omitted.

ROTATING MACHINES

FUNCTIONAL CLASSIFICATION OF ROTATING MACHINES

101. Generator. A machine which transforms mechanical power into electrical power.

102. Motor. A machine which transforms electrical power into mechanical power.

* This has been the accepted standard value for many years and was formerly considered to correspond accurately to 45 deg. latitude and sea level. Later researches, however, have shown that the most reliable value for 45 deg. and sea-level is slightly different; but this does not affect the standard value given above.

motion of the machine; *i.e.*, having a frequency strictly proportional to the speed of the machine. They may be subdivided as follow:

134. An alternator is a synchronous alternating-current generator, either single-phase or polyphase.

135. A polyphase alternator is a polyphase synchronous alternating-current generator, as distinguished from **a single-phase alternator.**

136. An inductor alternator is an alternator in which both field and armature windings are stationary, and in which masses of iron or inductors, by moving past the coils, alter the magnetic flux through them. It may be either single-phase or polyphase.

137. A synchronous motor is a machine structurally identical with an alternator, but operated as a motor.

138. Induction machines include apparatus wherein primary and secondary windings rotate with respect to each other; *i.e.*, induction motors, induction generators, certain types of frequency converters and certain types of rotary phase-converters.

139. An induction motor is an alternating-current motor, either single-phase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding receives power from the primary by electromagnetic induction.

140. An induction generator is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

141. Unipolar or acyclic machines are direct-current machines, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

SPEED CLASSIFICATION OF MOTORS

150. Motors may, for convenience, be classified with reference to their speed characteristics as follows:

151. Constant-speed motors, whose speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct-current shunt motors.

152. Multispeed motors (two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load; such as motors with two armature windings, or induction motors in which the number of poles is changed by external means.

153. Adjustable-speed motors, in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load, such as shunt motors designed for a considerable range of speed variation.

154. Varying-speed motors, or motors in which the speed varies with the load, ordinarily decreasing when the load increases; such as series motors, compound-wound motors, and series-shunt motors. As a subclass of varying-speed motors, may be cited, **adjustable varying-speed motors,** or motors in which the speed can be varied over a considerable range at any given load, but when once adjusted, varies with the load; such as compound-wound motors arranged for adjustment of speed by varying the strength of the shunt field.

CLASSIFICATION OF ROTATING MACHINES RELATIVE TO THE DEGREE OF ENCLOSURE OR PROTECTION

160. The following types are recognised:

Open	Self-ventilated
Protected	Drip-proof
Semi-enclosed	Moisture-resisting
Enclosed	Submersible
Separately ventilated	Explosion-proof
Water-cooled	Explosion-proof slip-ring enclosure

161. An "open" machine is of either the pedestal-bearing or end-bracket type where there is no restriction to ventilation, other than that necessitated by good mechanical construction.

162. A "protected" machine is one in which the armature, field coils,

206. The **"current ratio"** of a current-transformer is the ratio of r.m.s. primary current to r.m.s. secondary current, under specified conditions of load.

207. The **"marked ratio"** of an instrument transformer is the ratio which the apparatus is designed to give under average conditions of use. When a precise ratio is required, it is necessary to specify the voltage, frequency, load and power-factor of the load.

208. Volt-ampere ratio of transformers. The volt-ampere ratio, which should not be confused with real efficiency, is the ratio of the volt-ampere output to the volt-ampere input of a transformer, at any given power-factor.

209. Auto-transformers have a part of their turns common to both primary and secondary circuits.

210. Voltage regulators have turns in shunt and turns in series with the circuit, so arranged that the voltage ratio of the transformation or the phase relation between the circuit-voltages is variable at will. They are of the following three classes:

211. Contact voltage regulators, in which the number of turns in one or both of the coils is adjustable.

212. Induction voltage regulators, in which the relative positions of the primary and secondary coils are adjustable.

213. Magneto voltage regulators, in which the direction of the magnetic flux with respect to the coils is adjustable.

214. Reactors, heretofore commonly called **reactance-coils,** also called **choke coils;** a form of stationary induction apparatus used to supply reactance or to produce phase displacement. See also Par. **82** and **736.**

METERS AND INSTRUMENTS

225. Although the terms **instruments** and **meters** are frequently used synonymously in referring to electrical measuring devices, the meter departments of manufacturing and operating companies commonly use the word "meters" in the collective sense to designate only those devices which register the total energy or quantity of electricity consumed in or supplied to a circuit, and reserve the term "instruments," in the collective sense, for all other electrical measuring or indicating devices.

226. In general, the names of meters and instruments are self-defining, particularly when considered in connection with existing definitions. The following terms are preferred to other terms sometimes used for the same devices: **Reactive-factor meter, power-factor meter, watt-hour meter,** etc.

227. Crest voltmeter. A voltmeter depending for its indications upon the crest, that is the maximum value of the voltage of the system to which it is connected. The instruments are so calibrated that they indicate the r. m. s. value of the sinusoidal voltage having the same crest value.

228. Synchronoscope (also called a synchroscope or synchronism indicator). A device which in addition to indicating synchronism between two machines, shows whether the speed of the incoming machine is fast or slow.

229. Reactive volt-ammeter (also called a reactive-volt-ampere indicator). An instrument which indicates the reactive volt-amperes of the circuit to which it is connected.

230. Line drop voltmeter compensator. A device used in connection with a voltmeter which causes it to indicate the voltage at some distant point of the circuit.

231. Recording ammeters, voltmeters, wattmeters, etc., are instruments which record graphically upon time-charts the values of the quantities they measure.

232. A demand meter is a device which indicates or records the demand or maximum demand (see Par. **57** and **58**). In practice two types are recognized:

233. An integrated-demand meter is one which indicates or records the maximum demand obtained through integration.

234. A lagged-demand meter is one in which the indication of maximum demand is subject to a characteristic time lag.

when operating with a cooling medium of the ambient temperature of reference (40 deg. for air or 25 deg. for water, see Par. **305** and **309**) and with barometric conditions within the range given in Par. **308**. See Par. **305A**, **307**, **320** and **321**.

266. The temperature rises specified in these rules apply to all ambient temperatures up to and including, but not exceeding, 40 deg. cent., for air and 25 deg. cent. for water. (For definition of ambient temperature see Par. **303**.)

267. Any machinery destined for use with higher ambient temperatures of cooling mediums, and also any machinery for operation at altitudes for which no provision is made in Par. **306**, should be the subject of special guarantee by the manufacturer. The methods of test and performance set forth in these rules will, however, afford guidance in such cases.

UNITS IN WHICH RATING SHALL BE EXPRESSED

274. The rating of **direct-current generators**, shall be expressed in kilowatts (kw.) available at the terminals.

275. The rating of **alternators** and **transformers**, shall be expressed in kilovolt-amperes (kv-a.) available at the output terminals, at a specified power factor.

276. It is strongly recommended that the **rating of motors** shall be expressed in kilowatts* (kw.) available at the shaft. (An exception to this rule is made in the case of Railway motors, which, for some purposes, are also rated by their *input*, see Par. **302**.)

277. Auxiliary machinery, such as regulators, resistors, reactors, balancer sets, stationary and synchronous condensers, etc.; shall have their ratings appropriately expressed. It is essential to specify also the voltage (and frequency, if a-c.), of the circuits on which the machinery may appropriately be used.

KINDS OF RATING

There are various kinds of rating such as:

281. Continuous rating. A machine, rated for continuous service, shall be able to operate continuously at its rated output, without exceeding any of the limitations referred to in Par. **260**.

282. Short-time rating. A machine rated for short-time service; (*i.e.*, service including runs alternating with stoppages of sufficient duration to ensure substantial cooling), shall be able to operate at its rated output during a limited period, to be specified in each case, without exceeding any of the limitations referred to in Par. **260**. Such a rating is a **short-time rating.**

283. Nominal ratings. For railway motors and sometimes for railway substation machinery, certain nominal ratings are employed. See Par. **765** and **800**. Nominal ratings for automobile propulsion motors and generators are not recommended; see Par. **837**.

284. Duty-cycle operation. Many machines are operated on a cycle of duty which repeats itself with more or less regularity. For purposes of rating, either a continuous or a short-time equivalent load, may be selected, which shall simulate as nearly as possible the thermal conditions of the actual duty cycle.

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* Since the input of machinery of this class is measured in electrical units and since the output has a definite relation to the input, it is logical and desirable to measure the delivered power in the same units as are employed for the received power. Therefore, the output of motors should be expressed in kilowatts instead of in horse power. However, on account of the hitherto prevailing practice of expressing mechanical output in horse power, it is recommended that for machinery of this class the rating should, for the present, be expressed both in kilowatts and in horse power; as follows:

kw.————approx. equiv. h.p.————

For the purposes of these rules the horse power shall be taken as 746.0 watts.

In order to lay stress upon the preferred future basis, it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the rating in horse power.

limits other than those of temperature; such as commutation, stalling load and mechanical strength. For similar reasons, load in excess of the rating should not be taken from a machine.

306. The permissible rises in temperature given in column 2 of Table III in Par. **276** have been calculated on the basis of the standard ambient temperature of reference, by subtracting 40 deg. from the highest temperatures permissible, which are given in column 1 of the same table.

307. A machine may be tested at any convenient ambient temperature, preferably not below 15 deg. cent., but *whatever be the value of this ambient temperature, the permissible rises of temperature must not exceed those given in column 2 of the table in Par.* **276.**

308. Altitude. Increased altitude has the effect of increasing the temperature rise of some types of machinery. In the absence of information in regard to the height above sea level at which the machine is intended to work in ordinary service, this height is assumed not to exceed 1,000 meters (3,300 ft.). For machinery operating at an altitude of 1,000 meters or less, a test at any altitude less than 1,000 meters is satisfactory, and no correction shall be applied to the observed temperatures. Machines intended for operation at higher altitudes shall be regarded as special. See Par. **267.** It is recommended that when a machine is intended for service at altitudes above 1,000 meters (3,300 ft.) the permissible temperature rise at sea level, until more nearly accurate information is available, shall be reduced by 1 per cent. for each 100 meters (330 ft.) by which the altitude exceeds 1,000 meters. Water-cooled oil transformers are exempt from this reduction.

309. Ambient temperature of reference for water-cooled machinery. For water-cooled machinery, the standard temperature of reference for incoming cooling water shall be 25 deg. cent., measured at the intake of the machine.

310. In testing of water-cooled transformers, it is not necessary to take into account the surrounding-air temperature, except where the cooling effect of the air is 15 per cent. or more of the total cooling effect, referred to the standard ambient temperature of reference of 25 deg. cent. for water and 40 deg. cent. for air. When the effect of the cooling air is 15 per cent. or more of the total, the temperature of the cooling water should be maintained within 5 deg. cent. of the surrounding air. Where this is impractical, the ambient temperature should be determined from the change in the resistance of the windings, using a disconnected transformer, supplied with the normal amount of cooling water, until the temperature of the windings has become constant.

311. In the case of rotating machines, cooled by forced draft, a conventional weighted mean shall be employed, a weight of four being given to the temperature of the circulating air supplied through ducts (see Par. **304**), and a weight of one to the surrounding room air. **In the case of air-cooled transformers,** see "exception" Par. **321.**

312. Machines cooled by other means. Machines cooled by means other than air or water shall receive special consideration.

313. Outdoor machinery exposed to sun's rays. Outdoor machinery not protected from the sun's rays at times of heavy load, must receive special consideration.

314. Measurement of the ambient temperature during tests of machinery. The ambient temperature is to be measured by means of several thermometers placed at different points around and half-way up the machine, at a distnce of 1 to 2 meters (3 to 6 ft.), and protected from drafts, and abnormal heat radiation, preferably as in Par. **316.**

315. The value to be adopted for the ambient temperature during a test, is the mean of the readings of the thermometers (placed as above), taken at equal intervals of time during the last quarter of the duration of the test.

316. In order to avoid **errors due to the time lag** between the temperature of large machines and the variations in the ambient air, all reasonable precautions must be taken to reduce these variations and the errors arising thereform. Thus, the thermometer for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, in a suitable heavy metal cup. This can be made to respond to various rates of change, by pro-

TEMPERATURE MEASUREMENTS

340. The life of the insulation of a machine depends in great measure upon the actual temperatures attained by the different parts, rather than on the rises of temperature in those parts.

341. The temperature in the different parts of a machine which it would be desirable to ascertain, are the maximum temperatures reached in those parts.

342. (Deleted in the last revision of the Standardisation Rules.)

343. As it is usually impossible to determine the maximum temperature attained in insulated windings, it is convenient to apply a correction to the observable temperature, so as to approximate the difference between the actual maximum temperature and the observable temperature by the method used. This correction, or margin of security, is provided to cover the errors due to fallibility in the location of the measuring devices, as well as inherent inaccuracies in measurement and methods.

344. In determining the temperature of different parts of a machine three methods are provided. The appropriate method for any particular case is set forth below.

345. Method No. 1. Thermometer method. This method consists in the determination of the temperature, by mercury or alcohol thermometers, by resistance thermometers, or by thermo-couples, any of these instruments being applied to the hottest accessible part of the *completed* machine, as distinguished from the thermo-couples or resistance coils embedded in the machine as described under method No. 3.

346. When method No. 1 is used, the hottest-spot temperature for windings shall be estimated by adding a hottest-spot correction of 15 deg. cent. to the highest temperature observed, in order to allow for the practical impossibility of locating any of the thermometers at the hottest spot.

347. Exception. When the thermometers are applied directly to the surfaces of bare windings, such as an edgewise strip conductor, or a cast copper winding, a hottest-spot correction of 5 deg. cent., instead of 15 deg. cent., shall be made. For commutators, collector rings, bare metallic surfaces not forming part of a winding, or for oil in which apparatus is immersed, no correction is to be applied.

348. Method No. 2. Resistance method. This method consists in the measurement of the temperature of windings by their increase in resistance, corrected* to the instant of shut-down when necessary. In the application of this method, thermometer measurements shall also be made whenever practicable without disassembling the machine† in order to increase the probability of revealing the highest observable temperature. Whichever measurement yields the higher temperature, that temperature shall be taken as the "highest observable" temperature and a hottest-spot correction of 10 deg. cent. added thereto.

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* Whenever a sufficient time has elapsed between the instant of shut-down and the time of the final temperature measurement to permit the temperature to fall, suitable corrections shall be applied, so as to obtain as nearly as practicable the temperature at the instant of shut-down. This can sometimes be approximately effected by plotting a curve, with temperature readings as ordinates and times as abscissas, and extrapolating back to the instant of shut-down. In other instances, acceptable correction factors can be applied. In transformers of 200 kv-a. and less the measured temperature shall be increased one degree for every minute between the instant of shut-down and the time of the final temperature measurement, provided this time does not exceed three minutes.

In cases where successive measurements show *increasing* temperatures after shut-down, the highest value shall be taken.

† As one of the few instances in which the thermometer check cannot be applied in Method No. 2, the rotor of a turbo-alternator may be cited.

in column 2, and are found by subtracting 40-deg. cent. from the figures in column 1. Whatever be the ambient temperature at the time of the test, the rise of temperature must never exceed the limits in column 2 of the table. The highest temperatures, and temperature rises, attained in any machine at the output for which it is rated, must not exceed the values indicated in the table and clauses following.

376. Permissible temperatures and temperature rises for insulating materials. Table III (following) gives the highest temperatures and temperature rises to which various classes of insulating materials may be subjected, based on a standard ambient temperature of reference of 40 deg. cent.

377. NOTE. The Institute recognizes the ability of manufacturers to ploy class B insulation successfully at maximum temperatures of 150 deg. cent. and even higher. However, a sufficient data covering experience over a period of years at such temperatures are at present unavailable, the institute adopts 125 deg. cent. as a conservative limit for this class of insulation, and any increase above this figure should be the subject of special guarantee by the manufacturer.

Table III.—Permissible Temperatures and Temperature Rises for Insulating Materials

		1	2
Class	Description of material	Maximum temperature to which the material may be subjected	Maximum temperature rise
A.	Cotton, silk, paper and similar materials, when so treated or impregnated as to increase the thermal limit, or when permanently immersed in oil; also enameled wire*	105 deg. cent.	65 deg. cent.
B.	Mica, asbestos and other materials capable of resisting high temperatures, in which any class A. material or binder is used for structural purposes only, and may be destroyed without impairing† the insulating or mechanical qualities of the insulation	125 deg. cent.	85 deg. cent.
C.	Fireproof and refractory materials, such as pure mica, porcelain, quartz, etc	No limits specified	

378. When a lower-temperature class material is comprised in a completed product to such an extent, or in such ways, that its subjection to the temperature limits allowed for the higher-temperature class material, with which it is associated, would affect the integrity of the insulation either mechanically or electrically, the permissible temperature shall be fixed at such a value as shall afford ample assurance that no part of the lower-temperature class material shall be subjected to temperatures higher than those approved by the Institute and set forth above.

* For cotton, silk, paper and similar materials, when neither treated, impregnated nor immersed in oil, the highest temperatures and temperature rises shall be 10 deg. cent. below the limits fixed for class A, in Table III.

† The word impair is here used in the sense of causing any change which would disqualify the insulation for continuous service.

386A. Enclosed motors and generators. In an enclosed machine (see Par. 164) the limiting observable temperature and the limiting observable temperature rise shall be taken as 5 deg. cent. higher than in Table IV. This is not to be interpreted as an increase in the permissible hottest spot temperature, but is in recognition of the lesser difference between the hottest spot temperature and the observable temperature within an enclosed machine. This rule does not apply to those types of machines defined in Par. 163, 165 and 167.

