...CTRICIANS' HANDBOOK

A REFERENCE BOOK FOR PRACTICAL ELECTRICAL WORKERS

BY
TERRELL CROFT
Consulting Electrical Engineer

FIRST EDITION
FIFTH IMPRESSION

TOTAL ISSUE, 28,500

McGRAW-HILL BOOK COMPANY, INC.
239 WEST 39TH STREET. NEW YORK

LONDON: HILL PUBLISHING CO., LTD.
6 & 8 BOUVERIE ST., E. C.
1913

First Edition

First Impression, December, 1913
Second Impression, April, 1914
Third Impression, October, 1915
Fourth Impression, October, 1917
Fifth Impression, August, 1918

THE · MAPLE · PRESS · YORK · PA

AMERICAN ELECTRICIANS' HANDBOOK

BOOKS BY

TERRELL CROFT

PUBLISHED BY

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PREFACE

This is a practical man's handbook.

In compiling it, the aim has been to collect such information as will enable practical electrical men—wiremen, contractors, linemen, small plant superintendents, operators and construction engineers—to select and install commercial electrical apparatus and materials intelligently for the performance of given services, and to qualify them for operating the equipment after it has been installed.

For a dozen years the compiler has maintained a personal file of loose-leaf notes on practical electrical subjects. This material constituted the nucleus around which The American Electricians' Handbook has been assembled. Additional matter has been collected from many sources. Extracts from standard books and from technical magazines have been utilized freely. Much of the text is from articles prepared by the compiler and printed in trade papers. The endeavor has been to give proper credit for all material that has appeared previously.

While this is not a so-called "theoretical" book it is theoretical to the extent that the information that it gives is based on sound physical laws, as all good engineering practice must be. However, the truths arising from the laws have been given rather than the deduction of the laws themselves. Theoretical discussion has been included only where it may be of assistance in enabling the reader to understand why he should do certain things in certain ways.

Some relatively simple subjects have been treated at considerable length, and others of a more complicated nature may, perhaps, appear to have been slighted. There are two reasons for this: *first*, space limitation considerations and *second*, the desire to cover thoroughly those things which the practical man encounters most frequently.

Illustrations and diagrams, every one of which has been especially prepared for this book, have been used very freely, because one illustration will frequently explain more than several pages of text. Many special problems are solved to indicate the proper application of the rules which are given. No attempt has been made to treat apparatus or materials involving voltages exceeding 2400.

Although this handbook has been prepared primarily for men of little schooling, it is designed to give practical information on materials, and suggestions for the selection, installation and operation of equipment, that will be of service to the technically trained engineer.

In books of this character some typographical errors are inevitable. The compiler and publishers will be glad to have notice of any that are discovered, and to have suggestions for the future enlargement and improvement of the book.

TERRELL CROFT.

UNIVERSITY CITY,
ST. LOUIS, MO.
November, 1913

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CONVERSION TABLES AND USEFUL FACTORS

CONVERSION FACTORS (*Standard Handbook*)

These factors were calculated with a double length slide-rule and checked with those given by Carl Hering in his "Conversion Tables."

1. Length

1 mil = 0.0254 mm. = 0.001 in.
1 mm. = 39.37 mils = 0.03937 in.
1 cm. = 0.3937 in. = 0.0328 ft.
1 in. = 25.4 mm. = 0.083 ft. = 0.0278 yd. = 2.54 cm.
1 ft. = 304.8 mm. = 12 in. = 0.333 yd. = 0.305 m.
1 yd. = 91.44 cm. = 36 in. = 3 ft. = 0.914 m.
1 m. = 39.37 in. = 3.28 ft. = 1.094 yd.
1 km. = 3,281 ft. = 1,094 yd. = 0.6213 miles.
1 mile = 5,280 ft. = 1,760 yd. = 1,609 m. = 1.609 km.

2. Surface

1 cir. mil = 0.7854 sq. mil = 0.0005067 sq. mm. = 0.0000007854 sq. in.
1 sq. mil = 1.273 cir. mil = 0.000645 sq. mm. = 0.000001 sq. in.
1 sq. mm. = 1,973 cir. mil = 1,550 sq. mil = 0.00155 sq. in.
1 sq. cm. = 197,300 cir. mil = 0.155 sq. in. = 0.00108 sq. ft.
1 sq. in. = 1,273,240 cir. mil = 6.451 sq. cm. = 0.0069 sq. ft.
1 sq. ft. = 929.03 sq. cm. = 144 sq. in. = 0.1111 sq. yd. = 0.0929 sq. m.
1 sq. yd. = 1,296 sq. in. = 9 sq. ft. = 0.00836 are = 0.000207 acre.
1 sq. m. = 1,550 sq. in. = 10.7 sq. ft. = 1.195 sq. yd. = 0.000247 acre.
1 acre = 43,560 sq. ft. = 4,840 sq. yd. = 4,047 sq. m. = 0.4047 hectare = 0.004047 sq. km. = 0.001562 sq. mile.
1 sq. mile = 27,880,000 sq. ft. = 3,098,000 sq. yd. = 2,590,000 sq. m. = 640 acres = 2.59 sq. km.

3. Volume

1 cir. mil-ft. = 0.0000094248 cu. in.
1 cu. cm. = .061 cu. in. = 0.0021 pt. (liq.) = 0.0018 pt. (dry).
1 cu. in. = 16.39 cu. cm. = 0.0346 pt. (liq.) = 0.0298 pt. (dry). = 0.0173 qt. (liq.) = 0.0148 qt. (dry) = 0.0164 l. or cu. dm. = 0.0036 gal. = 0.0005787 cu. ft.
1 pt. (liq.) = 473.18 cu. cm. = 28.87 cu. in.
1 pt. (dry) = 550.6 cu. cm. = 33.60 cu. in.

1 qt. (liq.) = 946.36 cu. cm. = 57.75 cu. in. = 8 gills (liq.) = 2 pt. (liq.) = 0.94636 l. or cu. dm. = 0.25 gal.

1 l. = 1,000 cu. cm. = 61.023 cu. in. = 2.1133 pt. (liq.) = 1.8162 pt. (dry) = 0.908 qt. (dry) = 0.2642 gal. (liq). = 0.03531 cu. ft.

1 qt. (dry) = 1,101 cu. cm. = 67.20 cu. in. = 2 pt. (dry) = 0.03889 cu. ft.

1 gal. = 3,785 cu. cm. = 231 cu. in. = 32 gills = 8 pt. = 4 qt. (liq.) = 3.785 l = 0.1337 cu. ft. = 0.004951 cu. yd.

1 cu. ft. = 28,317 cu. cm. = 1,728 cu. in. = 59.84 pt. (liq.) = 51.43 pt. (dry) = 29.92 qt. (liq). = 28.32 l. = 25.71 qt. (dry) = 7.48 gal. = 0.03704 cu. yd. = 0.02832 cu. m. or stere.

1 cu. yd. = 46,656 cu. in. = 27 cu. ft. = 0.7646 cu. m. or stere.

1 cu. m. = 61,023 cu. in. = 1,000 l = 35.31 cu. ft. = 1.308 cu. yd.

4. Weight

1 mg. = 0.01543 gr. = 0.001 g.

1 gr. = 64.80 mg. = 0.002286 oz. (av.)

1 g. = 15.43 gr. = 0.03527 oz. (av.) = 0.002205 lb. (av.)

1 oz. (av.) = 437.5 gr. = 28.35 g. = 16 drams (av.) = 0.0625 lb. (av.)

1 lb. (av.) = 7,000 gr. = 453.6 g. = 256 drams = 16 oz. = 0.4536 kg.

1 kg. = 15,432 gr. = 35.27 oz. = 2.205 lb.

1 ton (short) = 2,000 lb. (av.) = 907.2 kg. = 0.9072 ton (metric) 0.8928 ton (long).

1 ton (long) = 2,240 lb. = 1.12 ton (short) = 1.016 ton (metric).

5. Energy

Torque units should be distinguished from energy units: Thus, foot-pound and kilogram-meter for energy, and pound-foot and meter-kilogram for torque. (See 1–88 for further information on torque.)

1 ft-lb.* = 13,560,000 ergs = 1.356 joules = 0.3239 g-cal. = 0.1383 kg-m. = 0.001285 B.t.u. = 0.0003766 watt-hr. = 0.0000005051 h.p.-hr.

1 kg-m. = 98,060,000 ergs = 9.806 joules = 7.233 ft-lb. = 2.34 g-cal. = 0.009296 B.t.u. = 0.002724 watt-hr. = 0.000003704 h.p.-hr. (metric).

1 B.t.u. = 1,055 joules = 778.1 ft-lb. = 252 g-cal. = 107.6 kg-m. = 0.5555 lb-centigrade heat unit = 0.2930 watt-hr. = 0.252 kg-cal. = 0.0003984 h.p.-hr. (metric) = 0.0003930 h.p.-hr.

1 watt-hr. = 3,600 joules = 2655.4 ft-lb. = 860 g-cal. = 367.1 kg-m. = 3.413 B.t.u. = 0.001341 h.p.-hr.

1 h.p.-hr. = 2,684,000 joules = 1,980,000 ft-lb. = 273,700 kg-cm. = 745.6 watt-hr.

1 kw-hr. = 2,655,000 ft-lb. = 367,100 kg-m. = 1.36 h.p.-hr. (metric) = 1.34 h.p.-hr.

6. Power

1 g-cm. per sec. = 0.00009806 watt.

1 ft-lb. per min. = 0.02260 watt = 0.00003072 h.p. (metric) = 0.00000303 h.p.

1 watt = 44.26 ft-lb. per min. = 6.119 kg-m. per min. = 0.001 kilowatt.

* The hyphen (-) as used here means "multiplied by."

1 **h.p.** = 33,000 ft-lb. per min. = 745.6 watts = 550 ft-lb. per sec. = 76.04 kg-m. per sec. = 1.01387 h.p. (metric).

1 **kw.** = 44256.7 ft-lb. per min. = 101.979 kg-m. per sec. = 1.3597 h.p. metric) = 1.341 h.p.

7. Resistivity

1 **ohm per cir. mil-ft.** = 0.7854 ohm per sq. mil-ft. = 0.001662 ohm per sq. mm-m. = 0.0000001657 ohm per cm.^{3} = 0.00000006524 ohm per in.^{3}

1 **ohm per sq. mil-ft.** = 1.273 ohms per cir. mil-ft. = 0.002117 ohm per sq. mm-m. = 0.0000002116 ohm per cm.^{3} = 0.00000008335 ohm per in.^{3}

1 **ohm per in.^{3}** = 15,280,000 ohms per cir. mil-ft. = 12,000,000 ohms per sq. mil-ft. = 25,400 ohms per sq. mm-m. = 2.54 ohms per cm.^{3}

8. Current Density

1 **amp. per sq. in.** = 0.7854 amp. per cir. in. = 0.1550 amp. per sq. cm. = 1,273,000 cir. mils per amp. = 0.000001 amp. per sq. mil.

1 **amp. per sq. cm.** = 6.45 amp. per sq. in. = 197 000 cir. mils per amp.

1,000 **cir. mils per amp.** = 1,273 amp. per sq. in.

1,000 **sq. mils per amp.** = 1,000 amp. per sq. in.

9. Table Showing Fractions of Inch Reduced to Decimal Equivalents

64ths	32ds	16ths	8ths	4ths	Halves	Decimal equivalents	64ths	32ds	16ths	8ths	4ths	Halves	Decimal equivalents
1/64						0.015625	33/64						0.515625
	1/32					0.031250		17/32					0.531250
3/64						0.046875	35/64						0.546875
		1/16				0.062500			9/16				0.562500
5/64						0.078125	37/64						0.578125
	3/32					0.093750		19/32					0.593750
7/64						0.109375	39/64						0.609375
			1/8			0.125000				5/8			0.625000
9/64						0.140625	41/64						0.640625
	5/32					0.156250		21/32					0.656250
11/64						0.171875	43/64						0.671875
		3/16				0.187500			11/16				0.687500
13/64						0.203125	45/64						0.703125
	7/32					0.218750		23/32					0.718750
15/64						0.234375	47/64						0.734375
				1/4		0.250000					3/4		0.750000
17/64						0.265625	49/64						0.765625
	9/32					0.281250		25/32					0.781250
19/64						0.296875	51/64						0.796875
		5/16				0.312500			13/16				0.812500
21/64						0.328125	53/64						0.828125
	11/32					0.343750		27/32					0.843750
23/64						0.359375	55/64						0.859375
			3/8			0.375000				7/8			0.875000
25/64						0.390625	57/64						0.890625
	13/32					0.406250		29/32					0.906250
27/64						0.421875	59/64						0.921875
		7/16				0.437500			15/16				0.937500
29/64						0.453125	61/64						0.953125
	15/32					0.468750		31/32					0.968750
31/64						0.484375	63/64						0.984375
					1/2	0.500000							

10. Trigonometric Functions

Angle ϕ or *lag angle*	Sin or *induction factor*	Cos or *power factor*	Tan	Angle ϕ or *lag angle*	Sin or *induction factor*	Cos or *power factor*	Tan
0	.000	1.000	.000	....	....	....	....
1	.017	.999	.017	46	.719	.695	1.04
2	.035	.999	.035	47	.731	.682	1.07
3	.052	.999	.052	48	.743	.669	1.11
4	.070	.998	.070	49	.755	.656	1.15
5	.087	.996	.087	50	.766	.643	1.19
6	.105	.995	.105	51	.777	.629	1.23
7	.122	.993	.123	52	.788	.616	1.28
8	.139	.990	.141	53	.799	.602	1.33
9	.156	.988	.158	54	.809	.588	1.38
10	.174	.985	.176	55	.819	.574	1.43
11	.191	.982	.194	56	.829	.559	1.48
12	.208	.978	.213	57	.839	.545	1.54
13	.225	.974	.231	58	.848	.530	1.60
14	.242	.970	.249	59	.857	.515	1.66
15	.259	.966	.268	60	.866	.500	1.73
16	.276	.961	.287	61	.875	.485	1.80
17	.292	.956	.306	62	.833	.469	1.88
18	.309	.951	.325	63	.891	.454	1.96
19	.326	.946	.344	64	.898	.438	2.05
20	.342	.940	.364	65	.906	.423	2.14
21	.358	.934	.384	66	.914	.407	2.25
22	.375	.927	.404	67	.921	.391	2.36
23	.391	.921	.424	68	.927	.375	2.48
24	.407	.914	.445	69	.934	.358	2.61
25	.423	.906	.466	70	.940	.342	2.75
26	.438	.898	.488	71	.946	.326	2.90
27	.454	.891	.510	72	.951	.309	3.08
28	.469	.883	.532	73	.956	.292	3.27
29	.485	.875	.554	74	.961	.276	3.49
30	.500	.866	.577	75	.966	.259	3.73
31	.515	.857	.601	76	.970	.242	4.01
32	.530	.848	.625	77	.974	.225	4.33
33	.545	.839	.649	78	.978	.208	4.70
34	.559	.829	.675	79	.982	.191	5.14
35	.574	.819	.700	80	.985	.174	5.67
36	.588	.809	.727	81	.988	.156	6.31
37	.602	.799	.754	82	.990	.139	7.12
38	.616	.788	.781	83	.993	.122	8.14
39	.629	.777	.810	84	.995	.105	9.51
40	.643	.766	.839	85	.996	.087	11.43
41	.656	.755	.869	86	.998	.070	14.30
42	.669	.743	.900	87	.999	.052	19.08
43	.682	.731	.933	88	.999	.035	28.64
44	.695	.719	.966	89	.999	.017	57.28
45	.707	.707	1.000	90	1.000	.000	Infinity

PRINCIPLES OF ELECTRICITY AND MAGNETISM—UNITS

11. It is not known just what electricity is and from a practical standpoint it does not appear to make much difference what it is. We know a great deal about certain things that it will do, can measure its effects and are familiar with many ways of utilizing it.

It has been established that electricity, whatever it may be, is not energy. (Energy, in the technical sense, is stored work or capacity for doing work.) Electricity and magnetism may be thought of as weightless mediums which carry energy just as do water (Fig. 1) or air or any other form of matter and the laws which govern the flow of electricity, in closed circuits, are, in general, similar to those governing the flow in closed water and air circuits. Electricity is not energy any more than the water flowing under pressure in the pipe line of Fig. 1 is energy. The water flowing in the pipe (Fig. 1) is a means of transmitting energy and so is the electricity flowing along the conductor of Fig. 2 a means of transmitting energy.

In Fig. 1, the energy developed by the steam engine is transmitted to the rotary pump by means of the belt. The rotary pump forces the water through the pipe to turn a water-motor

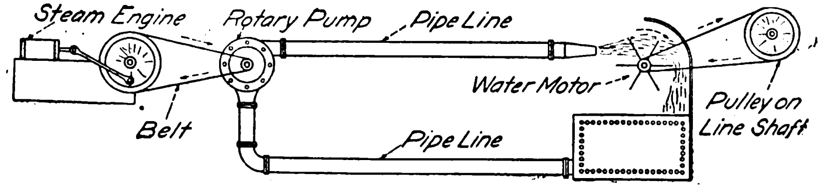


FIG. 1.—Transmitting energy with water.

which, in turn, through a belt, drives a line shaft. Thus, a belt, a rotary pump, a water-motor and another belt have all been mediums in the transmission of energy from the engine to the line shaft. In Fig. 2 an electric generator or dynamo is substituted for the rotary pump, conductors for the pipe line, and an electric motor for the water-motor. In Fig. 2 electricity instead of water is the medium by means of which energy is transmitted over the long distance, otherwise the two transmission systems are somewhat similar. In either Fig. 1 or Fig. 2 a long belt might be arranged between the engine and the line-shaft pulley and it would transmit energy just as do water or electricity, though possibly not as efficiently. (Obviously, belt transmission over any great

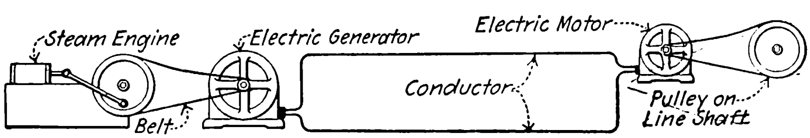


FIG. 2.—Transmitting energy with electricity.

distance is not feasible.) These illustrations have been given to show that **electricity is merely a medium for the transmission of energy** and that it is not energy.

12. Current. Amperes.—The practical unit of electric current is the ampere. If a pressure of 1 volt is impressed on a closed circuit having a resistance of 1 ohm, 1 ampere will flow. The flow of water in a pipe is measured by the quantity of water that flows through in a second as 1 gal. per sec., 8 gal. per sec., etc. Similarly the flow of electricity in a circuit is measured by the amount of electricity that flows along it in a second, as "1 coulomb per second." The **coulomb** is the name given to a certain quantity of electricity just as the gallon is the name given a certain quantity of water. The name given to a rate of flow of *a coulomb per second* is the ampere. If 2 coulombs per second flow the current is 2 amperes; if 20 coulombs per second flow the current is 20 amperes. It is the amount of electricity that flows in a second rather than the total amount that flows that is of importance. Hence the unit of amount, the coulomb, is practically never used by the electrician.

13. **The volt** is the practical unit of electromotive force or electrical pressure. The volt is that difference in pressure that will force a current of 1 ampere through a resistance of 1 ohm. "Electromotive force" is abbreviated e.m.f.

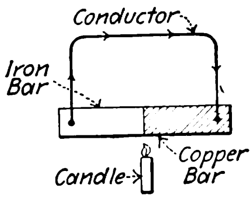


FIG. 3.—E.m.f. generated by heat.

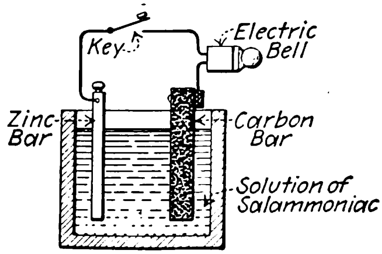


FIG. 4.—E.m.f. generated by chemical action.

14. **Electromotive forces may be generated in three different ways,** viz.: (1) *By contact of unlike substances either by the application of heat or by chemical action.* Heat applied to the junction of two dissimilar metals (Fig. 3) will generate an e.m.f., but it will be relatively small. This method is not commercial. If a piece of carbon and a piece of zinc (Fig. 4) are immersed in a solution of sal-ammoniac a battery results that will generate an e.m.f. If the key is closed an electric current will flow and the bell will ring. (2) *By magnetic flux.* If the conductor, Fig. 5, be moved

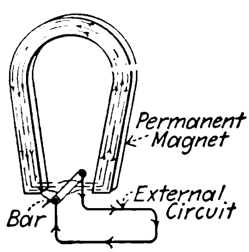


FIG. 5.—E.m.f. generated by magnetic flux.

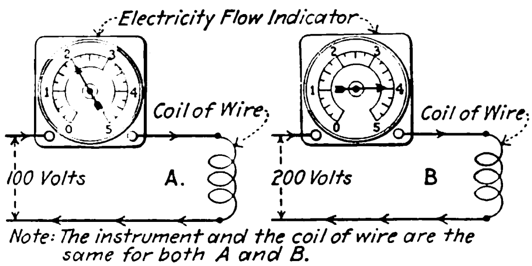


FIG. 6.—Illustrating the effect of increasing electric pressure.

up and down so as to cut the lines of force between the poles of the magnet an e.m.f. will be generated. This illustrates the principle of the dynamo and the principle of the cheapest way to generate an e.m.f. if a large quantity of electricity is required. (3) *By dielectric flux.* Illustrations are the e.m.f. generated by rubbing a comb through the hair, and that generated by the slipping of a belt on a pulley. The electricity produced is called static electricity. This method is of little commercial importance.

15. **Hydraulic Analogy of e.m.f.**—The number of gallons per second (Timbie's Elements of Electricity) of water flowing

through a pipe depends, to a large extent on the hydraulic pressure on the pipe. (Water pressure is measured in pounds per square inch.) Similarly, electric pressure or e.m.f., measured in volts, causes electricity to flow. A volt means somewhat the same thing in speaking of a flow of electricity as a pound pressure does in speaking of a flow of water. A higher hydraulic pressure is required to force a given amount of water through a small pipe than through a large one. Similarly a higher voltage is required to force a given

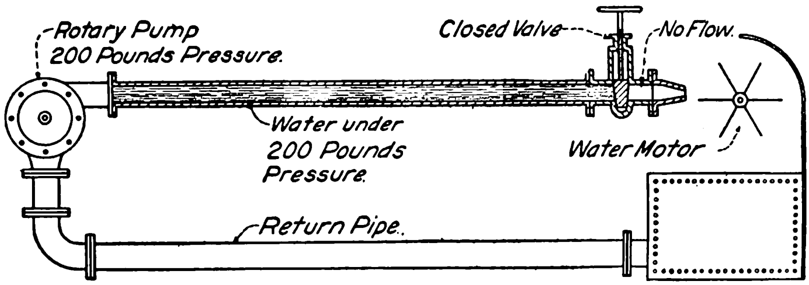


FIG. 7.—Water flow blocked by a closed valve.

amount of electricity through a small wire than through a large one. If the voltage impressed on a circuit is increased the current will be correspondingly increased. See Fig. 6.

16. **The distinction between amperes and volts** should (Timbie) be clearly understood. The amperes represent the rate of electricity flow (see Par. 12) through a circuit while the volts represent the pressure causing the flow. In the case of both electricity and water there may be great pressure and yet no current. If the path of the water is blocked by a closed valve (Fig. 7) there

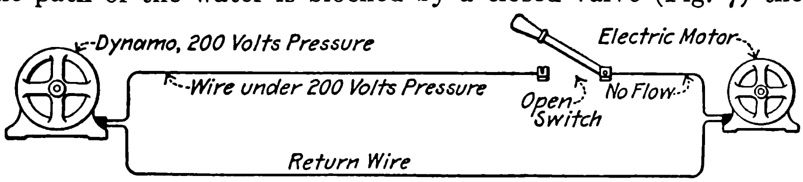


FIG. 8.—Electricity flow blocked by an open switch.

will be no current (flow of water)yet there may be high pressure. If the path of electricity is blocked by an open switch, Fig. 8, there will be no current of electricity, though the pressure (voltage) might be high. Furthermore, it is evident that, with a given hydraulic pressure, more water will flow through a large pipe than through a small one. Similarly with a given voltage, more electricity will flow through a large wire than through a small one.

17. **Resistance** is the physical property of a material by virtue of which it opposes the flow of an electric current. **The ohm** is the practical unit of resistance. If a pressure of 1 volt is impressed on a circuit and 1 ampere flows, that circuit has a resistance of 1 ohm. A column of mercury 106.3 cm. long, having a cross-sectional area of 1 square millimeter will have a resistance of 1 ohm. A piece of No. 10 copper wire 1000 ft. long has a resistance of almost exactly 1 ohm.

18. **A resistor** is an object having resistance; specifically, a resistor is a conductor inserted in a circuit to introduce resistance. **A rheostat** is a resistor so arranged that its effective resistance can be varied.

19. **What Determines Resistance.**—The amount of resistance offered to the flow of water through a pipe or to the flow of electricity through a conductor is determined by somewhat analogous properties of the pipe and of the conductor respectively, as follows:

20. Properties Determining Flow

Of water through a pipe	Of electricity through a wire
1. Diameter of pipe. 2. Length of pipe. 3. Material of pipe and its internal smoothness.	1. Diameter of wire. 2. Length of wire. 3. Material of wire and its temperature.

With both electricity and water flow (assuming a constant pressure) the longer the wire or pipe the less the flow; the smaller the diameter of wire or pipe, the less the flow and vice versa.

21. **The resistances of different materials** vary greatly. Some, such as the metals, conduct electricity very readily, hence are called conductors. Others such as wood or slate are, at least when moist, partial conductors. Still others, such as glass, porcelain and paraffin, are called insulators because they are practically non-conducting. No material is a perfect conductor and no material is a perfect insulator.

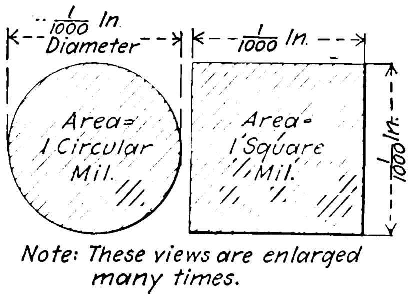


FIG. 9.—Circular mil and square mil.

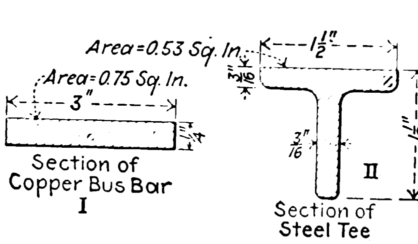


FIG. 10.—Conductor sections.

22. **A circular mil** is the area of a circle $\frac{1}{1000}$ in. in diameter. A mil is $\frac{1}{1000}$ of an inch. See Fig. 9. The areas of electric conductors are usually measured in cir. mils. Since the area of any figure varies as the square of its similar dimensions, the area of any circle can be expressed in cir. mils by squaring its diameter expressed in thousandths. Thus, since $\frac{3}{8} = \frac{375}{1000} = 0.375$, the area of a circle $\frac{3}{8}$ in. in diameter would be $375 \times 375 = 140{,}625$ cir. mils. The area of a circle 0.005 in. diameter would be $5 \times 5 = 25$ cir. mils.

23. **A square mil** is the area of a square having sides $\frac{1}{1000}$ in. long. See Fig. 9. Areas of rectangular conductors are sometimes measured in square mils. Areas in sq. mils are obtained by multiplying together the length and breadth of the rectangle expressed in thousandths of an inch. Thus, the area of a rectangle $\frac{1}{2}$ in. wide and 2 in. long would be $500 \times 2000 = 1{,}000{,}000$ sq. mils. In actual area, a circular mil is about $\frac{8}{10}$ as great as a square mil.

24. **To reduce square mils or square inches to circular mils or the reverse** use the following formulas:

$$\text{Sq. mils} = \text{cir. mils} \times 0.7854$$

$$\text{Cir. mils} = \frac{\text{sq. mils}}{0.7854}$$

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854}$$

$$\text{Sq. in.} = \text{cir. mils} \times 0.0000007854$$

Example.—The sectional area of the bus bar, in Fig. 10, I, is in cir. mils:

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} = \frac{3 \times \frac{1}{4}}{0.0000007854} = \frac{0.75}{0.0000007854} = 955{,}000 \text{ cir. mils.}$$

Example.—The sectional area of the steel tee, shown in Fig. 10, II, in cir. mils is:

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} = \frac{0.53}{0.0000007854} = 674{,}800 \text{ cir. mils.}$$

25. **The circular mil-foot** (cir. mil-ft.) is the unit conductor. A wire having a sectional area of one circular mil and a length of one foot is a cir. mil-ft. of conductor. The resistance of a cir. mil-ft. of a metal is sometimes called its **specific resistance** or **its resistivity.** The resistance of a cir. mil-ft. of copper under different conditions is given in Fig. 11. Resistances for other metals and alloys are given in Table 28.