387. Railway motor temperature limits, see Par. 804 and 805.

387A. Automobile propulsion motors and generators, see Par. 838.

388. Squirrel-cage and amortisseur windings. In many cases the insulation of such windings is largely for the purpose of making the conductors fit tightly in their slots, and the slightest effective insulation is ample. In other cases, there is practically no insulating material on the windings. Consequently, the temperature rise may be of any value such as will not occasion mechanical injury to the machine.

389. Collector rings. The temperature of collector rings shall not be permitted to exceed the "hottest spot" values set forth in Par. 376 and 379 for the insulations employed either in the collector rings themselves, or in adjacent insulations whose life would be affected by the heat from the collector rings.

390. Commutators. The observable temperature shall in no case be permitted to exceed the values given in Par. 376 and 379 for the insulation employed, either in the commutator or in any insulation whose life would be affected by the heat of the commutator. These temperature limits are intended only to protect the insulation of the commutator and of the adjacent parts, and are not intended as a criterion of successful commutation. See Par. 402.

391. Cores. The temperature of those parts of the iron core in contact with insulating materials must not be such as to occasion in those insulating materials temperatures or temperature rises in excess of those set forth in Par. 376 and 379.

392. Other parts, (such as brush-holders, brushes, bearings, pole-tips, cores, etc.) All parts of electrical machinery other than those whose temperature affects the temperature of the insulating material, may be operated at such temperatures as shall not be injurious in any respect.

METHODS OF LOADING TRANSFORMERS FOR TEMPERATURE TESTS

393. Whenever practicable, transformers should be tested under conditions that will give losses approximating as nearly as possible to those obtained under normal or specified load conditions, maintained for the required time. See Par. 322–324. The maximum temperature rises measured during this test should be considered as the observable temperature rises for the given load.

An approved method of making these tests is the **"loading-back"** method. The principal variations of this method are:

394. With duplicate single-phase transformers. Duplicate single-phase transformers may be tested in banks of two, with both primary and secondary windings connected in parallel. Normal magnetizing voltage should then be applied and the required current circulated from an auxiliary source. One transformer can be held under normal voltage and current conditions, while the other may be operating under slightly abnormal conditions.

395. With one 3-phase transformer. One 3-phase transformer may be tested in a manner similar to (a), provided the primary and secondary windings are each connected in delta for the test. Normal 3-phase magnetizing voltage should be applied and the required current circulated from an auxiliary single-phase source.

396. With three single-phase transformers. Duplicate single-phase transformers may be tested in banks of three, in a manner similar to (b) by connecting both primary and secondary windings in delta, and applying normal 3-phase magnetizing voltage and circulating the required current from an auxiliary single-phase source.

In calculating plant or system efficiency it may be desirable to calculate the losses in each individual machine or part of the system at the actual temperature of that machine or part during the specified interval. These losses may be appreciably different from the losses at 75 deg. cent., which latter shall be the standard temperature of reference for all efficiency guarantees. See Par. **432**.

422. In the case of machinery two efficiencies are recognized, conventional efficiency (see Par. **423**) and directly measured efficiency. Unless otherwise specified, the conventional efficiency is to be employed. When the efficiency of a machine is stated without specific reference to the load conditions, rated load is always to be understood whether the efficiency be the conventional or directly measured efficiency.

423. Conventional efficiency of machinery is the ratio of the output to the sum of the output and the losses; or of the input minus the losses to the input; when, in either case, conventional values are assigned to one or more of these losses. The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practicably indeterminable, and must, in many cases, either be approximated by an approved method of test, or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "conventional efficiency."

424. (Deleted in last revision of Standardisation Rules.)

425. Directly measured efficiency. Input and output determinations of efficiency may be made directly, measuring the output by brake, or equivalent, where applicable. Within the limits of practical application, the circulating-power method, sometimes described as the Hopkinson or "loading-back" method, may be used.

426. Values of the indeterminate losses may also be obtained by brake or other direct test, and used in estimating actual efficiencies of similar machines, by the separate-loss method.

427. Normal conditions. The efficiency shall correspond to, or be corrected to, the normal conditions herein set forth, which shall be regarded as standard. These conditions include voltage, current, power-factor, frequency, wave shape, speed, temperature, or such of them as may apply in each particular case.

428. Measurement of efficiency. Electric power shall be measured at the terminals of the apparatus. In polyphase machines, sufficient measurements shall be made on all phases to avoid errors of unbalance.

429. Point at which mechanical power shall be measured. Mechanical power delivered by machines, shall be measured at the pulley, gearing, or coupling, on the rotor shaft, thus excluding the loss of power in the belt or gear friction. See, however, an exception in Par. **800**.

430. The efficiency specified for alternators and transformers shall be of the ratio of the kilowatt output to the kilowatt input at the rated kv-a. and power factor.

431. Efficiency of alternating-current machinery in regard to wave shape. In determining the efficiency of alternating-current machinery, the sine-wave is to be considered as standard, unless a different wave form is inherent in the operation of the system. See Par. **405**.

432. Temperature of reference for machine efficiency. The efficiency, at all loads, of all apparatus, shall be corrected to a reference temperature of 75 deg. cent., but tests may be made at any convenient ambient temperature, preferably not less than 15 deg. cent. See Par. **348** and **445**.

433. The losses in constant-potential machinery, either of the stationary type, or of the constant-speed rotary type, are of two classes, namely, those which remain substantially constant at all loads, and those which vary with the load. The former include iron losses, windage and friction, also I^2R losses in any shunt windings. The latter include I^2R losses in series windings. The constant losses may be determined by measuring the power required to operate the machine at no-load, deducting any series I^2R losses. The variable loss at any load may be computed from the measured resistance of the series windings and the given load current.

method of determination has been found, shall be included as zero per cent. in estimating conventional efficiency.

441. Synchronous motors and generators.

Core losses. See Par. **452.**

I^2R loss in all windings, based upon rated k-va. and power factor.

Stray load-losses. In approximating these losses, the method described in Par. **458** shall be employed.

Friction of bearings and windage.

Brush friction and brush-contact loss is negligible, except in the case of revolving armature machines.

Rheostat losses, when present. corresponding to rated kv-a. and power factor.

442. Induction machines.

Core losses. See Par. **452.**

I^2R losses in all windings.

Stray load-losses. In approximating these losses, the method described in Par. **459** shall be employed.

Brush friction when collector rings are present.

Brush-contact loss. Unless otherwise specified, use the Institute standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See Par. **454.**

Friction of bearings and windage.

443. Communicating a-c. machines.

Core losses. See Par. **452.**

I^2R losses in all windings.

Brush friction.

Brush-contact loss. Unless otherwise specified, use the Institute standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See Par. **454** and **819.**

Friction of bearings and windage.

Short-circuit loss of commutation. Iron loss due to flux distortion. Eddy-current losses due to fluxes varying with load and saturation.	The Institute is not at this time prepared to make recommendations for approximating these losses.

444. Synchronous converters.

Core losses. See Par. **452.**

I^2R losses in all windings, based on rated kw. and unity power factor. The I^2R losses in the armature winding shall be derived from those corresponding to its use as a direct-current generator, by using suitable factors.

Brush friction.

Rheostat losses when present, corresponding to rated kw. and unity power factor.

Brush-contact loss. Unless otherwise specified, use the Institute standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See Par. **454.**

Short-circuit loss of commutation. Iron loss due to flux distortion when present. Eddy-current losses due to fluxes varying with load and saturation.	These losses, while usually of low magnitude, are erratic, and the institute is not at this time prepared to make recommendations for approximating them.

Friction of bearings and windage.

For the booster type of synchronous converter, where the booster forms an integral part of the unit, its losses shall be included in the total converter losses in estimating the efficiency.

445. Transformers.

No-load losses. These include the core loss, and the I^2R loss due to the exciting current, also the dielectric loss in the insulation. See Par. **470.**

Load losses. These include I^2R losses, and stray load-losses due to eddy currents caused by fluxes varying with load. See Par. **471.**

DETERMINATION OR APPROXIMATION OF LOSSES IN ROTATING MACHINERY

450. Bearing friction and windage may be determined as follows. Drive the machine from an independent motor, the output of which shall be suitably determined. The machine under test shall have its brushes

Stray load-losses are to be determined by operating the machine on short circuit and at rated-load current. This, after deducting the windage and friction and I^2R loss, gives the stray load-loss for polyphase generators and motors. These losses in single-phase machines are large; but the institute is not yet prepared to specify a method for measuring them.

459. Stray load-losses in induction machines. These include eddy-current losses in the stator copper, and other eddy-current losses due to fluxes varying with the load. In windings consisting of relatively small conductors, these eddy-current losses are usually negligible.

With rotor removed, measure the power input to the stator with different values of current at the rated frequency. The curve plotted with these values gives the combined I^2R and stray load-losses due to eddy currents in the stator copper. Deduct the I^2R loss determined from the resistance, and the difference will represent the stray load-losses corresponding to the various currents. While this method is not accurate for some types of motors it usually represents a sufficiently good approximation.

460. Polyphase induction-motor rotor I^2R loss. This should be determined from the slip, whenever the latter is accurately determinable, using the following equation:

$$\text{Rotor } I^2R \text{ loss} = \frac{\text{output} \times \text{slip}}{1 - \text{slip}}$$

In large slip-ring motors, in which the slip cannot be directly measured by loading, the rotor I^2R loss shall be determined by direct resistance measurement; the rotor full-load current to be calculated by the following equation:

$$\text{Current per ring} = \frac{\text{watts output}}{\text{rotor voltage at stand-still} \times \sqrt{3} \times K}$$

This equation applies to 3-phase rotors. For rotors wound for 2 phase, use 2 instead of the $\sqrt{3}$. K may be taken as 0.95 for motors of 150 kw. or larger. The factor K usually decreases as the size of motor is reduced, but no specific value can be stated for smaller sizes.

DETERMINATION OR APPROXIMATION OF LOSSES IN TRANSFORMERS

470. No-load losses. These shall be measured with open secondary circuit at the rated frequency, and with an applied primary voltage giving the rated secondary voltage plus the IR drop which occurs in the secondary under rated load conditions.

471. Load losses. These include I^2R and stray load-losses. They shall be measured by applying a primary voltage, preferably at rated frequency, sufficient to produce rated load current in the windings, with the secondary windings short circuited.

TESTS OF DIELECTRIC STRENGTH OF MACHINERY

480. Basis for determining test voltages. The test voltage which shall be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the machinery, and its normal operating voltage, upon the nature of the service in which it is to be used, and upon the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended, have been determined as reasonable and proper for the great majority of cases, and are proposed for general adoption, except when specific reasons make a modification desirable.

481. Condition of machinery to be tested. Commercial tests shall, in general, be made with the completely assembled machinery and not with individual parts. The machinery shall be in good condition, and high-voltage tests, unless otherwise specified, shall be applied before the machine is put into commercial service, and shall not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests shall be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial testing. High-voltage tests to determine whether specifications are fulfilled, are admissible on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine shall be understood as being made at the factory.

482. Points of application of voltage. The test voltage shall be sucstandstill with normal voltage impressed on the primary.

When induction motors with phase-wound rotors are reversed, while running at approximately normal speed, by reversing the primary connections, the test shall be four times the normal induced voltage, plus 1,000 volts.

509. Exception—switches and circuit control apparatus above 600 volts, shall be tested with two and one-fourth times rated voltage, plus 2,000 volts. See Par. **720** to **741**.

510. Exception—assembled apparatus. Where a number of pieces of apparatus are assembled together and tested as an electrical unit, they shall be tested with 15 per cent. lower voltage than the lowest required on any of the individual pieces of apparatus.

510A. Exception—meters and instruments. The Institute is not at present in a position to make a recommendation in regard to the dielectric tests of meters and instruments.

511. Testing transformers by induced voltage. Under certain conditions it is permissible to test transformers by inducing the required voltage in their windings, in place of using a separate testing transformer. By "required voltage," is meant a voltage such that the line end of the windings shall receive a test to ground equal to that required by the general rules.

512. Transformers with graded insulation shall be so marked. They shall be tested by including the required test-voltage in the transformer and connecting the successive line leads to ground.

Transformer windings permanently grounded within the transformer shall be tested by inducing the required test voltage in such windings. (See Par **500**.)

MEASUREMENT OF VOLTAGE IN DIELECTRIC TESTS OF MACHINERY

530. Use of voltmeters and spark-gaps in insulation tests. When making insulation tests on electrical machinery, every precaution must be taken against the occurrence of any spark-gap discharges in the circuits from which the machinery is being tested. A non-inductive resistance of about 1 ohm per volt shall be inserted in series with one terminal of the spark gap. If the test is made with one electrode grounded, this resistance shall be inserted directly in series with the non-grounded electrode. If neither terminal is grounded, one-half shall be inserted directly in series with each electrode. In any case this resistance shall be as near the measuring gap as possible and not in series with the tested apparatus. The resistance will damp high-frequency oscillations at the time of breakdown and limit the current which will flow. A water-tube is the most reliable form of resistor. Carbon resistors should not be used because their resistance may become very low at high voltages.

531. For machinery of low capacitance. When the machinery under test does not require sufficient charging current to distort the high-voltage wave shape, or change the ratio of transformation, the spark-gap should be set for the required test voltage and the testing apparatus adjusted to give a voltage at which this spark-gap just breaks down. This adjustment should be made with the apparatus under test disconnected. The apparatus should then be connected, and with the spark gap about 20 per cent. longer, the testing apparatus is again adjusted to give the voltage of the former breakdown, which is the assumed voltage of test. This voltage is to be maintained for the required interval.

532. For machinery of high capacitance. When the charging current of the machinery under test may appreciably distort the voltage wave or change the effective ratio of the testing transformer, the first adjustment of voltage with the gap set for the test voltage should be made with the apparatus under test connected to the circuit and in parallel with the spark-gap.

When making arc-over tests of large insulators, leads, etc., partial arc-

Diameter of sphere in mm.	Distance between contact points in mm.	
	Maximum	Minimum
62.5	35	25
125.0	45	35
250.0	65	45
500.0	100	65

539A. In using sphere gaps constructed as above, it is assumed that the apparatus will be set up for use in a space comparatively free from external dielectric fields. Care should be taken that conducting bodies forming part of the circuit, or at circuit potential, are not so located with reference to the gap that their dielectric fields are superposed on the gap; *e.g.*, the protecting resistance should not be arranged so as to present large masses or surfaces near the gap, even at a distance of two sphere diameters.

In case the sphere is grounded, the spark point of the grounded sphere should be approximately five diameters above the floor or ground.

540. The sparking distances between different spheres for various r.m.s. sinusoidal voltages shall be assumed to be as follows:

Table IX.—Sphere-gap Spark-over Voltages
(At 25 deg. cent. and 760 mm. barometric pressure)

Kilovolts	Sparking distance in millimeters							
	62.5 mm. spheres		125 mm. spheres		250 mm. spheres		500 mm. spheres	
	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated
10	4.2	4.2	......	......	......	......	......	......
20	8.6	8.6	......	......	......	......	......	......
30	14.1	14.1	14.1	14.1	......	......	......	......
40	19.2	19.2	19.1	19.1	......	......	......	......
50	25.5	25.0	24.4	24.4	......	......	......	......
60	34.5	32.0	30.0	30.	29	29	......	......
70	46.0	39.5	36.0	36.	35	35	......	......
80	62.0	49.0	42.0	42.	41	41	41	41
90	......	60.5	49.0	49.	46	45	46	45
100	......	......	56.0	55.	52	51	52	51
120	......	......	79.7	71.	64	63	63	62
140	......	......	108.	88.	78	77	74	73
160	......	......	150	110.	92	90	85	83
180	......	......	......	138.	109	106	97	95
200	......	......	......	......	128	123	108	106
220	......	......	......	......	150	141	120	117
240	......	......	......	......	177	160	133	130
260	......	......	......	......	210	180	148	144
280	......	......	......	......	250	203	163	158
300	......	......	......	......	......	231	177	171
320	......	......	......	......	......	265	194	187
340	......	......	......	......	......	......	214	204
360	......	......	......	......	......	......	234	221
380	......	......	......	......	......	......	255	239
400	......	......	......	......	......	......	276	257

The order of magnitude of the values obtained by this rule is shown in the following table:

Table XI.—Insulation Resistance of Machinery

Rated voltage of machine	Megohms		
	100 kv-a.	1,000 kv-a.	10,000 kv-a.
100	0.091	0.05	.....
1,000	0.91	0.50	0.091
10,000	9.1	5.0	0.91
100,000	.....	50.0	9.1

551. It should be noted that the insulation resistance of machinery is of doubtful significance by comparison with the dielectric strength. The insulation resistance is subject to wide variation with temperature humidity and cleanliness of the parts. When the insulation resistance falls below that corresponding to the above rule, it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying out the machine. The insulation-resistance test may therefore afford a useful indication as to whether the machine is in suitable condition for the application of the dielectric test.

REGULATION

DEFINITIONS

560. Regulation. The regulation of a machine in regard to some characteristic quantity (such as terminal voltage or speed) is the change in that quantity occurring between any two loads. Unless otherwise specified, the two loads considered shall be zero load and rated load, and at the temperature attained under normal operation. The regulation may be expressed by stating the numerical values of the quantity at the two loads, or it may be expressed by the "percentage regulation," which is the percentage ratio of the change in the quantity occurring between the two loads, to the value of the quantity at either one or the other load, taken as the normal value. It is assumed that all parts of the machine affecting the regulation maintain constant temperature between the two loads, and where the influence of temperature is of consequence, a reference temperature of 75 deg. cent. shall be considered as standard. If change of temperature should occur during the tests, the results shall be corrected to the reference temperature of 75 deg. cent.

The normal value may be either the no-load value, as the no-load speed of induction motors; or it may be the rated-load value, as in the voltage of a-c. generators.

It is usual to state the regulation of d-c. generators by giving the numerical values of the voltage at no-load and rated load, and in some cases it is advisable to state regulation at intermediate loads.

561. The **regulation of d-c. generator** refers to changes in voltage corresponding to gradual changes in load and does not relate to the comparatively large momentary fluctuations in voltage that frequently accompany instantaneous changes in load.

In determining the regulation of a compound-wound d-c. generator, two tests shall be made, one bringing the load down and the other bringing the load up, between no-load and rated load. These may differ somewhat, owing to residual magnetism. The mean of the two results shall be used.

562. In **constant-potential a-c. generators**, the regulation is the rise in voltage (when the specified load at specified power factor is reduced to zero) expressed in per cent. of normal rated-load voltage.

563. In **constant-current machines**, the regulation is the ratio of the maximum difference of current from the rated-load value (occurring in the range from rated-load to short-circuit, or minimum limit of operation), to the rated-load current.

564. In **constant-speed d-c. motors**, and induction motors, the regulation is the ratio of the difference between full-load and no-load speeds to the no-load speed.

necessary to determine the regulation from such other tests as can be readily made.

585. Method b. This consists in computing the regulation from experimental data of the open-circuit saturation curve and the zero power-factor saturation curve. The latter curve, or one approximating very closely to it, can be obtained by running the generator with overexcitation on a load of idle-running underexcited synchronous motors. The power-factor under these conditions is very low and the load saturation curve approximates very closely the zero power-factor saturation curve. From this curve and the open circuit curve, points for the load saturation curve, for any power-factor, can be obtained by means of vector diagrams.

To apply Method b, it is necessary to obtain from test, the open-circuit saturation curve *OA*, Fig. 1, and the saturation curve *BC* at zero power-factor and rated-load current. At any given excitation *Oc*, the voltage that would be induced on open circuit is *ac*, the terminal voltage at zero power-factor is *bc*, and the apparent internal drop is **ab**. The terminal voltage *dc* at any other power-factor can then be found by drawing an e.m.f. diagram* as in Fig. 2, where ϕ is an angle such that $\cos\phi$ is the power-factor of the load, *be* the resistance drop (*IR*) in the stator winding, *ba* the total internal drop, and *ac* the total induced voltage; *ba* and *ac* being laid off to correspond with the values obtained from Fig. 1. The terminal voltage at power-factor $\cos\phi$, is then *cb* of Fig. 2, which, laid off in Fig. 1, gives point *d*. By finding a number of such points, the curve *Bdd'* for power-factor $\cos\phi$ is obtained and the regulation at this power-factor (expressed in per cent.) is $\frac{100\times a'd'}{d'c'}$, since *a'd'* is the rise in voltage when the load at power-factor $\cos\phi$ is thrown off at normal voltage *c'd'*.

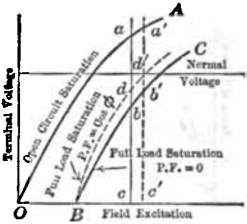

Fig. 1.

Generally, the ohmic drop can be neglected, as it has very little influence on the regulation, except in very low-speed machines where the armature resistance is relatively high, or in some cases where regulation at unity power-factor is being estimated. For low power-factors, its effect is negligible in practically all cases. If resistance is neglected, the simpler e.m.f. diagram, Fig. 3, may be used to obtain points on the load saturation curve for the power-factor under consideration.

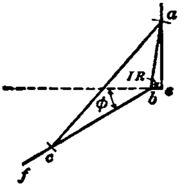

Fig. 2.

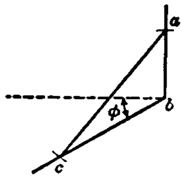

Fig. 3.

586. Method c. Where it is not possible to obtain by test a zero power-factor saturation curve as in Method b, this curve can be estimated closely from open-circuit and short-circuit curves, by reference to tests at zero power-factor on other machines of similar magnetic circuit. Having obtained the estimated zero power-factor curve, the load saturation for any other power-factor is obtained as in Method b.

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* Method b, for deducing the load saturation curve, at any assigned power-factor, from no-load and zero power-factor saturation curves obtained by test, must be regarded as empirical. Its value depends upon the fact that experience has demonstrated the reasonable correctness of the results obtained by it.

connections, and all terminals and taps of the transformer shall be marked to correspond with letters and numbers in the sketch. This sketch should preferably be on a metal plate on the transformer case.

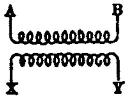
SINGLE-PHASE TRANSFORMERS

601. Marking of leads. The leads of single-phase transformers shall be distinguished from each other by marking the high-voltage leads with the letters *A* and *B*, and the low-voltage leads with the letters *X* and *Y*.

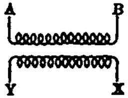
The terminals (by terminals is meant the ends of the windings) shall be so marked that the potential difference in all windings at any instant shall have the same sign, that is, the potential difference between *A* and *B* shall have the same sign at any instant as the potential difference between *X* and *Y*.*

602. In accordance with the above rule, the terminals of single-phase transformers shall be marked as follows:

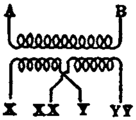
(1) High- and low-voltage windings in phase:



603. (2) High- and low-voltage windings 180 deg. apart in phase:

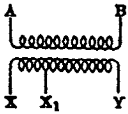


604. Single-phase transformers with more than two windings. Transformers with three or more windings (each provided with separate outgoing leads) shall have the leads of two of their windings lettered in accordance with the preceding paragraph. The remaining leads shall be designated *AA*, *BB*, etc. in the case of high-voltage leads and *XX*, *YY*, etc. in the case of low-voltage leads. For example, transformers having four secondary leads from two distinct, similar windings shall be lettered as follows:



This indicates that the low-voltage winding consists of two disconnected parts, one part having terminals *X*, *Y* and the other part having terminals *XX*, *YY*. For multiple connection, *X* and *XX* are to be connected and *Y* and *YY* are to be connected. For series operation, *Y* is to be connected to *XX*.

605. Tap connections. All tap connections which are not brought outside the transformer case shall be marked serially with numerals only. Where tap leads are brought out of the transformer case they shall be given the letter designation together with a subscript indicating the relative position of the tap, as in the following diagram.



* To test the correctness of single-phase markings, connect *A* to *X* and apply voltage to the high voltage winding *A-B*. Voltage *B-Y* must be numerically less than voltage *A-B*.

610. Angular displacement. The angular displacement between high-nd low-voltage windings, is the angle in the diagram in Par. **608** between the nes passing from the neutral point through A and X respectively for three-hase transformers and through A and U for six-phase transformers. Thus, n group 1, the angular displacement is zero degrees; in group 2, the angular isplacement is 180°, and in group 3, the angular displacement is 30°.

611. Parallel operation. Three-phase and six-phase transformers narked as above may be operated in parallel, by connecting similarly marked erminals together, provided their ratios, voltages, resistances, reactances and ngular displacements are such as to permit parallel operation.

NFORMATION ON THE RATING PLATE OF A MACHINE

620. It is recommended that the rating plate of machines which comply ith the Institute rules shall carry a distinctive special sign, such as A. I. E. E. 1916 Rating" or "A 16" Rating.

621. The absence of any statement to the contrary on the rating plate of a nachine implies that it is intended for continuous service and for the stand-rd altitude and ambient temperature of reference. See Par. **287, 305, 308,** nd **309.**

622. The rating plate of a machine intended to work under various kinds f rating must carry the necessary information in regard to those kinds f ratings.

623–630. (Deleted in the last revision of the Standardization Rules.)

STANDARDS FOR WIRES AND CABLES

TERMINOLOGY*

635. Wire. A slender rod or filament of drawn metal.

The definition restricts the term to what would ordinarily be understood by ne term "solid wire." In the definition, the word "slender" is used in the ense that the length is great in comparison with the diameter. If a wire is overed with insulation, it is properly called an insulated wire; while pri-narily the term "wire" refers to the metal, nevertheless when the context nows that the wire is insulated, the term "wire" will be understood to nclude the insulation.

636. Conductor. A wire or combination of wires not insulated from ne another, suitable for carrying a single electric current.

The term "conductor" is not to include a combination of conductors nsulated from one another, which would be suitable for carrying several ifferent electric currents.

Rolled conductors (such as bus bars) are, of course, conductors, but are not onsidered under the terminology here given.

637. Stranded conductor. A conductor composed of a group of wires, r of any combination of groups of wires.

The wires in a stranded conductor are usually twisted or braided together.

638. Cable. (1) A stranded conductor (single-conductor cable); or (2) combination of conductors insulated from one another (multiple-conductor able).

The component conductors of the second kind of cable may be either solid r stranded, and this kind of cable may or may not have a common insulat-g covering. The first kind of cable is a single conductor, while the second nd is a group of several conductors. The term "cable" is applied by some anufacturers to a solid wire heavily insulated and lead-covered; this usage ises from the manner of the insulation, but such a conductor is not included nder this definition of "cable." The term "cable" is a general one and, in ractice, it is usually applied only to the larger sizes. A small cable is called "stranded wire" or a "cord," both of which are defined below. Cables ay be bare or insulated, and the latter may be armored with lead or with eel wires or bands.

639. Strand. One of the wires, or groups of wires, of any stranded con-uctor.

640. Stranded wire. A group of small wires, used as a single wire.

A wire has been defined as a slender rod or filament of drawn metal. If ch a filament is subdivided into several smaller filaments or strands, and is

* From Circular No. 37 of the Bureau of Standards.

Table XII.—Standard Stranding of Concentric-lay Cables

Size (see note 1)	Number of wires (see note 2)	
	A Bare, insulated or weather-proof cables for aerial use	B Insulated cables for other than aerial use
2.0 cir. in.	91	127
1.5 cir. in.	61	91
1.0 cir. in.	61	61
0.6 cir. in.	37	61
0.5 cir. in.	37	37
0.4 cir. in.	19	37
0000 A.W.G.	19 or 7 (See note 3)	19
00 A.W.G.	7	19
2 A.W.G.	7	7
7 and smaller	..	7

NOTE 1. For intermediate sizes, use stranding for next larger size.
NOTE 2. Conductors of 0000 A.W.G. and smaller are often made solid and this table of stranding should not be interpreted as excluding this practice.
NOTE 3. Class A cable, sizes 0000 and 000 A.W.G., is usually made of 7 strands when bare and 19 strands when insulated or weatherproof.

Table XIII.—Proposed Standard Stranding of Flexible Cables

Nearest A.W.G. size (see note 1)	Circular mils (see note 3)	Diameter of cable, mils	Number of wires	Size of each wire A.W.G.	Diameter, mils	Make-up (see note 2)
....	2,039,000	1,836.	703	15.5	53.9	37×19
....	1,816,000	1,778.	703	16.0	50.8	37×19
....	1,617,000	1,680.	703	16.5	48.0	37×19
....	1,440,000	1,586.	703	17.0	45.3	37×19
....	1,282,000	1,495.	703	17.5	42.7	37×19
....	1,103,000	1,372.	427	16.0	50.8	61×7
....	874,500	1,223.	427	17.0	45.3	61×7
....	693,400	1,088.	427	18.0	40.3	61×7
....	550,000	969.	427	19.0	35.9	61×7
....	436,400	864.	427	20.0	32.0	61×7
....	345,900	770.	427	21.0	28.5	61×7
....	274,300	686.	427	22.0	25.4	61×7
....	264,700	672.	259	20.0	32.0	37×7
0000	209,800	599.	259	21.0	28.5	37×7
000	171,300	539.	133	19.0	35.9	19×7
00	135,900	480.	133	20.0	32.0	19×7
0	107,700	428.	133	21.0	28.5	19×7
1	82,780	332.	91	20.5	30.2	Concentric
2	65,660	296.	91	21.5	26.9	Concentric
3	58,460	279.	91	22.0	25.4	Concentric
4	39,190	229.	61	22.0	25.4	Concentric
5	31,080	203.	61	23.0	22.6	Concentric
6	24,650	181.	61	24.0	20.1	Concentric
8	17,400	152.	61	25.5	16.9	Concentric
10	10,560	118.	37	25.5	16.9	Concentric
12	6,442	94.	37	27.5	13.4	Concentric
14	4,177	74.	37	29.5	10.6	Concentric
Smaller	......	.....	To equal required size	30.0	....	Bunched

NOTE 1. The A.W.G. sizes except for 61 strands are approximated within 2 per cent. In the case of 61-strand cables the approximation is 6 per cent.
NOTE 2. "61 × 7" signifies a rope-lay cable composed of 61 strands of 7 wires each.
NOTE 3. Circular mils are based on theoretical diameters of A.W.G. sizes which vary above or below values given in table by less than 0.1 mil.

657. The lay of any layer of wires of a cable or strand shall not exceed 5 times the pitch diameter of that layer. The lay of any layer of strands f rope-lay cables shall not exceed 12 times the pitch diameter of the layer.

CONDUCTIVITY OF COPPER

675. The following I. E. C. rules are adopted:*

The following shall be taken as normal values for standard annealed opper:

(1) At a temperature of 20 deg. cent., the resistance of a wire of standard nnealed copper 1 m. in length and of a uniform section of 1 sq. mm. is ; ohm = 0.017241 . . . ohm.

(2) At a temperature of 20 deg. cent., the density of standard annealed opper is 8.89 g. per cu. cm.

(3) At a temperature of 20 deg. cent., the "constant mass" temperature oefficient of resistance of standard annealed copper, measured between two otential points rigidly fixed to the wire, is 0.00393 = $\frac{1}{254.45}$ . . . per deg. nt.

(4) As a consequence, it follows from (1) and (2) that, at a temperature of) deg. cent., the resistance of a wire of standard annealed copper of uniform ction, 1 m. in length and weighing 1 g., is $(\frac{1}{58})\times 8.89 = 0.15328$ . . . ohm.†‡

676. **Copper-wire tables.** The copper-wire tables published by the ureau of Standards in Circular No. 31 are adopted. These tables are based pon the I. E. C. rules stated in Par. 675.

HEATING AND TEMPERATURE OF CABLES

677. **Maximum safe limiting temperatures.** The maximum safe niting temperature in deg. cent. at the surface of the conductor in a cable all be:

For impregnated paper insulation	$(85-E)$
For varnished cambric	$(75-E)$
For rubber insulation	$(60-0.25E)$

here E represents the r.m.s. operating e.m.f. in kilovolts between conictors.

Thus, at a working pressure of 3.3 kv., the maximum safe limiting temrature at the surface of the conductor, or conductors, in a cable would be:

For impregnated paper	81.7 deg. cent.
For varnished cambric	71.7 deg. cent.
For rubber insulation	59.2 deg. cent.

ELECTRICAL TESTS

678. **Lengths tested.** Electrical tests of insulation on wires and cables all be made on the entire lengths to be shipped.

679. **Immersion in water.** Electrical tests of insulated conductors not closed in a lead sheath, shall be made while immersed in water after an mersion of twelve (12) consecutive hours, if insulated with rubber comund, or if insulated with varnished cambric. It is not necessary to imerse in water insulated conductors enclosed in a lead sheath.

In multiple-conductor cables, without waterproof overall jacket of insulan, no immersion test should be made on finished cables, but only on the lividual conductors before assembling.

680. **Dielectric-strength tests. Object of tests.** Dielectric tests are ended to detect weak spots in the insulation and to determine whether e dielectric strength of the insulation is sufficient for enabling it to withind the voltage to which it is likely to be subjected in service, with a suitle factor of assurance.

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* See I. E. C. Publication No. 28 "International Standard of Resistance for opper" March, 1914.

† Paragraphs (1) and (4) of Par. 675 define what are sometimes called olume resistivity," and "mass resistivity" respectively. This may be exessed in other units as follows: volume resistivity = 1.7241 microhm-cm. microhms in a cm. cube) at 20 deg. cent. = 0.67879 microhm-in. at 20 g. cent., and mass resistivity = 875.20 ohms (mile, pound) at 20 deg. cent.

‡ For detailed specifications of commercial copper, see the "Standard ecifications" of the American Society for Testing Materials.

690. Linear insulation resistance, or the insulation resistance of unit length, shall be expressed in terms of the megohm-kilometer, or the megohm-mile, or the megohm-thousand-feet.

691. Megohms constant. The megohms constant of an insulated conductor shall be the factor "K" in the equation

$$R = K \log_{10} \frac{D}{d}$$

where R = The insulation resistance, in megohms, for a specified unit length.
D = Outside diameter of insulation.
d = Diameter of conductor.

Unless otherwise stated, K will be assumed to correspond to the mile unit of length.

692. Test. The apparent insulation resistance should be measured after the dielectric-strength test, measuring the leakage current after a 1-min. electrification, with a continuous e.m.f. of from 100 to 500 volts, the conductor being maintained negative to the sheath or water.

693. Multiple-conductor cables. The insulation resistance of each conductor of a multiple-conductor cable shall be the insulation resistance measured from such conductor to all the other conductors in multiple with the sheath or water.