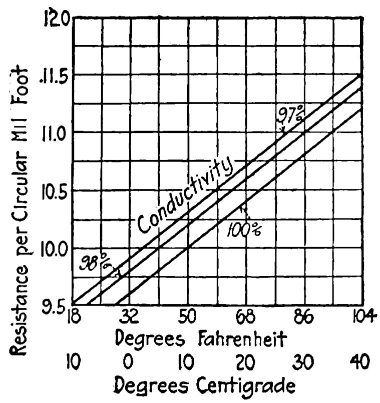


FIG. 11.—Curves showing resistance per circular mil-foot of pure copper at various temperatures and conductivities.

26. **To obtain the resistance of a conductor of any common metal or alloy** use the value given for the resistance of a cir. mil-ft. of the material in Table 28 in the following formula:

$$R = \frac{p \times l}{\text{cir. mils}} \quad \text{or} \quad \frac{p \times l}{d^2}$$

Wherein R = resistance of the conductor in ohms, p = resistance of a cir. mil-ft. of the material composing the conductor, from Table 28, l = length of conductor in feet, d = diameter in mils and d^2 = diameter in mils squared or, what is the same thing, the area of the conductor in circular mils. The other forms of the formula are:

$$p = \frac{d^2 \times R}{l} \qquad l = \frac{d^2 \times R}{p} \qquad d = \sqrt{\frac{p \times l}{R}}$$

Example.—Taking from the Table 29 the resistance of a cir. mil-ft. of copper at 23° C. (75° F.) as 10.5 ohms, what is the resistance of 500 ft. of copper wire, 0.021 in. diameter?

Solution.—Substituting in the formula:

$$R = \frac{pl}{d^2} = \frac{10.5 \times 500}{21 \times 21} = \frac{5250}{441} = 11.9 \text{ ohms.}$$

27. **The resistances of conductors that are not circular in section can be computed** by first getting their areas in sq. in. and then reducing this sq. in. value to cir. mils as indicated above. Then proceed with the formula in the preceding paragraph.

28. Approximate Specific Resistances and Temperature Coefficients of Metals and Alloys

(International Textbook Company—Electrical Engineer's Handbook)

Metal	ρ Resistance of 1 cir. mil-foot in ohms		a Average temperature coefficient per degree C. between 0° and 100° C.	a Average temperature coefficient per degree F. between 32° and 212° F.	Percentage conductivity	Relative resistance
	0° C. or 32° F.	23.8° C. or 75° F.				
Silver, pure annealed	8.831	9.674	0.004000	0.002220	108.60	0.925
Copper, pure annealed	9.390	10.351	0.004280	0.002380	102.10	0.980
Copper, annealed	9.590	10.505	0.004020	0.002230	100.00	1.000
Copper, hard-drawn	9.810	10.745	0.004020	0.002230	97.80	1.022
Gold (99.9% pure)	13.216	14.404	0.003770	0.002090	72.55	1.378
Aluminum (99.5% pure)	15.219	16.758	0.004230	0.002350	63.00	1.587
(Commercial—97.5% pure)	16.031	17.699	0.004350	0.002420	59.80	1.672
Zinc (very pure)	34.595	37.957	0.004060	0.002260	27.72	3.608
Iron, (approx. pure)	54.529	62.643	0.006250	0.003470	17.50	5.714
Iron "E. B. B." iron wire	58.702	65.190	0.004630	0.002570	16.20	6.173
Platinum (pure)	65.670	71.418	0.003669	0.002038	14.60	6.845
Iron, "B. B." iron wire	68.680	76.270	0.004630	0.002570	13.50	7.407
Nickel	74.128	85.138	0.006220	0.003460	12.94	7.726
Tin (pure)	78.489	86.748	0.004400	0.002450	12.22	8.184
Steel (wire)	81.179	90.150	0.004630	0.002570	11.60	8.621
Substance						
Brass	43.310	....	....	....	22.15	4.515
Phosphor-bronze	51.005	....	0.000640	0.000356	18.80	5.319
Aluminum bronze	73.989	....	0.001000	0.000556	12.96	7.714
German silver *Cu* 50, *Zn* 35, *Ni* 15	127.800	....	0.000400	0.000220	7.50	17.300
Platinoid, *Cu* 59, *Zn* 25.5, *Ni* 14, *W* (tungsten) 55	251.030	....	0.000310	0.000172	3.82	26.180
Manganin *Cu* 84, *Ni* 4, *Mn* 12	280.790	....	0.000000	....	3.41	29.330
Constantan, *Cu* 58, *Ni* 41, *Mn* 1	{300.77 / 312.80}	....	±0.000010	0.000005	{3.19 / 3.07}	{31.35 / 32.57}
Gray cast iron	684.000	....	....	....	....	....

29. Change of Resistance with Change of Temperature.—The resistance of all pure metals increases as they become hot. The resistance of certain alloys is not affected by the temperature. In wiring for light and power, changes in resistance due to changes in temperature are so slight that they may be wholly disregarded. Sometimes, with electrical machinery, changes in resistance due to changes in temperature may be of importance, in that speeds, voltages or currents may be appreciably affected thereby. The proportion that resistance increases per degree rise in temperature is called the **temperature coefficient of resistance.** See Table 28 for values. For all pure metals, the coefficient is practically the same and is 0.004 for temperatures in degrees Centigrade and 0.0023 for temperatures in degrees Fahrenheit.

30. To find the resistance of a conductor at any ordinary temperature, use this formula:

$$R_h = R_c + a \times R_c\ (T_h - T_c) \text{ or } T_h - T_c = \frac{R_h - R_c}{a \times R_c}$$

Wherein R_h = resistance in ohms hot, R_c = resistance in ohms cold, T_h = temperature of conductor hot, in degrees, T_c = temperature of conductor cold in degrees and a = the temperature coefficient of the material of the conductor from Table 28. (This is an approximate method, but it is sufficiently accurate for all ordinary work.)

Example.—The resistance of a cir. mil-ft. of annealed copper is 9.59 ohms at 32° F. What will its resistance be at 75° F.?

Solution.—From Table 28 the coefficient is 0.00223. Substitute in the formula:

$$\begin{aligned} R_h = R_c + a \times R_c(T_h - T_c) &= 9.59 + 0.00223 \times 9.59(75 - 32) \\ &= 9.59 + 0.00223 \times 9.59 \times 43 \\ &= 9.59 + 0.92 \\ &= 10.51 \text{ ohms, at } 75° \text{ F.} \end{aligned}$$

31. The Temperature Rise in a Conductor can be Determined with the above Formula by Measuring Hot and Cold Resistance.—The expression "$T_h - T_c$" is the difference between the hot and cold temperature and is therefore the temperature rise or fall.

Example.—The resistance of a set of copper coils measured 20 ohms at a room temperature of 20° C. After carrying current for some time the resistance measured 20.78 ohms. What was the temperature rise in the coil?

Solution.—The temp. coef. of copper per degree C. is, from Table 28, 0.004. Substitute in the formula:

$$T_h - T_c = \frac{R_h - R_c}{aR_c} = \frac{20.78 - 20.0}{0.004 \times 20} = \frac{0.78}{0.08} = 9.75° \text{ C.}$$

Therefore the average temperature rise in the coil was $9\frac{3}{4}$° C.

32. Contact resistance is the resistance at the point of contact of two conductors. Heat is always developed at such a point when current flows. The greater the clamping pressure between the conductors in contact and the greater the area of contact, the less the contact resistance will be. The nature of the surfaces in contact must also be considered. Smooth surfaces have less contact resistance than do rough surfaces. Contacts should always be so designed that, for a given current, the area of contact will be large enough that the contact resistance will not be so great as to cause excessive heating. Table 33 indicates safe values.

33. Safe Current Densities for Electrical Contacts and for Cross Sections

Kind of contact	Material	Current density: Amperes per square inch	Current density: Square mils per ampere
Sliding contact (brushes)	Copper brush	150 to 175	5700 to 6700
	Brass gauze brush	100 to 125	8000 to 10000
	Carbon brush	30 to 40	25000 to 33300
Spring contact (switch blades)	Copper on copper	60 to 80	12500 to 16700
	Composition on copper	50 to 60	16700 to 20000
	Brass on brass	40 to 50	20000 to 25000
Screwed contact	Copper to copper	150 to 200	5000 to 6700
	Composition to copper	125 to 150	6700 to 8000
	Composition to composition	100 to 125	8000 to 10000
Clamped contact	Copper to copper	100 to 125	8000 to 10000
	Composition to copper	75 to 100	10000 to 13000
	Composition to composition	70 to 90	11000 to 14000
Fitted contact (taper plugs)	Copper to copper	125 to 175	5700 to 8000
	Composition to copper	100 to 125	8000 to 10000
	Composition to composition	75 to 100	10000 to 13000
Fitted and screwed contact	Copper to copper	200 to 250	4000 to 5000
	Composition to copper	175 to 200	5000 to 5700
	Composition to composition	150 to 175	5700 to 6700
Cross section	Copper wire	1200 to 2000	500 to 800
	Copper wire cable	1000 to 1600	600 to 1000
	Copper rod	800 to 1200	800 to 1200
	Composition casting	500 to 700	1400 to 2000
	Brass casting	300 to 400	2500 to 3300
	Brass rod	575 to 750	1300 to 1700

34. **Ohm's Law.**—There is a simple relation between the electromotive force (volts), the current (amperes) and the resistance (ohms) in an electric circuit. This relation is expressed by Ohm's law, viz: *The electric current in a conductor equals the electromotive force divided by the resistance.* Expressing this law in symbols:

$$I = \frac{E}{R} \qquad \text{or} \qquad R = \frac{E}{I} \qquad \text{or} \qquad E = I \times R$$

Wherein, I = the current in amperes, E = the electromotive force in volts and R = the resistance in ohms.

In the above form, Ohm's law applies only to direct-current circuits or non-inductive alternating-current circuits. Where inductive alternating-current circuits are involved it must be modified before application. See index.

35. **In applying Ohm's law** many errors are made. It can be applied to an entire circuit or to only a portion of a circuit. When applied to an entire circuit (Timbie): *The current (amperes) in the entire circuit equals the voltage across the entire circuit divided by the resistance (ohms) of the entire circuit.* Note that the word *entire* applies to current, voltage and resistance alike. When applied to but part of a circuit (Timbie): *The current in a certain part of a*

circuit equals the voltage across that same part divided by the resistance of that part.

36. Examples of the Application of Ohm's law.

Example.—What will be the current in the circuit of Fig. 12?

Solution.—An entire circuit is shown. It is composed of a dynamo, line wires and a resistance coil. The e.m.f. developed by the dynamo (do not confuse this with the e.m.f. impressed by the dynamo on the line), is 120 volts. The resistance of the entire circuit is the sum of the resistances of dynamo, line wires and resistance coil. Substituting in the formula:

$$I = \frac{E}{R} = \frac{120}{1+1+9+1}$$
$$= \frac{120}{12} = 10 \text{ amp.}$$

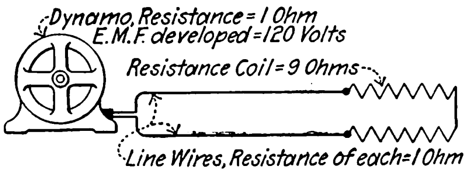


FIG. 12.—An entire dynamo circuit.

Example.—What current will flow in the circuit of Fig. 13?

Solution.—This again is an entire circuit. Substituting in the formula:

$$I = \frac{E}{R} = \frac{1}{0.5+0.5+2+0.5}$$
$$= \frac{1}{3.5} = 0.28 \text{ amp.}$$

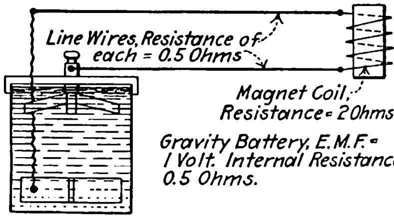


FIG. 13.—An entire battery circuit.

Note that the internal resistance of the battery must be considered.

Example.—With 10 amp. flowing, what will be the voltage or drop across each of the line wires in Fig. 14?

Solution.—Each has a resistance of 0.1 ohm, hence

$$E = I \times R = 10 \times 0.1 = 1 \text{ volt.}$$

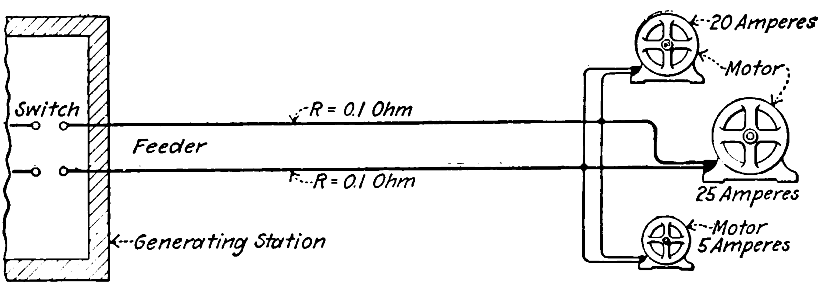


FIG. 14.—Feeder to motors.

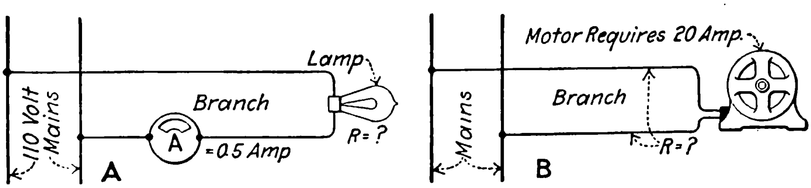


FIG. 15.—Portions of circuits.

Example.—What is the resistance of the incandescent lamp of Fig. 15? It is tapped to a 110-volt circuit and the ammeter reads 0.5 amperes. The branch wires are so short that their resistance can be neglected.

Solution.—Substitute in the formula:

$$R = \frac{E}{I} = \frac{110}{0.5} = 220 \text{ ohms.}$$

Example.—The motor of Fig. 15*B* takes 20 amperes and the drop in voltage in the branch wires should not exceed 5 volts. What is the greatest resistance that can be permitted in the branch conductors?

Solution.—Substitute in the formula:

$$R = \frac{E}{I} = \frac{5}{20} = 0.25 \text{ ohms.}$$

This (0.25 ohm) is the resistance of both wires. Each would have a resistance of 0.125 ohm.

Example.—The arc lamp Fig. 16 takes 5 amperes. The resistance of each branch wire is 0.1 ohm. What will be the drop in volts in each branch wire?

Solution.—Substitute in the formula:

$$E = R \times I = 0.1 \times 5 = 0.5 \text{ volts.}$$

In both branch wires or in the branch circuit the volts lost would be $2 \times 0.5 =$ 1 volt.

Example.—Three motors (Fig. 14) taking respectively 20 amperes, 25 amperes and 5 amperes (these values were stamped on the name plates of the motors) are located at the end of a feeder having a resistance of 0.1 ohm on each side. What will be the volts drop in the feeder?

Solution.—Substitute in the formula:

$$E = R \times I = (0.1 + 0.1) \times (20 + 25 + 5) = 0.2 \times 50 = 10 \text{ volts.}$$

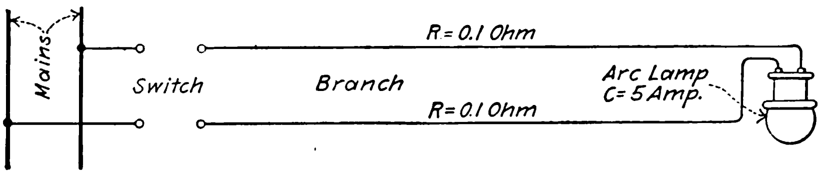


FIG. 16.—Portion of a circuit.

37. **Power in direct-current circuits** is equal to the product of volts and amperes. (For "power in other alternating-current circuits" see index.) Expressing this as a formula:

$$P = I \times E \qquad P = \frac{E^2}{R} \qquad P = I^2 \times R$$

and also

$$I = \frac{P}{E} \qquad I = \sqrt{\frac{P}{R}} \qquad E = \frac{P}{I} \qquad E = \sqrt{R \times P}$$

$$R = \frac{E^2}{P} \qquad R = \frac{P}{I^2}$$

Wherein, I = current in amperes, E = voltage or electromotive force in volts, R = resistance in ohms and P = the power in watts.

38. **In applying the above equations** be careful that the values of current, voltage, and resistance used in any one problem all apply to the same circuit or to the same portion of a circuit.

Example.—How many watts are consumed by the incandescent lamp in Fig. 17?

Solution.—Substitute in the formula:

$$P = I \times E = 5 \times 110 = 55 \text{ watts.}$$

Example.—How many watts are taken by the motor of Fig. 18? How many kw.? How many h.p.?

Solution.—Substitute in the formula:

$$P = I \times E = 70 \times 220 = 15{,}400 \text{ watts.}$$

$$\text{kw.} = \frac{\text{watts}}{1000} = \frac{15400}{1000} = 15.4 \text{ kw.}$$

$$\text{h.p.} = \frac{\text{watts}}{746} = \frac{15400}{746} = 20.6 \text{ h.p.}$$

Example.—In the transmission line of Fig. 19, what amount of power will be lost in the line wires to the motor?
Solution.—Substitute in the formula:

$$P = I^2 \times R = (40 \times 40) \times (0.3 + 0.3) = 1600 \times 0.6 = 960 \text{ watts.}$$

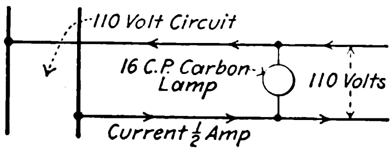


FIG. 17.—Incandescent lamp branch circuit.

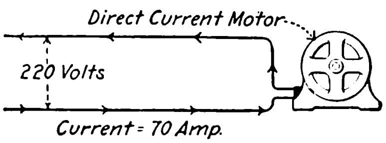


FIG. 18.—Electric motor.

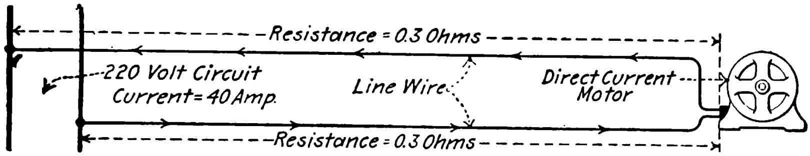


FIG. 19.—Transmission line.

39. Watts, Kilowatts and Horse-power.—One horse-power equals 746 watts, therefore:

$$\text{h.p.} = \frac{\text{watts}}{746} = \text{watts} \times 0.0013 \qquad \text{watts} = \text{h.p.} \times 746$$

$$\text{h.p.} = \frac{\text{kw.}}{0.746} = \text{kw.} \times 1.34 \qquad \text{kw.} = \text{h.p.} \times 0.746.$$

Example.—Watts = 2460, h.p. = ?.
Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{\text{watts}}{746} = \frac{2460}{746} = 3.3 \text{ h.p.}$$

Example.—A motor takes 30 kw. How many horse-power is it taking?
Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{\text{kw.}}{0.746} = \frac{30}{0.746} = 40.2 \text{ h.p.}$$

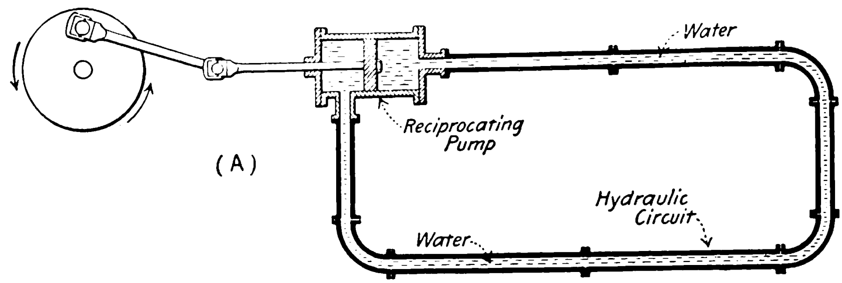
or

$$\text{h.p.} = \text{kw.} \times 1.34 = 30 \times 1.34 = 40.2 \text{ h.p.}$$

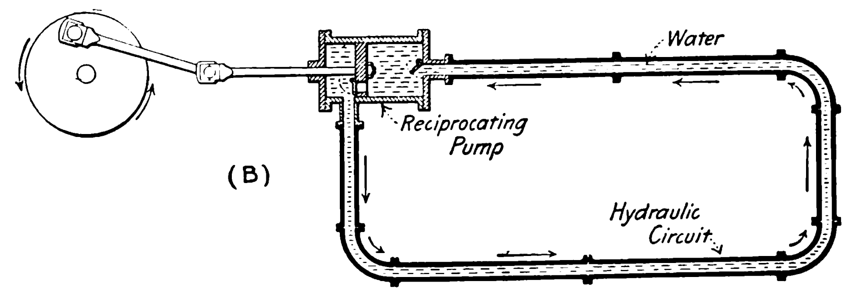
40. An alternating current is one that reverses in direction at regular intervals. In Fig. 20*A* as the hydraulic pump operates, the current of water will flow back and forth through the pipe. This action is analogous to that of an alternating current of electricity. With the arrangement of Fig. 20*B*, corresponding to a direct-current circuit, the current of water will always be in the same direction. For a true analogy the pump of Fig. 20*B* should be of the centrifugal type because with that type the hydraulic pressure is constant. With the reciprocating pump of Fig. 20*B* the water pressure (corresponding to the voltage of an electric circuit) would vary, although it would always be in the same direction. In the ordinary direct-current circuit the pressure is constant.

41. A cycle is a complete set of values through which an alternating current repeatedly passes. See Fig. 21. The expression "60 cycles per second means that the current referred to makes 60 complete cycles in a second. It therefore requires $\frac{1}{60}$ second to complete 1 cycle. See Fig. 21. With a 25-cycle current, $\frac{1}{25}$ second is required to complete 1 cycle. See Fig. 22.

42. **The frequency** of an alternating current is the number of cycles completed in a second. A frequency of 60 cycles (Fig. 21) is common for lighting and power installations while (Fig. 22) 25 cycles is used for power transmission. When used for lighting,



Hydraulic Analogy to Alternating Current Generator and Circuit.



Hydraulic Analogy to Direct Current Generator and Circuit.

FIG. 20.—Hydraulic analogies.

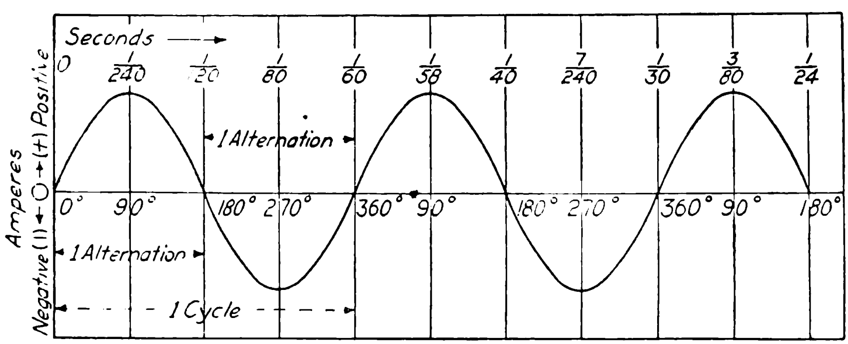


FIG. 21.—Curve of a 60-cycle alternating current.

there is sometimes a flickering of incandescent lamps on 25 cycles. Some arc lamps do not operate well on 25 cycles. Frequencies much lower than 25 cycles cannot be used for incandescent lighting. Some of the older stations generate at 125 or 133 cycles and 15 cycles has been used for railway work.

43. **The word "phase,"** when properly used in alternating-current terminology, refers to time. When two alternating currents are in phase they reach their corresponding zero, maximum and intermediate values at exactly the same instants. If currents or voltages are not in phase they reach corresponding values at different instants.

A three-phase current consists of three different alternating currents out of phase 120 degrees (which are really time degrees—

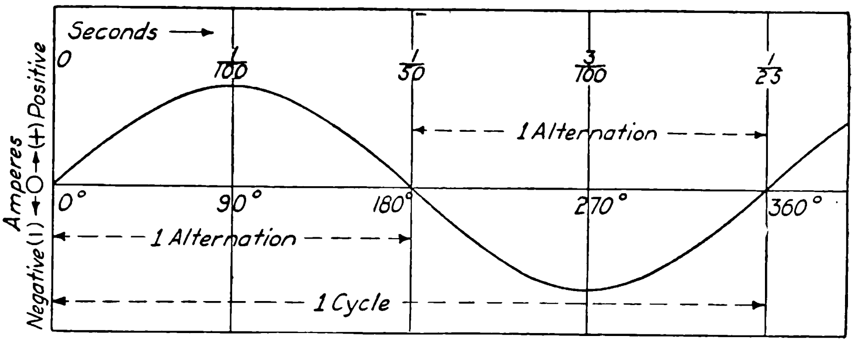


FIG. 22.—Curve of a 25-cycle alternating current.

each degree representing a certain definite amount of time) with each other. A two-phase current consists of two different alternating currents out of phase 90 degrees (which represents a certain definite amount of time) with each other.

Sometimes each of the three wires of a three-phase circuit is called a "phase wire" or for short a "phase." Also, any pair of wires of a polyphase circuit across which the normal voltage of the circuit should exist is sometimes referred to as a "phase" of the circuit.

44. **The effective value of an alternating current** is that value which will produce the same heating effect as will the same intensity of direct current. Measuring instruments indicate effective values. An effective alternating current of 10 amp. will produce the same heating effect as 10 amp., direct current. A similar statement is true for any other values of alternating and direct currents. Alternating e.m.fs. and currents are constantly changing in value, within a certain range, from instant to instant even if the load is constant. It is not practicable to deal with or indicate with instruments these constantly changing values. Effective values are ordinarily referred to when speaking of alternating currents. The practical man deals almost exclusively with effective values. See Fig. 23. Effective values are sometimes called virtual values.

45. **The maximum value of an alternating current or voltage** is the greatest value that it attains. This is an instantaneous value. See Fig. 23.

$$\text{Effective value} = 0.707 \times \text{maximum value}$$

$$\text{Maximum value} = \frac{\text{effective value}}{0.707}$$

Example.—What is the effective voltage of a circuit that has a maximum voltage of 156?

Solution.—Substitute in the formula:

Effective value $= 0.707 \times$ maximum value $= 0.707 \times 156 = 110$ volts.

Example.—If a voltmeter on an alternating-current circuit reads 2200, what is the maximum instantaneous voltage?

Solution.—Substitute in the formula:

$$\text{Maximum value} = \frac{\text{Effective value}}{0.707} = \frac{2200}{0.707} = 3110 \text{ volts.}$$

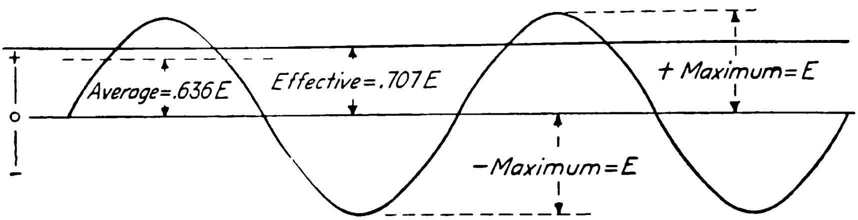


FIG. 23.—Alternating electromotive-force values.

46. The instantaneous value of an alternating current or voltage is its value at some designated instant or, in other words, at some designated point in its cycle.

47. The effect of resistance in alternating-current circuits is the same as in direct-current circuits and Ohm's law is used in calculating its effect. This is true only when there is no inductance or permittance (capacity) in the circuit.

48. The power loss in any conductor traversed by an alternating current or a direct current is

$$P = I^2 \times R \text{ or } I = \sqrt{\frac{P}{R}} \text{ or } R = \frac{P}{I^2}$$

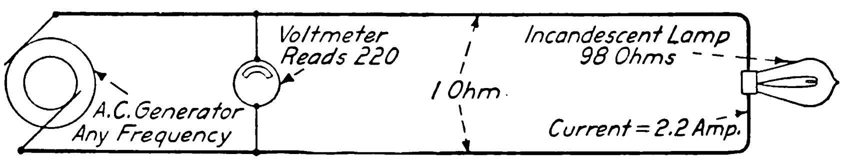


FIG. 24.—Resistance in an alternating-current circuit.