CAPACITANCE OR ELECTROSTATIC CAPACITY

694. Capacitance is ordinarily expressed in microfarads. Linear capacitance, or capacitance per unit length, shall be expressed in microfarads per unit length (kilometer, or mile, or 1,000 ft.) and shall be corrected to a temperature of 15.5 deg. cent.

695. Microfarads constant. The microfarads constant of an insulated conductor shall be the factor "K" in the equation

$$C = \frac{K}{\log_{10} \frac{D}{d}}$$

where C = the capacitance in microfarads per unit length.
D = the outside diameter of insulation.
d = the diameter of conductor.

Unless otherwise stated, K will be assumed to refer to the mile unit of length.

696. Measurement of capacitance. The capacitance of low-voltage cable, shall be measured by comparison with a standard condenser. For long lengths of high-voltage cables, where it is necessary to know the true capacitance, the measurement should be made at a frequency approximating the frequency of operation.

697. Paired cables. The capacitance shall be measured between the two conductors of any pair, the other wires being connected to the sheath or ground.

698. Electric light and power cables. The capacitance of low-voltage cables is generally of but little importance. The capacitance of high-voltage cables should be measured between the conductors, and also between each conductor and the other conductors connected to the lead sheath or ground.

699. Multiple-conductor cables (not paired). The capacitance of each conductor of a multiple-conductor cable shall be the capacitance measured from such conductor to all of the other conductors in multiple with the sheath or the ground.

STANDARDS FOR SWITCHES AND OTHER CIRCUIT-CONTROL APPARATUS*

SWITCHES

720. The following rules apply to switches of above 600 volts. (For 600 volts and below, see *National Electric Code.*†)

* These rules do not apply to magnetically-operated or air-operated switches used for motor control.

† By the term "Code" is meant "National Electrical Code" as recommended by the National Fire Protection Association.

highest temperature for the fuse proper should not exceed the safe limit for the material employed (*e.g.*, the temperature of the fibre tube of an enclosed fuse should not exceed the safe limit for this material, but an open-link metal fuse may be run at any temperature which will not injure the fuse material; except that no application of the above rule shall contravene the *National Electric Code*).

732. Test. For fuses intended for use on circuits of small capacity, or in protected positions on systems of large capacity, see *National Electric Code*. For large power fuses intended for service similar to that required of circuit breakers, see Par. **724** to **728**, or the *National Electric Code*, as far as the latter applies.

NOTE.—Complete standardization of these fuses above 600 volts, according to the method of the *National Electric Code*, is not advisable at this time, but is expected to be accomplished by an eventual extension of the *National Electric Code*. Until such extension is made, the following definitions and ratings may be followed.

LIGHTNING ARRESTERS

733. Definition. A lightning arrester is a device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration.

734. Rating. Arresters shall be rated by the voltage of the circuit on which they are to be used.

Lightning arresters may be divided into two classes: (*a*) Those intended to discharge for a very short time. (*b*) Those intended to discharge for a period of several minutes.

735. Performance and tests. Dielectric test same as Par. **723**.

The resistance of the arrester at double potential and also at normal potential, shall be determined by observing the discharge currents through the arrester.

(*c*) In the case of any arrester using a gap, a test shall be made of the spark potential on either direct-current or 60-cycle a-c. excitation. (*d*) The equivalent sphere gap under disruptive discharge shall also be measured, using a considerable quantity of electricity. (*e*) The endurance of the arrester to continuous surges shall be tested.

PROTECTIVE REACTORS

736. Definition. A reactor (see Par. **82** and **214**) is a device for protecting circuits by limiting the current flow and localising the disturbance under short-circuit conditions.

737. Rating. (*a*) In kilovolt-amperes absorbed by normal current. (*b*) By the normal current, frequency and line (delta) voltage for which the reactor is designed. (*c*) By the current which the device is required to stand under short-circuit conditions.

738. Performance and tests. **The heat test** shall be made with normal current and frequency applied until the temperature is constant. The temperature should not exceed the safe limits for the materials employed. See Par. **276** to **279**.

739. Dielectric test. Two and one-fourth times line voltage plus 2,000, for 1 min., from conductor to ground.

NOTE.—The reactor shall be so designed as to be capable of withstanding, without mechanical injury, rated current at normal frequency, suddenly applied.

RESISTOR OR RHEOSTAT

740. Definition. Any device heretofore commonly known as a resistance, used for operation or control. (Par. **81**.) See *National Electric Code*.

INSTRUMENT TRANSFORMERS

741. Definition. An instrument transformer is a transformer for use with measuring instruments, in which the conditions in the primary circuit as to current and voltage are represented with high numerical accuracy in the secondary circuit.

Under this heading and for more general use: (*a*) A current transformer is a transformer designed for series connection in its primary circuit with the ratio of transformation appearing as a ratio of currents. (*b*) A

772. Gage of third rail. The distance, measured parallel to the plane of running rails, between the gage line of the nearer track rail and the inside gage line of the *contact surface* of the third rail.

773. Elevation of third rail. The elevation of the contact-surface of the third rail, with respect to the plane of the tops of running rails.

774. Standard gage or third rails. The gage of third rails shall be not less than 26 in. (66 cm.) and not more than 27 in. (68.6 cm.).

775. Standard elevation of third rails. The elevation of third rails shall be not less than 2¾ in. (70 mm.), and not more than 3½ in. (89 mm.).

776. Third rail protection. A guard for the purpose of preventing accidental contact with the third rail.

777. Trolley wire. A flexible contact conductor, customarily supported above the cars.

778. Messenger wire or cable. A wire or cable running along with and supporting other wires, cables or contact conductors.

A primary messenger is directly attached to the supporting system. A secondary messenger is intermediate between a primary messenger and the wires, cables or contact conductors.

779. Classes of construction. Overhead trolley construction will be classed as *direct suspension* and *messenger or catenary suspension.*

780. Direct suspension. All forms of overhead trolley construction in which the trolley wires are attached, by insulating devices, directly to the main supporting system.

781. Messenger or catenary suspension. All forms of overhead trolley construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables, which in turn may be carried either in *simple catenary, i.e.,* by primary messengers, or in *compound catenary, i.e.,* by secondary messengers.

782. Supporting systems shall be classed as follows:

783. Simple cross-span systems. Those systems having at each support a single flexible span across the track or tracks.

784. Messenger cross-span systems. Those systems having at each support two or more flexible spans across the track or tracks, the upper span carrying part or all of the vertical load of the lower span.

785. Bracket systems. Those systems having at each support an arm or similar rigid member, supported at only one side of the track or tracks.

786. Bridge systems. Those systems having at each support a rigid member, supported at both sides of the track or tracks.

787. Standard height of trolley wire on street and interurban railways. It is recommended that supporting structures shall be of such height that the lowest point of the trolley wire shall be at a height of 18 ft. (5.5 m.) above the top of rail under conditions of maximum sag, unless local conditions prevent. On trackage operating electric and steam road equipment and at crossings over steam roads, it is recommended that the trolley wire shall be not less than 21 ft. (6.4 m.) above the top of rail, under conditions of maximum sag.

RAILWAY MOTORS

RATING

800. Nominal rating. The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90 deg. cent. at the commutator, and 75 deg. cent. at any other normally accessible part after 1 hr.'s continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature as measured by resistance, shall not exceed 100 deg. cent.*

* This definition differs from that in the 1911 edition of the Rules, principally by the substitution of a kilowatt rating for the horse-power rating

(*Cont. on next page.*)

806. Field-control motors. The nominal and continuous ratings of field-control motors shall relate to their performance with the operating field which gives the maximum motor rating. Each section of the field windings shall be adequate to perform the service required of it, without exceeding the specified temperature rises.

CHARACTERISTIC CURVES

810. The characteristic curves of railway motors shall be plotted with the current as abscissas and the tractive effort, speed and efficiency as ordinates. In the case of a-c. motors, the power factor shall also be plotted as ordinates.

811. Characteristic curves of direct-current motors shall be based upon full voltage, which shall be taken as 600 volts, or a multiple thereof.

812. In the case of field-control motors, characteristic curves shall be given for all operating field connections.

EFFICIENCY AND LOSSES

815. The efficiency of railway motors shall be deduced from a determination of the losses enumerated in Par. **816** to **820**. (See also Par. **1100** and **1101**.)

816. The copper loss shall be determined from resistance measurements corrected to 75 deg. cent.

817. The no-load core loss, brush friction, armature-bearing friction and windage shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for any given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above-mentioned, is equal to the product of the counter-electromotive force and the armature current.

818. The **core loss** in direct-current motors shall be separated from the friction and windage losses above described by measuring the power required to drive the motor at any given speed without gears, by running it as a series motor on low voltage and deducting this loss from the sum of the no-load losses at corresponding speed. (See Par. **1101** for alternative method.)

The friction and windage losses under load shall be assumed to be the same as without load, at the same speed.

The core loss under load shall be assumed as follows:

Table XVII.—Core Loss in D-C. Railway Motors at Various Loads

Per cent. of input at nominal rating	Loss as per cent. of no-load core loss	Per cent. of input at nominal rating	Loss as per cent. of no-load core loss
200	165	75	125
150	145	50	123
100	130	25 and under	122

NOTE.—With motors designed for field control the core losses shall be assumed as the same for both full and permanent field. It shall be the mean between the no-load losses at full and permanent field, increased by the percentages given in the above table.

819. The brush-contact resistance loss to be used in determining the efficiency, may be obtained by assuming that the sum of the drops at the contact surfaces of the positive and negative brushes is 3 volts.

820. The losses in gearing and axle bearings for single-reduction single-geared motors, varies with type, mechanical finish, age and lubrication. The following values, based on accumulated tests, shall be used in the comparison of single-reduction single-geared motors.

ILLUMINATION AND PHOTOMETRY

The following paragraphs, **850** to **895**, are the rules of the Nomenclature and Standards Committee of the Illuminating Engineering Society. They are here included by permission.

850. Luminous flux is radiant power evaluated according to its capacity to produce the sensation of light.

851. The stimulus coefficient $K\lambda$ for radiation of a particular wave-length, is the ratio of the luminous flux to the radiant power producing it.

852. The mean value of the stimulus coefficient, K_m, over any range of wave-lengths, or for the whole visible spectrum of any source, is the ratio of the total luminous flux (in lumens) to the total radiant power (in ergs per second, but more commonly in watts).

853. The luminous intensity of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

Defining equation:

Let I be the intensity, F the flux and ω the solid angle.

Then if the intensity is uniform,

$$I = \frac{F}{\omega},$$

854. Illumination, on a surface, is the luminous flux-density over that surface, or the flux per unit of intercepting area.

Defining equation:

Let E be the illumination and S the area of the intercepting surface.

Then when uniform,

$$E = \frac{F}{S},$$

855. Candle, the unit of luminous intensity maintained by the National Laboratories of France, Great Britain, and the United States.*

856. Candle-power, luminous intensity expressed in candles.

857. Lumen, the unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of 1 candle-power.†

858. Lux, a unit of illumination equal to one lumen per sq. m. The C.G.S. unit of illumination is one lumen per sq. cm. For this unit Blondel has proposed the name "Phot." One millilumen per sq. cm. (milliphot) is a practical derivative of the C.G.S. system. One foot-candle is one lumen per sq. ft., and is equal to 1.0764 milliphots.

859. (Deleted in the last revision of the Standardization Rules.)

860. Specific luminous radiation, the luminous flux-density emitted by a surface, or the flux emitted per unit of emissive area. It is expressed in lumens per sq. cm.

Defining equation:

Let E' be the specific luminous radiation.

Then, for surfaces obeying Lambert's cosine law of emission.

$$E' = \pi b_0$$

861.
862. } (Deleted in the last revision of the Standardization Rules.)

863. The lambert, the C.G.S. unit of brightness, the brightness of a perfectly diffusing surface radiating or reflecting one lumen per sq. cm. This is equivalent to the brightness of a perfectly diffusing surface having a coefficient of reflection equal to unity and illuminated by one phot.

864. For most purposes, the millilambert (0.001 lambert) is the preferable practical unit. A perfectly diffusing surface emitting one lumen per sq. ft. will have a brightness of 1.076 millilamberts.

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* This unit, which is used also by many other countries, is frequently referred to as the international candle.

† A uniform source of one candle emits 4π lumens.

recommended that in vertical distribution curves, angles of elevation shall e counted positively from the nadir as zero, to the zenith as 180 deg. In ne case of incandescent lamps, it is assumed that the vertical distribution urve is taken with the tip downward.

880. Mean horizontal candle-power of a lamp—the average candle- ower in the horizontal plane passing through the luminous center of the amp.

It is here assumed that the lamp (or other light source) is mounted in the sual manner, or, as in the case of an incandescent lamp, with its axis of ymmetry vertical.

881. Mean spherical candle-power of a lamp—the average candle- ower of a lamp in all directions in space. It is equal to the total luminous ux of the lamp, in lumens, divided by 4π.

882. Mean hemispherical candle-power of a lamp (upper or lower)— he average candle-power of a lamp in the hemisphere considered. It is qual to the total luminous flux emitted by the lamp, in that hemisphere, ivided by 2π.

883. Mean zonal candle-power of a lamp—the average candle-power f a lamp over the given zone. It is equal to the total luminous flux emitted y the lamp in that zone, divided by the solid angle of the zone.

884. Spherical reduction factor of a lamp—the ratio of the mean spher- cal to the mean horizontal candle-power of the lamp.*

885. Photometric tests in which the results are stated in candle-power hould be made at such a distance from the source of light that the latter nay be regarded as practically a point. Where tests are made in the neasurement of lamps with reflectors, the results should always be given as 'apparent candle-power" at the distance employed, which distance should lways be specifically stated.

886. The output of all illuminants should be expressed in lumens.

887. Illuminants should be rated upon a lumen basis instead of a andle-power basis.

888. The specific output of electric lamps should be stated in lumens er watt; and the specific output of illuminants depending upon combustion hould be stated in lumens per b.t.u. per hour. The use of the term "effi- iency" in this connection should be discouraged.

When auxiliary devices are necessarily employed in circuit with a lamp, he input should be taken to include both that in the lamp and that in the uxiliary devices. For example, the watts lost in the ballast resistance of an rc lamp are properly chargeable to the lamp.

889. The specific consumption of an electric lamp is its watt consump- ion per lumen. "Watts per candle" is a term used commercially in con- nection with electric incandescent lamps, and denotes watts per mean orizontal candle-power.

890. Life tests. Electric incandescent lamps of a given type may be ssumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life-test results, in order to be compared, must be either conducted under, or reduced to, comparable conditions of operation.

891. In comparing different luminous sources, not only should their andle-power be compared, but also their relative form, brightness, distri- ution of illumination and character of light.

892. Lamp accessories. A reflector is an appliance, the chief use of which is to redirect the luminous flux of a lamp in a desired direction or directions.

893. A shade is an appliance, the chief use of which is to diminish or to nterrupt the flux of a lamp in certain directions, where such flux is not desirable. The function of a shade is commonly combined with that of a reflector.

894. A globe is an enclosing appliance of clear or diffusing materials, the chief use of which is either to protect the lamp, or to diffuse its light.

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* In case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.

force of given frequency is the ratio of the conductance of the condenser or simple circuit at that frequency, to twice the capacity of the condenser at the same frequency.

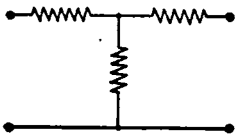
Applied to the reactance of a coil or other simple circuit having inductive reactance, the damping constant for a harmonic current of given frequency is the ratio of the resistance of the coil or circuit at that frequency, to twice the inductance at the same frequency.

913. Equivalent circuit. An equivalent circuit is a simple network of series and shunt impedances, which, at a given frequency, is the approximate electrical equivalent of a complex network at the same frequency and under steady-state conditions.

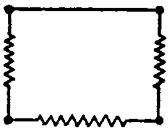
NOTE.—As ordinarily considered, the simple networks as defined are the electrical equivalents of complex networks only with respect to definite pairs of terminals, and only as to sending-end impedances and total attenuation. A further requirement is that the only connections between the pairs of terminals are those through the network itself.

914. "T" equivalent circuit. A "T" equivalent circuit is a triple-star or "Y" connection of three impedances externally equivalent to a complex network.

915. "U" equivalent circuit. A "U" equivalent circuit is a delta connection of three impedances externally equivalent to a complex network. It is also called a "Π" equivalent circuit.



Symbol for "T" equivalent circuit.



Symbol for "U" equivalent circuit.

IMPEDANCE

916. Mutual impedance. The mutual impedance, for alternating currents, between a pair of terminals and a second pair of terminals of a network, under any given condition, is the negative vector ratio of the electromotive force produced between either pair of terminals on open circuit, to the current flowing between the other pair of terminals.

917. Self impedance. The self impedance between a pair of terminals of a network, under any given condition, is the vector ratio of the electromotive force applied across the terminals to the current produced between them.

LINE CHARACTERISTICS

918. Characteristic impedance. The characteristic impedance of a line is the ratio of the applied electromotive force to the resulting steady-state current upon a line of infinite length and uniform structure, or of periodic recurrent structure.

NOTE.—In telephone practice, the terms (1) line impedance, (2) surge impedance, (3) iterative impedance, (4) sending-end impedance, (5) initial sending-end impedance, (6) final sending-end impedance, (7) natural impedance, and (8) free impedance have apparently been more or less indefinitely and indiscriminately used as synonyms with what is here defined as "characteristic impedance."

919. Sending-end impedance. The sending-end impedance of a line is the vector ratio of the applied electromotive force to the resulting steady-state current at the point where the electromotive force is applied.

NOTE.—See note under "Characteristic Impedance." In case the line is of infinite length, of uniform structure or of periodic recurrent structure, the sending-end impedance and the characteristic impedance are the same.

920. Propagation constant. The propagation constant per unit length of a uniform line, or per section of a line of periodic recurrent structure, is the natural logarithm of the vector ratio of the steady-state currents at various points separated by unit length in a uniform line of infinite length, or at successive corresponding points in a line of recurrent structure of infinite

957. Resonance. Resonance of a harmonic alternating current of given frequency, in a simple series circuit, containing resistance, inductance and capacity, is the condition in which the positive reactance of the inductance is numerically equal to the negative reactance of the capacity. Under these conditions, the current flow in the circuit with a given electromotive force is a maximum.

958. Retardation coil. A retardation coil is a reactor (reactance coil) used in a circuit for the purpose of selectively reacting on currents which vary at different rates.

NOTE.—In telephone and telegraph usage, the terms "impedance coil," "inductance coil," "choke coil" and "reactance coil" are sometimes used in place of the term "retardation coil."

959. Skin effect. Skin effect is the phenomenon of the non-uniform distribution of current throughout the cross-section of a linear conductor, occasioned by variations in the intensity of the magnetic field due to the current in the conductor.

960. Telephone receiver. A telephone receiver is an electrically operated device designed to produce sound waves or vibrations which correspond in form to the electromagnetic waves or vibrations actuating it.

961. Telephone transmitter. A telephone transmitter is a sound-wave or vibration-operated device designed to produce electromagnetic waves or vibrations which correspond in form to the sound waves or vibrations actuating it.

962. The coefficient of coupling of a transformer. The coefficient of coupling of a transformer at a given frequency, is the vector ratio of the mutual impedance between the primary and secondary of the transformer, to the square root of the product of the self-impedances of the primary and of the secondary.

963. Repeating coil. A term used in telephone practice meaning the same as transformer, and ordinarily a transformer of unity ratio.

APPENDIX I

STANDARDS FOR RADIO COMMUNICATION

The following Par. 1000 to 1028 have been abstracted from the report of the Standardisation Committee of the Institute of Radio Engineers, and are here included by permission as an Appendix, until further revised. For full particulars, see the I.R.E. Standardisation Committee report.

1000. Acoustic resonance device. One which utilises, in its operation, resonance to the audio frequency of the received signals.

1001. Antenna. A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.

1002. Atmospheric absorption. That portion of the total loss of radiated energy due to atmospheric conductivity.

1003. Audio frequencies. The frequencies corresponding to the normally audible vibrations. These are assumed to lie below 10,000 cycles per second.

1004. Capacitive coupler. An apparatus which, by electric fields, joins portions of two radio frequency circuits, and which is used to transfer electrical energy between these circuits through the action of electric forces.

1005. Coefficient of coupling (inductive). The ratio of the effective mutual inductance of two circuits to the square root of the product of the effective self-inductances of each of these circuits.

1006. Direct coupler. A coupler which magnetically joins two circuits having a common conductive portion.

1007. Counterpoise. A system of electrical conductors forming one portion of a radiating oscillator, the other portion of which is the antenna. In land stations a counterpoise forms a capacitive connection to ground.

1008. A damped alternating current is an alternating current whose amplitude progressively diminishes.

1024. A standard resonance curve is a curve the ordinates of which are the ratios of the square of the current at any frequency to the square of the resonant current, and the abscissas are the ratios of the corresponding wave length to the resonant wave length; the abscissas and ordinates having the same scale.

1025. (Deleted in the last revision of the Standardization Rules.)

1026. Sustained radiation consists of waves radiated from a conductor in which an alternating current flows.

1027. Tuning. The process of securing the maximum indication by adjusting the time period of a driven element. (See Resonance.)

1028. A wave-meter is a radio frequency measuring instrument, calibrated to read wave lengths.

1029. (Deleted in the last revision of the Standardization Rules.)

1030. Decremeter. An instrument for measuring the logarithmic decrement of a circuit or of a train of electromagnetic waves.

1031. Attenuation, radio. The decrease with distance from the radiating source, of the amplitude of the electric and magnetic forces accompanying (and constituting) an electromagnetic wave.

1032. Attenuation coefficient of (radio). The coefficient, which, when multiplied by the distance of transmission through a uniform medium, gives the natural logarithm of the ratio of the amplitude of the electric or magnetic forces at that distance, to the initial value of the corresponding quantities.

1033. Coupler. An apparatus which is used to transfer radio-frequency energy from one circuit to another by associating portions of these circuits.

APPENDIX II

ADDITIONAL STANDARDS FOR RAILWAY MOTORS

1100. In comparing projected motors, and in case it is not possible or desirable to make tests to determine mechanical losses, the following values of these losses, determined from the averages of many tests over a wide range of sizes of single-reduction single-geared motors, will be found useful, as approximations. They include axle-bearing, gear, armature-bearing, brush-friction, windage, and stray-load losses.

Table XX.—Approximate Losses in D-c. Railway Motors

Input in per cent. of that at nominal rating	Losses as per cent. of input	Input in per cent. of that at nominal rating	Losses as per cent. of input
100 or over	5.0	40	8.8
75	5.0	30	13.3
60	5.3	25	17.0
50	6.5		

1101. The core loss of railway motors is sometimes determined by separately exciting the field, and driving the armature of the motor to be tested, by a separate motor having known losses and noting the differences in losses between driving the motor light at various speeds and driving it with various field excitations.

1102. Selection of motor for specified service. The following information relative to the service to be performed, is required, in order that an appropriate motor may be selected.

(*a*) Weight of total number of cars in train (in tons of 2,000 lb.) exclusive of electrical equipment and load. (*b*) Average weight of load and durations of same, and maximum weight of load and durations of same. (*c*) Number of motor cars or locomotives in train, and number of trailer cars in train. (*d*) Diameter of driving wheels. (*e*) Weight on driving wheels, exclusive of electrical equipment. (*f*) Number of motors per motor car. (*g*) Voltage at train with power on the motors—average, maximum and minimum. (*h*) Rate of acceleration in miles per hr. per sec. (*i*) Rate of

1111. (*d*) The thermal capacity of a motor is approximately measured by he ratio of the electrical loss in kw. at its nominal (1-hr.) capacity, to he corresponding maximum observable temperature rise during a 1-hr. est starting at ambient temperature.

1112. (*e*) Consider any period of peak load and determine the electrical osses in kilowatt-hours during that period from the *electrical* efficiency curve. Find the excess of the above losses over the losses with r.m.s. service current nd equivalent voltage. The excess loss, divided by the coefficient of thermal capacity, will equal the extra temperature rise due to the peak load. This temperature rise added to that due to the r.m.s. service current, and quivalent voltage, gives the total temperature rise. If the total temperaure rise in any such period exceeds the safe limit, the motor is not sufficiently owerful for the service.

1113. (*f*) If the temperature reached, due to the peak loads, does not exceed he safe limit, the motor may yet be unsuitable for the service, as the peak oads may cause excessive sparking and dangerous mechanical stresses. It s, therefore, necessary to compare the peak loads with the short-period overload capacity. If the peaks are also within the capacity of the motor, it nay be considered suitable for the given duty cycle.

APPENDIX III

BIBLIOGRAPHY OF LITERATURE RELATING TO ELECTRICAL ENGINEERING STANDARDIZATION

1114. Engineering Manual of the American Electric Railway Engineering Association.

Standardisation Rules of the Electric Power Club.

Report of the Committee on Standardisation of the Institute of Radio Engineers.

National Electric Code.

Meter Code—Code for Electricity Meters of the A. E. I. C. and N. E. L. A.

Standardisation Reports of the Association of Railway Electrical Engineers.

Publications of American Society for Testing Materials.

The U. S. Bureau of Standards' various publications including Circulars 15, 22, 23, 29, 31, 34, and 37.

Reports of Committee on Nomenclature and Standards of Illuminating Engineering Society.

National Electric Light Association.

American Institute of Electrical Engineers, Specifications.

FOREIGN PUBLICATIONS

Publications of the Engineering Standards Committee of Great Britain.

Institution of Electrical Engineers, London, Wiring Rules and other publications.

Verband Deutscher Elektrotechniker.

British Electrical and Allied Manufacturers' Association, Reports.

INTERNATIONAL PUBLICATIONS

Publications of the International Electrotechnical Commission.

SECTION 25

GENERAL ENGINEERING ECONOMICS AND CENTRAL STATION ECONOMICS

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CONTENTS

(*Numbers refer to Paragraphs*)

GENERAL ENGINEERING ECONOMICS

CENTRAL STATION ECONOMICS

general subject. Those principles of economics which are especially useful to the engineer are covered or touched upon in the succeeding treatment.

4. Engineering economics may be defined as that field or body of knowledge which is concerned with the *economic* results of engineering, and the application of the principles and laws of economics to engineering undertakings. Since the purpose of all engineering is avowedly utilitarian, it seems unnecessary to offer proof that engineering should invariably justify itself upon economic grounds. Obviously no contemplated engineering project can be reasonably sure of success, however sound it may be upon purely technical grounds, until it has been most carefully considered on economic grounds and the conclusion reached that barring unforeseen casualties it will become a paying and profitable enterprise.

5. The fundamental elements of engineering economics may be grouped into four broad classes, with certain subdivisions, as indicated below. This classification is here presented for the first time and hence it should be regarded as tentative. The main thought, however, is to make as clear as possible the principal economic considerations in engineering work as they exist to-day.

The Elements of Engineering Economics
- Cost Analysis
  - Principles of accountancy
  - Capital and operating charges
  - Total annual charges
  - Costs per unit
  - Fixed and variable costs
  - Cost balance
- Social-Economic Investigations
  - Traffic analysis
  - Statistics of consumption
  - Probable future development
- Valuation of Property
  - Purchase or sale
  - Rate making
  - Taxation
  - Issuance of securities
  - Adjustment of book values
- Rate Making
  - Public utilities
  - Common carriers

The skeleton definition of engineering economics given above should be interpreted in a somewhat liberal sense; the predominant idea to be emphasized is the unavoidable contact of the modern engineer with countless economic questions involving cost, price and value, and those social-economic questions connected with the operation and development of engineering projects directly affecting the public or the public welfare.

The subsequent presentation of the subject is not offered in the sense that it is complete or exhaustive; on the contrary, it is somewhat fragmentary, but has been prepared with the object of making it as useful as possible.

VALUE, PRICE AND COST

6. Value defined in the economic sense is power in exchange, or purchasing power. Ely states that value in the generally accepted sense is exchange value, or objective value as distinguished from subjective value. The measure of importance attached to a commodity or article by some one individual is subjective value, and obviously may differ in extreme degree from the value placed upon the same commodity or article by some other person. Hadley states that value is essentially an ethical term and therefore there may be as many theories of value as there are views of business ethics; he also points out that while the term value may be used in the sense of utility, it ordinarily means the proper and legitimate price, or an estimate of what the price ought to be. Walker drew a very careful distinction between value and utility, the latter being always present where there is value, whereas utility alone does not invariably imply value in the economic sense. Utility does not imply value in the economic sense until it is coupled with desire. Among other elements which go to comprise economic value, the factors of time, place, cost and demand are of major importance. Therefore in speaking of value it is essential to employ such qualifying adjectives or phrases as will serve to make clear the particular kind of value in mind. The term value should never be confused with the terms price or cost, since the several meanings are distinctly different.

n the market. When the price increases, the supply will increase; and conversely, when the price drops, the supply will fall. This relation is expressed by the supply curve in Fig. 1, which occupies different positions for different commodities.

In a stable market the supply will equal the demand, at the normal price. If the price is forced upward, the demand will fall and the supply will increase; the attendant reaction will naturally tend to restore the normal conditions. If the price is manipulated downward the demand will increase, but the supply will diminish; and the attendant natural reaction is again such as to tend toward the restoration of normal conditions.

Should there come about a permanent condition in the market, resulting in greater normal demand, the position of the demand curve will shift in such manner that the demand at the former normal price will be greater than before. The result will be a higher normal price at increased normal quantity or sales. In like manner, a permanent reduction in demand will result in a lower normal price, at diminished normal quantity. A permanent change in the supply, such as might result from a decrease in the sources of raw materials, or, on the other hand, a discovery of new sources of raw materials, will likewise cause the supply curve to shift to a new position.

Generally speaking, a condition of gradually rising normal demand is closely succeeded by a rise in prices, until the demand reaches an even level. A falling demand is similarly followed by diminishing prices, until the demand strikes bottom. Such phenomena will be observed quite generally in studying the prices of any article through a series of years.

CAPITAL, RENT AND INTEREST

12. Wealth in the economic sense may be defined as all property which possesses money value or economic utility. In the broadest possible sense it means an abundance of things which are objects of human desire, but especially an abundance of worldly estate or riches, such as land, goods, money and securities.

13. Property is defined by Webster as follows: The exclusive right to possess, enjoy, and dispose of, a thing; ownership; in a broad sense, any valuable right or interest considered primarily as a source or element of wealth; practically all valuable rights except, generally, those involved in public or family relations; various incorporeal rights, patents, copyrights, rights of action, etc.; anything, or those things collectively, in or to which a man has a right protected by law. Property is commonly regarded as comprising two kinds: real property, or land, buildings, fixed plant and improvements in connection therewith; personal property, or furniture, tools, implements, live stock, money, securities, etc. There is also a more modern distinction, as between tangible and intangible property: the former includes real and personal property which exists in tangible physical form; intangible property comprises rights, franchises, good will, going-concern value, patents, copyrights and contracts.

14. Capital may be defined in the economic sense as a stock of accumulated wealth; or the amount of property owned by an individual or a corporation at a specified time, in distinction from the income received during a given period. Capital may be in the form of money, or some readily salable article for which there is a constant and general demand, in which case it is said to be liquid capital; or it may be in the form of property which is not readily salable on sudden notice, such as land, buildings, or manufacturing plant, in which case it is termed invested capital. In other words, liquid capital can be readily and quickly converted into money if it is not already such, whereas invested capital usually cannot.

15. Money is a common medium of exchange, issued by duly constituted authorities, and, as such, is a commodity the same as any other article which passes frequently from hand to hand in trade or exchange. Therefore, being a commodity, the price of money is regulated by the law of supply and demand. Thus when money is scarce and the demand normal, or heavy, it will command a premium; conversely, if money is overplentiful and the demand low, it can be had at a discount. While true in theory, such fluctuations in the price of money from its face or par value, are disturbing to trade and therefore undesirable; one of the fundamental purposes of our present currency system is to provide elasticity in the supply of money, in order suitably to meet changes in the demand for it and avoid both premiums and

20. Interest rates vary to a considerable extent, depending upon the class of investment. U. S. Government bonds pay different rates, from 2 per cent. to 4 per cent.; savings-banks deposits, from 3 to 4 per cent.; checking deposits in banks, above a certain minimum amount, frequently draw 2 per cent. on daily balances; certificates of bank deposit, or time deposits, 3 per cent.; railroad and public utility bonds, from 3.5 to 6 per cent.; industrial bonds, 5 to 7 per cent.; short-term notes of railroads and public utilities, 5 to 6 per cent.; real-estate mortgages, 5 to 6 per cent.; railroad and public utility stocks; whatever may be earned, but seldom in excess of 8 per cent.

21. Compound interest is based upon the computation of simple interest for stated periods and the addition of the interest to the principal at the end of each period, thus enlarging the principal for each consecutive period, progressively. Let

P = the principal in dollars.

n = the number of years for which the compound interest is to be computed.

t = the ratio of 1 year to the period during which simple interest is computed; thus if compounded annually, $t = 1$ and if compounded semi-annually, $t = 0.5$.

r = the annual percentage rate of interest expressed as a decimal; thus if the rate is 6 per cent., $r = 0.06$.

S = the amount of P dollars at compound interest for n years, compounded at intervals of t years, at the annual rate r

The formula for calculating S is as follows:

$$S = P\,(1+tr)^{\frac{n}{t}} \qquad \text{(dollars)} \tag{1}$$

This can also be expressed in another form

$$\log S = \log P + \frac{n}{t}\log\,(1+tr) \tag{2}$$

The latter form indicates the manner of calculating problems; in most cases the interest is compounded annually, which makes $t = 1$.

22. Present worth of a future lump payment. If the sum of S dollars is due at the end of n years, the amount which would have to be set aside at the present date, compounded at intervals of t years at the annual interest rate r (decimally expressed), is expressed by the following formula:

$$P = \frac{S}{(1+tr)^{\frac{n}{t}}} \qquad \text{(dollars)} \tag{3}$$

This can also be expressed in a form suitable for numerical calculation:

$$\log P = \log S - \frac{n}{t}\log\,(1+tr) \tag{4}$$

The symbols used have the same significance as stated in Par. **21.**

23. Annuities. An annuity is a fixed sum of money payable at equal intervals of time (see Wells, W. "College Algebra;" chapter on "Compound Interest and Annuities"). In most discussions of the subject it is assumed that the payments are made annually and the interest compounded annually. When an annuity is defined as beginning at a certain date, the first payment will fall due 1 year from that date.

24. The present worth of an annuity of A dollars per annum, commencing at once and continuing for n years, allowing interest compounded annually at the annual rate r (decimally expressed), may be calculated from the following formula:

$$P = \frac{A}{r}\left[\frac{(1+r)^n - 1}{(1+r)^n}\right] \qquad \text{(dollars)} \tag{5}$$

The present worth of a perpetual annuity, commencing at once, is equal to A/r.