Wherein P = the power lost in the conductor in watts, I = current in amperes in the conductor and R = resistance of conductor in ohms. This rule is perfectly general and applies to all direct current circuits and all alternating-current circuits of ordinary voltages and frequencies. The watts power loss, P, reappears as heat power and heats the conductors. See 304 and 305 for another way of stating this law.

Example.—What is the power loss in the incandescent lamp in Fig. 24?

Solution.—Substitute in the formula:

$$P = I^2 \times R = (2.2 \times 2.2)98 = 4.84 \times 98 = 474 \text{ watts.}$$

Example.—What is the power loss in the inductive winding of Fig. 25, with an alternating current of 3 amp.?

Solution.—Substitute in the formula:

$$R = I^2 \times R = (3 \times 3)7 = 9 \times 7 = 63 \text{ watts.}$$

49. Inductance in alternating-current circuits has very pronounced effects. When an alternating current flows through an inductance a counter e.m.f. is generated. This counter e.m.f. opposes the e.m.f. developed by the generator, with the result that the active e.m.f., that which actually forces current through the circuit, is less than the impressed e.m.f. The amount that it is less depends on the amount of inductance. The subject is too complicated for a full discussion here. The practical man can calculate his circuits with the formulas found in this book without a thorough understanding of the matter.

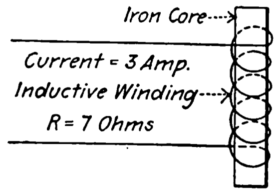


FIG. 25.—Inductive resistance in an alternating-current circuit.

50. Impedance is the name given to that quantity which represents the combined resisting effect of actual (ohmic) resistance and of the inductive resistance (reactance). If impedance in ohms is multiplied by current in amperes the resulting value will be the impressed e.m.f.

51. Power in Alternating-current Circuits.—Power factor is the ratio of true watts to apparent watts in an alternating-current circuit. It is the number by which the apparent power must be multiplied to obtain the real power. Power factor is usually expressed in a per cent. and cannot be greater than 100 per cent.

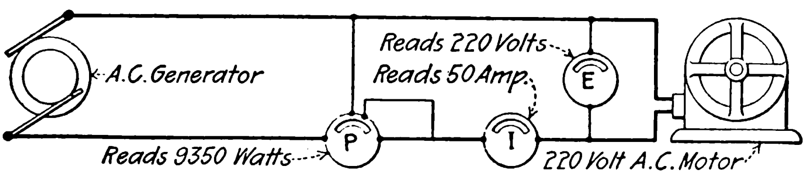


FIG. 26.—Example of power factor.

For Example.—In Fig. 26, which shows a single-phase circuit, the ammeter, I, reads 50 amp. and the voltmeter, E, 220 volts. The apparent power is the product of volts and amperes or $IE = 50 \times 220 = 11000$ watts. But the wattmeter, P, reads 9350 watts. A wattmeter always indicates real or true power. Therefore the power factor (for a single-phase circuit) =

$$\text{power factor} = \frac{\text{true watts}}{\text{apparent watts}} = \frac{9350}{11000} = 0.85 \text{ or } 85 \text{ per cent.}$$

52. The power factor in a non-inductive circuit, one containing resistance only, is always 1, or 100 per cent., that is, the product of volts and amperes in such a circuit gives true power.

53. The power factor in a circuit containing inductance or capacity may be anything between 0 and 1 (0 and 100 per cent.), depending on the amount of inductance or capacity in the circuit.

54. Effects of Low Power Factor (*General Electric Co. publication*).—It is usually considered that the wattless component of a current at low power factor is circulated without an increase of mechanical input over that necessary for actual power requirements. This is inaccurate because internal work or losses due to this extra current are produced and must be supplied by the prime mover. Since these extra losses manifest themselves in heat, the capacity of the machine is reduced. Also wattless components of current heat the line conductors, just as do energy components, and cause losses in them. The loss in any conductor is always (see 48)

$$P = I^2R$$

where P = the loss in watts, I = the current in amperes in the conductor and R = the resistance in ohms. However, the increase in losses in the generating equipment and line due to low power factor are usually relatively small and it can be said that very little more coal is burned to supply energy at low power factor than at high power factor. This statement is made with the assumption that the efficiency of the prime mover at different loads is constant.

55. Correction of Low Power Factor.—In industrial plants, excessively low power factor is usually due to underloaded induction motors because the power factor of motors is much less at partial loads than at full-load. Where motors are underloaded new motors of smaller capacity should be substituted. (See Induction Motors, Index.) Power factor can be corrected by installing synchronous motors (see Index) which, when overexcited, have the property of neutralizing the wattless or induction components of currents inherent to low power factor.

56. The Cosine of the Angle of Lag is Equal to the Power Factor.—Cosines for different angles can be found in trigonometric tables in handbooks. (See **10**.) The symbol ϕ, a Greek letter, pronounced phi, is often used to designate the angle of lag, hence power factor is sometimes referred to as "Cos ϕ" (Cosine phi). This means the cosine of the angle ϕ.

57. Typical power factors of various kinds of central-station loads as given by F. D. Newbury before the 1911 convention of the N.E.L.A. are given below.

INCANDESCENT LIGHTING WITH SMALL LOWERING TRANSFORMERS.—Power factor, 0.90 to 0.95.

ALTERNATING-CURRENT INCLOSED-ARC LAMPS WITH CONSTANT-CURRENT TRANSFORMERS.—Power factor, from 0.60 to 0.75, depending upon whether the transformers are carrying their rated number of lamps. Average 0.70.

DIRECT-CURRENT METALLIC-ARC LAMPS WITH RECTIFIERS.—Power factor, from 0.55 to 0.70, depending upon whether or not the rectifiers are carrying their rated number of lamps. Average 0.65.

SINGLE-PHASE INDUCTION MOTORS, SQUIRREL-CAGE ROTOR.—$\frac{1}{20}$ h.p. to 1 h.p., power factor, 0.55 to 0.75, average 0.68 at rated load; 1 h.p. to 10 h.p., power factor, 0.75 to 0.86, average 0.82, at rated load.

POLYPHASE INDUCTION MOTORS, SQUIRREL-CAGE ROTOR.—1 h.p. to 10 h.p., power factor, 0.75 to 0.91, average 0.85 at rated load; 10 h.p. to 50 h.p., power factor, 0.85 to 0.92, average 0.89, at rated load.

POLYPHASE INDUCTION MOTORS, PHASE-WOUND ROTORS.—5 h.p. to 20 h.p., power factor, 0.80 to 0.89, average 0.86 at rated load; 20 h.p. to 100 h.p., power factor, 0.82 to 0.90, average 0.87 at rated load.

INDUCTION MOTOR LOADS IN GENERAL.—Power factor, from 0.60 to 0.85, depending on whether motors are carrying their rated loads.

Rotary Converters, Compound Wound.—Power factor at full-load can be adjusted to practically 100 per cent. At light loads it will be lagging, and at overloads slightly leading.

Rotary Converters, Shunt Wound.—The power factor can be adjusted to any desired value, and will be fairly constant at all loads with the same field rheostat adjustment. Rotary converters, however, should not be operated below 0.95 power factor leading or lagging at full-load or overload.

Small Heating Apparatus.—This load has the same characteristics as an incandescent-lighting load. The power factor of the load unit is practically unity, but the distributing transformers will lower it to some extent.

Arc Furnaces.—Power factor, 0.80 to 0.90.

Induction Furnaces.—Power factor, 0.60 to 0.70.

Electric-welding Transformers.—Power factor, 0.50 to 0.70.

Synchronous Motors.—Adjustment between practically zero power factor leading to zero power factor lagging.

The author made the following general statements regarding probable power factors: (1) Operating power factors above 0.95 will be obtained only when practically all of the load is synchronous motors or converters which may be operated at practically unity power factor. Even with this character of load the generators should be capable of operating satisfactorily at 0.93 power factor to provide for unforeseen contingencies. (2) Power factors of 0.90 to 0.95 can be safely predicted only when the load is entirely incandescent lighting or heating, or if a large non-inductive load, such as synchronous motors or converters, is used with a smaller proportion of inductive motor load. (3) For the average central-station load, consisting of lighting and motor service, a power factor of 0.80 should be assumed. (4) A power factor of 0.70 should be assumed for a plant having a large proportion of induction motors, arc lighting, electric furnaces or electric welding load.

58. Kilowatts and Kilovolt-amperes (*General Electric Company*).—The term kilowatt (kw.) indicates the measure of power which is all available for work. Kilovolt-amperes (kva.) indicate the measure of apparent electrical power made up of two components, an energy component and a wattless or induction component. Kw. indicates real power and kva. apparent power. They are identical only when current and voltage are in phase, that is, when the power factor is 1. Ammeters and voltmeters indicate total effective current and voltage regardless of the power factor, while a wattmeter indicates the effective product of the instantaneous values of electromotive force and current. A wattmeter, then, indicates real power.

Standard guarantees on alternating-current generators are made on the basis of loads at 100 per cent. power factor, because this has seemed to be the best method, but it must not be inferred that a given generator will deliver its rated power output at all power factors. The generator rating in kw. will be reduced in proportion to the power factor and probably in a greater ratio if the power factor is very low. In general, a generator will carry a kva. load to the extent of its normal kw. rating if the power factor of the load is not below 80 per cent. The actual power output, however, must be reduced in proportion to the power factor. The method of rating alternating-current generators by kva. instead of by kw. is now in general use.

In discussing an alternating-current load, it is well to state it in terms of kw., power factor and kva. thus: 200 kw., 80 per cent. power factor (250 kva.). This shows that the current in the circuit corresponds to 250 kva. and heats the generator and conductors to that extent, but that only 200 kw. is available for doing work.

59. For a single-phase circuit the relations between kilowatts and kilovolt-amperes are:

$$\text{kilovolt-amperes} = \frac{\text{volts} \times \text{amperes}}{1000} \qquad \text{or kva.} = \frac{E \times I}{1000}$$

$$\text{kw.} = \text{kva.} \times \text{power factor} \qquad \text{kva.} = \frac{\text{kw.}}{\text{power factor}}$$

$$\text{power factor} = \frac{\text{kw.}}{\text{kva.}}$$

For an example see Fig. 27.

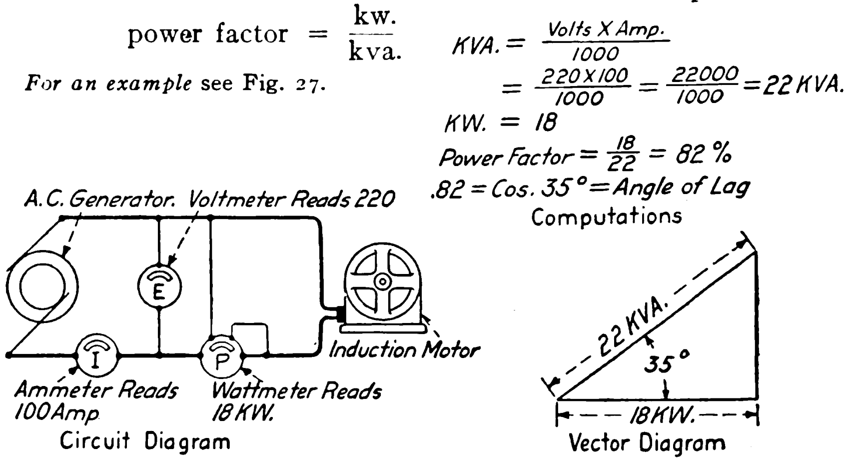


FIG. 27.—Illustrating the distinction between kw. and kva.

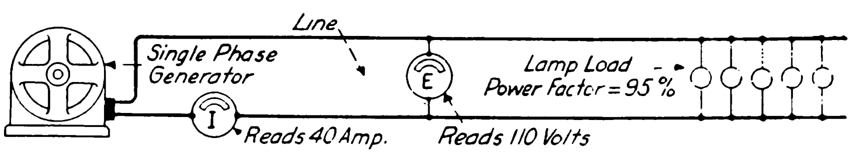


FIG. 28.—A power factor problem.

59A. For a single-phase circuit the following equations show the relations between power, current, voltage and power factor.

$$I = \frac{P}{E \times p.f.} \qquad E = \frac{P}{I \times p.f.} \qquad P = E \times I \times p.f. \qquad p.f. = \frac{P}{E \times I}$$

Wherein, I = current in amperes, P = power in watts, E = pressure in volts between lines and $p.f.$ = power factor.

Examples.—Figs. 27 and 28 show examples of the application of the above equations. The product of volts and amperes (EI) is called volt-amperes; see above paragraph.

Example.—In the circuit of Fig. 28, what is the actual load in watts? In kilowatts? Current = 40 amp., voltage at load = 110, power factor of load = 95 per cent.

Solution.—Substitute in the formula

$$P = E \times I \times p.f. = 110 \times 40 \times 0.95 = 4{,}180 \text{ watts}$$

$$\text{kw.} = \frac{\text{watts}}{1000} = \frac{4180}{1000} = 4.18 \text{ kw.}$$

60. **To find amperes in the line in single-phase circuits** (*Westinghouse Diary*) multiply the power in kilowatts by the value, for the proper voltage and power factor, shown in table 61.

61. Amperes per Phase per Kilowatt, Single-phase Circuits

Volts	Power factor			
	100 per cent.	90 per cent.	80 per cent.	70 per cent.
110	9.09	10.01	11.36	12.98
220	4.54	5.05	5.68	6.49
440	2.27	2.52	2.84	3.24
1,100	0.909	1.01	1.136	1.298
2,200	0.454	0.505	0.568	0.649

62. **A two-phase current** consists of two currents that differ in phase by 90°. See curves of Fig. 29. If two sets of coils are arranged on an armature (Fig. 29) so that the e.m.f. in one set will

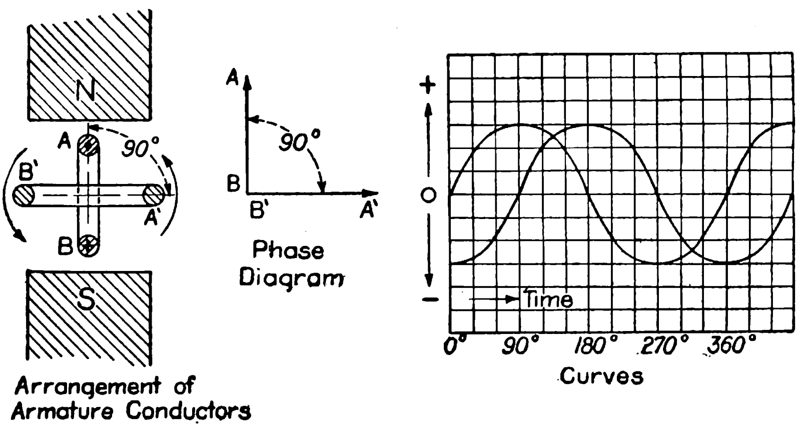


FIG. 29.—Diagrams for two-phase currents.

attain its maximum value 90° later than that in the other, the e.m.fs. will force two-phase currents through an external circuit. Instead of being on the same armature each of the sets of coils might be on different armatures which are so mechanically connected together as to preserve the 90° phase relation. (See section on "Motors and Generators" for information on practical machines.)

63. **Application of the Two-phase System.**—Several years ago certain engineers advocated two-phase generators and distributing systems in preference to three-phase, as it was believed that unbalanced load on the phases would have less adverse effect on the performance of the two-phase equipment. Recent experience

seems to indicate that the three-phase system is preferable to the two-phase for both transmission and distribution. It is seldom that two-phase equipment is now purchased except for additions to existing two-phase installations. See Par. 243 for relative weights of copper for different systems.

64. To find amperes per phase in two-phase circuits (*Westinghouse Diary*) multiply the load in kw. by the value in the following table corresponding to the proper power factor and voltage.

65. Amperes per Phase per Kilowatt, Two-phase Circuits

Volts	Power factor			
	100 per cent.	90 per cent.	80 per cent.	70 per cent.
110	4.54	5.04	5.67	6.48
220	2.27	2.52	2.83	3.24
440	1.13	1.26	1.41	1.62
1,100	0.454	0.504	0.567	0.648
2,200	0.227	0.252	0.283	0.324

66. A three-phase current consists of three alternating currents that differ in phase by 120°, as indicated in Fig. 30. If three coils be arranged 120° apart on an armature (Fig. 30) rotated in a mag-

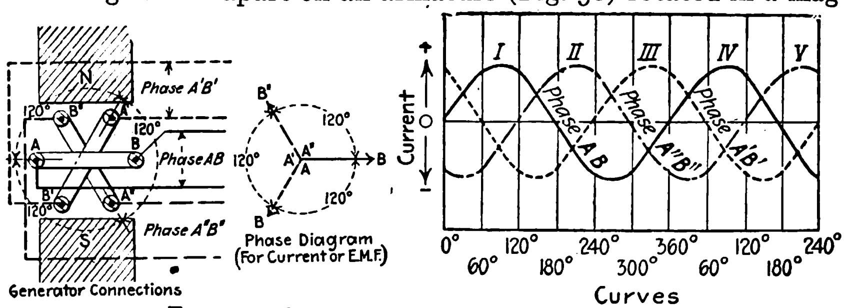


FIG. 30.—Principles of three-phase circuits.

netic field and connected (through collector rings not shown) each to an external circuit, an alternating e.m.f. will be impressed by each coil on its external circuit. The e.m.fs. will differ in phase by 120° and therefore will constitute a three-phase e.m.f. The currents in the circuits will constitute a three-phase current. Three single-phase generators, if mechanically coupled together so as to maintain a 120° phase relation, would produce a three-phase e.m.f. Practical three-phase generators usually have more than two poles and consequently have more coils than indicated in Fig. 30. Modern alternating-current generators have revolving fields and stationary armatures.

66A. Coil Connections.—Fig. 31 shows four methods of connecting three-phase generator (or other apparatus) coils and the external circuits for each. *Method I*, although it would work, is seldom if ever used for economic reasons hereinafter given. It shows the elementary three-phase circuit and illustrates the principle. Each of the three-phases would carry a current differing in phase by 120°

from the currents in the other two. One common return, as shown at *II* can be substituted for the three return wires of *I*. Now with a balanced load, *i.e.*, one loading each of the phases equally, this return wire would carry no current, hence it is usually omitted (**star** or **Y-connection** of *III*). In *IV* is shown the delta connection.

67. The voltage and current relations in a star or Y-connected three-phase circuit are indicated in Fig. 32. Although the armature coils of the generator are said to be 120° apart, when they are Y-connected as shown in *I*, the e.m.fs. in any two are 60° apart and

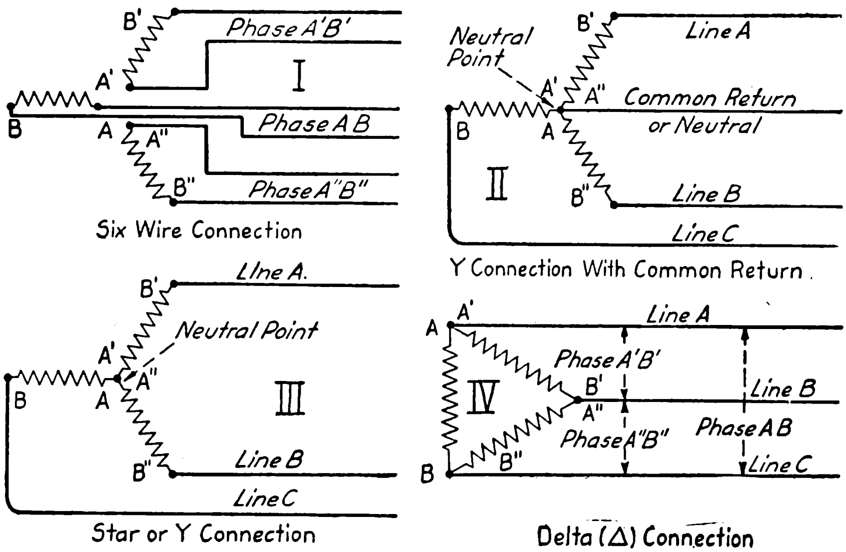


FIG. 31.—Connections for three-phase generator windings.

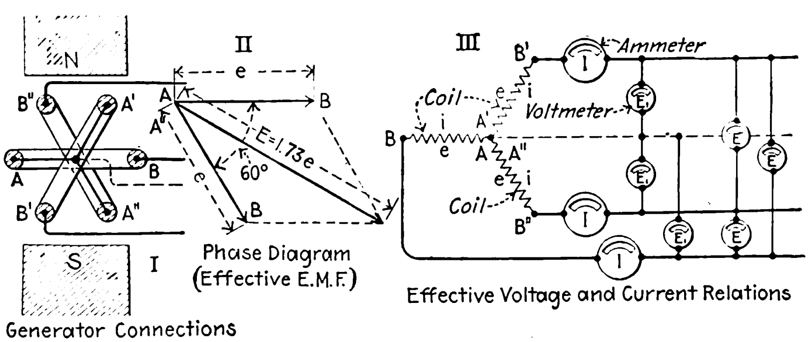


FIG. 32.—Properties of a star, or Y-connected three-phase circuit.

these e.m.fs. are added as shown in the *phase diagram II*. The sum of the voltages of any two coils is then equal to $\sqrt{3}$ or 1.73 times the voltage developed in 1 coil. The following formulas show the relation of voltage and current in the circuit. (All are effective values and balance is assumed.) See Fig. 32.

$$I = i$$
$$E = E_1 \times \sqrt{3} = E_1 \times 1.73$$
$$E_1 = \frac{E}{\sqrt{3}} = \frac{E}{1.73} = E \times 0.577 \text{ or approximately } E_1 = 0.58E$$
$$E_1 = e$$

Wherein I = amp. per phase in the line, i = amp. per phase in each coil, E = volts between phase wires on the line, e = volts across each group of armature coils connected across each phase, E_1 = volts between phase wires and neutral. The coils in Fig. 32 *III* may represent the phase windings of a three-phase generator or trans-

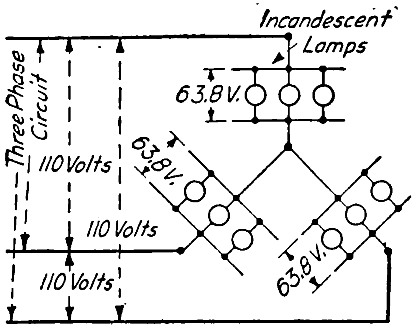


FIG. 33.—Y-connected incandescent lamps.

former, or each coil may represent a transformer or other device, three of which are Y-connected on a three-phase line.

Example.—What will be the voltage across each of the incandescent lamps, which are Y-connected across a 110-volt, three-phase circuit, in Fig. 33?

Solution.—Substitute in the formula:

$$E_1 = 0.58E = 0.58 \times 110 = 63.8 \text{ volts.}$$

68. Relations for a delta (Δ) connected, three-phase circuit are shown in Fig. 34. When armature coils of a generator, see *I*, are connected as indicated, the voltages generated in them are 120°

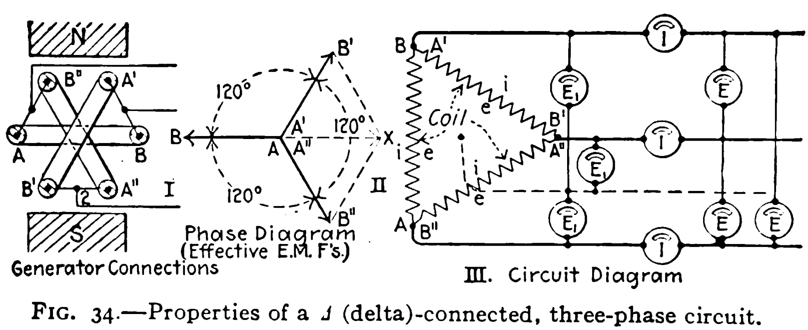


FIG. 34.—Properties of a Δ (delta)-connected, three-phase circuit.

apart. It would appear that the current might flow around through the coils and not into the external circuit, but it is evident from the phase diagram, *II*, that the sum of the effective voltages generated by two of the coils is equal and opposite to that of the third. Hence instead of tending to force current around internally, the voltages tend to force current out into the line. The following formulas indicate the relations of the voltages and currents. (All are effective values and the circuit is assumed to be balanced.) See Fig. 34.

$$I = i \times \sqrt{3} = i \times 1.73$$

$$i = \frac{I}{\sqrt{3}} = I \times 0.577 \text{ or approximately } i = I \times 0.58$$

$$E = e$$

$$E_1 = \frac{e}{\sqrt{3}} = e \times 0.577 \text{ or approximately } E_1 = e \times 0.58$$

Wherein the symbols have the same meanings as in the preceding paragraph.

Each coil (Fig. 34) may represent the phase windings of a three-phase transformer or generator or each coil may represent a transformer or other device three of which are Δ-connected on a three-phase line.

Example.—Each of the groups of incandescent lamps, delta-connected across the 110-volt, three-phase circuit of Fig. 35, takes 10 amp. What is the current in the line wires?

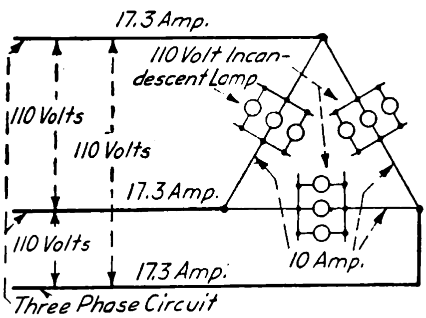


FIG. 35.—Delta (Δ)-connected incandescent lamps.

Solution.—Substitute in the formula:

$$I = i \times 1.73 = 10 \times 1.73 = 17.3 \text{ amp.}$$

69. Relations of voltage, current and power that apply to any three-wire three-phase circuit either Δ- or Y-connected.—Refer to Fig. 36 for a key to the letters that appear in the following formulas.

For a non-inductive load:

$$I = \frac{P}{E \times \sqrt{3}} = \frac{0.577 \times P}{E} \text{ or approximately } = \frac{0.58 \times P}{E}$$

$$E = \frac{P}{I \times \sqrt{3}} = \frac{0.577 \times P}{I} \text{ or approximately } = \frac{0.58 \times P}{I}$$

$$P = E \times I \times \sqrt{3} = 1.73 \times E \times I$$

For an inductive load:

$$p.f. = \frac{P}{1.73 \times I \times E} = \frac{0.577 \times P}{I \times E} \text{ or approximately } = \frac{0.58 \times P}{I \times E}$$

$$E = \frac{P}{p.f \times 1.73 \times I} = \frac{0.577 \times P}{p.f. \times I} \text{ or approximately } = \frac{0.58 \times P}{p.f. \times I}$$

$$I = \frac{P}{p.f. \times 1.73 \times E} = \frac{0.577 \times P}{p.f. \times E} \text{ or approximately } = \frac{0.58 \times P}{p.f. \times E}$$

$$P = 1.73 \times E \times I \times p.f.$$

Wherein $I=$ line current in amperes, $P=$ the power transmitted in watts, $E=$ voltage across lines and $p.f.$ is the power factor of the circuit.

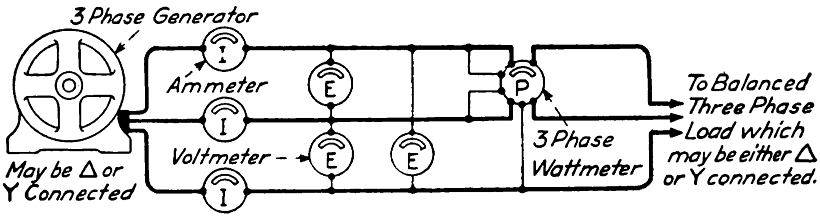


FIG. 36.—Relations for any (Δ- or Y-connected), three-phase circuit.

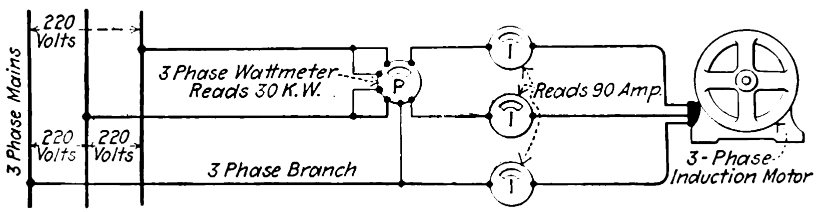


FIG. 37.—Motor on a three-phase circuit.

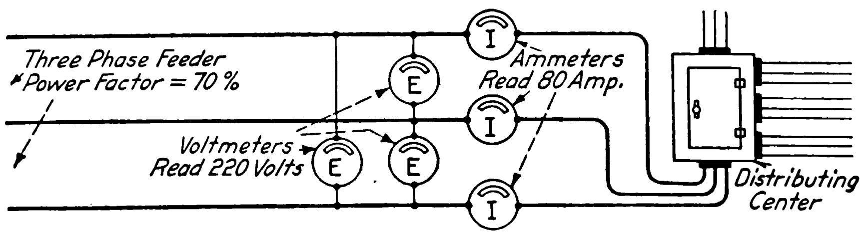


FIG. 38.—Load on a three-phase circuit.

Example.—What is the power factor in the 220-volt circuit to the motor in Fig. 37? The three ammeters each indicate 90 amp. and the three-phase wattmeter indicates 30 kw. (30,000 watts).

Solution.—Substitute in the formula:

$$p.f. = \frac{0.577 \times P}{I \times E} = \frac{0.577 \times 30{,}000}{90 \times 220} = \frac{17{,}310}{19{,}800} = 0.88 = 88 \text{ per cent. power factor.}$$

Example.—The power factor on the feeder of Fig. 38 is known to be 70 per cent. The current in each line is 80 amp. and the voltage across each phase is 220. What actual power is being delivered to the panel box?

Solution.—Substitute in the formula:

$$P = 1.73 \times E \times I \times p.f. = 1.73 \times 220 \times 80 \times 0.70 = 21313.6 \text{ watts}$$

$$kw. = \frac{\text{watts}}{1{,}000} = \frac{21313.6}{1{,}000} = 21.3 \text{ kw.}$$

Examples.—Fig. 39 shows some numerical examples of voltage and current relations in a three-phase circuit. For convenience the voltage on the main is taken as 100. For any other voltage the values given in the illustration would vary proportionally. For 200 volts they would be twice as great as

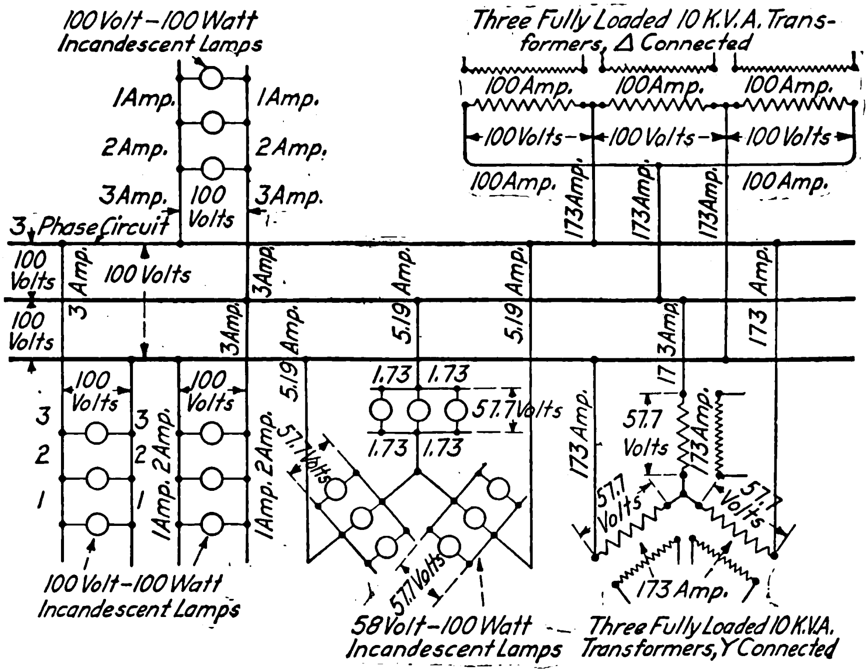


FIG. 39.—Examples of current and voltage relations with three-phase circuits.

shown, for 220 volts they would be 2.2 times as great, etc. Note that when a group of three devices is connected in Δ, each device has line voltage impressed on it and must be designed for that voltage; the current in the line will be 1.73 times the current through the device. When Y-connected, each of the three devices must be designed for $\frac{1}{1.73}$ or 0.577 times the line-voltage and the line current will be the same as the current through it.

70. To find amperes per phase in three-phase circuits multiply the load in kw. by the value in table 71 corresponding to the proper power factor and voltage.

71. Amperes per Kilowatt in Each Leg of a Balanced

Power factor	Volts between						
	100	110	125	200	220	250	440
50	11.55	10.50	9.24	5.77	5.25	4.62	2.62
51	11.32	10.29	9.06	5.66	5.15	4.53	2.57
52	11.10	10.09	8.88	5.55	5.05	4.44	2.52
53	10.89	9.90	8.72	5.44	4.95	4.36	2.47
54	10.69	9.72	8.55	5.34	4.86	4.28	2.43
55	10.50	9.54	8.40	5.25	4.77	4.20	2.38
56	10.31	9.37	8.25	5.15	4.69	4.12	2.34
57	10.13	9.21	8.10	5.06	4.60	4.05	2.30
58	9.96	9.05	7.96	4.98	4.53	3.98	2.26
59	9.79	8.90	7.83	4.89	4.45	3.92	2.22
60	9.62	8.75	7.70	4.81	4.37	3.85	2.18
61	9.46	8.61	7.57	4.73	4.30	3.79	2.15
62	9.31	8.47	7.45	4.65	4.23	3.72	2.11
63	9.17	8.33	7.33	4.58	4.16	3.67	2.08
64	9.02	8.20	7.22	4.51	4.10	3.61	2.05
65	8.88	8.07	7.10	4.44	4.03	3.55	2.02
66	8.75	7.95	7.00	4.37	3.97	3.50	1.99
67	8.62	7.83	6.89	4.31	3.91	3.45	1.96
68	8.49	7.72	6.79	4.24	3.86	3.40	1.93
69	8.37	7.61	6.69	4.18	3.80	3.34	1.90
70	8.25	7.50	6.60	4.13	3.75	3.30	1.87
71	8.13	7.39	6.50	4.06	3.69	3.25	1.85
72	8.02	7.29	6.41	4.01	3.64	3.20	1.83
73	7.91	7.19	6.33	3.95	3.59	3.16	1.80
74	7.80	7.09	6.24	3.90	3.54	3.12	1.77
75	7.70	7.00	6.16	3.85	3.50	3.08	1.75
76	7.60	6.91	6.08	3.80	3.45	3.04	1.73
77	7.50	6.82	6.00	3.75	3.41	3.00	1.70
78	7.40	6.73	5.92	3.70	3.36	2.96	1.68
79	7.31	6.64	5.85	3.65	3.32	2.92	1.66
80	7.22	6.56	5.77	3.61	3.28	2.88	1.64
81	7.13	6.48	5.70	3.56	3.24	2.85	1.62
82	7.04	6.40	5.63	3.52	3.20	2.82	1.60
83	6.96	6.32	5.56	3.48	3.16	2.78	1.58
84	6.87	6.25	5.50	3.43	3.12	2.75	1.56
85	6.79	6.17	5.43	3.39	3.09	2.72	1.54
86	6.71	6.10	5.37	3.35	3.05	2.68	1.52
87	6.64	6.03	5.31	3.32	3.01	2.66	1.51
88	6.56	5.96	5.25	3.28	2.98	2.62	1.49
89	6.49	5.90	5.19	3.24	2.95	2.59	1.47
90	6.41	5.83	5.13	3.20	2.91	2.56	1.46
91	6.34	5.77	5.08	3.17	2.88	2.54	1.44
92	6.28	5.70	5.02	3.14	2.85	2.51	1.42
93	6.21	5.64	4.97	3.10	2.82	2.48	1.41
94	6.14	5.58	4.91	3.07	2.79	2.46	1.39
95	6.08	5.52	4.86	3.04	2.76	2.43	1.38
96	6.01	5.47	4.81	3.00	2.73	2.40	1.37
97	5.95	5.41	4.76	2.97	2.70	2.38	1.35
98	5.89	5.36	4.71	2.94	2.68	2.35	1.34
99	5.83	5.30	4.66	2.91	2.65	2.33	1.32
100	5.75	5.25	4.62	2.88	2.63	2.31	1.31

72. Methods of determining the power factor of circuits are described in the division of this section subjected "Measurements, Testing and Instruments."

73. Skin Effect.—When an alternating current flows through a conductor there is an inductive action whereby the current in the conductor is forced toward its surface. The current density is greater at the surface than at the center and under certain condi-

Three-phase Line (*Power*, Nov. 21, 1911)

any two wires							Power factor
500	550	1,100	1,150	2,200	2,300	6,600	
2.31	2.10	1.050	1.004	0.525	0.502	0.175	50
2.26	2.06	1.029	0.985	0.515	0.492	0.172	51
2.22	2.02	1.009	0.966	0.505	0.483	0.168	52
2.18	1.98	0.990	0.947	0.495	0.474	0.165	53
2.14	1.94	0.972	0.930	0.486	0.465	0.162	54
2.10	1.91	0.954	0.913	0.477	0.456	0.159	55
2.06	1.87	0.937	0.897	0.469	0.448	0.156	56
2.03	1.84	0.921	0.881	0.460	0.440	0.153	57
1.99	1.81	0.905	0.866	0.453	0.433	0.151	58
1.96	1.78	0.890	0.851	0.445	0.425	0.148	59
1.92	1.75	0.875	0.837	0.437	0.418	0.146	60
1.89	1.72	0.861	0.823	0.430	0.411	0.143	61
1.86	1.69	0.847	0.810	0.423	0.405	0.141	62
1.83	1.67	0.833	0.797	0.416	0.398	0.139	63
1.80	1.64	0.820	0.784	0.410	0.392	0.137	64
1.78	1.61	0.807	0.772	0.403	0.386	0.134	65
1.75	1.59	0.795	0.761	0.397	0.380	0.132	66
1.72	1.57	0.783	0.749	0.391	0.374	0.130	67
1.70	1.54	0.772	0.738	0.386	0.369	0.129	68
1.67	1.52	0.761	0.728	0.380	0.364	0.127	69
1.65	1.50	0.750	0.717	0.375	0.359	0.125	70
1.63	1.48	0.739	0.707	0.369	0.354	0.123	71
1.60	1.46	0.729	0.697	0.364	0.349	0.121	72
1.58	1.44	0.719	0.688	0.359	0.344	0.120	73
1.56	1.42	0.709	0.678	0.354	0.339	0.118	74
1.54	1.40	0.700	0.669	0.350	0.334	0.117	75
1.52	1.38	0.691	0.661	0.345	0.330	0.115	76
1.50	1.36	0.682	0.652	0.341	0.326	0.114	77
1.48	1.35	0.673	0.644	0.336	0.322	0.112	78
1.46	1.33	0.664	0.636	0.332	0.318	0.111	79
1.44	1.31	0.656	0.628	0.328	0.314	0.109	80
1.43	1.30	0.648	0.620	0.324	0.310	0.108	81
1.41	1.28	0.640	0.612	0.320	0.306	0.107	82
1.39	1.26	0.632	0.605	0.316	0.302	0.105	83
1.37	1.25	0.625	0.598	0.312	0.299	0.104	84
1.36	1.23	0.617	0.591	0.309	0.295	0.103	85
1.34	1.22	0.610	0.584	0.305	0.292	0.102	86
1.33	1.21	0.603	0.577	0.301	0.288	0.100	87
1.31	1.19	0.596	0.570	0.298	0.285	0.099	88
1.30	1.18	0.590	0.564	0.295	0.282	0.098	89
1.28	1.17	0.583	0.558	0.291	0.279	0.097	90
1.27	1.15	0.577	0.552	0.288	0.276	0.096	91
1.26	1.14	0.570	0.546	0.285	0.273	0.095	92
1.24	1.13	0.564	0.540	0.282	0.270	0.094	93
1.23	1.12	0.558	0.534	0.279	0.267	0.093	94
1.22	1.10	0.552	0.528	0.276	0.264	0.092	95
1.20	1.09	0.547	0.523	0.273	0.261	0.091	96
1.19	1.08	0.541	0.518	0.270	0.259	0.090	97
1.18	1.07	0.536	0.512	0.268	0.256	0.089	98
1.17	1.06	0.530	0.507	0.265	0.254	0.088	99
1.16	1.05	0.525	0.502	0.263	0.252	0.087	100

tions there may be practically no current flowing along the axis of the conductor. Although skin effect and self induction both originate from the same magnetic field they are not otherwise related. Since it increases voltage drop and energy loss, skin effect amounts to an increase in resistance and is so considered. The following table gives values by which actual resistances of conductors must be multiplied to obtain their virtual resistances to alternating currents. Non-conducting cores are sometimes placed in the centers of large cables for alternating currents so that all of the metal will be worked at the best possible efficiency. See Table 182 for such conductors.

74. **Skin effect in conductors of magnetic materials** is much greater than in those of non-magnetic materials due to the stronger magnetic field that a given current will set up in a magnetic metal. See the tables in the *Standard Handbook.*

75. **Skin effect in stranded conductors** is, for all practical purposes, equal to that in solid conductors of equal diameters. Table 76 gives values for solid conductors.

76. **Skin Effect Factors For Copper Wire.**—Values by which the real (ohmic) resistance of solid, round, copper conductors must be multiplied to obtain their virtual resistance to alternating currents of commercial frequencies.

Frequency	Factors for different copper wire sizes (B. & S. Gage) and diameters							
	4	3	2	1	0	00	000	0000
25 cycles..	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001
60 cycles..	1.000	1.000	1.000	1.000	1.001	1.002	1.005	1.006
130 cycles..	1.000	1.001	1.002	1.005	1.008	1.010	1.017	1.027

Frequency	Factors for different copper wire sizes (B. & S. Gage) and diameters.—*Continued*							
	1/2"	3/4"	1"	1 1/8"	1 1/4"	1 1/2"	1 3/4"	2"
25 cycles..	1.002	1.007	1.020	1.035	1.053	1.098	1.170	1.265
60 cycles..	1.008	1.040	1.111	1.168	1.239	1.420	1.622	1.826
130 cycles..	1.039	1.156	1.397	1.545	1.694	1.983	2.272	2.560

Example.—A No. 000 wire 1,000 ft. long has an actual resistance of 0.0489 ohms. Its resistance to a 130-cycle alternating current would be $0.0489 \times 1.017 = 0.0497$ ohms.

77. **Self induction** is the phenomena whereby an e.m.f. is induced in a conductor by a change of current in the conductor itself. Such an e.m.f. always produces currents and magnetic fields in such a direction that they tend to oppose the inducing currents and fields.

78. **Work** is the overcoming of mechanical resistance through a certain distance. Work is measured by the product of the mechanical resistance times the space through which it is overcome. Work is measured by the product of the moving force times the distance through which the force acts in overcoming the resistance. Work is, therefore, measured in foot-pounds (ft-lb.).

Example.—What work is done if a weight of 6 lb. is lifted through a distance of 8 ft.?

Solution.—Work = ft. × lb. = $8 \times 6 = 48$ ft-lb.

Example.—If 20 gal. of water are pumped to a vertical height of 32 ft. what work has been done?

Solution.—A gallon of water weighs 8 lb. therefore

Work = ft. × lb. = $32 \times (20 \times 8) = 5{,}120$ ft-lb.

Example.—If the piston in a steam engine travels, during a certain interval, $1\frac{1}{2}$ ft. and the total pressure on the piston is 40,000 lb., what work is done during the interval?

Solution.—Work = ft. × lb. = 1.5 × 40,000 = 60,000 ft-lb.

79. **Energy** is capacity for doing work. Any body or medium which is of itself capable of doing work is said to possess energy. A coiled clock spring possesses energy because, in unwinding, it can do work. A moving projectile possesses energy because it can overcome the resistance offered by the air, by armor plate, etc., and thus do work. A charged storage battery possesses energy because it can furnish electricity to operate a motor. Energy can be expressed in foot-pounds.

80. **Energy of one sort may be transformed into energy of another sort.** Heat energy in coal may be transformed (with a certain loss) with a boiler, a steam engine and a generator, into electrical energy. The energy possessed by a stream of falling water may be transformed, with a waterwheel and generator, into electrical energy. There is a definite numerical relation between different sorts of energy. Thus 1 B.T.U., the unit of heat energy = 778 ft-lb. In electrical units, energy is expressed in watt-hours or kilowatt-hours.

81. **A kilowatt-hour** represents the energy expended if work is done for one hour at the rate of 1 kw.

82. **A horse-power-hour** represents the energy expended if work is done for one hour at the rate of 1 h.p.

83. **Power** is rate of doing work. The faster work is done the greater the power that will be required to do it. For example, if a 10-h.p. motor can raise a loaded elevator a certain distance in 2 minutes a 20-h.p. motor will (approximately) be required to raise it the same distance in 1 minute.

84. **The horse-power** is the unit of power and is about equal to the power of a strong horse to do work for a short interval. Numerically a horse-power is 33,000 ft-lb. per minute, = 550 ft-lb. per second, = 1,980,000 ft-lb. per hour. Expressed as a formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{\text{foot-pounds per minute}}{33{,}000}$$

Wherein, h.p. = horse-power, L = distance, in feet, through which W is raised or overcome; W = weight, in pounds, of the thing lifted or the push or pull in pounds of the force overcome, and t is the time in minutes required to move or overcome the weight W through the distance L.

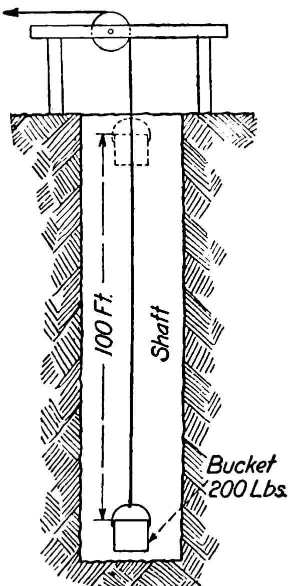


FIG. 40.—Bucket in shaft.

Example.—What horse-power is required in raising the load and bucket, weighing 200 lb., shown in Fig. 40, from the bottom to the top of the shaft, a distance of 100 ft., in 2 minutes?

Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{100 \times 200}{33{,}000 \times 2} = 0.3 \text{ h.p.}$$

Example.—What average horse-power is required while moving the box loaded with stone, in Fig. 41, from *A* to *B*, 650 ft., in 3 minutes? It takes a horizontal pull of 150 lb. to move the box.

Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{650 \times 150}{33{,}000 \times 3} = 0.98 \text{ h.p.}$$

85. Electric power is expressed numerically in watts or in kilowatts. A kilowatt is 1,000 watts. The watt represents the amount of power in a circuit when the current in that circuit is 1 amp. and the electromotive force is 1 volt.

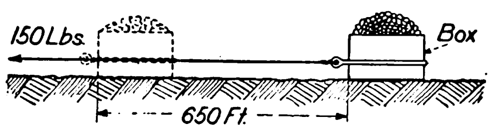


FIG. 41.—Moving loaded box.

86. Efficiency is the name given to the *ratio of output to input.* No machine gives out as much energy or power as is put into it. There are some losses in even the most perfectly constructed machines. Efficiency is usually expressed as a percentage, thus, "the efficiency of a certain motor is 80 per cent." This means that only 80 per cent. of the energy or power received by the motor as electricity is delivered by the motor at the pulley. Another way of stating the definition is:

$$\text{efficiency} = \frac{\text{output}}{\text{input}}$$

It follows that

$$\text{input} = \frac{\text{output}}{\text{efficiency}}$$

and, $\text{output} = \text{input} \times \text{efficiency}.$

When using the formulas, output and input must be expressed in the same units.

87. Output is the useful energy delivered by a machine and **input** is the energy supplied to a machine.

Example.—If 45 kw. is supplied to a motor and its output is found to be 54.2 h.p., what is its efficiency?

Solution.—Since 1 h.p. = 0.746 kw., 54.2 h.p. = 54.2 × 0.75 = 40.6 kw. Then substituting in the formula

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{40.6}{45} = 0.90 = 90 \text{ per cent. efficiency.}$$

88. Torque is the measure of the tendency of a body to rotate. It is the measure of a turning or twisting effort and it is usually expressed in pounds-foot or in pounds force at a given radius. Torque may exist even if there be no motion. Thus, in Fig. 42, the torque at the circumference of the drum is 50 lb. so long as the weight is supported, whether the drum be moving or standing still. It is assumed that the hoisting rope has no weight. Torque is sometimes expressed as the product of the force introducing the tendency to rotate times the distance from the center of rotation to the point of application of the force. For instance, in Fig. 43 the torque tending to turn the cylinder in the brick wall would be 100 × 12 = 1,200 lb-ft. (In some text-books this would, inaccurately, be expressed as 1,200 ft-lb.) The cylinder cannot turn and no work could be done, yet there is torque. Probably the most preferable way of expressing the torque is in terms of pressure (or force) and radius. Thus: "100 lb. force at 12 ft. radius." Ordinarily the expression is given for unit or 1-ft. radius. Then, for the case of Fig. 43, the torque would be 1,200 lb. at 1 ft. radius. Because of the fact that many **writers and engineers erroneously express units of both work and torque** in foot-pounds, a confusion sometimes exists regarding the distinction between the two. Work (see **78**) is properly expressed in foot-pounds (ft-lb.), while torque should be expressed in pounds-feet (lb-ft.), or preferably in pounds at a given radius.

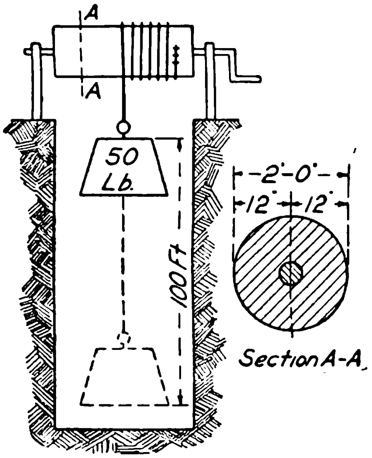


FIG. 42.—Example of work and of torque.

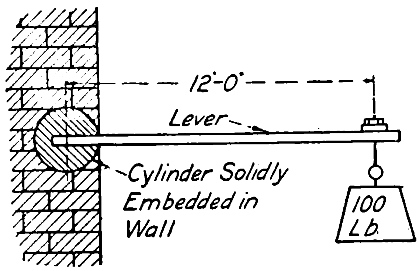


FIG. 43.—An example of torque.

89. Centigrade and Fahrenheit Thermometer Scales

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.
0	32.	21	69.8	41	105.8	61	141.8	81	177.8
1	33.8	22	71.6	42	107.6	62	143.6	82	179.6
2	35.6	23	73.4	43	109.4	63	145.4	83	181.4
3	37.4	24	75.2	44	111.2	64	147.2	84	183.2
4	39.2	25	77.	45	113.	65	149.	85	185.
5	41.	26	78.8	46	114.8	66	150.8	86	186.8
6	42.8	27	80.6	47	116.6	67	152.6	87	188.6
7	44.6	28	82.4	48	118.4	68	154.4	88	190.4
8	46.4	29	84.2	49	120.2	69	156.2	89	192.2
9	48.2	30	86.	50	122.	70	158.	90	194.
10	50.	31	87.8	51	123.8	71	159.8	91	195.8
11	51.8	32	89.6	52	125.6	72	161.6	92	197.6
12	53.6	33	91.4	53	127.4	73	163.4	93	199.4
13	55.4	34	93.2	54	129.2	74	165.2	94	201.2
14	57.2	35	95.	55	131.	75	167.	95	203
15	59.	36	96.8	56	132.8	76	168.8	96	204.8
16	60.8	37	98.6	57	134.6	77	170.6	97	206.6
17	62.6	38	100.4	58	136.4	78	172.4	98	208.4
18	64.4	39	102.2	59	138.2	79	174.2	99	210.2
19	66.2	40	104.	60	140.	80	176.	100	212.
20	68.	......	......	......	......	......	......	......	......

For values not appearing in the table use the following formulas:

$$\text{Temp. C.} = \tfrac{5}{9} \times (\text{Temp. F.} - 32.)$$

$$\text{Temp. F.} = (\tfrac{9}{5} \times \text{Temp. C.}) + 32.$$

MEASURING, TESTING AND INSTRUMENTS

90. Electricians often test circuits for the presence of voltage by touching the conductors with the fingers. This method is safe where the voltage does not exceed 250 and is often very convenient for locating a blown-out fuse or for ascertaining whether or not a circuit is alive. Some men can endure the electric shock that results without discomfort whereas others cannot. Therefore, the method is not feasible in some cases. Which are the outside wires and which is the neutral wire of a 110–220 volt, three-wire system can be determined in this way by noting the intensity of the shock that results by touching different pairs of wires with the fingers. Use the method with caution and be certain that the voltage of the circuit does not exceed 250 before touching the conductors. (This and the several paragraphs that follow are taken from *Electrical Engineering*.)

91. The presence of low voltages can be determined by "tasting." The method is feasible only where the pressure is but a few volts and hence is used only in bell and signal work. Where the voltage is very low, the bared ends of the conductors constituting the two sides of the circuit are held a short distance apart on the tongue. If voltage is present a peculiar mildly burning sensation results which will never be forgotten after one has experienced it. The "taste" is due to the electrolytic decomposition of the liquids on the tongue which produces a salt having a taste. With relatively high voltages, possibly 4 or 5 volts, due to as many cells of battery,

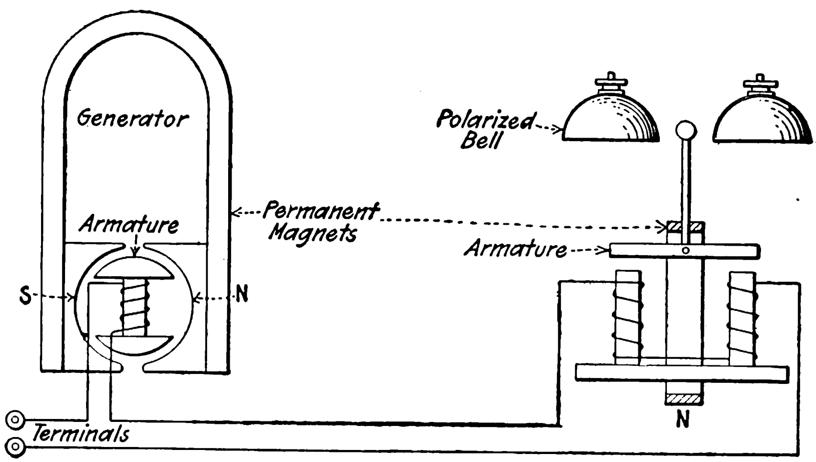


FIG. 44.—Circuits of testing magneto.

it is best to first test for the presence of voltage by holding one of the bared conductors in the hand and touching the other to the tongue. Where a terminal of the battery is grounded, often a taste can be detected by standing on moist ground and touching a conductor from the other battery terminal to the tongue. Care should be exercised to prevent the two conductor ends from touching each other at the tongue, for if they do a spark can result that may burn.

92. **The magneto test set** is one of the most valuable testing instruments to the practical man because of its simplicity and the fact that it is always ready for service. Fig. 44 shows the circuit and Fig. 45 a perspective view of a testing magneto. The apparatus consists of a small hand-operated alternating-current generator in series with a polarized electric bell. Alternating current will ring bells of this type. If the external circuit connected to the terminals of the magneto is closed and the crank of the generator is turned, current will flow and the bell will ring.

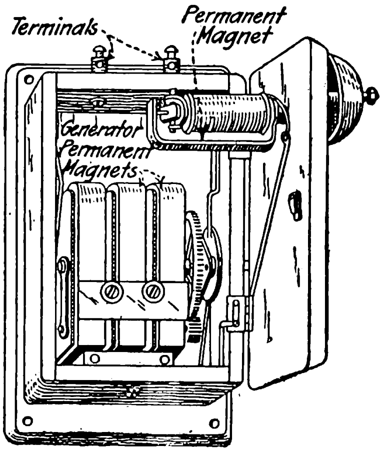


FIG. 45.—Assembly of testing magneto.

The resistance through which magnetos will ring is determined by their design. An ordinary magneto will ring through possibly 20,000 to 40,000 ohms. Electrostatic capacity effects must be considered when testing with a magneto. When testing long circuits, such as telephone lines or circuits that are carried in cable for a considerable distance, the bell of the magneto may ring, due to capacity, apparently indicating a short-circuit, whereas the circuit may be perfectly clear or open. Circuits associated with iron, such as field coils of generators, may have considerable inductance. With highly inductive circuits under test, the magneto may "ring open"; that is, the bell may not ring at all, even though the inductive circuit connected to it be actually closed. In ordinary wiring work the effects of capacity and inductance are usually negligible and the true condition of the circuit will be indicated by the performance of the magneto bell.

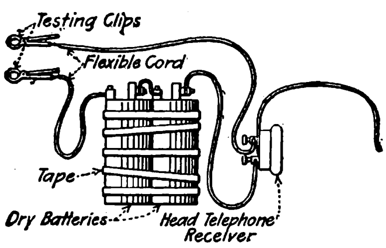


FIG. 46.—Head-telephone and dry-battery testing set.