The present worth of an annuity to commence after m years and then continue for n years, is expressed by the formula,

$$P = \frac{A[(1+r)^n - 1]}{r(1+r)^{m+n}} \qquad \text{(dollars)} \tag{6}$$

(2) expenditures for salaries, wages, rents, taxes, insurance, depreciation, repairs, supplies, etc., all constituting charges to operation, or **operating expenses**. The distinction between these two classes of costs is fundamental in its importance.

28. Cost comparisons are of two kinds: (1) comparisons of capital costs, or construction costs; (2) comparisons of operating costs. When comparing one plant with another, as to overall results, it is necessary to reduce all costs to one basis; this is most frequently done by comparing the total annual charges (Par. **29**), but in some instances the operating expenses (excluding interest and profits) are capitalized at the prevailing interest rate and added to the capital or investment. The latter method is rarely used.

29. The total annual charges may be defined as the sum of all operating expenses (Par. **27**) plus interest and profit on the investment or capital; or the total charge for operation. The total annual charges may be classified as shown below.

Total annual charges for operation	Investment costs	Taxes
		Insurance
		Depreciation
		Maintenance
		Interest
		Profits
	Production costs	Traffic
		Transportation
		Operating
		Commercial
		General

These charges are defined in the succeeding paragraphs.

30. Taxes constitute a charge based on the assessed value of the property and require no explanation. This charge varies from about 1 per cent. to 2 per cent. per annum on the capital invested in physical or tangible property.

31. Insurance can be defined as a cooperative method of distributing the burden of losses or casualties. The annual assessments or rates are determined by actuaries who apply the theory of probability to the problem of determining the probable risk of loss or damage, based upon the statistics of a large number of past losses. There are many different kinds of insurance, such as life, health, fire, boiler, accident, marine, employers' liability, automobile, plate glass, burglar, hurricane, cyclone, etc. The insurance rate is usually based on a percentage of the investment in insured property, or face value of the total risk, per unit of time or per annum.

32. Depreciation is fully covered in another portion of this section; see Par. **41**, *et seq*. It is quite as much an expense of operation as the cost of labor, supplies and other items which are currently paid by the day, week or month.

33. Maintenance defined in its broadest sense means upkeep of all kinds, including both repairs and renewals, but in the technical sense in which it is usually employed it means repairs exclusively. The repair charge is frequently reduced to terms of a percentage of the capital invested in plant, or the original cost of the plant.

34. Interest has been defined at length in Par. **17** to **20**, and need not be further considered here.

35. Profits represent a return on the investment over and above the normal rate of interest. For instance, a return of 8 per cent. has been held reasonable in the case of certain public utilities, on the theory that in addition to interest at a rate, say, of 6 per cent., the investor is entitled to a profit of 2 per cent. as an inducement to himself and others to engage in the particular class of business in question. The term profit is often employed, however, in the sense of including true interest in addition to true profit.

36. Investment costs are those, as the name implies, which bear some direct ratio or proportion to the investment. They are defined in Par. **29** to **35**, above. In the case of maintenance expense, there is probably some portion of it, but not all, which is more nearly a production expense than an investment expense; this seems to be obviously true, because of the fact th-

43. The two classes of depreciation usually recognized are physical depreciation and functional depreciation. These are defined in the next succeeding paragraphs.

44. Physical depreciation is the result of age, wear and tear, corrosion, and decay. This form of depreciation is constantly in progress; the rate of its progress depends upon the conditions of service or use, protection from ravaging elements, and the degree of care exercised in making prompt repairs when necessary. This rate of course varies greatly with different forms of machinery, apparatus, plant, etc.

45. Functional depreciation is the result of failure to function properly, in consequence of lack of adaptation to the service demanded. It has two principal causes, inadequacy and obsolescence.

46. Inadequacy is the result of unexpected or premature growth in the demand for service, requiring enlarged capacity which can be provided only by removing the old plant or equipment to make way for new before physical depreciation has run its full course. Depreciation resulting from this cause usually makes it imperative to replace equipment or plant sooner than otherwise, but the displaced equipment is sometimes useful for a further period if re-installed in a new location or in some other plant where its capacity is suited to the demands for service. One of the functions of sound engineering, of course, is to study the probable future demands and so arrange a plant or installation that new units can be provided as occasion may demand, without disturbing the units already in operation. In other words, part of the inherent economy in efficient engineering consists in securing if possible the maximum physical life from any piece of plant or apparatus, unless, of course, it appears conclusively that the total annual charges (Par. **29**) will be actually lessened by deviating to some other plan or policy. It is conceivable, for instance, that the maximum physical life will exceed the economical life, but this is predicated upon the assumption of a progressively diminishing efficiency with increasing age, attended by a marked increase in the total annual charges per unit of production or output before approaching the end of the maximum physical life.

47. Obsolescence is that form of functional depreciation which results from new inventions or radical improvements in the art, causing a set-back of present methods or machinery in the scale of efficiency, or creating new demands which it was not possible to serve under the past state of the art. Whether all forms of obsolescence, or allowances for their probable occurrence and effect, should be included in depreciation is perhaps an open question. Many advances in the art relate wholly to improvements in efficiency or reductions in the cost of production. When comparing a new and improved machine with one of obsolete type but not yet worn out in the physical sense, the question whether the new shall immediately supplant the old is usually regulated by the consideration whether the saving in total annual charges (Par. **29**) resulting from the substitution will extinguish the remaining service value of the old machine within a reasonable period, or much sooner than the expiration of the probable life period of the new machine. Thus there are certain types of cases in which obsolescence is not a proper charge against depreciation, but should be amortized (Par. **68**) through the application of those annual charges which represent the savings in operation secured by discarding obsolete machinery or plant. Cases of the latter type are probably typical, as a rule, of the greater number of advances in the art; whereas that type of obsolescence which makes it almost imperative to discard the old for the new, springs into existence with the relatively infrequent advances in the arts which are fundamental or revolutionary in character, as distinguished from those advances which can be classed as mere improvements of things which are already old in the arts.

48. The insurance element in depreciation. It is almost self-evident that any provision in depreciation for probable future inadequacy and obsolescence partakes of the nature of insurance to cover a risk. In this sense, therefore, provisions for future inadequacy and obsolescence are, in reality, insurance charges, and not depreciation in the technical sense—at least not in the physical sense. Such provisions should be based, therefore, upon the law of probability applied to the statistics of past occurrences with respect to the abandonment of plant or machinery strictly on account of inadequacy and obsolescence. This mode of procedure will develop the monetary

60. The annual depreciation charge (d) is the ratio of the number of dollars which must be set aside every year and placed in the depreciation reserve, to the original cost or investment; it is usually expressed as a percentage. The yearly (or monthly) accretions to the **depreciation reserve** are calculated in such manner as to produce, at the end of the life expectancy, a total fund equal to the wearing value. The annual sum (D), in dollars, charged to expense and credited to the depreciation reserve, can then be expressed by $D = dI$.

61. Segregation of plant into classes, for the purpose of computing the annual depreciation charge, is very essential for the reason that different kinds and types of plant have different life expectancies, and therefore depreciate at different rates. After the segregation process is completed and the annual depreciation is determined for each class or type, the sum of the annual charges for all the classes, in dollars, will give the total charge in dollars; the latter sum divided by the original cost or physical value of the whole plant will give the **composite depreciation charge** for the physical property as a whole.

62. Theories of depreciation.* There is no agreement at present concerning the question as to how, or in what manner, depreciation accrues from year to year during the life period. The discussion centres for the most part, in this country, around two well-known theories, one known as the straight-line method and the other as the sinking-fund method. There is also the method of diminishing values or reducing balances, and the annuity method. The first two methods are presented briefly in the following paragraphs.

63. The straight-line method is based on the assumption that depreciation accrues according to a straight-line law, in the simple ratio of age to life, as shown in Fig. 2. The formulas expressing the several relationships among the foregoing quantities or values (Par. 50 to 60) are as follows:

$$\left.\begin{aligned} &d = \frac{W}{lI} \quad \text{(per cent.)}; && A = adI \quad \text{(dollars)} \\ &p = 1 - \frac{a}{l} = 1 \div \frac{A}{W} \quad \text{(per cent.)}; && P = I(1 - ad) \quad \text{(dollars)} \end{aligned}\right\} \quad (12)$$

The values of W and I are expressed in dollars and a and l in years. This method, as ordinarily applied, depends in no way upon the amount or rate of interest earned by the depreciation reserves, pending their use for renewals. The straight-line method of computing depreciation is in wide use and has received the approval of several Public Utility Commissions.

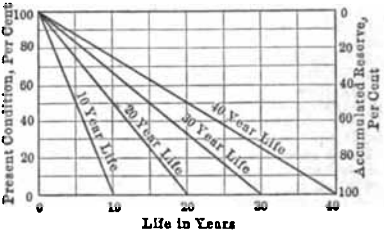

Fig. 2.—Depreciation diagram; straight-line theory.

64. The sinking-fund method is based on the assumption that depreciation accrues according to the law which expresses the accumulation of a sinking fund at compound interest (Par. 25), as shown in Fig. 3. The formulas for use in this case are as follows:

$$\left.\begin{aligned} d &= \frac{W}{I}\left[\frac{r}{(1+r)^l - 1}\right] && \text{(per cent.)} \\ p &= \frac{(1+r)^l - (1+r)^a}{(1+r)^l - 1} && \text{(per cent.)} \\ A &= W(1-p) && \text{(dollars)} \\ P &= I - A = pW - R + S && \text{(dollars)} \end{aligned}\right\} \quad (13)$$

* Erickson, H. "Depreciation;" address before Central Water Works Association, Detroit, Mich., Sept. 25, 1912. Also see Bibliography, Par. 88.

The values of W and I are expressed in dollars, a and l in years, and the annual rate of interest on the fund, decimally expressed. This me requires that the depreciation reserves be left undisturbed for the e period of life expectancy, in order that the full amount or sum require extinguish the wearing value may be realized; otherwise the sums rece as interest will be impaired. The sinking-fund method has been empl by the Railroad Commission of Wisconsin: also see Floy, H., "Valuatio Public Utility Properties;" New York, 1912; Chap. VIII.

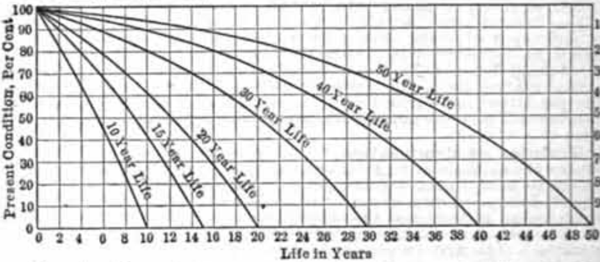

FIG. 3.—Depreciation curves; based on 5 per cent. sinking fund.

65. The method of reducing balances is rarely used in this coun It consists briefly in reducing the book value or worth of the plant each by a fixed percentage. If this figure, for instance, is 10 per cent., the v at the commencement of the second year will be 90 per cent.; the third y 81 per cent.; the fourth year, 72.9 per cent., etc. This method is interes theoretically, but is not regarded as very practical.

66. Reserves for accrued depreciation. Expert opinions differ whether it is necessary to lay aside depreciation reserves for future use. the case of a new property, just starting operations, there is no doubt it is very essential to lay aside something for accruing depreciation, u low finances make it absolutely impossible; unquestionably the time arrive, at some future date, when replacements in this plant become ne sary and the current revenues will be inadequate to meet the outlay, so the wisdom of setting up a reserve is almost self-evident. The case just represents one extreme, in the range of possible or probable cases; the illustration will be at the opposite extreme. Conceive a very large prop highly diversified as to different kinds and types of plant or equipment, built up by piecemeal growth extending over a very long series of y in this case the renewals from year to year probably will not vary to great extent in number and cost, but perhaps increase slightly from ye year, on the whole, as the property increases in total bulk or size. T are many properties which are intermediate between these two extre and a reserve for accrued depreciation is therefore a very wise, if not a ne sary provision; at the same time, this is not the universally accepted v

From another standpoint, however, there is a very strong reason creating depreciation reserves. Quite aside from the question as to whe a reserve is necessary in order to distribute the cost of renewals unifo from year to year in the expenses of operation, it is unquestionably true plants of practically every kind depreciate with age; that is to say, depr tion is always going on, beyond any power to prevent it. This being s becomes evident that the present worth of almost every kind of plant c mences to decrease from the first day it enters service; therefore it is esse from the standpoint of the stockholder or investor, to protect the orig investment by creating a reserve to offset the accrued depreciation. the depreciation which accrues annually is offset by charging an equal to expenses and crediting it to the reserve, each year, and if the cost o newals as they occur is charged to the reserve, the whole matter of protec the investment will take care of itself, in theory. In other words, under plan, the sum of the present worth of the property plus the total reserv hand, at any date, will always equal the original investment; this wi true, whether the property grows rapidly, or slowly, and without regard to the size of the expenditures for renewals, provided only that the life expectancy of each increment or fragment of the property is realized with substantial accuracy.

67. Investment of depreciation reserves. The proper disposition of depreciation reserves, pending their use for the purpose originally intended, is a subject which has received much discussion without evolving any hard-and-fast rule that meets with general approval. If the funds are not invested in some form of security, or in a business enterprise, they can hardly draw a rate of interest in excess of the usual rates on time deposits, or say 3 per cent. per annum. If invested in conservative bonds, the rate may be as high as 5 per cent. If the property is one which earns more than 5 per cent., there will be some advantage in investing the depreciation reserve, or some portion of it, in extensions of the plant. The last plan also possesses the advantage of reducing the requirements for fresh capital in extending the business; indeed, in some cases it has become the policy to invest the whole depreciation reserve in this manner.

When the depreciation reserve is set up on the basis that the total reserve should always equal the accrued depreciation on the entire property, and the entire reserve is invested in the property, there is one consequence which it is important not to overlook; namely, the present worth of the property will always be equal, in theory, to the total investment in it by the stockholders or owners, assuming that the property is free of debt of any kind. The propriety of investing the whole depreciation reserve in this manner is probably open to some question: in new plants just commencing operations, this procedure may possibly lead to financial embarrassment some years later, when extensive renewals become necessary during some particular year, and the necessary cash is not available except through the sale of new securities; in properties, however, of a highly diversified character as to types and kinds of plant, built up by piecemeal growth through a long series of years, the funds required for renewals during any particular year are not likely to exceed the total sum set aside that year for accrued depreciation, and therefore this plan is not very likely to lead to difficulties in such cases. Between these extremes, nevertheless, there are many intermediate situations, and the ruling local conditions in each instance must largely determine the best course to pursue.

In the case of public utilities, or quasi-public corporations, the depreciation reserve is virtually a trust fund created by public contribution through the assessments or charges for service, and the income from the fund is properly returnable to the fund and belongs thereto; but whether this income is treated as a credit against current charges (expense) for accrued depreciation, or whether it is treated as part of the total corporate income, makes no difference in fixing the amount of the reasonable return on the investment.

Those who are particularly interested in this question should read the literature which is to be found in the transactions of engineering societies, the technical press, the literature of accountancy and the authorities cited in the Bibliography, Par. 86.

68. Amortization is a term used in finance and accounting in the sense of extinguishment; for example, to amortize a debt by means of a sinking fund (Par. 25), or to amortize the principal of an issue of bonds, or an indebtedness represented by an issue of notes. The term should not be confused with depreciation. It can be correctly said, however, that the annual sums set aside for depreciation, and placed in a reserve fund, are for the purpose of amortizing the wearing value. Amortization means merely the extinguishment of a parcel of value or money equivalent, by means of periodical charges spread over a period of time.

69. Depreciation accounting is too extended a subject to explain briefly. In general, the periodical sums necessary to cover depreciation are charged to operating expenses and concurrently credited to the reserve for accrued depreciation. When plant is displaced, its original cost is credited to the fixed capital account and charged to the reserve; the reserve is also charged with the cost of removal and credited with the salvage, the latter being concurrently charged to supplies. The new plant, which displaces the old, is charged to the fixed capital account, under the appropriate sub-accounts. Some authorities hold that accrued depreciation should be

75. Application of the law of probability. Experience shows that demand and consumption fluctuate to some extent, under similar conditions as to time, locality, weather, etc., even when the periods compared are separated by no more than a day or a week intervening. Given a sufficient number of observations on demand or consumption, taken under precisely similar conditions but on successive occasions, it becomes quite evident that the mathematical law of probability may be useful in computing the most probable demand or consumption, and also in computing the probability that the demand or consumption will deviate by a specified amount from the most probable value. The theory of probability constitutes the entire foundation for the discussion of precision of measurements (Sec. 3), and has been applied in a number of other connections in engineering, among them being the analysis of telephone traffic. It also forms the whole basis, of course, of every form of insurance.

VALUATION AND RATE MAKING

76. General. Valuation and rate making have become so important that at least five important and authoritative works dealing with this field have been published since 1911. Only the barest outlines of the subject can be given here, with references in the succeeding paragraphs and the Bibliography to some of the principal authorities. Central-station valuation and rate making are treated at some length in Par. **128 to 158**, which should also be consulted for a more detailed exposition of the fundamentals of the subject.