93. **A telephone receiver in combination with one or two dry cells constitutes an excellent equipment for certain tests.** A "head" telephone receiver (Fig. 46) is usually preferable to those of the watch-case types, because it is held on the head by the metal strap, allowing the unrestricted use of both hands. Metal testing clips—suspender clips will do—are soldered to the flexible testing cords. The telephone receiver is extremely sensitive and will give a weak "click" even when the current to it passes through an exceedingly high resistance. In using, one clip is gripped on one conductor of the circuit to be tested and the other clip is tapped against the other conductor. Prolonged connection should be avoided because it will "run down" the battery. A vigorous click of the receiver indicates

a closed circuit, while a weak click or none at all, indicates an open circuit. After practice it is possible to determine approximately the resistance of the circuit under test by the intensity of the receiver click. When the battery and receiver test set are connected to a circuit having some electrostatic capacity, the receiver will give a vigorous click when the clips are first touched to the circuit terminals, even though the circuit be open. With successive touchings the click will diminish in intensity if the circuit is open, but will not diminish appreciably if the circuit is closed.

94. **The advantages of the telephone receiver over the magneto** for work of certain classes are: (1) The receiver and battery outfit costs little. (2) The outfit can be made so compact that it can be carried in the pocket. (3) In making insulation tests with a magneto the circuit may "ring clear"; that is, the bell will not ring, apparently indicating high insulation resistance, whereas the circuit may not be clear, but instead the magneto may be out of order or its local circuit open. The indication is negative. With the telephone receiver a slight click is produced even when testing through the highest resistances. The absence of a click usually signifies an open in the testing apparatus itself. Thus the telephone receiver indication is positive.

95. **A telegraph sounder is sometimes used for testing.** It is connected in the same way as the telephone receiver of Fig. 47, and is adaptable for rough work. When the circuit under test is closed and the flexible cord clips are touched to the circuit conductors, the sounder clicks. Where the circuit is open there is no click. One feature of the sounder method is that the click is audible at a considerable distance from the instrument.

96. **An electric bell outfit for testing** is shown in Fig. 47. When the free ends for testing are touched to a closed circuit of not too high resistance the bell rings. Where the circuit is open the bell will not ring. Flexible cord can be used for the testing conductors of the outfit and testing clips can be provided as in Fig. 47.

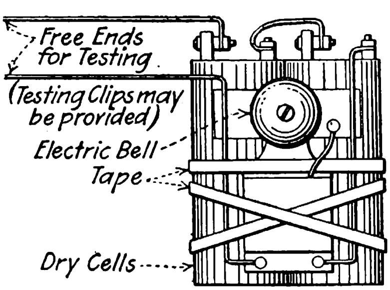


FIG. 47.—Electric bell testing outfit.

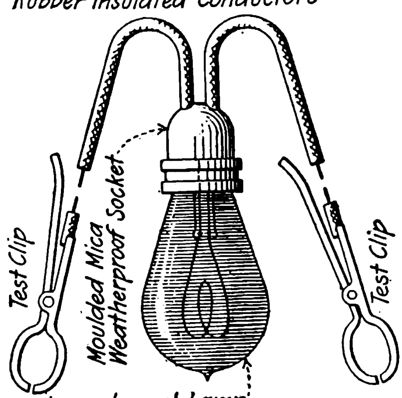


FIG. 48.—A practical test-lamp outfit.

97. **A test lamp** (Fig. 48), consisting merely of a weatherproof socket of moulded mica, into which is screwed an 8 or 16 c-p. carbon lamp of the voltage of the circuits involved, is very conve-

nient for rough tests on interior-lighting and motor-wiring systems. Porcelain sockets are undesirable because they are so readily broken. Brass sockets should not be used because they may fall across conductors and thereby cause short-circuits. Testing clips may be soldered to the ends of the leads which are moulded in the socket. Some uses of the testing lamp are given in a following paragraph, and it is very convenient for testing for defective fuses.

98. **Rules for Use of Ammeter and Voltmeter** (*Timbie's Elements of Electricity*).—Place ammeter in series, always using a short-circuiting switch, where possible, as shown in Fig. 49, to pre-

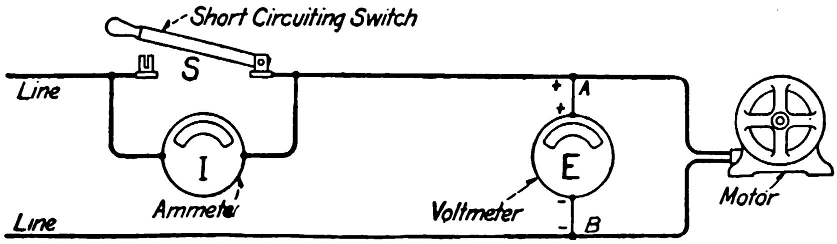


FIG. 49.—Ammeter and voltmeter connections.

vent injury to the instrument. Place voltmeter in shunt (Fig. 49). Put the + side of the instrument on the + side of the line. Fig. 49 shows the correct use of an ammeter and a voltmeter to measure the current and the voltage supplied to the motor. The short-circuiting switch *S* must be opened before the ammeter is read. All the current that enters the motor must then flow through the ammeter and be indicated. The ammeter is of very low resistance (about 0.001 or 0.002 ohm) and does not appreciably cut down the flow of current. The voltmeter is of very high resistance (about 15,000 ohms) and does not allow any appreciable current to flow

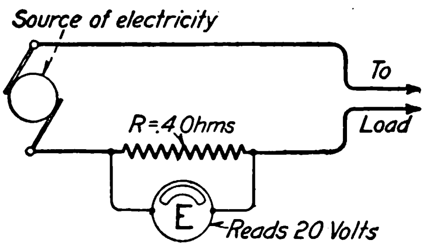


FIG. 50.—Current measurement with voltmeter.

through itself. Yet enough goes through the voltmeter to cause it to indicate the voltage across the terminal *AB* of the motor. Suppose the voltage across the motor to be 110, what would happen if an ammeter of 0.002 ohm resistance were by mistake placed across *AB*? (Remember Ohm's law is always in operation.)

99. **Ohm's law is often applied in making determinations** of resistance, voltage, current and power. In 35 and 36 examples are given that indicate the application of Ohm's law to measurements.

100. A method of measuring current with a voltmeter is shown in Fig. 50. If a resistor of known resistance be connected in series in a circuit and the voltage across the coil measured with a voltmeter the current can be determined by Ohm's law thus:

Example.—(Fig. 50.) If the drop around 0.4 ohm resistance in series in a circuit is 20 volts, what is the current in the circuit?

Solution.—Substitute in the Ohm's law formula:

$$I = \frac{E}{R} = \frac{20}{0.4} = 50. \text{ amp.}$$

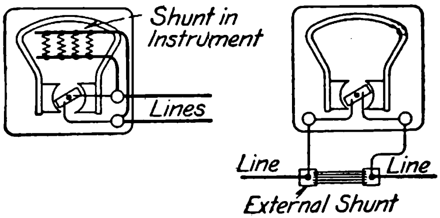


FIG. 51.—Millivoltmeters and shunts.

101. A millivoltmeter is generally used for making measurements like that of 99. A millivoltmeter reads in thousandths of volts so that a resistor of small resistance can be used. Ammeters, particularly those for large currents, are often millivoltmeters calibrated in amperes which are connected around a resistor, in series with the circuit (Fig. 51). The resistor is sometimes in the instrument case and is sometimes inserted in the bus-bars of a switchboard. See Fig. 51. Such resistors are called **shunts** and when furnished by instrument makers are carefully calibrated.

102. Resistance can be measured with a voltmeter as indicated in Fig. 52. A resistor of known resistance, a source of electricity

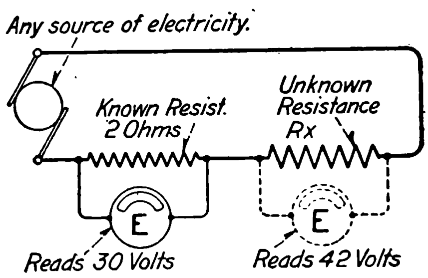


FIG. 52.—Resistance measurement.

and one voltmeter is required. The same constant current flows through both the known and the unknown resistance. The voltmeter reading E is taken and then the reading Ex. The voltage drops will be proportional to the resistances or:

$$\frac{R}{E} = \frac{R_x}{E_x} \text{or } R_x = \frac{E_x \times R}{E}$$

Example.—Substituting the values from Fig. 52 in the formula:

$$R_x = \frac{E_x \times R}{E} = \frac{42 \times 2}{30} = \frac{84}{30} = 2.8 \text{ ohms.}$$

103. Very small resistances can be measured, as indicated in Fig. 53, with an ammeter and a millivoltmeter. This method is convenient for measuring the resistance of bus-bars, joints between conductors, switch contacts, brush-contact resistance and other low resistances. As large a current as is feasible should be used. This is another application of Ohm's law.

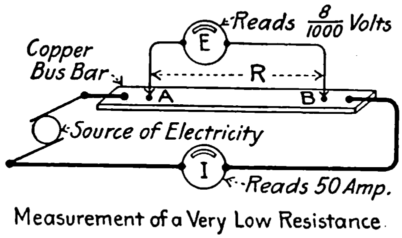


FIG. 53.—Measurement of very low resistance.

Example.—What is the resistance of the portion of the bus-bar between A and B, Fig. 53?
Solution.—Substitute in Ohm's law formula:

$$R' = \frac{E}{I} = \frac{0.008}{50} = 0.00016 \text{ ohms.}$$

104. Insulation resistance is usually measured as suggested in Fig. 54. A voltmeter of known resistance, preferably of high resistance, and a source of e.m.f. (batteries or a generator), are required. First the voltage of the e.m.f. source is taken as shown

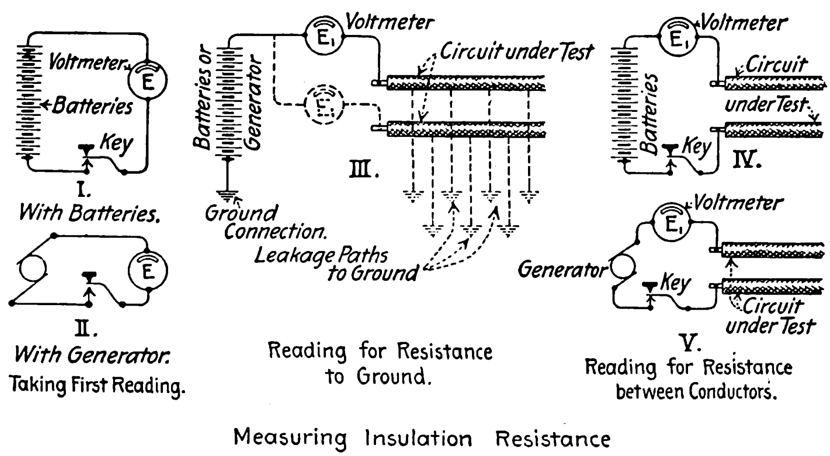


FIG. 54.—Measuring insulation resistance.

at I or II. The apparatus is then arranged as shown at III to measure the resistance from each side of the circuit to ground. At IV or V are shown the connections for measuring the resistance between conductors. If E = voltage of e.m.f. source, E_1 = reading of voltmeter when connected in series with insulation resistance to be measured, R_v = resistance, in ohms, of voltmeter and R_x insulation resistance sought, the following formula is used:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) \text{ (See Fig. 54.)}$$

Example.—In a certain (Fig. 55) test where a 110-volt generator was used as a source of e.m.f. and a voltmeter having a resistance of 15,000 ohms was used to read voltages, the readings indicated in Fig. 55 were obtained. What was the insulation resistance to ground of each side of the circuit and what was the insulation resistance between circuits?

Solution.—For the resistance of *conductor* 1 (see Fig. 55) substitute in the formula:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{5} - 1\right) = 15{,}000(22 - 1) = 15{,}000 \times 21$$

$= 315{,}000$ ohms = insulation resistance of conductor 1 to ground.
For the resistance of conductor 2 (see Fig. 55, *III*):

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{4} - 1\right) = 15{,}000(27.5 - 1) = 15{,}000 \times 26.5$$

$= 397{,}500$ ohms = insulation resistance of conductor 2 to ground.
For the insulation resistance between conductors:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{2} - 1\right) = 15{,}000(55 - 1) = 15{,}000 \times 54$$

$= 810{,}000$ ohms = insulation resistance between conductors 1 and 2.

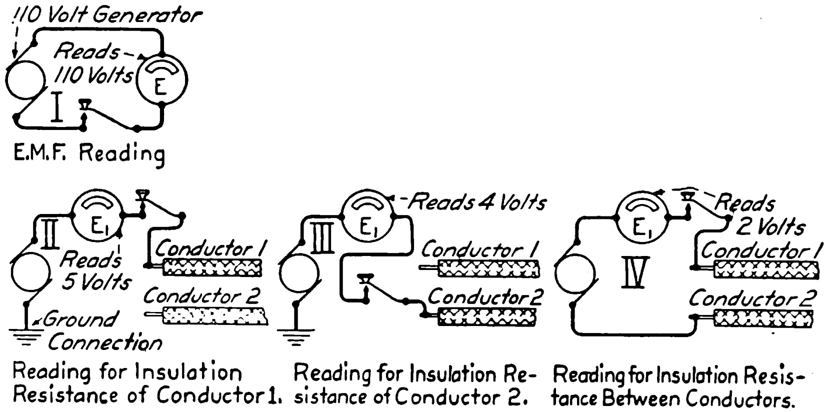


FIG. 55.—Example of insulation resistance measurement.

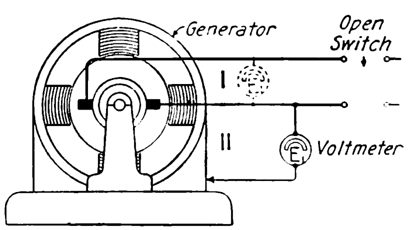


FIG. 56.—Measuring insulation resistance of a generator.

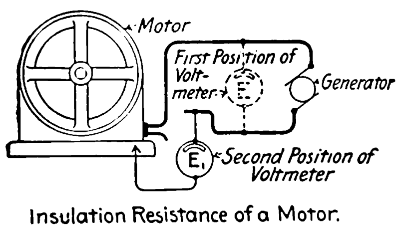


FIG. 57.—Measuring insulation resistance of a motor.

105. The insulation resistance of a generator can be determined with a voltmeter of known resistance which is successively connected and read in positions *I* and *II*, Fig. 56. The formula of **104** is used. The external circuit connected to the generator should be cut off while the measurements are being taken so that its insulation resistance will not affect the readings.

106. The insulation resistance of a motor can be measured with a voltmeter as suggested in Fig. 57. The formula of **104** is used. Unless the external circuit has high insulation resistance its resistance will affect the result.

107. Power, in direct-current or non-inductive alternating-current electric circuits, **can be measured** with a voltmeter and an ammeter. For two-wire circuits the power in watts, in accordance with Ohm's law, equals the product of volts times amperes, thus:

$$P = I \times E$$

Wherein P is the power in watts, I is the current in amperes and E is the e.m.f. in volts.

Example.—See 38 for examples of power problems. Although no instruments are shown in these, the principles are the same as if instruments were used.

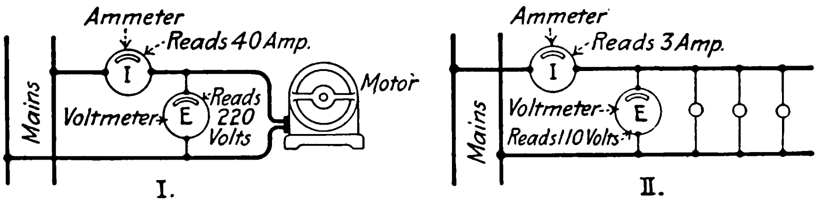


FIG. 58.—Power measurements.

Example.—In Fig. 58, *I*, the power taken by the motor is, substituting in the formula:

$$P = I \times E = 40 \times 220 = 8{,}800 \text{ watts}$$

or in kilowatts $= \dfrac{8800}{1000} = 8.8$ kw.

Example.—In Fig. 58, *II*, the power taken by the lamps is:

$$P = I \times E = 3 \times 110 = 330 \text{ watts}$$

or in kilowatts $\dfrac{330}{1000} = 0.33$ kw.

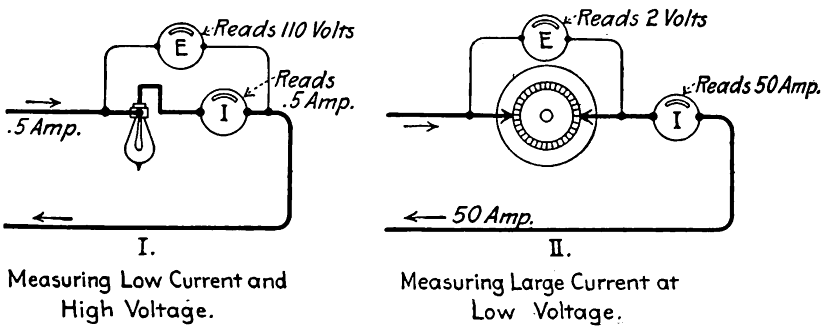


FIG. 59.—Correct methods of connecting instruments.

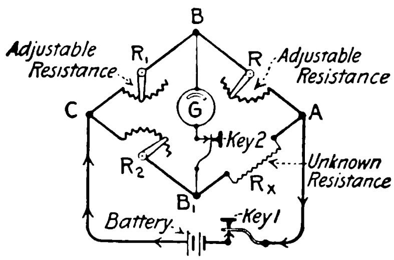
108. Methods of measuring power in alternating-current circuits are given in Pars. 59, 59A, and 148A to 151.

109. All ammeters and voltmeters (except electrostatic) consume power when in use and introduce some error (*Timbie's Elements of Electricity*). For minimum error (see Fig. 59, *I*) *when measuring a low current and high voltage, the voltmeter should be placed around both the ammeter and the apparatus under test.*

When measuring the power consumed by a piece of apparatus, through which a large current at low voltage is flowing, the voltmeter *should be placed immediately across the piece of apparatus under test and not across the ammeter.* (Fig. 59II.)

110. The Wheatstone bridge is an instrument for measuring medium and high resistances. It is not suitable for measuring resistances of less than 1 ohm. An elementary diagram is shown in Fig. 60. R_1, R_2 and R are adjustable resistances, R_x is the unknown resistance and G is a delicate galvanometer. A battery supplies electricity. It can be shown that if, when both keys are pressed, the galvanometer shows no deflection:

$$\frac{R_1}{R} = \frac{R_2}{R_x} \quad \text{or} \quad R_x = \left(\frac{R_2}{R_1}\right) R.$$



Wheatstone Bridge Diagram.

FIG. 60.—Elementary diagram of the Wheatstone bridge.

Example.—If $R_2 = 100$ ohms, $R_1 = 10$ ohms and $R = 672$ ohms what is the value of the unknown resistance?

Solution.—Substitute in the formula:

$$R_x = \left(\frac{R_2}{R_1}\right) R = \left(\frac{100}{10}\right) 672 = 10 \times 672 = 6{,}720 \text{ ohms.}$$

The unknown resistance is 6,720 ohms.

In commercial bridges, the adjustable resistances R_2 and R_1 are usually so arranged that the ratio $\frac{R_2}{R_1}$ will be a fraction like $\frac{1}{10}$ or $\frac{1}{100}$ or a number like 10 or 100 so that R_x can be obtained readily

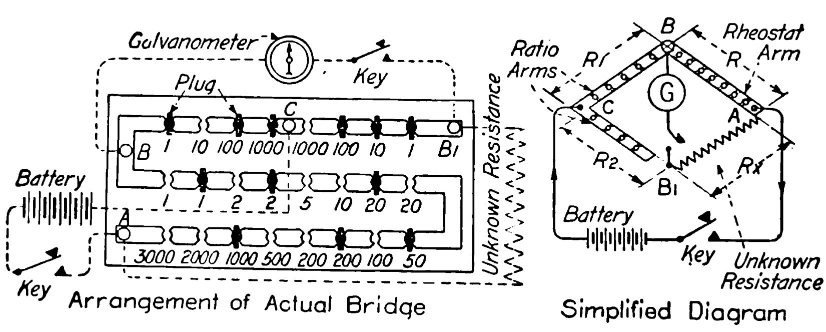


FIG. 61.—Post-office pattern of Wheatstone bridge.

by dividing or multiplying R by an easily handled number. R_1 and R_2 are sometimes called the ratio arms and R is called the rheostat arm. For most accurate results the resistances R, R_1, and R_2 should be as nearly as possible equal to R_x.

111. **A diagram of a commercial bridge of the post-office pattern** is shown in Fig. 61. Its principle is similar to that of Fig. 60. Brass plugs are used to vary the resistance in arms R, R_1 and R_2. When a plug is inserted in the opening between two resistance coils it shunts out the coil. In using this bridge the ratio $\frac{R_2}{R_1}$ is arranged by the operator to correspond to R_x. Then R is adjusted until a balance is obtained. When R_x is greater than R the ratio must be 10, 100 or 1,000, and when R_x is smaller than R the ratio must be 0.1 or 0.01 or 0.001. If $R_1 = R_2$ the value of R_x equals R.

112. **Directions for using a Wheatstone Bridge.**—(1) Insert the unknown resistance. (2) Make a mental estimation of the probable value of the unknown resistance. If it is not greater than the total resistance in the arm R or smaller than that of any one coil in R, R_1 and R_2 may be made equal by taking plugs from the proper holes. (3) Take a plug from a coil, in R, of about the

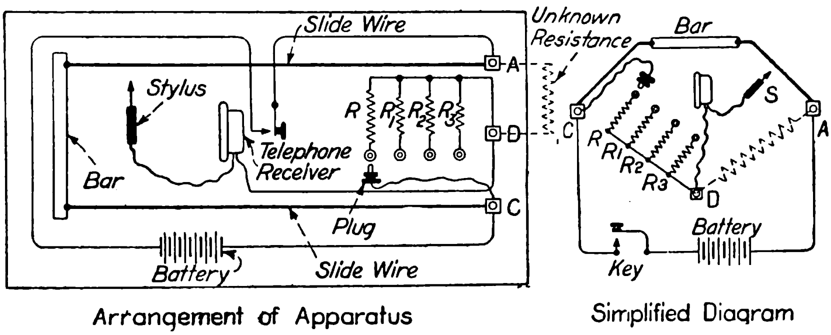


FIG. 62.—The ohmmeter.

estimated resistance of R_x and press the keys. Note the deflection of the needle, whether it is to the right or left. Now unplug a coil in R of about twice the resistance of the first one unplugged. If the needle now deflects in the opposite direction the value of R_x lies between these two values. If the deflection is in the same direction the unplugged resistance in R is too great and a value of about one-half that originally selected should be tried. Systematically narrow down the limits until the best possible balance is obtained. (4) Usually it is impossible to secure an exact balance. When this is the case proceed as indicated in the following example: Assume that the coil of smallest resistance in the R arm is of 0.1 ohm. With this added the galvanometer deflects two divisions to the right. The deflection without is three divisions to the left. Therefore a difference of 0.1 ohm makes a difference of five scale divisions. The resistance that would give no deflection is $\frac{3}{5} \times 0.1 = 0.06$ ohm. (5) Be careful not to allow the metal parts of the bridge plugs to become wet or greasy from the hands. (6) Use a twisting motion when inserting the plugs. Put them in firmly but do not use enough force to twist off the insulating handles. (7) When closing the keys, close the battery key first and in opening the keys open the galvanometer key first.

113. How to Make a Slide-wire Bridge (*J. W. Himmelsbach, Power*, June 4, 1912).—The very satisfactory apparatus described in Fig. 63 can be easily and cheaply made. The only expensive part is a direct-reading, differential millivoltmeter having the zero in the middle of the scale, which reads 75 millivolts on either side of the zero point. Mount on a piece of well-seasoned 5×18×1-in. oak four binding-posts, *A*, *B*, *C*, *D*, and two lamp sockets, *L*, *L*, as shown; *M* and *N* are two small wire brads driven in the board, leaving only $\frac{1}{8}$ in. projecting.

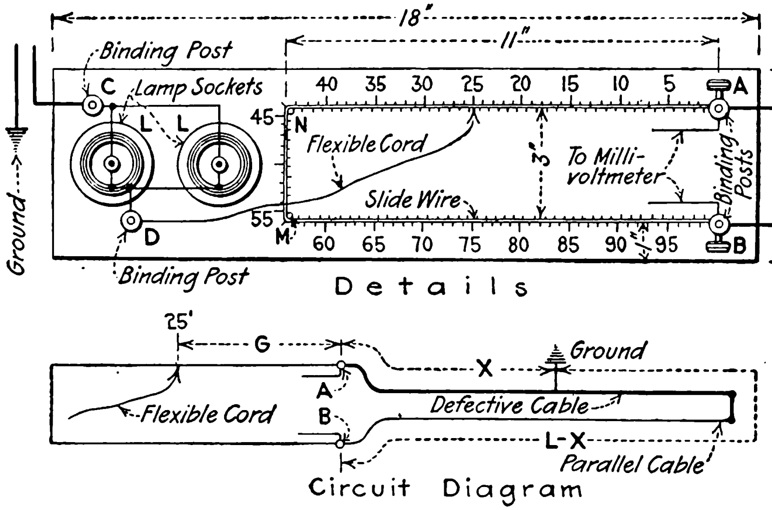


FIG. 63.—Home-made testing set and its application.

From *A* to *N*, *N* to *M*, and *M* to *B*, paste strips of paper 1 in. wide upon which a scale has been drawn, with divisions every $\frac{1}{8}$ in., which will give 200 divisions. Mark every second division from 0 to 100, starting at *A*. Then stretch a piece of No. 26 or 28 B & S. gage, german-silver wire from *A* around *N* and *M* to *B*. This wire must be stretched tightly so that reading the scale will give correct proportional lengths of wire.

The lamp sockets are to be wired in parallel. Connect permanently to *D* a piece of flexible wire (lamp cord will do) to the end of which is soldered a knife-edge contact. This wire must reach from post *D* to post *A*. Binding posts *A* and *B* must have two connectors, as two sets of leads are fastened to them; this completes the testing set.

114. To Prepare for Testing for a Cable-ground with the Home-made Slide-wire Bridge.—Connect to the binding posts *A* and *B* respectively (Fig. 63), one lead to the available end of the grounded conductor and one lead to a conductor parallel to the grounded conductor and having the same destination. The ends of these two conductors, away from the testing set, must be joined together. Connect the millivoltmeter to the posts *A* and *B*.

If a 125-volt, direct-current circuit is available, connect one side to post *C* and ground the other, and place two 16 c-p. lamps in the sockets. If no direct-current circuit is available, five or six battery cells connected in series can be used. Connect one terminal to C and ground the other; short-circuit the lamp sockets with a plug fuse.

115. To locate the grounded point in a cable with the home-made slide-wire bridge, run the knife-edge contact connected to D (Fig. 63) along the graduated wire until the millivoltmeter reads zero. Suppose the reading on the wire is 25 divisions from A. Referring to the lower diagram, if the total length of the cable loop is L, and the distance from the station to the ground is X, then the following proportion holds good:

$$25 : X = 75 : L - X$$

solving for X,

$$75X = 25L - 25X$$
$$100X = 25L$$
$$X = 0.25L$$

and if the length of the cable is known, the distance X can readily be determined.

Designating the distance from A to the point on the slide wire which gives zero deflection on the millivoltmeter as G, and the distance from B around to this point as H, also the total loop length of the conductor, and the distance from the station to the ground, L and X, respectively, as before, then:

$$G : X = H : L - X$$
$$GL - GX = HX \qquad (1)$$

but G plus H equals 100; therefore,

$$H = 100 - G \qquad (2)$$

substituting (2) in (1),

$$GL - GX = 100X - GX$$
$$100X = GL$$
$$X = \frac{G \times L}{100}$$

which is the formula to be used when locating grounds with this apparatus.

If the ground is due to water—which will mean that it is not confined to one point—this method is not very satisfactory. If two or three conductors in the faulty cable are grounded, thus making it impossible to get a cable clear from ground for a return, it will, in all probability, be unnecessary to make the location test as a double ground is equivalent to a short-circuit, and short-circuits are usually very apparent.

116. The ohmmeter is a special form of slide-wire Wheatstone bridge. There are several types. One is shown in Fig. 62. The slide wire connected through a bar of practically zero resistance forms two arms of the bridge. A known resistance R, R_1, R_2, or R_3, forms the third arm and the unknown resistance forms the fourth arm. Instead of a galvanometer a telephone receiver is used. It is connected to a metal-pointed stylus which can be touched at any point along the slide wire. The battery key is on the telephone receiver. At the point where tapping the slide wire with the stylus produces no sound in the receiver the unknown resistance is indicated directly in ohms on a scale under the slide wire.

Several scales indicating ohms can be provided under the slide wire and each scale may be printed in a different color. The holes of R, R_1, R_2, and R_3 are marked each with the color corresponding to the scale that is to be used when the plug is in the corresponding hole. A battery is used in some ohmmeters and an induction coil or a magneto in others.

117. To use the ohmmeter of Fig. 62, connect the unknown resistance as shown. Close the key. Pass the stylus along the wire gently tapping it and hold the telephone receiver to the ear. The unknown resistance will be indicated on the scale at the point where tapping produces no sound in the receiver. The plug P must be in some one of the resistance holes while the test is being made. Read from the scale of the color corresponding to the color at the hole in which P is inserted.

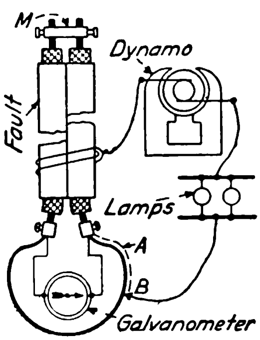


FIG. 64.—Locating a fault in a cable.

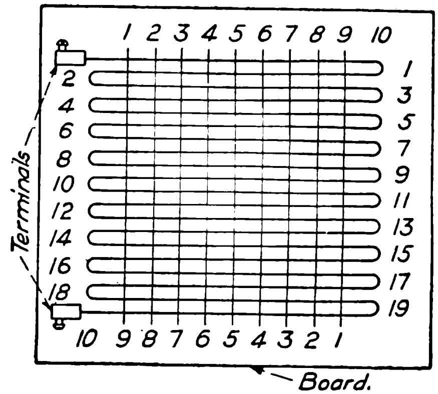


FIG. 65.—Home-made wire bridge.

118. Locating Faults in a Cable (*Standard Underground Cable Co.*).—Fig. 64 shows a simple method, using a dynamo, a galvanometer, and 10 or 15 ft. of bare wire. This method is only applicable when both conductors of the cable are of the same size. After making the connections shown it is only necessary to move the stylus b along the bare wire until the galvanometer is not deflected in either direction.

Let A = the length of the wire between the balance point B and the faulty conductor, C = the total length of the wire, and L = the total length of the cable circuit, = twice the length of the cable.

Then distance to the fault $= \dfrac{A \times L}{C}$.

Fig. 65 shows a simple form of wire bridge which can be used for tests of this kind. The length A can be read directly and the value of C is 200. If a galvanometer is not available a telephone receiver can be used in its place. While the use of alternating currents may introduce errors due to self induction and capacity, such errors will not generally be sufficiently great to interfere with practical results.

119. Testing Cables For Insulation with a Telephone Receiver and Battery (*Standard Underground Cable Co.*).—An extremely simple way to determine whether or not the insulation resistance of any particular wire is high or not, is as follows: A telephone receiver and battery are connected as shown in Fig. 66. One side of the battery is attached to the lead sheath of the cable or to ground, and the other side to a telephone receiver. A rubber insulated wire is attached to the other side of the telephone. To test, press the telephone receiver to the ear, and touch the wire L to the conductor E; a click will always be heard the first time. After keeping both wires in contact for several seconds, break and make the connection once more; if no sound is heard at the instant of reconnection the wire is not faulty. With intervals of time between break and make of one second with a battery of 1 volt it can be assumed that no click indicates at least a resistance of 50 megohms. When more battery is used this number is increased about in proportion to the number of cells. Care must be taken that sounds in the telephone due to induction are not misconstrued for those produced by leaks.

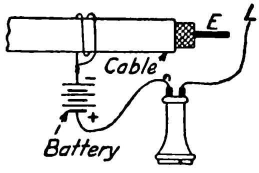


FIG. 66.—Test for insulation resistance.

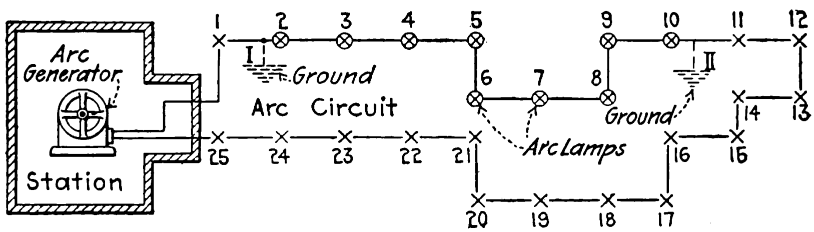


FIG. 67.—Effect of two grounds on an arc circuit.

120. Grounds on series arc or incandescent lighting circuits frequently reveal their locations automatically. If there are two good grounds on the circuit the lamps connected in the line between the grounds will not burn because the grounds will shunt them out. For example, in Fig. 67 with a good ground at I and II, the lamps Nos. 2 to 10 would be shunted out. Sometimes there may be two grounds on a circuit, but they may not be "good" enough to shunt out the lamps. (This paragraph and those that follow on testing arc circuits are from *Electrical World*.)

The presence of but one ground on a circuit, irrespective of how "good" it is, will not reveal itself automatically and the proper operation of the circuit will not be affected by one ground. However, where there is one ground, it constitutes a serious menace to the lives of the station operators and trouble-men. Furthermore, another ground may occur at any time that may cause the shunting out of lamps or possibly a fire or destruction of equipment. Hence, it is very desirable to maintain the circuits entirely clear of grounds. It is the practice in all well-maintained stations to test each series circuit for grounds, some time during every afternoon, and if a ground is discovered a trouble-man is sent out to locate and clear it before the circuit is thrown into service for the night.

121. **The usual method of testing dead series circuits for grounds** is to disconnect the circuit from all station apparatus and then to connect one terminal of a magneto test set to the circuit and the other to ground. If the bell rings vigorously when the crank is turned, the circuit is grounded. If it does not, the circuit is clear. If the circuit is very long or in cable for a considerable portion of its length, the bell may ring some even if the circuit be clear of grounds.

122. **The method of locating a ground on a dead arc circuit** is illustrated in Fig. 68. Disconnect all station apparatus and temporarily ground one side of the circuit as at *B* (Fig. 68). Proceed out along the line and connect some testing instrument (a

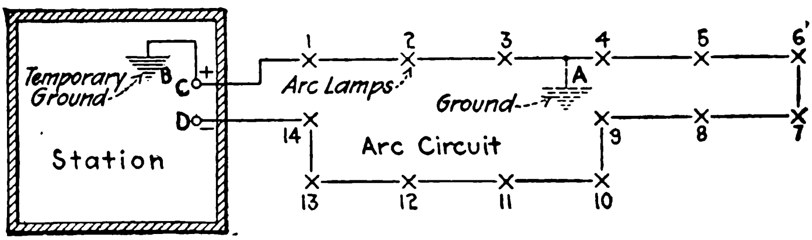


FIG. 68.—Locating a ground on a dead arc circuit.

magneto test set is most frequently used) in series with the circuit at some point. If when the crank is turned the magneto bell rings, indicating a closed circuit, the tester is between the station ground and the ground on the circuit. If the magneto "rings open," the tester is between the circuit ground and the ungrounded station end of the circuit. If in Fig. 68 the test is inserted at lamps 1, 2 or 3, the magneto should ring "closed," while if inserted at any of the other lamps it should ring "open."

123. **In locating either a ground or an open on a series circuit,** unless the tester has an idea as to the location of the trouble, he should proceed first to the middle point of the circuit and there make his first test. This first test will indicate on which side of the middle point the trouble is. He should then proceed to the middle point of the half of the circuit that shows trouble and there make another test. This will localize the trouble to one quarter of the circuit. This "halving" of the sections of the circuit should be continued until the trouble is finally found.

If there is more than one ground on a series circuit the trouble is tedious to locate. If the tests made at different points on the circuit are confusing, indicating the existence of several grounds, the best procedure is to open the circuit into several distinct sections and then test each one as a unit, following the methods described in preceding paragraphs.

124. A ground on a series circuit can sometimes be located with the current from the arc generator or rectifier by placing a temporary ground on the circuit at the station. For example, if in Fig. 68 a temporary ground is connected to terminal *B* and the device that supplies the operating current to the circuit is connected to terminals *C* and *D* and normal operating current thrown out on the circuit, the lamps 1, 2, and 3 will not burn, indicating that the ground is between lamps 3 and 4. The use of this method is attended by some fire risk; hence, the method should be used with caution.

125. A method of locating a ground on a series circuit with a lamp bank is suggested in Fig. 69. A bank of 110-volt incandescent lamps, each of the same candle-power, is connected in series as

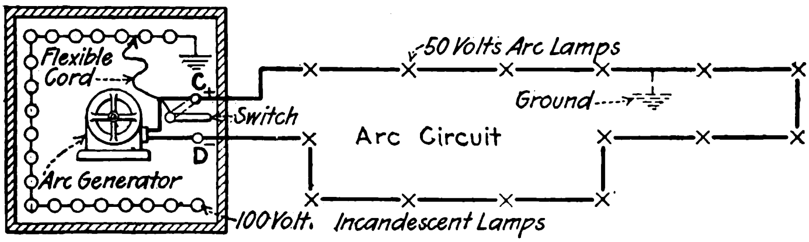


FIG. 69.—Locating a ground on a "live" arc circuit with an incandescent lamp bank.

indicated and one end of the bank is permanently grounded. There should be a sufficient number of lamps in the bank so that the sum of the voltages of all of the lamps is at least equal to the voltage impressed on the series circuit by the arc generator or the regulator. For instance, if the voltage impressed on the series circuit is 6,600, there should be at least sixty 110-volt incandescent lamps in the bank (6,600 ÷ 110 = 60).

In locating a ground, the flexible cord which is connected to the center point of the double-throw switch is successively placed on different points on the conductor that connects the incandescent lamps in series, the switch being thrown to one or the other of the circuit terminals, *C* or *D*. Move the flexible cord along until the incandescent lamps in the bank, between the point of connection of the cord and the permanent ground, burn at about full brilliancy. When this condition obtains, the voltage impressed across the lamps that are burning fully brilliant is approximately equal to the voltage impressed on the portion of the arc circuit (to which the switch connects) between the station and the ground. The voltage required across each lamp of the outside circuit being known, the number of lamps between the station and the ground can be readily computed, and thereby the ground is located.

Great care must be exercised in using this method. Practically all series lighting circuits operate at very high voltage. Hence, when the flexible cord is being moved along the conductor, the arc generator or regulator should be entirely disconnected. If it is not some one may be killed.

Example.—Consider Fig. 69. There is a ground on the circuit. It is found that two of the incandescent lamps of the bank burn at full brilliancy between the flexible-cord connector and the lamp-bank ground. Since 110-volt lamps are used in the bank the voltage across these two is 220. This means that the voltage on the arc circuit between points *C* and *G* is about 220. Since the arc lamps each require about 50 volts there must be $220 \div 50 = 4.4$, or in round numbers 4, arc lamps between *C* and the ground *G*. After making a test with the switch point on *C*, it should be thrown over to *D*, and a check test made from the other end of the circuit. The method of figuring is the same in each case.

126. **To locate an "open" on a series circuit** ground one end of the circuit at the station as in Fig. 68. Then make tests at different points out on the circuit with the magneto connected in between line and ground. So long as the magneto bell indicates a closed circuit, the open is on the line side of the tester. When the magneto indicates an open circuit the open is toward the station from the tester.

127. **The testing out of a concealed wiring system for proper connections** is illustrated in Fig. 70. It is assumed that the wires are installed and that the locations of their runs are concealed

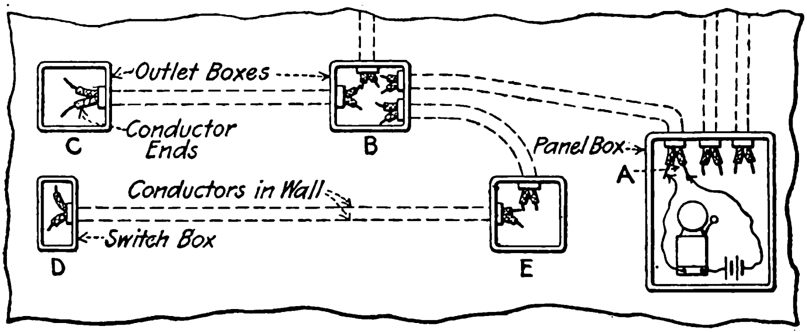


FIG. 70.—Testing out wiring for proper connections.

by the plastering. Only the ends of the conductors are visible at the outlets. It is necessary to identify the conductor ends at each outlet. These tests are usually made with an electric-bell outfit (Fig. 47) because the sound of the bell will indicate a closed circuit to the wireman in a distant room. Hence, a single man can test out such a system. In testing out, first skin the ends of all of the conductors and see that none is in contact with any other or with the outlet box. Next, select a pair of conductors (Fig. 70*A*), preferably the pair that serves the group, and connect the bell outfit to the ends of the pair as shown. Then proceed to the outlet (Fig. 70*B*) at which the pair of conductors should terminate and successively touch together the ends of all the wires that terminate in that box until a pair is discovered that, touching together the ends of which, rings the bell. This identifies one pair. Tag this pair so that it can be readily found again and repeat the process on some other pair. Continue this until all of the conductors are identified. (This paragraph and those that follow on practical electrical tests from *Electrical Engineering*.)

128. **The method of testing out the connections for three-way**

switches is shown in Fig. 71. When finally connected the circuits should be as shown at *I*. It is assumed that the conductors are in place and concealed within walls or ceilings and that only the ends are visible at the outlets, as at Fig. 71, *II*. First, identify the feed conductors and bend back their ends at the outlet box as at A_3. Next, twist together, temporarily, the bared ends of any two of the conductors at each of the switch outlets as at A_3 and C_3. The conductors having their ends thus twisted together will be the switch conductors. Now, at the lamp outlet, or outlets, identify the short-circuited switch conductors as directed in a

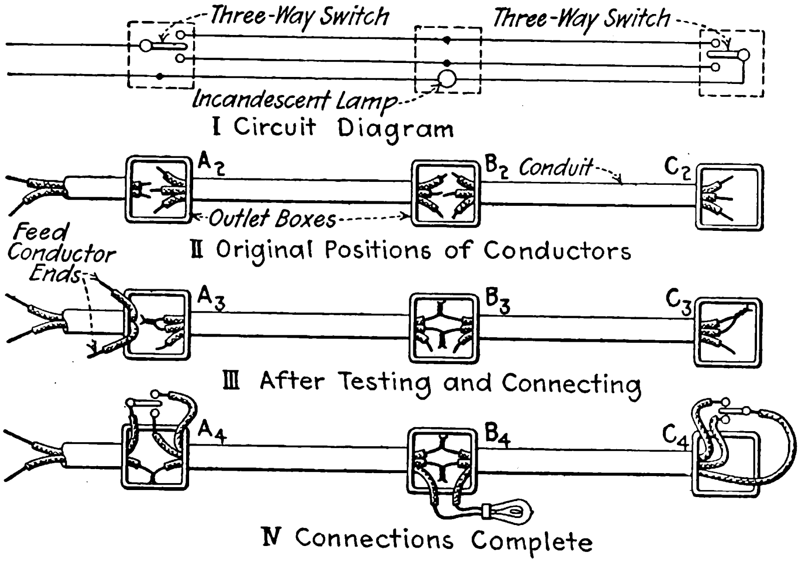


FIG. 71.—Testing out three-way switch connections.

preceding paragraph and connect and solder these switch conductors together as at B_3. Connect the remaining conductor ends at the lamp outlets to the lamps, B_4, connect one of the feed conductors to the center point of the three-way switch (A_4), and connect the other feed conductor to the lamp wire. The switch conductors are connected to the two points of the switch. At C_4 the same procedure is followed.

129. **In testing out a new wiring installation for faults** each branch circuit, main and feeder should be treated individually. It is usually impracticable to test an installation as a unit, as open switches and loose connections in cut-outs may render such a test worthless. If a test is made from the cut-out, on the two conductors of each individual circuit, the above-mentioned possible elements of uncertainty are eliminated. Test each side of each circuit separately unless the lamps are in position.

130. **Open circuits in multiple wiring installations are usually readily located.** If the lamps are in position and lighting voltage available, it can be impressed on the circuit. The lamps on the generator side of the "open" will then burn while those on the far side will not, which localize the "open." Where lighting voltage is

not available, all of the lamps can be taken out of the sockets and each of the sides of the circuit can be grounded at the cut-out. Then a telephone-and-battery, a bell-and-battery, or a magneto test set can be connected temporarily and successively between one line and ground and between the other line and ground at each outlet on the branch. When the test set indicates an open circuit, the "open" is between the tester and the ground made at the cut-out.

131. **The test for short-circuits on a multiple system** is made by temporarily connecting a test set across the terminals of each branch and circuit at the cut-out. If there is a short-circuit on the lines under test, its presence will be immediately evident.

132. **The test for continuity of multiple wiring circuits** is made by temporarily connecting a test set across the terminals of each branch cut-out and successively short-circuiting, one at a time, the sockets of the branch with a screw-driver, a nail, or other metal object. The test set will then indicate whether the wiring of the circuit is open or closed. Where lighting voltage is available and plug cut-outs are used, a lamp can be screwed into one socket of the cut-out and a plug-fuse into the other. Then the tester can proceed from socket to socket and short-circuit each. Where circuit to the socket is continuous the lamp will light when the socket is short-circuited.

133. **The test for grounds on a multiple wiring installation** is made by temporarily connecting between line and ground a test set of one of the types hereinbefore described. If the test set indicates a short-circuit, the line being tested is grounded.

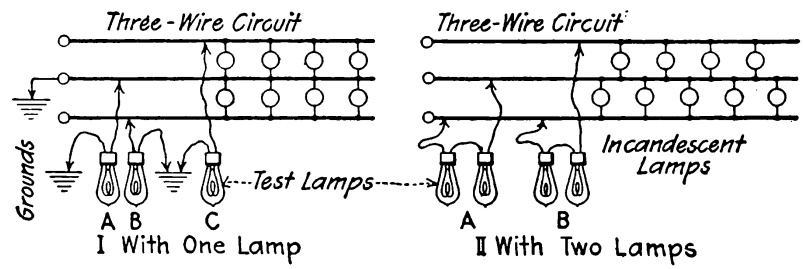


FIG. 72.—Locating neutral wire with test lamp.

134. **The testing of three-wire circuits to identify the neutral,** is effected as suggested in Fig. 72. Where the neutral is grounded, a test lamp can be successively connected between each of the three conductors and ground (Fig. 72, *I*). When the ungrounded side of the lamp is touched to the neutral wire it will not burn, but when touched to either of the outside wires it will burn. A method that can be used with either a grounded or an ungrounded neutral is illustrated in Fig. 72, *II*. Connect the two test lamps in series successively between one of the line wires and the other two. When connected across the two outer wires both lamps will burn at full voltage, but when connected between one of the outer wires and neutral they will burn at only half voltage. The "touching" test described in a previous paragraph (90) can also be applied.

135. Polarity of direct-current circuits can be determined by holding the two conductors in a glass vessel of water as indicated in Fig. 73. It may be necessary to pour a little common salt or

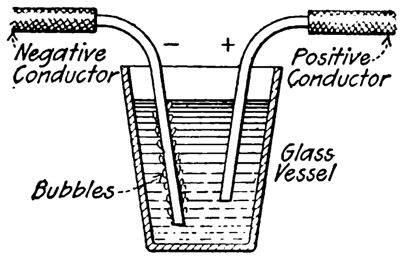


FIG. 73.—Determination of polarity with conductor ends in water.

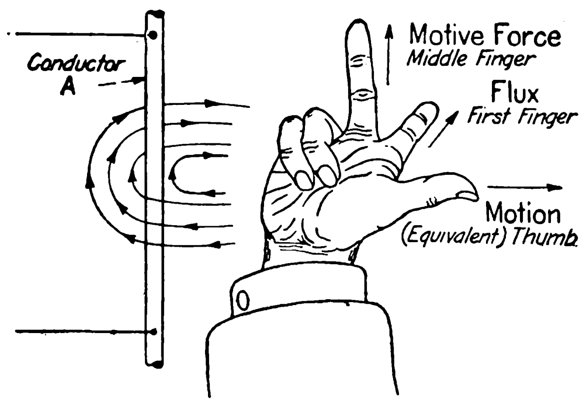


FIG. 74.—Application of right-hand rule.

acid into the water to render it conducting. Pure water is a poor conductor. Bubbles will form only on the negative conductor, indicating the presence of current and the polarity of the circuit. Be careful not to touch the conductor ends together which will cause a short-circuit.

136. A Hand Rule to Determine the Direction of an Induced e.m.f.—(See Fig. 74.) Use the *right hand.* Extend the thumb in the direction of the motion, or of the equivalent motion, of the conductor and the forefinger in the direction of the magnetic flux. Then the middle finger will point in the direction of the induced e.m.f. (Magnetic flux flows from the north (*N*) to the south (*S*) pole of a magnet.) This rule can be remembered by associating the sounds of the following word groups: "thumb—motion," "forefinger—force" and "middle finger—motive force."

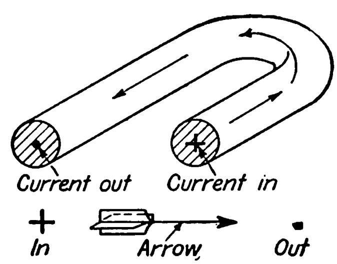


FIG. 75.—Symbols indicating direction of current flow.

137. Symbols for indicating the direction of an e.m.f. or current into or out of the end of a conductor are shown in Fig. 75.

138. Hand Rule for Direction of Magnetic Field about a Straight Wire.—(See Fig. 76.) If a wire, through which electricity is flowing, is so grasped with the *right hand* that the thumb points in the direction of electricity flow, the fingers will point in the direction of the magnetic field and vice versa.

139. Hand Rule for Polarity of a Solenoid or Electromagnet.—(See Fig. 77.) If a solenoid or an electromagnet be so grasped

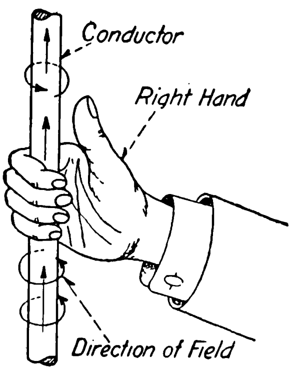


FIG. 76.—Hand rule for direction of field.

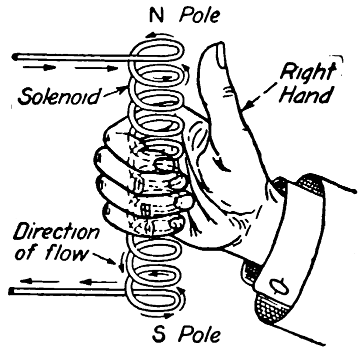


FIG. 77.—Hand rule for determining polarity of a solenoid.

with the *right hand* that the fingers point in the direction of electricity flow, the thumb will point toward the north (−) pole.

140. Rule for Determining Direction of Current Flow with a Compass.—(See Fig. 78.) If a compass is placed under a conductor, in which electricity is flowing from south to north, the north end of the needle will be deflected to the west. If the compass is placed over the conductor, the north end of the conductor will be deflected to the east. If the direction of current flow in the conductor is reversed the direction of deflection of the needle will be reversed correspondingly.

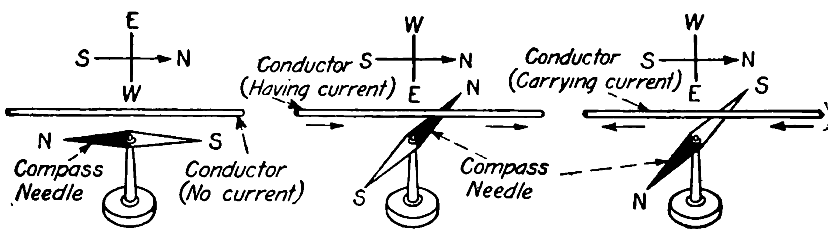


FIG. 78.—Performance of a compass needle near a conductor.

141. Ground Detectors.—(*Factory Mutual Insurance Co's. Book of Rules.*) The purpose of the ground detector is to give a warning when the first break in insulation occurs, thereby giving time to repair it before the second one, with its possible accompanying fire, can follow. The instant a detector shows a ground, steps should be taken to find and remedy it. By throwing off one circuit after another, the one on which the ground exists will soon be found, as when it is cut off the detector lamps will again burn with equal brilliancy. Inspection along this circuit will then generally soon disclose the trouble. Where the circuits are not well sub-divided by switches, fuses may be removed to accomplish the same result.

142. Ground Detectors for Two-wire Direct-current Circuits.—Fig. 79 shows a very good and simple detector for any two-wire low-voltage system. The lamps for the detector should each be of the same candle-power and voltage—the voltage being about the same as that of the regular lamps in the plant—and two lamps should be selected which, when connected in series, burn with equal brilliancy. Although somewhat greater sensitiveness can be obtained with low candle-power lamps, such as 8 c-p., for example, it is believed in general to be preferable to use lamps of same candle-power as those throughout the plant, as then a burned-out or broken detector lamp can be immediately replaced by a good lamp from the regular stock, thus avoiding the necessity of keeping on hand a few spare special lamps.

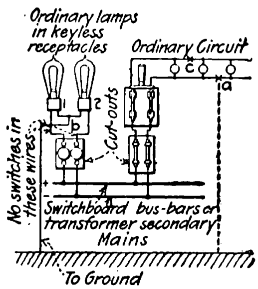


FIG. 79.—Two-lamp ground detector.

The detector lamps, being two in series across the proper voltage for one lamp, burn only dimly. If, however, a ground occurs on any circuit, as at *a*, the current from the positive bus-bar through lamp No. 1 divides on reaching *b*, instead of all going through lamp No. 2, as it did when there was no ground. Part now goes down the ground wire and through the ground to *a*, as indicated by the broken line, and thence through the wires to the negative bus-bar. This reduces the resistance from *b* to the negative bus-bar, and therefore more current flows through lamp No. 1 than before, while less current flows through lamp No. 2. Lamp No. 1 consequently brightens and lamp No. 2 dims. If the ground had occurred at *c* instead of *a*, lamp No. 2 would have brightened and lamp No. 1 dimmed.

Attention is called to the following points, which are frequently neglected in this form of detector:

1. The lamp receptacles should be keyless and there should be no switches of any kind in any of the connecting wires, so that the detector will always be in operation. In order to be of the greatest value, the indications must be given instantly when a ground occurs. The observer should not have to wait until the engineer or electrician remembers to close a switch.

2. The wires should be protected by small fuses where they connect to the bus-bars. If these fuses are omitted, a short-circuit across these wires would either burn up the wires or blow the main generator fuses.

3. The lamps should be placed very close together, within 1 or 2 in. of each other if possible. The farther apart they are, the harder it is to detect any slight difference in brilliancy between them.

4. The ground wire should be carefully soldered to a pipe which is thoroughly connected to the ground, or some other equally good ground connection should be provided.

143. A lamp ground detector for a three-wire Edison system is shown in Fig. 80. In principle it is exactly the same as the two-lamp detector of Fig. 79. Its indications are as follows:

Switch on point No. 1	Ground at *a*—A bright, B and C dim. Ground at *b*—B and C bright, A dim. Ground at *c*—A bright, B and C dim.
Switch on point No. 2	Ground at *a*—A and B bright, C dim. Ground at *b*—C bright, A and B dim. Ground at *c*—C bright, A and B dim.

With the lamp switch at point No. 1, grounds at *a* and *c* give the same indication, but by throwing the switch to point No. 2, it will be at once evident whether the ground is on the positive or negative side. It is to remove the uncertainty which would otherwise exist that this switch is needed. It should have no "off" position.

The man in charge of a plant can readily familiarize himself with the indications of the detector by purposely putting a ground on the different wires and noting the indications.

If the neutral is permanently grounded, a ground detector is, of course, of no use.