77. Standards of value by which to measure the fair value of a public utility have been the subject of extended discussion and litigation, without establishing up to this time any well-defined conclusions except of the broadest character. Although the matter is still in its formative phases, the general principle that investors in public utility enterprises are entitled to fair and reasonable treatment at the hands of the public is well recognized. An excellent discussion of the present status of the matter will be found in Dr. R. H. Whitten's "Valuation of Public Service Corporations;" Supplement, 1914, Chap. II.

The courts have held that original cost, estimated present reproduction cost, and outstanding securities issued against the property, are all competent evidence on the question of value; but the conclusion in every case must be tempered by a consideration of all the facts and circumstances. This is very well expressed by the decision in the Minnesota Rate Cases (230 U. S. 352, 33 Sup. Ct. 729, June 9, 1913), "It is not a matter of formulas, but there must be a reasonable judgment having its basis in a proper consideration of all relevant facts."

78. Valuations under the cost-of-reproduction theory resolve themselves into two main questions: (1) What is the value of the tangible property; (2) what is the value of the intangible property?

79. Tangible property consists of physical plant, such as right-of-way, land, buildings, machinery, distribution system, meters, etc., organization and engineering expense, interest and taxes during construction; supplies and materials on hand, and working capital.

80. Intangible property consists of franchises, licenses, rights, contracts, good will and going value. The modern rule is to allow nothing for **franchise value** unless something was or is actually paid for it, or unless some value for it has been capitalized in the past with public approval. Under monopoly, **good will** has been held to have no value for rate-making purposes. **Going value**, or going-concern value, has been extensively discussed by engineers and commissions, but no recognized or authoritative rule is yet in existence; an excellent summary of the theories of going value, and the tendencies of courts and commissions with respect thereto, is contained in Dr. Whitten's two volumes on "Regulation of Public Service Corporations." See also Par. **156**.

81. Valuation of tangible property under the cost-of-reproduction theory involves two separate steps or procedures: (1) The preparations of an **inventory** of the property; (2) the determination of **unit costs** and their application to the quantities in the inventory, for the purpose of computing the total reproduction cost-value, new or undepreciated. The unit costs should be those, if possible, determined from the actual current construction costs shown by the corporate books, unless known to be objectionable for

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Also see the Transactions of the national engineering societies; files of the technical and engineering periodicals; files of accounting periodicals; other sections of this book, including Sec. 10, 11, 12 and 13.

CENTRAL STATION ECONOMICS

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CENTRAL-STATION FACTORS RELATING TO UTILIZATION OF INVESTMENT AND APPARATUS

89. Definition. In all engineering study of the economics of central stations for the supply of electric light and power for various purposes in a community, it is convenient and customary to use certain factors or unit values derived from other similar plants. The factors given here apply to electric generating and distribution systems only and do not include other utilities such as electric railways, water works, gas works, ice plants and steam heating systems sometimes operated in connection with electric light and power plants and included in their reports.

90. Cost of plant per kw. of yearly maximum load. Since the cost of a plant depends so much upon the maximum load it must carry, this is an important factor as showing the amount of money actually invested to create a plant sufficient to carry a given maximum load. This cost usually varies between $200 and $500 per kw. The average is probably somewhere between $250 and $300 per kw. Of this 50 to 75 per cent. is usually in the distribution systems leaving 25 to 50 per cent. for the power plant. The cost of the distribution system part will be highest with underground distribution or where the consumers are scattered, and will be the least with overhead construction or in those localities where the density of consumption per mile of distribution mains is greatest. The cost of steam power plants will be from $55 per kw. up to $150. The lower figure is for the largest steam-turbine stations in locations where land is cheap and there are no expensive preparations of the site. The higher figure is for reciprocating-engine plants on expensive land, with all refinements, so situated that the labor cost of construction is high. If a plant has a very large reserve amount of apparatus in excess of that required to carry the maximum load of the year, this first cost per kw. of peak load will, of course, be higher than if there is little or no reserve.

91. Cost of plant per kw. of maximum capacity. This item is similar to the foregoing item except that it is based on the maximum capacity of the plant rather than the maximum load on the plant. It will consequently vary within about the same limits as the previous item. In general it is not as useful a unit of comparison as the previous item because it is more likely to be affected by increase of the power plant from time to time in excess of the actual maximum demand.

92. Gross annual earnings per kw. of yearly maximum load. These usually are between the limits of $60 and $140. They are most frequently between $80 and $100. This factor indicates whether the gross is now common in the smaller plants having a moderate amount of power business. In some manufacturing cities load factors over 50 per cent. have sometimes been attained, but such cases are rare. A combination of lighting, power, and railway loads in a large city gives a load factor between 40 and 45 per cent. The load factor indicates the percentage of time which the plant apparatus is lying idle, and it is the constant aim of central station companies to increase the load factor and reduce the idle time, because interest must be paid on the investment whether the apparatus is in use or not.

CENTRAL STATION FACTORS RELATING TO TERRITORY SERVED BY SYSTEM

101. Gross yearly earnings per capita of population. This factor varies through a large range. Ten dollars per capita may be considered near the maximum at the present writing. This factor is usually higher in the Western part of the United States than in the Eastern. Some engineers in making preliminary estimates on the possibilities of future gross earnings, adopt a step-by-step schedule which increases from East to West. Gross earnings of $6 to $7 per capita may now be considered reasonably attainable under ordinary conditions in most towns on the western side of the Mississippi Valley.

102. Cost of plant per capita. This is a factor used by some engineers to indicate whether an excessive amount of plant has been put in for the population to be served. Aside from this it is evidently dependent upon the gross earnings per capita and the degree to which the territory has been developed for electric service. An investment of $40 per capita in an electric plant might be justified if the gross earnings were $10 per capita. In practice we find this varying from $3 to $35 per capita.

103. Watts maximum load per capita. This factor is also an indication of the extent to which the territory has been developed. If excessive in proportion to gross earnings per capita, it would indicate bad management. It usually ranges from 30 to 100.

104. Population per consumer. This will range from 5 to an indefinite figure. Of course 5 represents near saturation. Such a condition can only be attained in a prosperous country or suburban town.

105. Gross earnings per consumer. This factor when taken in connection with a knowledge of the territory served may help to indicate whether the large manufacturing power business or the small residential business has been neglected. This factor may vary between $18 and $159, but its most usual range is between $40 and $70.

106. Demand factor. This is the actual maximum demand divided by the connected load, expressed in per cent. It may be applied to a system, a group of consumers or any individual consumer. It is useful in determining the apparatus which must be provided and the rates which can be made for serving any given class of business. These factors can be determined only by actual measurement for different classes of customers with maximum-demand meters.

For example, suppose we find by inserting maximum-demand meters in the services supplying a number of drug-stores that the total maximum demand made by these stores during a year is 75 per cent. of what it would have been had the total connected load been turned on by each consumer at some time during the year. We would then say that the demand factor of these drug-store consumers is 75 per cent. In figuring on the amount of apparatus needed to serve other drug-stores we would multiply the connected load by the demand factor which would give the probable maximum demand.

Mr. E. W. Lloyd in a paper entitled "Compilation of Load Factors," before the National Electric Light Association in 1909, gave the results of the experience of the Commonwealth Edison Co. of Chicago with a large number of consumers equipped with maximum-demand meters. The demand factors of some of the most important classes of small and medium lighting consumers given by Mr. Lloyd are shown by the table in Par. 107, where the classification is according to business, without regard to the size of the installation. Some of the more important demand factors of power consumers taken from the same paper are also given in Par. 109, where the classification is by size of installation. The load and demand factors of a number of larger consumers using both power and light as given by Mr. Lloyd appear in Par. 108.

108. Demand and load factors of large Chicago consumers; combined power and light
(E. W. Lloyd)

Kind of business	Load factor 8,760-hr. year, per cent.	Demand factor (ratio of actual max. to connected load, per cent.)
Butter and creamery	20	60
Breweries	45	60
Brass and iron beds	20	60
Biscuit manufacturers	35	55
Boots and shoes	25	65
Brass manufacturing	28	50
Boiler shops	18	45
Can manufacturers	30	70
Candy manufacturers	18	45
Clothing manufacturers	15	55
Clubs (large)	40	85
Department stores (large)	30	55
Electrical manufacturing	25	55
Express companies	40	60
Electroplating	25	75
Engraving and printing	19	60
Fertilizer manufacturing	75	40
Furniture manufacturing	28	65
Foundries	15	75
Forge shops	30	49
Grain elevators	10	75
Glove manufacturing	25	55
Grocers (wholesale)	20	55
Hotels (small)	35	50
Hotels (large)	50	40
Ice-cream manufacturing	45	75
Jewelry manufacturing	18	50
Laundries	25	70
Machine shops	26	55
Newspapers	20	75
Packing houses	30	75
Paint, lead and ink manufacturers	23	45
Paper-box manufacturers	25	50
Plumbing and pipe fitting	26	55
Post offices	50	30
Power buildings	27	40
Refrigeration	50	90
Railroad depots	50	50
Pneumatic tube	50	90
Soap manufacturers	25	60
Seed cleaners	25	55
Screw manufacturers	30	75
Spice mills	20	55
Saw manufacturers	30	55
Structural steel	22	40
Sheet-metal manufacturers	18	70
Stone cutters	17	55
Twine mills	30	60
Theatres	16	60
Large restaurants	50	60
Small restaurants	30	70
Woolen mills	27	80
Wood-working	28	65
Textile mills	20	65

112. Demand factors compiled by Wisconsin commission from companies using Wright demand meters

	Per cent.		Per cent.
Stores	40 to 100	Laundries	60 to 75
Offices	57 to 87	Livery stables	52 to 58
Saloons	62 to 92	Lodge and dance halls	68
Restaurants	52 to 62	Depots	75 to 95
Factories	53 to 56	Theatres	49 to 89
Churches	56 to 85	Shops	55
Hotels	28	Machine shops	37 to 54
Clubs	28	Blacksmith shops	66
Schools	37 to 52	County and federal building	33 to 31

113. Diversity factor, as here used is the maximum simultaneous demand of a number of individual services for a specified period, such as 1 hr., divided by the sum of the individual maximum demands of these services for the same period, this result being expressed in per cent. For example, suppose two consumers each have a maximum demand of 50 kw. The sum of their maximum demands would therefore be 100 kw. Suppose, however, these maximum demands do not occur at the same time so that a maximum demand indicator connected to supply both services would indicate a maximum of only 75 kw. The diversity factor would then be 75 kw. divided by 100 kw. or 75 per cent. In other words, the actual maximum demand on a feeder or power plant supplying these two consumers would be only 75 per cent. of their combined maximum demands.

If the consumer's maximum demand is known and the diversity factor for that class of business is also known, the maximum effective demand of the consumer at a given point (such as transformers or power station) is determined by multiplying the consumer's actual maximum demand by the diversity factor (expressed in per cent.) between the consumer and the point under consideration.

The diversity factor is a most important element in central station electric supply; in fact it is one of the economic foundation stones upon which the central station industry is built. But for the fact that the various combined maximum demands of various consumers do not coincide, greater plant capacity would be required to serve them and rates for service would necessarily be high, because of the higher investment required. One hundred per cent. less the diversity factor represents the percentage of apparatus which can be dispensed with by combining the supply of the consumers onto one system.

Thorough study of diversity factors can be made only where maximum-demand meters are used for each consumer. Mr. H. B. Gear, distribution engineer of the Chicago central-station system has reported the results of such investigations at various times as indicated in the Bibliography at the end of this section. The accompanying table gives a summary of Mr. Gear's figures on diversity factors for lighting and power loads (Par. 115).

114. Classification of diversity factor. In an electric light and power distribution system there is first a diversity factor between the individual consumers and the transformer serving a group of such consumers because the maximum demands of the individual consumers do not come at the same time. There is next a diversity factor between different transformers and their feeders for similar reasons. Going back another step there is a diversity factor between various feeders entering a power-house or substation and the bus bars and on large systems there is a diversity factor between various substations, and the power station bus bars.

Par. 115 gives the diversity factor for each step from the consumer to the generating station in the first four items, while the last four items give the diversity factors step by step from consumer to generator.

To combine the demand and diversity factors so as to determine the maximum demand on a transformer, feeder or station, as caused by a given connected load, multiply the diversity factor by the demand factor and multiply their product by the connected load.

The yearly diversity factor between lighting and power load, and electric street and elevated railway loads in Chicago is reported by Mr. Samuel usually the amount of capital, over and above the cost of the physical plant, upon which the property will be permitted to pay common current interest or dividend rates.

120. The market value of such a property, if it has such value over and above its physical value, is evidently its value to a prospective purchaser, and the purchaser usually pays a price based on present and prospective earnings. What these earnings will be depends on the possibilities of the territory served and if there be a rate regulating public service commission, it will also depend on the rate of return on the investment which will be allowed by the public service commission.

121. Central-station operation in connection with ice plant. As many of the smaller light and power central stations are operated in connection with ice plants the effect upon the first cost and earnings by adding such a plant is given in two cases. The amount of ice manufactured per year, which determines the gross and net income, depends so much on the latitude in which the plant is located that considerable allowance must be made for this fact.

Ice plants, such as are mentioned in cases 4 and 5 (Par. 126 and 127), might earn double the gross and about double the net earnings if located in the extreme southern part of the United States. The income from ice depends also a great deal on whether it is sold wholesale or retail, or whether it simply supplies the population in its own town, or in addition ships to other nearby points.

In comparing the typical cases given for the various sizes of plants, it will be seen that in general the gross earnings per $100 invested are larger in the successful small plants than in the large ones, but in the smaller plants the operating expenses are likely to be a larger percentage of the gross receipts. The larger plants can also obtain capital at a lower rate of interest.

The larger the plants the smaller the ratio of gross earnings to capital invested. This is mainly due to the higher cost of transmission and distribution plants necessary to serve the larger territories supplied from the larger generating stations. In some cases it is also due to the higher cost of underground as compared to overhead distribution, and to a more substantial character of construction.

122. Type of plant affecting various items. The typical examples given are for steam-driven stations where the cost of fuel is near average. Higher fuel cost will, of course, raise the percentage of operating expenses, or, if more expensive machinery is put in to keep the fuel cost down, the capital account will be increased per kilowatt of peak load. Hydroelectric plants operating central-station lighting and power systems frequently involve higher first cost per kilowatt of peak load, and a consequent low ratio of gross earnings to capitalization. Such high first cost, of course, can only be justified by the decreased operating expenses caused by fuel saved by water power operation.

123. Typical earnings of central stations. Case 1.

First cost of physical property		$37,500
Intangible value		12,500
Total capitalization		$50,000
Gross earnings (40 per cent. of capital)	$20,000	
Operating expenses (60 per cent. of gross)		$12,000
Depreciation at 6 per cent. on physical value		2,250
Net earnings for interest or dividends		5,750
	$20,000	$20,000

124. Typical earnings of central stations. Case 2.

First cost of physical property		$75,000
Intangible value		25,000
Total capitalization		$100,000
Gross earnings (33 per cent. of capital)	$33,000	
Operating expenses (58 per cent. of gross)		$19,140
Depreciation at 6 per cent. on physical value		4,500
Net earnings for interest or dividends		9,360
	$33,000	$33,000
Peak load of plant 300 kw.		
Gross income per kw. of peak		$110

rise to so great abuses in the rates of central station enterprises as might be at first supposed, because, although the central station frequently has a monopoly of electric service in a community, it has on every hand to meet the competition of other methods. Electric lighting comes into competition with gas and oil, and electric power with gas, steam and oil engines. However, as electric service becomes more and more of a necessity and less of the nature of a luxury, the tendency to regulate its rates in accordance with the cost of service to the producer rather than according to the value of service to the more or less helpless consumer, becomes stronger.

130. The cost-of-service theory of rate making is that all rates should be proportioned among the various consumers according to the cost of serving them. The term "Cost" in this case is assumed to include a reasonable profit. The cost-of-service theory is the one now generally used by the various public service commissions intrusted by law with the work of regulating and adjusting the rates of public service enterprises. The theory upon which the majority of such commissions are proceeding is that, on account of the monopolistic character of a public utility, its rates should be regulated in accordance with the cost of service including a fair return upon the capital invested in the public utility.

131. Definitions. The following definitions used in connection with electric central-station rates have been adopted by the Rate Research Committee of the National Electric Light Association. (Examples of all the forms of rates defined are given in Par. 151.)

Flat rate. The term "Flat rate" is applicable to any method of charge for electric service which is based on the consumer's installation of energy-consuming devices or on a fixed sum per consumer. Meters are not used.

Demand rate. The term "Demand rate" is applicable to any method of charge for electric service which is based on the maximum demand during a given period of time. The demand is expressed in such units as kilowatts or horse-power. Maximum-demand indicators or graphic meters are used.

Meter rate. The term "Meter rate" is applicable to any method of charge for electric service which is based on the amount used. This amount is expressed in units, as kilowatt-hours of electricity. Integrating meters or graphic meters are used.

Consumer's output rate. The term "Consumer's output rate" is applicable to any method of charge for electric service based on the consumer's output. The unit of the consumer's output may, for example, be a gallon of water pumped, a barrel of flour, or a ton of ice made.

Two-charge rate. The term "Two-charge rate" is applicable to any method of charge for electric service in which the price per unit of metered electric energy for each bill period is based upon both the actual or assumed quantity of electric energy consumed and the actual or assumed capacity or demand of the installation.

Three-charge rate. The term "Three-charge rate" is applicable to any method of charge for electric service in which the charge made to the consumer for each bill period consists of, (a) a sum based upon the quantity of electric energy consumed, (b) a sum based upon the actual or assumed capacity or demand of the installation, (c) a charge per consumer.

Straight line. The term "Straight line," as used in connection with and as applied to any method of charge, indicates that the price charged per unit is constant, *i.e.*, does not vary on account of any increased or decreased number of units. The total sum to be charged is obtained by multiplying the total number of units by the price per unit.

Block. The term "Block," as used in connection with and as applied to any method of charge, indicates that a certain specified price per unit is charged for all or any part of a block of such units, and reduced prices per unit are charged for all or any part of succeeding blocks of the same or a different number of such units, each such reduced price per unit applying only to a particular block or portion thereof. The total sum to be charged is obtained by multiplying the number of units in the first block by the price per unit for that block and adding thereto the number of units in the second block times the price per unit for that block, and so on until the sum of the units falling within the different blocks equals the number of units to be charged for.

Step. The term "Step," as used in connection with and as applied to ixed items, such as taxes and insurance, which are dependent entirely upon he size of the plant and which go on continually without regard to the kilo-ratt-hours output of the plant. Such fixed charges are evidently propor-ional to the maximum demand of the customer without any regard to his onsumption of electrical energy. If we find, for example, that the cost of he power station and distribution system per kw. of maximum load is 300, then that consumer who requires 1 kw. maximum should pay ontinuously, per month or per year, the interest, profit, taxes, depreciation, nsurance, etc., upon this $300 investment. This should be paid without egard to whether he uses a large or small amount of electrical energy in ilowatt-hours, because the investment has been made to serve him. In ddition to this he should pay a meter rate or charge per kilowatt-hour. This latter is to pay for the variable cost, principally fuel and labor, which aries according to the output of the station. As a matter of fact there re some labor and fuel costs which are dependent more upon the peak oad of a station than upon the kilowatt-hours output and some authorities vould include some of these costs in the fixed yearly or monthly maximum lemand charge. However these are details aside from the main principle nvolved. Plant conditions change with increasing load and it is more cus-omary to count these fuel and labor items as variable in proportion to the ilowatt-hours output than as charges in proportion to the maximum de-nand. We see then that the cost of serving a customer is divided into two listinct elements, viz., maximum demand, and kilowatt-hours, which hould be combined in making up a rate. The **demand charge** is sometimes alled a **readiness to serve charge.**

Following up our specific example; in the case of the customer making a naximum demand of 1 kw. upon the system at the time of maximum ystem load, the fixed or maximum demand charges against such a customer night then be found to be per year as follows:

Interest and profit on $300 per kilowatt plant and distribution system investment at 8 per cent.	$24.00
Taxes and insurance, 2 per cent. on $300	6.00
Depreciation at 6 per cent. on $300	18.00
Total fixed annual charges per kilowatt demand	$48.00

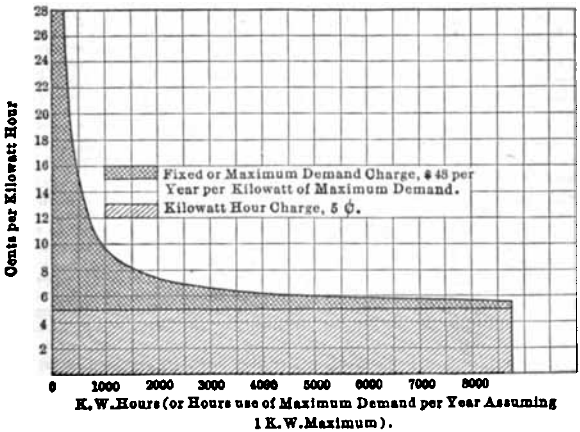

FIG. 5.—Typical form of cost curve for electrical energy supply.

mum load determines the amount of business which can be carried and the consequent gross revenue. A demand rate in effect is very similar to a flat rate. The only difference is that the consumer's maximum demand instead of being contracted for in advance is measured continuously and can be varied by the consumer from time to time without violation of contract.

139. Demand factor or the maximum demand made by the consumer is determined for rate-making purposes in various ways. The most common method with small consumers is to assume the consumer's demand factor or in other words to assume that the consumer's maximum demand is a certain percentage of the connected load. Such demand factors may be determined for different classes of consumers by test of a sufficient number of consumers with maximum demand meters and the results of such tests then taken as the basis of assumptions for all similar consumers. Such a method is of course somewhat inaccurate but it avoids the investment expense of a maximum demand meter for each consumer; which is an important item with small consumers. Demand factors as determined by various authorities for some classes of business are given in Par. **107 to 112.**

With large consumers it is frequently the practice to measure the maximum demand for a comparatively short period of time by means of an indicating instrument inserted at times of greatest load and assume that the maximum demand thereafter is the same as that measured.

140. Maximum-demand meters. In the Wright demand system of charging (Par. **136**) the maximum demand is determined by **a Wright demand meter** kept continuously in circuit alongside the kilowatt-hour meter. The Wright demand meter is an instrument for recording the maximum current which has passed and operates by the expansion and pouring over of a liquid by the heating effects of the current. It measures maximum amperes, not kilowatts.

A printing attachment on a recording watt-hour meter can be arranged to print at regular intervals the reading of the meter at that instant. The difference between two succeeding readings divided by the hours elapsed between readings gives the average demand in kilowatts between readings. By arranging the instrument to print at intervals of a few minutes, peak loads of very short duration can be measured. Such an instrument also shows the time at which the maximum demand is taken, thus showing whether at the time of the maximum load on the system or not; which in some cases is important as explained later in connection with off peak or limited hour rates. The paper rolls need be removed but once a month.

Watt-hour meters with attachments for recording maximum demand are available, such attachments depending upon the torque exerted upon the meter at any instant; this torque being proportional to the maximum demand.

A curve-drawing watt-meter which draws a curve of the load upon a roll of paper is sometimes used for determining maximum demand where the meters can be looked after with sufficient frequency. It is usually considered practicable only in large installations.

141. The maximum demand in the case of residences is sometimes assumed to be proportional to the room area or to the number of certain kinds of rooms in a house. This is sometimes called the **Detroit system**, having been first used in America at Detroit. Under this system the residence consumer's maximum demand is assumed to be a certain number of watts for each different kind of room. Not all rooms are counted as only those rooms termed active are included and the number of watts per room is varied according to a schedule believed from experience to correspond to the average actual demand of such rooms. While such a method of figuring maximum demand would appear peculiar at first sight it is nevertheless probably as fair as an assumption that the maximum demand is a certain proportion of the connected load. Basing assumed maximum demand upon connected load in a residence has the serious drawback that it practically puts a penalty on the wiring of a house with a large number of closet lights and similar conveniences. These have but little influence upon the maximum demand but are nevertheless very convenient for the consumer and have much to do in persuading him to use electric light. Basing the maximum demand upon the active rooms in a house or upon the size of the house eliminates this unfairness and helps to cultivate the residence business.

from. It is not however customary to attempt to charge each consumer with the exact feeder investment necessary to serve him. Some consumers are a considerable distance from the power station and others are near, and making an exact analysis would complicate matters to such an extent that it is customary to take the complete feeder and pole-line equipment reduced to a cost per kw. of demand basis and to charge this investment equally among all consumers.

145. Off-peak rates, sometimes called limited rates are sometimes made for classes of business where the maximum demand of the consumer is limited to certain hours of the day so that all or a large portion, of the consumer's load is turned off during the hours of maximum central station load. In this way the power station and distribution system investment which is installed to provide for the demands of ordinary consumers can be made to do double duty and the demand charge is considerably reduced. There is a difference of opinion among rate experts as to how much of the demand charge should be borne by the off-peak consumer in such cases. Some argue that, inasmuch as the station and meter capacity are already installed for serving the peak-load consumer, it is proper to eliminate a considerable percentage of the demand charge for the off-peak consumer, because the power-station capacity service supplied to such a customer is in the nature of a by-product which would not otherwise be utilized. The general practice is to divide such charges between the peak and the off-peak consumers. However, in cases where it is necessary for competitive reasons to remove the demand charge of the off-peak consumers in so far as it applies to investment already made for peak consumers, and allow it to be borne altogether by the peak consumers, the by-product theory offers an excellent argument. Further, the taking on of such off-peak business, even though it bears but a small percentage of the maximum-demand charge, increases the net income of the company and assists in a more economical production, so that ultimately reduced rates can be instituted for all consumers. As a general policy the leaders of the central-station industry as well as public service commissions recognize fully that any rates which help to increase and build up the volume of central-station business help ultimately to reduce the cost of service to all consumers.

146. The practical deviations of rates from the cost-of-service theory are necessarily numerous. It is not feasible to determine the exact investment required to serve each consumer. Consumers must rather be taken by classes. Furthermore, the rate per kw-hr. to each consumer using electricity but a few hours per month based upon the cost of service, would be astonishingly high. If the rates charged on this business were based strictly on cost of service, there would be so much public protest that both central-station companies and rate-regulating commissions apparently have concluded that it is best to allow this class of business to be taken at a loss and let the losses be made up by other consumers, inasmuch as the gross revenue from such business is a small proportion of the whole.

147. Limited-demand flat rates are sometimes used for small residence lighting where it is desired to cut out the expense of meter investment, meter readings and bookkeeping. Such rates also appeal to a certain class of small consumers who wish to know definitely what their lighting bills will be per month without the uncertainty of a meter. One trouble with flat rates has been that consumers put in larger lamps or other devices than they contract to pay for. Under the limited-demand flat rate system the consumer is served through a limiting device of some sort which periodically interrupts the current and flickers the lamps whenever the contracted maximum demand is exceeded. The consumer is thus warned to turn off one or more lamps and prevented from using an excess demand over that contracted for.

The limited-demand flat rate has some of the disadvantages of all flat rates namely that consumers waste electrical energy by keeping lights on when not needed. Where such rates are in use, however, this tendency is somewhat restricted by making the consumer pay for lamp renewals, and if lamp renewals are sufficiently expensive there is some incentive to turn out lamps when not needed in order to save renewal costs. However such flat rates must always be made high enough to allow for considerable waste on the part of the consumer. The principal use for such a rate is in the supply of very small residences where the cost of bookkeeping, meter reading and than the first 30 hr. use per month of the active connected load. Secondary rate, 8 cents per kw-hr. for additional energy used. (In this case the active connected load is the assumed maximum demand.)

Where the active room plan is used as a basis of estimating maximum demand of residences, the following is an example of one method of estimating: multiply the number of rooms in the house by 0.04 kw., but do not count bathrooms, basements, cellars, porches, stairways, attics, store rooms, small halls, entrances, woodsheds, or barns.

Three-charge rate. Six dollars per year per consumer (as a consumer charge) plus $30 per year per kw. of maximum demand (as a demand charge sometimes called a readiness to serve charge) plus 6 cents per kw-hr. for electrical energy used.

Block meter rate. For the first 250 kw-hr. monthly consumption, 10 cents per kw-hr.; for the next 250 kw-hr. monthly consumption, 9 cents per kw-hr.; for the next 250 kw-hr. monthly consumption, 8 cents per kw-hr.

Step meter rate. For the first 250 kw-hr. of monthly consumption 12 cents per kw-hr.; for a monthly consumption between 250 and 500 kw-hr., 11 cents per kw-hr.; for a monthly consumption between 500 and 750 kw-hr., 10 cents per kw-hr. (Note that under the foregoing schedule a consumer of 249 kw-hr. per month would pay more than a consumer of 251, in actual dollars and cents. There is evident injustice in this and also in the fact that the discount is applied in sharp steps rather than gradually.)

152. Discounts for prompt payment are sometimes allowed and as the majority of consumers will take advantage of such discount the rate should be adjusted so that they will yield the owners of the property a fair profit after the discount is taken off. In order that a discount for prompt payment may be legally sustained it is necessary that it should not be a very large discount. About 10 per cent. is common. Discounts in excess of this are in danger of being set aside by courts or commissions as being unfair to the consumer who does not take advantage of the discount.

VALUATIONS FOR RATE-MAKING PURPOSES

153. Classification of purposes for which valuations are made. The laws of many states where public service or public utility commissions have been created for the purpose of public-utility regulation, provide for the valuation of public utility properties for purposes of establishing reasonable rates. The theory upon which these laws are based (although it is not always expressly so stated) is that of allowing the investor in public utility properties a fair and reasonable rate of return (interest and profit) upon his investment.

Valuations made for rate-making purposes may be very different from valuations made for other purposes. If a property is to be appraised or valued for the purposes of an ordinary business purchase, the fundamental question to be solved is the probable earning power of the property both present and prospective. In valuations for rate making, however, the earning power of the property should receive no consideration, because the earning power is dependent upon the very rates which it is proposed to regulate, and to value a property on its earnings would defeat the entire end in view.

154. The purpose of a valuation to be used in rate making, should be to determine as nearly as possible the actual fair investment in the property to the end that rates may be so adjusted that a fair annual return (interest and profit) will be made to the investor upon the amount invested in the property after all expenses are paid. If this end were kept constantly in view many of the disputes and discussions in connection with such valuations would be obviated.

If the actual cost of a public-utility property could always be obtained from the construction or property accounts, the problem would be simple. However, it is frequently the case that construction costs are not kept in such shape that they can be accepted unquestionably by the appraiser. It may also happen that part of the books and records of the enterprise is destroyed or unavailable. In any case the engineer making the valuation must be prepared by knowledge of other plants to check the accuracy of any figures submitted to him or even to value a plant entirely in accordance with costs of similar plants elsewhere if no figures whatever are available on the actual cost of the plant under consideration. The value of a public utility property is usually classified under two heads, tangible and intangible.

payable until some time in the future (see Par. 42). If the earnings in the past have not been sufficient to pay all such expenses and a loss has resulted from operation, such losses should be included in intangible or going value after making the proper deductions as stated.

158. The per cent. upon the investment which a public utility is allowed to earn as a fair and reasonable annual interest and profit upon its value as taken for rate-making purposes is a matter for commissions and courts to decide in accordance with the prevalent or market interest rate upon investments in similar securities. Public utility securities must compete in the financial market with other securities or they will not be sold. These are financial rather than engineering questions, but, since the engineer must frequently deal with them in the course of his business, the following points are given as presenting current practice.

Where part of the money to pay for the construction of a plant is raised by a bond issue, it is customary to sell the bonds at a discount below par, a part or all of which discount is taken by the bond broker as his commission for finding purchasers for the bonds. As the bonds must be redeemed at par when they are due, the discount upon the bonds must be added to the total annual interest paid on the bonds, in order to determine the actual annual cost to the public utility for the use of the money. This is a point sometimes overlooked in figuring the fixed charges which a public utility must carry. The principal question is to determine what rate of interest and profit a public utility must pay after discounts or commission on sale of securities are included. It is not a question of theory but of market conditions.

Mr. Halford Erickson member of the Railroad and Public Service Commission of Wisconsin in a public address 1914 (see Bibliography) gives the following figures as to rates actually paid by public utilities for money: Ten representative first mortgage bond issues covering electric-lighting and street-railway plants, brought out in 1913 and bearing interest at 5 per cent. on par value, were placed on the market at prices at which they would yield the investor an income of from 5 to 6 per cent. The cost to the issuing company of obtaining this capital amounted to from 1 per cent. minimum to over 11 per cent. maximum for discount and about 3 per cent. for selling expenses. The total average was about 6.2 per cent. During the same period 10 representative second mortgage bond issues covering gas, electric-lighting, and railway plants, bearing interest at 5 per cent., were offered at prices that would net investors an income of 5 to 6.2 per cent. On these issues the discount varied from 1 to over 12 per cent. and the selling expense stood at about 3 per cent. The total cost to the companies for this financing ranged from 5.2 to about 7 per cent., the average being about 6.4 per cent. Twelve note issues were offered to the public at prices which placed them upon a 6.2 per cent. income basis to the investors. When the discounts and selling expenses were taken into account, the cost to the companies of the bonds thus obtained was found to be about 9.4 per cent. per annum. In this case the discounts ranged from less than 1 to about 2.34 per cent. The selling costs, however, were rather heavy since they appear to have ranged from about 5 to over 8 per cent. Five preferred-stock issues were sold on a basis whose average yield to the investor was about 7.3 per cent. Since the discounts varied from 3 to 12.5 per cent. and the selling expense also had to be met, the cost to the companies was, of course, much greater than the price to the public. For about 40 plants in Wisconsin whose appraised value varied from about $20,000 to about $2,000,000 per plant, the bonds, when discounts and selling expenses are included, have of late years been selling at prices under which the cost of financing on the plant ranges from about 5.5 to fully 6.5 per cent. per annum. In these cases the bonds covered from 50 per cent. to more than 85 per cent. of the values of the plants and their business, while the net earnings of the plant did not amount to less than twice as much as the interest on the bonds.

In further explanation of Mr. Erickson's figures it should be said that this is in a state where most of the public utility companies are protected from competition as a recompense for commission regulation of rates and service, and that such securities, therefore, would present to the investor the minimum amount of hazard to be found in public utilities of any given size. Mr. Erickson's figures probably represent minimum interest rates obtainable by the public-utility properties in the United States of the kind and at the times stated.

INDEX

Note.—Numbers in parentheses ( ) refer to Sections, or Chapters, only: all other numbers refer to paragraphs.
For instance: (14) 60, *refers to Paragraph* 60 *of Section* 14. *To find this reference turn to page marked Sec.* 14.—60, *at the outside top corner of the page.*
Page numbers are not used in this Index.

C.

(References are to sections and paragraphs—not pages)

(References are to sections and paragraphs—not pages)

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