144. The same degree of sensitiveness on both sides can be obtained by means of the lamp switch in Fig. 80, but for grounds on the neutral, there is never more than half the full voltage avail-

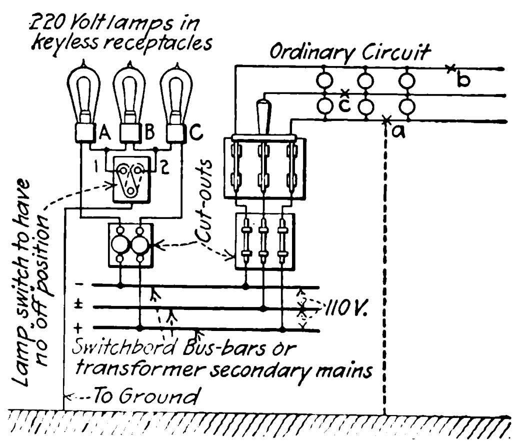


FIG. 80.—Lamp ground detector for three-wire system.

able to operate the lamps, so that the indications are necessarily less sensitive.

145. An ordinary voltmeter can be used as an intermittent ground detector on direct-current circuits of any voltage, as shown in Fig. 81. The voltmeter ordinarily used to indicate the pressure on the system can, of course, be used for this purpose, the voltmeter switch shown in the cut being arranged to give the different desired connections.

If, for example, the system shown in Fig. 81 were of about 100 volts, the voltmeter would register 100 when the levers of the switch were on the inside contact points as shown. If, now, the right-hand lever were moved to the outside contact point as shown dotted, and there were a ground on the system, as at *a*, current would pass from the positive bus-bar through the circuit to *a*, thence through the ground to the ground wire, and through the voltmeter to the negative bus-bar, causing the voltmeter to read something below 100, unless the ground at *a* were practically a perfect connection, in which case the voltmeter reading would be 100. If the positive side of the system were entirely free from grounds, the voltmeter reading would be 0.

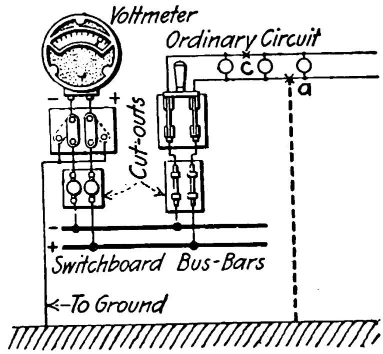


FIG. 81.—Voltmeter ground detector.

Assume that under these conditions the voltmeter reads 50, and that the resistance of the voltmeter itself was 20,000 ohms, it will be evident that if, with no external resistances, as when connected directly to the bus-bars, the voltmeter reads 100, while now it reads 50, the total resistance under the new conditions must be 40,000 ohms, of which $40{,}000 - 20{,}000 = 20{,}000$ ohms must be the resistance of the ground at *a*.

If the voltmeter had read only 20 the total resistance would have been $\frac{100}{20} \times 20{,}000 = 100{,}000$, and the resistance of the ground $100{,}000 - 20{,}000 = 80{,}000$ ohms.

146. Ground Detectors for Ordinary Low-voltage Three-phase Alternating-current Circuits.—A lamp detector connected as in Fig. 82 may be used. The indication is the same as that with the lamp detectors described above. Thus, when a ground comes on one wire, the lamp attached to that wire dims and the other two brighten.

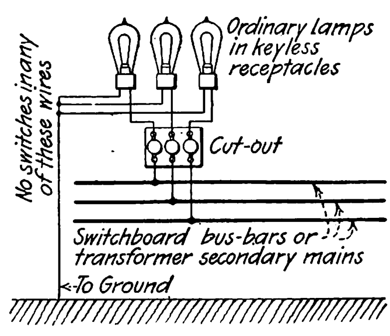


FIG. 82.—Three-phase lamp detector.

For ordinary two-phase (or quarter-phase) systems, where the phases are entirely insulated from each other, the two-lamp detector can be used, one detector on each phase. There are, however, in this class of wiring several complicated systems, to all of which the lamp detector principle is applicable, although the exact method of connections differs in each case, so that no general rule can be given.

147. The testing of lighting fixtures prior to installation is best accomplished with a voltmeter, Fig. 83. The test for short-circuit and continuity is illustrated at *I*. If the voltmeter does not give a reading with the lamps out of the sockets, the fixture wiring is clear of short-circuits. After the test for short-circuits has been made each socket is short-circuited with a metal object —a screw-driver is frequently used—and if the voltmeter indicates the full voltage of the circuit each time a socket is short-circuited, it signifies that the circuit to that socket is continuous.

The fixture can be tested for grounds as at Fig. 83, *II*. If there is no deflection of the voltmeter with one lead from the voltmeter touching the metal work of the fixture and the other successively each of the fixture conductors, the fixture is clear of grounds. Be certain that one voltmeter terminal is in actual contact with the metal work of the fixture and not insulated therefrom by the lacquer finish. This test should be made with the lamps out of the socket.

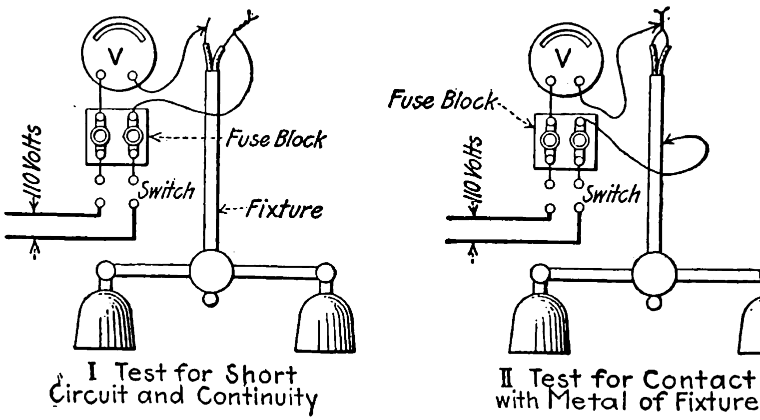


FIG. 83.—Methods of "testing out" fixtures.

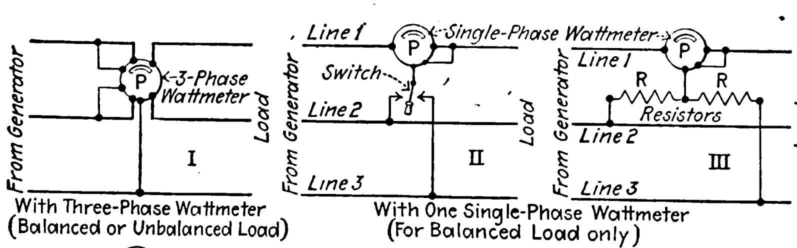
148. The measurement of the power in a single-phase circuit is described in a preceding paragraph.

148 A. Power in a two-phase system. In the four-wire circuit each phase is treated as if it were a separate circuit and the total power is equal to the arithmetic sum of readings, P_1 and P_2. In the three-wire circuit the total power is equal to the algebraic sum of the wattmeter readings. That is:

$$\text{Total power} = P_1 + P_2 \text{ in watts.}$$

149. Power in three-phase circuits can be measured with wattmeters by several different methods. See Fig. 84. At *I* a polyphase wattmeter is shown. An instrument of this type automatically adds the portions of power consumed in each phase and indicates their sum. Instruments made by different manufacturers are arranged differently and must be connected accordingly. Directions accompany each instrument. Diagrams *II* and *III* show how the power can be measured, in a balanced circuit, with one wattmeter. One pressure lead is connected to the line in which the wattmeter is inserted and the other pressure lead is connected successively to the other two lines. *The total power in I is equal to the sum or difference of the two readings.* If resistors are used as indicated in *III*, the power can be ascertained without any shifting of leads. The wattmeter reading of *III* multiplied by 3 will be the true power in a balanced circuit. The resistance of each of the resistors *R* and *R* must be equal to the resistance of the potential or voltage coil of the wattmeter.

With two wattmeters (as in Fig. 84, *IV*) the total power is equal to the (sum or difference) of the two wattmeter readings. If the power factor is greater than 0.50 the total power is their arithmetical sum of the readings. If it is lower than 0.50 one of the readings is negative and the power is their arithmetical difference.



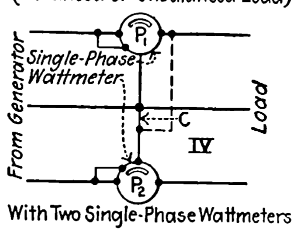


FIG. 84.—Three-phase power measurements with wattmeters.

To ascertain whether one of the wattmeters is reading negative, temporarily transfer the connection of one of the potential wires (for example *c* in *IV*, as shown by the dotted line) from the middle wire to the outside wire. If its wattmeter reverses, one of the instruments, that of the lesser indication, is reading negatively. The nature of the load usually enables one to judge roughly what the power factor is. With incandescent lamps and fully loaded motors the power factor will be high, but with under and lightly loaded motors it is likely to be low. See **151** for method of determining the **power factor** of three-phase circuits **with wattmeters.**

150. The methods of measuring the power factors of circuits are described in other paragraphs.

151. The method of determining three-phase power factor with wattmeters was well described by C. E. Howell in *Electrical World.* It is necessary to know the power factor in order to connect watt-hour meters correctly where the wiring is concealed. An abstract follows:

Fig. 85 shows the power-factor curve for two single-phase meters on a polyphase circuit. It also gives a diagram of connections and instructions as to how to use the curve. The figure should be self-explanatory. Fig. 86 gives, first, a method of checking results obtained by employing the curve given in Fig. 85 and a diagram of the connections for obtaining data for the check. The second part of Fig. 86 gives a method of determining the correct connections for two single-phase meters, or one polyphase meter, on a three-phase circuit. If this part of Fig. 86 is employed, errors in meter connections on three-phase circuits due to the power factor being near 50 per cent. should be a minimum.

To illustrate the use of the above instructions: A 100-h.p., three-phase, 440-volt induction motor was operating on 30 per cent. full-load or 40 h.p. (29.8 kw.) at 60 per cent. power factor (afterward determined) when an order "came through" to place a polyphase watt-hour meter on the installation. Immediately after the meter had been connected the following question was asked:

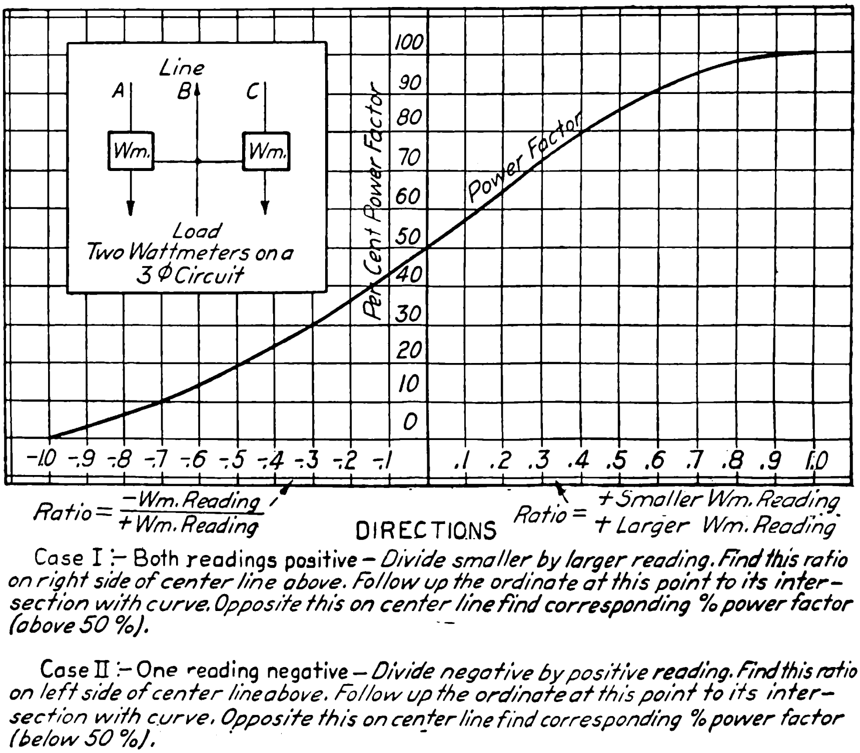
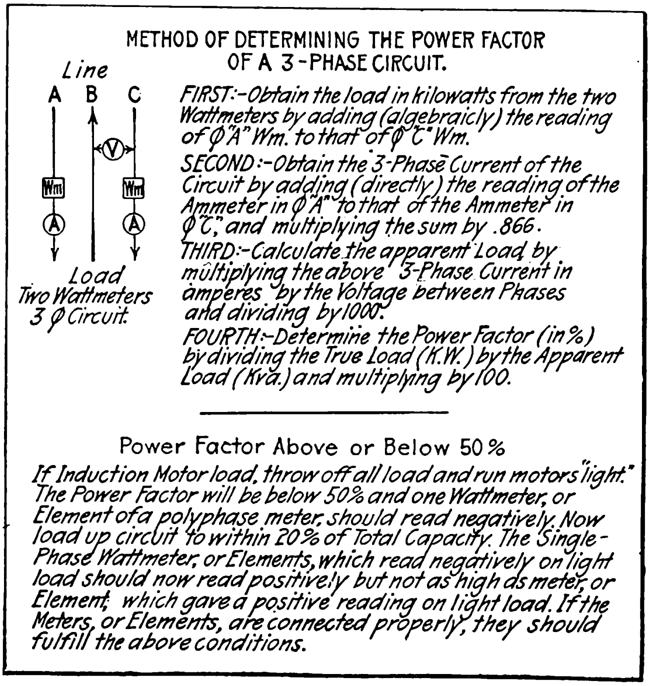


FIG. 85.—Power factor curve.

"Should the light element add to or subtract from the heavy element; that is, is the power factor above or below 50 per cent.?" As the meter leads were incased in pipe, they could not be traced, therefore the instructions in the second figure pertaining to this point were applied. The connected load of the motor having been thrown off, it was found that one element of the meter gave a negative reading. Sufficient load was then put on to bring the motor to about 80 per cent. of its full-load rating. Each element of the meter (taken separately) now read positively, but the element which on no-load gave a negative reading on 80 per cent. load read lower than the heavy element. The meter had been correctly connected when installed. Later both methods given above to determine the power factor of a three-phase circuit were applied and both gave approximately 60 per cent. power factor (at 30 per cent. load).

152. **To correctly read the consumption indicated on the dials of a recording watt-hour meter** (sometimes, but erroneously, called a recording wattmeter) these directions should be followed: (*Rules and Regulations of the Commonwealth Edison Co., Chicago.*) See Fig. 87 for examples.



Note.—This is based on the fact that on "no-load" the Power Factor of an Induction Motor is below 50%.

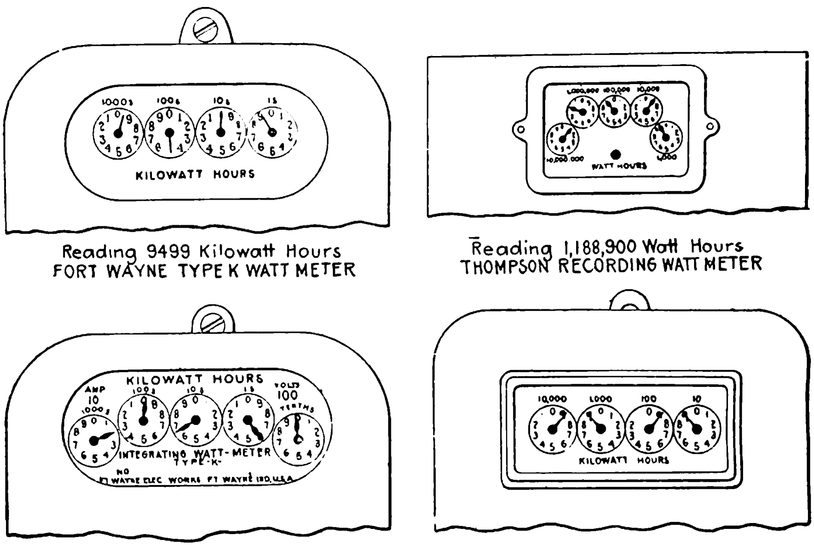
Fig. 86.—Chart of instructions for power factor test.

The pointer on the right-hand dial of a five-dial meter registers $\frac{1}{10}$ (one-tenth) of a kilowatt-hour or 100 watt-hours for each division of the dial. A complete revolution of the hand of this dial will move the hand of the second dial one division and register 1 (one) kw-hr. or 1,000 watt-hr. A complete revolution of the hand of the second dial will move the third hand 1 (one) division and register 10 kw-hr. or 10,000 watt-hr. and so on.

Accordingly, read the hands from left to right and add 2 (two) ciphers to the reading of the lowest dial to obtain the reading of the meter in watt-hours. Where there are 4 dials on the meter, the pointer on the right-hand dial registers 1 kw-hr. or 1,000 watt-hr. for each division of the dial, and it is necessary to add 3 (three) ciphers to the reading of the lowest dial to obtain the reading in watt-hours, or the meter reads directly in kilowatt-hours.

Hands should always be read as indicating the figure which they have last passed, and not the one to which they are nearest.

Thus, if a hand is very close to a figure, whether it has passed this figure or not must be determined from the next lower dial. If the hand of the lower dial has just completed a revolution, the hand of the higher dial has passed the figure, but if the hand of the lower dial has not completed a revolution, the hand of the higher dial has not yet reached the figure, even though it may appear to have done so.



Reading 9499 Kilowatt Hours
FORT WAYNE TYPE K WATT METER

Reading 1,188,900 Watt Hours
THOMPSON RECORDING WATT METER

Reading 1965.9 Kilowatt Hour
FORT WAYNE TYPE K WATT METER

Reading 8889 Kilowatt Hours
THOMPSON RECORDING WATT METER

FIG. 87.—Examples of watthour meter readings.

When 1 (one) pointer is on 9 (nine), special care must be taken that the pointer on the next higher dial is not read too high, as it will appear to have reached the next number, but will not have done so until the hand at 9 (nine) has come to zero.

The hands on adjacent dials revolve in opposite directions. Therefore a reading should always be checked after being written down, as it is easy to mistake the direction of the rotation.

To determine the consumption for a given time, subtract the reading at the beginning of the period from the reading at the end. Always observe if a constant is marked at the bottom of the dial plate. If so, the difference of the readings must be multiplied by this constant to obtain the consumption.

153. Test to Determine the Horse-power of an Electric Motor.—Applying the principles, outlined elsewhere in this section, to a motor under test for output, the power delivered being measured with a prony brake, Fig. 88, may be taken as an example.

Example.—The torque is 10 lb. at 3 ft. radius, or 30 lb-ft., or 30 lb. at 1 ft. radius. Since the motor pulley is turning at the rate of 1000 r.p.m. a point on its circumference travels $2\pi rR = 2 \times 3.14 \times 1 \times 1000 = 6,280$ ft. per minute. At its circumference the pulley is overcoming a resistance of 30 lb. Therefore it is doing work at the rate of $30 \times 6,280 = 188,490$ ft-lb. per minute. Since, when work is done at the rate of 33,000 ft-lb. per minute, a horse-power is developed, the motor is delivering 188,490 ÷ 33,000 = 5.7 h.p. It should be noted that, though the torque at the circumference of the motor pulley was considered in the example, it is not necessary to take the torque at that point. The torque may be taken at any point if the radius to that

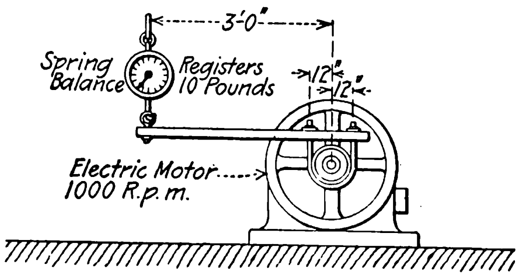


FIG. 88.—Horse-power determination with a prony brake.

point is used instead of the radius of the pulley. The formula for determining the horse-power output of a motor under test with a prony brake is

$$\text{h.p.} = 2 \times \pi T S \div 33{,}000,$$

where $\pi = 3.1416$, T = torque in pounds-feet and S is the speed of the motor in revolutions per minute. Substituting the values from the above example in this formula:

$$\text{h.p.} = 2 \times 3.14 \times 30 \times 1{,}000 \div 33{,}000 = 5.7 \text{ h.p.}$$

This is the same result secured by the former and longer method. In metric units, work is expressed in kilogram-meters, so, conversely, torque should be expressed in meter-kilograms or in kilograms at a given radius in meters.

154. **The testing of motors and generators for faults** is treated in the section on motors and generators which occupies an independent portion of this book.

PROPERTIES AND SPLICING OF CONDUCTORS

155. **Electric Wire and Cable Terminology.**—(*U. S. Bureau of Standards Publication No.* 37.)

Wire.—A slender rod or filament of drawn metal. (The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire; while primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated the term "wire" will be understood to include the insulation.)

Conductor.—A wire or combination of wires not insulated from one another, suitable for carrying a single electric current. (The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents. Rolled conductors, such as bus-bars, are, of course, conductors, but are not considered under the terminology here given.)

Stranded Conductor.—A conductor composed of a group of wires or any combination of groups of wires. (The wires in a stranded conductor are usually twisted or braided together.)

Cable.—(1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several *conductors.* The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one and in practice it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord," both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead or with steel wires or bands.

Strand.—One of the wires or groups of wires of any stranded conductor.

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 such a filament is subdivided into several smaller filaments or strands, and is used as a single wire, it is called "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable." If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord," defined below.)

Cord. A small cable, very flexible and substantially insulated to withstand wear. (There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Usually the insulation of a cord contains rubber.)

Concentric Strand.—A strand composed of a central core surrounded by one or more layers of helically laid wires or groups of wires.

Concentric Lay Cable.—A single-conductor cable composed of a central core surrounded by one or more layers of helically laid wires.

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.

155A. The weights of wires, of the metals that are ordinarily used, can be computed for wires of any diameter and any length with the following formula, by using values from Table **156.**

$$W = k \times D^2 \times l \text{ or } D = \sqrt{\frac{W}{k \times l}}$$

or

$$W = k \times \text{cir. mil} \times l$$

Wherein W = weight in pounds, k = constant from **156,** differing in value for each metal and equal to the weight of a cir. mil-ft. of the metal, D = the diameter of the wire in mils or thousandths of an inch and l is the length of the wire in feet.

Example.—What is the weight of a bare 500,000 cir.-mil copper cable 2,000 ft. long?

Solution.—Substitute in the formula:

$$W = k \times \text{cir. mil} \times l = 0.00000303 \times 500{,}000 \times 2{,}000 = 3{,}030 \text{ lb.}$$

The wire will weigh 3,030 lb.

156. Weights of 1 Cir. Mil-ft. of Metals

Metal	k Weight in pounds of 1 cir. mil-ft.
Copper	0.00000303
Aluminum	0.000000916
Galvanized iron	0.00000264
Galvanized crucible steel	0.00000264

157. Wire Gages.—Diameters of wires are usually expressed according to some wire gage. Unfortunately there are many gages originated by different manufacturers for their products. Wire sizes are referred to by gage numbers and, usually, the smaller the number the bigger the wire. The ordinary uses of the different gages are indicated in **162.** The only legal gage in this country is the U. S. standard for plate. Wire-measuring gages (Figs. 89 and 90) are made of steel plate. With the kind shown in Fig. 89 the wire being measured is inserted in the slots in the periphery until a slot is found in which the wire just fits. Its gage number is indicated opposite the slot. A measuring gage like that of Fig. 89 indicates the numbers of one gage or system only. A gage like that of Fig. 90 indicates the numbers of four gages but has the disadvantage that, to use it, the end of the wire must be available to push through the slot. The wire is pushed as far toward the small end of the slot as it will go and its gage number will be indicated opposite the point where the wire stops. The gage of Fig. 90 is arranged to indicate gage

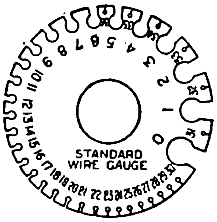


FIG. 89.—Standard wire gage (greatly reduced).

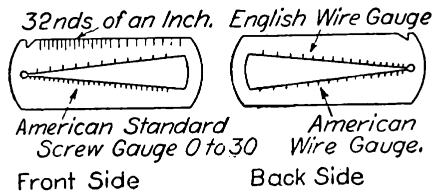


FIG. 90.—Angular wire gage (greatly reduced).

numbers for the American Screw Gage, English Wire Gage, American Wire Gage and one scale is divided into 32nds of an inch.

158. Wire gage systems and wire-measuring gages are inconvenient and confusing and the practice of **measuring wires and plates with a micrometer** (Fig. 91) is becoming prevalent. Some concerns now make a practice of specifying the diameters of all wires in thousandths of an inch and, doubtless, the practice will ultimately become universal. The micrometer measures

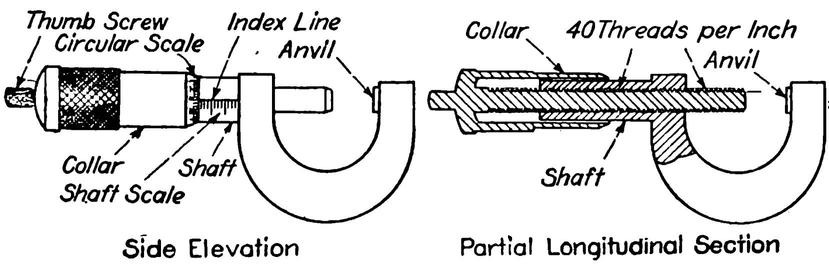


FIG. 91.—A micrometer caliper.

very accurately to thousandths of an inch and ten thousandths can be estimated. The wire to be measured is placed between the *thumb screw* and the *anvil* (Fig. 91) and the screw turned until the wire is lightly held between the screw and the anvil. The screw has 40 threads to the inch so that one complete turn of the screw in a left-handed direction will open the micrometer $\frac{1}{40}$ of an inch. On the edge of the *collar* is a *circular scale* divided into 25 divisions, hence, when the screw is turned through one of these divisions, the micrometer will open $\frac{1}{25}$ in. $\times \frac{1}{40}$ in. $= \frac{1}{1000}$ in. The *shaft* on which the *collar* turns is marked into tenths of an inch and each $\frac{1}{10}$ is subdivided into four parts. Each of these parts must be equal to $\frac{1}{10}$ in. by $\frac{1}{4}$ in. $= \frac{1}{40}$ in. $= 0.025$ in. Therefore a complete rotation of the collar or 25 of its divisions will equal one division of the shaft or 0.025 in.

159. **To read a micrometer** (see Fig. 92 and the paragraph above) note the number on the *circular scale* nearest the *index line.* This indicates the number of thousandths. Note the number of small divisions uncovered on the *shaft scale.* Each one of these small divisions indicates 0.025 in. ($\frac{25}{1000}$). Add together the number of thousandths indicated on the *circular* scale and 0.025 × the number of small divisions wholly uncovered on the shaft scale. The sum will be the distance that the jaws are apart.

Examples are shown in Fig. 92.

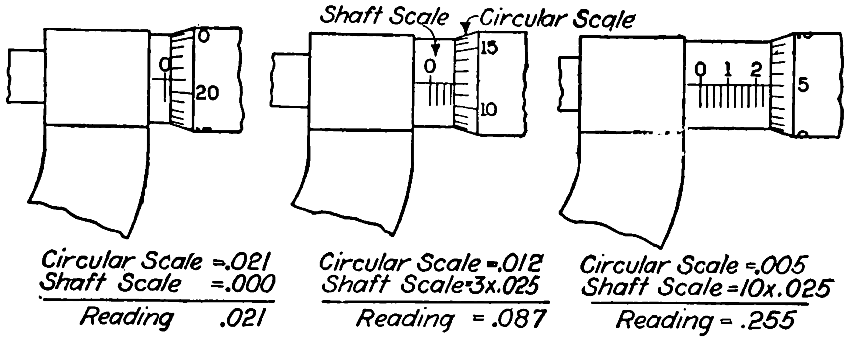


FIG. 92.—A micrometer caliper.

160. **The most important of the different gages** that are in use in this country are indicated by numerical comparison in Table **164.** Some of these gages are known by several names. The **different names for each gage** system, their abbreviations and the materials **ordinarily measured by each** are indicated in table **162.**

161. Tensile Strength of Pure Copper Wire in Pounds

Size, B. & S.	Hard drawn		Annealed		Size, B. & S.	Hard drawn		Annealed	
	Actual	Average per square inch	Actual	Average per square inch		Actual	Average per square inch	Actual	Average per square inch
0000	8,260	49,700	5,320	32,000	7	1050.0	64,200	556.0	34,000
000	6,550	49,700	4,220	32,000	8	843.0	65,000	441.0	34,000
00	5,440	52,000	3,340	32,000	9	678.0	66,000	350.0	34,000
0	4,530	54,600	2,650	32,000	10	546.0	67,000	277.0	34,000
1	3,680	56,000	2,100	32,000	12	343.0	67,000	174.0	34,000
2	2,970	57,000	1,670	32,000	14	219.0	68,000	110.0	34,000
3	2,380	57,600	1,323	32,000	16	138.0	68,000	68.9	34,000
4	1,900	58,000	1,050	32,000	18	86.7	68,000	43.4	34,000
5	1,580	60,800	884	34,000	19	68.8	68,000	34.4	34,000
6	1,300	63,000	700	34,000	20	54.7	68,000	27.3	34,000

162. Different Names, Abbreviations and Uses of the Principal Wire and Sheet Metal Gages

Column No. in Table 164	Common name and abbreviation	Other names and abbreviations	Ordinarily used for measuring
1	Brown & Sharpe (B. & S.).	American Wire Gage (A.W. G.). United States Standard. American Standard Wire Gage.	Almost universally used in America in lighting and power practice for measuring bare and insulated copper wire under ½ in. in diameter. All electrical wires and rod except those of iron and steel. All metal plates except those of copper, iron, steel and zinc. Thickness of wall of brazed brass, zinc and copper tubing.
2	Birmingham (B. W. G.).	Stubs Iron Wire Gage (Not Stubs Steel Wire Gage). Old English Standard (Not English Standard). Iron Wire Gage.	Galvanized iron and steel wire. Norway iron wire. Iron rivets, copper rivets. Thickness of wall of all seamless tubing except iron and steel. Sometimes used by A. T. & T. Co. for bare copper telephone line wire. Sheet copper.
3	Trenton........	....	Trenton Iron Works iron wire. Quite similar to Washburn and Mohn Gage. Seldom used.
4	American Screw.	....	Numbered sizes of wood and machine screws, particularly those smaller than 0.2421 in. (No. 14).
5	New British Standard (N. B. S.).	Standard Wire Gage (S. W. G.). British Imperial (I. W. G.). English Legal Standard (S. W. G.). British Standard.	Seldom used in America in lighting and power practice. Used by some American telephone and telegraph companies for bare copper line wire.
6	Washburn & Mohn (W. & M.).	Roebling. American Steel and Wire Co's. Iron Wire Gage (A. S. W.). G. W. Prentiss Gage, Holyoke, Mass.	Iron and steel wire. Sometimes used for galvanized iron telephone and telegraph wire. Wire nails. Brass and iron escutcheon pins.

162. Different Names, Abbreviations and Uses of the Principal Wire and Sheet Metal Gages (*Continued*)

Column No. in Table 164	Common name and abbreviation	Other names and abbreviations	Ordinarily used for measuring
7	London Gage....	Old English (Not Old English Standard), from Brass Manufacturers list.	For brass wire, but seldom used.
8	Stubs Steel Wire Gage.	(Not Stubs Iron Wire Gage).	Drill rod.
9	Steel Music Wire Gage (M. W. G.).	Hammacher & Schlemmer (H. & S.). Felten & Guilleanme (F. & G.).	Steel music wire.
10	United States Standard (U. S. S.).	....	Iron and steel plate. This is the legal standard in America for these materials.

163. Equivalent Cross-sections of Wires

Brown & Sharpe Gage

Equivalent section	Number of wires of various sizes						
	2	4	8	16	32	64	128
0000	0	3	6	9	12	15	18
000	1	4	7	10	13	16	One each
00	2	5	8	11	14	17	1 and 3
0	3	6	9	12	15	18	2 " 4
1	4	7	10	13	16	..	3 " 5
2	5	8	11	14	17	..	4 " 6
3	6	9	12	15	18	..	5 " 7
4	7	10	13	16	..	..	6 " 8
5	8	11	14	17	..	..	7 " 9
6	9	12	15	18	..	..	8 " 10
7	10	13	16	..	..	..	9 " 11
8	11	14	17	..	..	..	10 " 12
9	12	15	18	..	..	..	11 " 13
10	13	16	..	..	..	..	12 " 14
11	14	17	..	..	..	..	13 " 15
12	15	18	..	..	..	..	14 " 16
13	16	..	..	..	..	..	15 " 17
14	17	..	..	..	..	..	16 " 18
15	18	..	..	..	..	..	..

Example.—Two No. 4, eight No. 10 and 32 No. 16 are all equivalent to a cross-section of one No. 1.

More current can be carried, with the same temperature rise, by using divided circuits. The greater the number of divided circuits, for the same equivalent cross-section, the greater the amount of current that the combination can carry. Consult Table 170 for safe carrying capacities of individual conductors.

164. Comparison of Wire

Dimensions in mils or

Gage No.	1 American. B. & S.	2 Birmingham Stubs.	3 Trenton	4 American Screw	5 British Imperial.
7-0	....	....	....	....	500.0
6-0	....	....	....	....	464.0
5-0	....	....	450.0	....	432.0
4-0	460.0	454.0	400.0	....	400.0
3-0	409.6	425.0	360.0	31.5	372.0
2-0	364.8	380.0	330.0	44.7	348.0
0	324.9	340.0	305.0	57.8	324.0
1	289.3	300.0	285.0	71.0	300.0
2	257.6	284.0	265.0	84.2	276.0
3	229.4	259.0	245.0	97.3	252.0
4	204.3	238.0	225.0	110.5	232.0
5	181.9	220.0	205.0	123.6	212.0
6	162.0	203.0	190.0	136.8	192.0
7	144.3	180.0	175.0	150.0	176.0
8	128.5	165.0	160.0	163.1	160.0
9	114.4	148.0	145.0	171.3	144.0
10	101.9	134.0	130.0	189.4	128.0
11	90.7	120.0	117.5	202.6	116.0
12	80.8	109.0	105.0	215.8	104.0
13	72.0	95.0	92.5	228.9	92.0
14	64.1	83.0	80.6	242.1	80.0
15	57.1	72.0	70.0	255.2	72.0
16	50.8	65.0	61.0	268.4	64.0
17	45.3	58.0	52.5	281.6	56.0
18	40.3	49.0	45.0	294.7	48.0
19	35.9	42.0	40.0	307.9	40.0
20	32.0	35.0	35.0	321.0	36.0
21	28.5	32.0	31.0	334.2	32.0
22	25.3	28.0	28.0	347.4	28.0
23	22.6	25.0	25.0	360.5	24.0
24	20.1	22.0	22.5	373.7	22.0
25	17.9	20.0	20.0	386.8	20.0
26	15.9	18.0	18.0	400.0	18.0
27	14.2	16.0	17.0	413.2	16.4
28	12.6	14.0	16.0	426.3	14.8
29	11.3	13.0	15.0	439.5	13.6
30	10.0	12.0	14.0	452.6	12.4
31	8.9	10.0	13.0	465.8	11.6
32	7.9	9.0	12.0	479.0	10.8
33	7.1	8.0	11.0	492.1	11.0
34	6.3	7.0	10.0	505.3	9.2
35	5.6	5.0	9.5	518.4	8.4
36	5.0	4.0	9.0	531.6	7.6
37	....	....	8.5	544.8	6.8
38	4.0	....	8.0	557.9	6.0
39	3.5	....	7.5	571.1	5.2
40	3.1	....	7.0	584.2	4.8

165. How to Remember the Brown & Sharpe Wire-gage Table (*Westinghouse Diary*).—A wire that is three sizes larger than another wire has half the resistance, twice the weight and twice the area. A wire that is ten sizes larger than another wire has one-tenth the resistance, ten times the weight and ten times the area. No. 10 wire is 0.10 in. in diameter (more precisely 0.102); it has an area of 10,000 cir. mils (more precisely 10,380); it has a resistance of 1 ohm per thousand feet at 20 deg. cent. (68 deg. fahr.), and weighs 32 lb. (more precisely 31.4 lb.) per thousand feet.

and Sheet Metal Gages

thousandths of an inch

6 W.&M. Roeb. A.S.W.	7 Old English London Gage	8 S.W.G.	9 H., S.&Co. "F.&G." Steel Music Wire Gage	10 U. S. Stand.	Gage No.
......	......	......	......	500.0	7–0
460.0	......	......	......	468.7	6–0
430.0	......	......	......	437.5	5–0
393.8	454.0	......	......	406.2	4–0
362.5	425.0	......	......	375.0	3–0
331.0	380.0	......	8.7	343.7	2–0
306.5	340.0	......	9.3	312.5	0
283.0	300.0	227.0	9.8	281.2	1
262.5	284.0	219.0	10.6	265.6	2
243.7	259.0	212.0	11.4	250.0	3
225.3	238.0	207.0	12.2	234.4	4
207.0	220.0	204.0	13.8	218.7	5
192.0	203.0	201.0	15.7	203.5	6
177.0	180.0	199.0	17.7	187.5	7
162.0	165.0	197.0	19.7	171.9	8
148.3	148.0	194.0	21.6	156.2	9
135.0	134.0	191.0	23.6	140.6	10
120.5	120.0	188.0	26.0	125.0	11
105.5	109.0	185.0	28.3	109.4	12
91.5	95.0	182.0	30.3	93.7	13
80.0	83.0	180.0	32.3	78.1	14
72.0	72.0	178.0	34.2	70.3	15
62.5	65.0	175.0	36.2	62.5	16
54.0	58.0	172.0	38.2	56.2	17
47.5	49.0	168.0	40.0	50.0	18
41.0	40.0	164.0	42.0	43.7	19
34.8	35.0	161.0	44.0	37.5	20
31.7	31.5	157.0	46.0	34.4	21
28.6	29.5	155.0	48.0	31.2	22
25.8	27.0	153.0	51.0	28.1	23
23.0	25.0	151.0	55.0	25.0	24
20.4	23.0	148.0	59.0	21.9	25
18.1	20.5	146.0	63.0	18.7	26
17.3	18.75	143.0	67.0	17.2	27
16.2	16.5	139.0	71.0	15.6	28
15.0	15.5	134.0	74.0	14.1	29
14.0	13.75	127.0	78.0	12.5	30
13.2	12.25	120.0	82.0	10.9	31
12.8	11.25	115.0	86.0	10.1	32
11.8	10.25	112.0	......	9.4	33
10.4	9.5	110.0	......	8.6	34
9.5	9.0	108.0	......	7.8	35
9.0	7.5	106.0	......	7.0	36
8.5	6.5	103.0	......	6.6	37
8.0	5.75	101.0	......	6.2	38
7.5	5.0	99.0	......	......	39
7.0	4.5	97.0	......	......	40

The weight of 1,000 ft. of No. 5 wire is 100 lb. The relative values of resistance (for decreasing sizes) and of weight and area (for increasing sizes) for *consecutive* sizes are: 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. The relative values of the diameters of *alternate* sizes of wire are: 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. To find resistance, drop one cipher from the number of circular mils; the result is the number of feet per ohm. To find weight, drop four ciphers from the number of circular mils and multiply by the weight of No. 10 wire.

166. Table of Wire Cables.

Number of wires used in cable		1	3	7	12	19	27
Inches per twist			2 1/6	3	4 1/6	5	6 1/6
Sizes of wire in cable			Circular mils				
B. & S. Ga. No.	Diam. mils	Circular mils					
30	0.0100	101	303	707	1212	1919	2727
29	0.0112	127	381	889	1524	2413	3429
28	0.0126	160	480	1120	1920	3040	4320
27	0.0142	202	606	1414	2424	3838	5454
26	**0.0159**	**254**	**762**	**1778**	**3048**	**4826**	**6858**
25	0.0179	321	963	2247	3852	6099	8667
24	0.0201	404	1212	2828	4848	7676	10908
23	0.0226	510	1530	3570	6120	9690	13770
22	0.0253	643	1929	4494	7716	12217	17361
21	**0.0285**	**810**	**2430**	**5670**	**9720**	**15390**	**21870**
20	0.0320	1022	3066	7154	12264	19418	27594
19	0.0359	1287	3861	9009	15444	24453	34749
18	0.0403	1624	4872	11368	19488	30856	43848
17	0.0452	2048	6144	14336	24576	38912	55295
16	**0.0508**	**2583**	**7749**	**18081**	**30996**	**49077**	**69741**
15	0.0571	3257	9771	22799	39084	61883	87939
061	0.0610	3733	11199	26131	44796	70927	100821
14	0.0641	4107	12321	28749	49284	78033	110889
065	0.0650	4225	12675	29575	50700	82725	114075
13	**0.0720**	**5179**	**15537**	**36253**	**62148**	**98401**	**139833**
075	0.0750	5632	16896	39424	67584	107008	152064
12	0.0808	6530	19590	45710	78360	124070	176310
083	0.0830	6905	20715	48335	82860	131195	186435
11	0.0907	8234	24702	57638	98808	156446	222318
095	**0.0950**	**9052**	**27156**	**63364**	**108624**	**171988**	**244404**
10	0.1019	10381	31143	72667	124572	197239	280287
9	0.1144	13004	39282	91658	157128	248746	353538
8	0.1285	16509	49527	105563	198108	313671	446743
7	0.1443	20816	62448	145712	....	....	....
6	0.1620	26251	78753	183757	....	....	....

167. Allowable Current-carrying Capacity of Copper Wires.—If there is too much current in a given conductor it will become so hot that it will be unsafe or may, if insulated, damage its insulation. Certain safe current values have been determined for different size conductors and some are listed in Table 170. Less current is permissible in rubber insulated wires than in wires insulated with other materials because relatively small temperature rises may injure rubber insulation. For interior wiring, the National Electrical Code values should be used, unless local municipal rules similar to the Chicago Rules are mandatory. A 50 deg. fahr. rise in temperature is permissible in bare line-wires suspended in air. The General Electric Co. values indicate what that concern recommends as safe practice, with an initial temperature of 20 deg. cent.

168. Slow-burning weather-proof conductors (Fig. 95) are sometimes used for interior exposed wiring in damp dark places, where there are corrosive vapors where the voltage does not exceed 550. They are cheaper than rubber-insulated conductors. The

Circular Mils in Strands. *The Benedict & Burnham Co.*

37	48	61	75	91	108	127	147	169
7	$8\frac{1}{6}$	9	$10\frac{1}{6}$	11	$12\frac{1}{6}$	13		

in cables

3737	4848	6161	7575	9191	10908	12827	14700	16900
4699	6096	7747	9525	11557	13716	16129	18522	21294
5920	7680	9760	11200	14560	17280	20320	23373	26871
7474	9696	12322	15150	18382	21816	25654	29547	33969
9398	**12192**	**15494**	**19050**	**23114**	**27432**	**32258**	**37338**	**42926**
11877	15408	19581	24075	29211	34668	40767	47040	54080
14948	19392	24644	30300	36764	43632	51308	59388	68276
18870	24480	31110	38250	46410	55080	64770	74823	86021
23791	30864	39223	48225	58513	69444	81661	94374	108498
29970	**38880**	**49410**	**60750**	**73710**	**87480**	**102870**	**119070**	**136890**
37814	49056	62342	76650	93002	110376	129794	150087	172549
47619	61766	78507	96525	117117	138996	163449	189189	217503
60088	77952	99064	121800	147784	175392	206248	238728	274456
75775	98304	124928	153600	186368	221184	260096	301056	346112
95571	**123984**	**157563**	**193725**	**235053**	**278964**	**328041**	**379554**	**436358**
120509	156336	198677	244375	296387	351756	413639	478632	550264
138131	179184	227713	279975	339703	403164	474091	546987	628849
151959	197136	250527	308025	373737	443656	521589	603582	693914
156325	202800	257725	316875	384475	556300	536575	621075	714025
191623	**248592**	**315919**	**388425**	**471289**	**559332**	**651733**	**761166**	**875082**
208384	270336	343552	422390	512512	608256	715264	826875	950625
241610	313440	398330	489750	594230	705240	829310	959763	1103401
255485	331440	421205	517875	628355	745740	876935	1012683	1164241
304658	395232	502274	617550	749294	889272	1045718	1210398	1391546
334924	**434496**	**552172**	**678900**	**822822**	**977616**	**1149604**	**1326675**	**1525225**
384097	498288	633241	778575	944671	1121148	1318387	1526007	1754389
484478	628512	798934	982050	1191554	1414152	1662938	1924818	2212886
610833	792432	1007049	1238175	1502319	1782972	2096643	2426823	2790021
....	......	....	....	....	....	....	....	....
....	......	....	....	....	....	....	....	....

insulation consists of an inner weather-proof coating and an outer fire-resisting coating. The code requires that the fire-resisting coating be $\frac{6}{10}$ the thickness of the entire coating. To meet this condition the manufacturers use one weather-proof braid and two fire-resisting braids. The fire-resisting compound consists of a mixture containing white lead, oxide of zinc, chalk, or some similar substance. The outer braid is rubbed smooth on the outside. The manufacture of slow-burning weather-proof conductors has been discontinued by some manufactures and they are now seldom used.

Wires with a fire-resisting outer coating have the advantage that dust and lint do not readily adhere to their outer surfaces, as is often the case with weather-proofed braids. If dust does collect, it can be easily swept off. Slow-burning weather-proof wire is cheaper than slow-burning wire. It is not suitable for out-of-door service. See Table 177 for properties.

169. Dimensions, Weights and Resistances of

American or Brown & Sharpe's

B. & S. or American Wire Gage No.	Diam., inches	Area: Circular mils. (d^2) 1 m. = 0.001 in.	Area: Sq. mils. ($d^2 \times 0.7854$)	Carrying capacities: Rubber ins., amps.	Carrying capacities: Other ins., amps.	Weight. Sp. gr. 8.9: Lbs. per 1,000 ft.	Weight. Sp. gr. 8.9: Pounds per mile
0000	0.460000	211600.00	166190.0	225	325	639.33	3375.7
000	0.409640	167805.00	131790.0	175	275	507.01	2677.0
00	0.364800	133079.40	104520.0	150	225	402.09	2123.0
0	**0.324860**	**105538.00**	**82887.0**	125	200	**318.86**	**1683.6**
1	0.289300	83694.20	65733.0	100	150	252.88	1335.2
2	0.257630	66373.00	52130.0	90	125	200.54	1058.8
3	0.229420	52634.00	41339.0	80	100	159.03	839.68
4	0.204310	41742.00	32784.0	70	90	126.12	665.91
5	**0.181940**	**33102.00**	**25998.0**	55	80	**100.01**	**528.05**
6	0.162020	26250.50	20617.0	50	70	79.32	418.81

No. 6 and larger conductors, where they are to be used in interior work or outside pole-line construction, solid wires up to and including No. 00 can the greater ease of handling stranded conductors. See Table 175 for proper-

7	0.144280	20816.00	16349.0	38	54	62.90	332.11
8	0.128490	16509.00	12966.0	35	50	49.88	263.37
9	0.114430	13094.00	10284.0	28	38	39.56	208.88
10	**0.101890**	**10381.00**	**8153.2**	25	30	**31.37**	**165.63**
11	0.090742	8234.00	6467.0	20	27	24.88	137.37
12	0.080808	6529.90	5128.6	20	25	19.73	104.18
13	0.071961	5178.40	4067.1	14	.....	15.65	82.632
14	0.064048	4106.70	3225.4	15	20	12.44	65.674
15	**0.057068**	**3256.70**	**2557.8**	.....	.....	**9.84**	**51.956**
16	0.050820	2582.90	2028.6	6	10	7.81	41.237
17	0.045257	2048.20	1608.6	.....	.....	6.19	32.683
18	0.040303	1624.30	1275.7	3	5	4.91	25.925
19	0.035876	1287.10	1011.69	.....	.....	3.88	20.507
20	**0.031961**	**1021.50**	**802.28**	The above values are those specified in the 1915 National Electrical Code. In lighting work, no wire smaller than No. 14 is used, except in fixtures		**3.09**	**16.315**
21	0.028462	810.10	636.25			2.45	12.936
22	0.025347	642.70	504.78			1.94	10.243
23	0.022571	509.45	400.12			1.54	8.1312
24	0.020100	404.01	317.31			1.22	6.4416
25	**0.017900**	**320.40**	**251.64**			**0.97**	**5.1216**
26	0.015940	254.01	199.50			0.77	4.0656
27	0.014105	201.50	158.26			0.61	3.2208
28	0.012641	159.79	125.50			0.48	2.5344
29	0.011257	126.72	99.526			0.38	2.0064
30	**0.010025**	**100.50**	**78.933**			**0.30**	**1.5840**
31	0.008928	79.71	62.604			0.24	1.2672
32	0.007950	63.20	49.637			0.19	1.0032
33	0.007080	50.13	39.372			0.15	0.7920
34	0.006304	39.74	31.212			0.12	0.6336
35	**0.005614**	**31.52**	**24.756**	....		**0.10**	**0.5280**
36	0.005000	25.00	19.635	....		0.08	0.4224
37	0.004453	19.83	15.567	....		0.06	0.3168
38	0.003965	15.72	12.347	....		0.05	0.2640
39	0.003531	12.47	9.7939	....		0.04	0.2112
40	0.003144	9.89	7.7076	....		0.03	0.1581

[1] Calculated on the basis of Dr. Matthiesen's standard, namely, 1 mil. of 59-9 deg. Fahr.

Pure, Solid, Bare Copper Wire.[1] **(Approximate)**

Gage (*Benedict & Burnham Co.*).

Length		Resistance at 75 deg. Fahr.			B. & S. or American Wire Gage No.
Feet per lb.	Feet per ohm, 75 deg. F.	R. ohms per 1,000 ft.	Ohms per mile	Ohms per lb.	
1.56	20383.0	0.04906	0.25903	0.000076736	0000
1.97	16165.0	0.06186	0.32664	0.00012039	000
2.49	12820.0	0.07801	0.41187	0.00019423	00
3.14	**10166.0**	**0.09838**	**0.51937**	**0.00038500**	**0**
3.95	8062.3	0.12404	0.65490	0.00048994	1
4.99	6393.7	0.15640	0.82582	0.00078045	2
6.29	5070.2	0.19723	1.0414	0.0012406	3
7.93	4021.0	0.24869	1.3131	0.0019721	4
10.00	**3188.7**	**0.31361**	**1.6558**	**0.0031361**	**5**
12.61	2528.7	0.39546	2.0881	0.0049868	6

are to be drawn into conduits, should be cables so they will be flexible. For be used but for larger conductors cables should be employed because of ties of bare cables.

15.90	2005.2	0.49871	2.6331	0.0079294	7
20.05	1590.3	0.62881	3.3201	0.012608	8
25.28	1261.3	0.79281	4.1860	0.020042	9
31.38	**1000.0**	**1.0000**	**5.2800**	**0.031380**	**10**
40.20	793.18	1.2607	6.6568	0.050682	11
50.69	629.02	1.5898	8.3940	0.080585	12
63.91	498.83	2.0047	10.585	0.12841	13
80.38	395.60	2.5278	13.347	0.20322	14
101.63	**321.02**	**3.1150**	**16.477**	**0.31658**	**15**
128.14	248.81	4.0191	21.221	0.51501	16
161.59	197.30	5.0683	26.761	0.81900	17
203.76	156.47	6.3911	33.745	1.3023	18
257.47	123.99	8.0654	42.585	2.0759	19
324.00	**98.401**	**10.163**	**53.658**	**3.2926**	**20**
408.56	78.067	12.815	67.660	5.2355	21
515.15	61.911	16.152	85.283	8.3208	22
649.66	49.087	20.377	107.59	13.238	23
819.21	38.918	25.695	135.67	21.050	24
1032.96	**30.864**	**32.400**	**171.07**	**33.466**	**25**
1302.61	24.469	40.868	215.79	35.235	26
1642.55	19.410	51.519	272.02	84.644	27
2071.22	15.393	64.966	343.02	134.56	28
2611.82	12.207	81.921	432.54	213.96	29
3293.97	**9.6812**	**103.30**	**545.39**	**340.25**	**30**
4152.22	7.8573	127.27	671.99	528.45	31
5236.66	6.0880	164.26	867.27	860.33	32
6602.71	4.8290	207.08	1093.4	1367.3	33
8328.30	3.8281	261.23	1379.3	2175.5	34
10501.35	**3.0363**	**329.35**	**1738.9**	**3458.5**	**35**
13238.83	2.4082	415.24	2192.5	5497.4	36
16691.06	1.9093	523.76	2765.5	8742.1	37
20854.65	1.5143	660.37	3486.7	13772.0	38
26302.23	1.2012	832.48	4395.5	21896.0	39
33175.94	0.9527	1049.7	5542.1	34823.0	40

pure copper wire of $\frac{1}{18}$ in. diameter equals 13.59 ohms at 15.5 deg. cent. or

170. Allowable or Safe Carrying

(Voltage drop is not taken into account in this

American or Brown and Sharpe gage number	Diam. of solid wire in mils	Area in circular mils	II National Electrical Code (inside wiring) 1915 Rules					
			Table A. Rubber insulation, amps.	Table B. Other insulations, amps.	C Drop in volts per 1,000 ft. of wires (500 ft. 2-wire circuit) with allowable currents		D Length in feet of 2-wire circuit (single distance) over which N.E.C. safe currents can be transmitted with 1-volt drop, assuming 11 ohms the resistance of a cir. mil foot of commercial copper wire	
					Table A. Rubber insulation, volts	Table B. Other insulations, volts	Table A	Table B
[1]18	40.3	1,624	3	5	......	......	....	....
[1]16	50.8	2,583	6	10	......	......	....	....
14	64.1	4,107	15	20	40.2	53.5	12.4	9.4
12	80.8	6,530	20	25	33.8	42.2	14.8	11.9
10	101.9	10,380	25	30	26.6	31.8	18.9	15.8
8	128.5	16,510	35	50	23.3	33.3	21.4	15.0
6	162.0	26,250	50	70	20.9	29.4	23.9	17.0
5	181.9	33,100	55	80	18.3	26.6	27.4	18.8
4	204.3	41,740	70	90	18.5	23.7	27.1	21.1
3	229.4	52,630	80	100	16.7	21.0	29.9	23.9
2	257.6	66,370	90	125	14.9	20.8	33.5	24.1
1	289.3	83,690	100	150	13.1	19.7	38.1	25.4
0	325.0	105,500	125	200	13.9	20.8	38.4	24.0
00	364.8	133,100	150	225	12.4	18.6	40.4	26.9
000	409.6	167,800	175	275	11.5	18.0	43.7	27.8
....	......	200,000	200	300	11.0	16.5	45.5	30.3
0000	460.0	211,600	225	325	11.7	16.9	42.7	29.6
		250,000	240	350	10.5	15.4	47.5	32.5
		300,000	275	400	10.0	14.7	49.5	34.0
		350,000	300	450	9.4	14.2	53.0	35.4
		400,000	325	500	8.9	13.8	56.0	36.4
		500,000	400	600	8.8	13.2	56.8	37.9
		600,000	450	680	8.2	12.5	60.6	40.2
		700,000	500	760	7.8	11.9	63.6	41.9
		800,000	550	840	7.5	11.5	66.5	43.3
		900,000	600	920	7.3	11.2	68.2	44.5
		1,000,000	650	1,000	7.1	11.0	70.0	45.5
		1,100,000	690	1,080	6.9	10.8	72.5	46.3
		1,200,000	730	1,150	6.7	10.5	74.8	47.5
		1,300,000	770	1,220	6.5	10.3	76.8	48.5
		1,400,000	810	1,290	6.4	10.1	78.6	49.5
		1,500,000	850	1,360	6.2	9.9	80.5	50.2
		1,600,000	890	1,430	6.1	9.8	81.8	50.8
		1,700,000	930	1,490	6.0	9.6	83.0	52.0
		1,800,000	970	1,550	5.9	9.5	84.5	52.8
		1,900,000	1,010	1,610	5.8	9.3	85.5	53.7
		2,000,000	1,050	1,670	5.7	9.2	86.5	55.5

[1] Wires smaller than No. 14 American Wire Gage shall not be used except

170A. The allowable or safe current-carrying capacity of aluminum wire is, where the wire is insulated, specified in the *Nat. Elec. Code* as 84 per cent. of the values for copper wire (with the same insulation) which are given in *Columns A* and *B* in **170.**

171. **Slow-burning conductors** (Fig. 95) are insulated with three braids impregnated with a fire-resisting compound, the same that is used on slow-burning weather-proof conductors. They are approved (N.E.C.) for interior exposed wiring, in dry places,

Capacity of Copper Wires, Amperes

table and should be considered separately)

E Bare wires in still air; temp. rise 50 deg. fahr. Std. U. G. Cable Co., amps.	General Electric Co., low tension cable Single conductor F Rubber insulation, 30 deg. cent. rise, amps.	General Electric Co., low tension cable Single conductor G Varnished cambric ins. or paper, 60 deg. cent. rise, amps.	General Electric Co., low tension cable Triple conductor H 30 deg. cent. rise, amps.	Circular mils	I National Electrical Code (inside wiring) 1911 Rules Now Obsolete Table A. Rubber insulation, amps.	I National Electrical Code (inside wiring) 1911 Rules Now Obsolete Table B. Other insulations, amps.
6.0	....	....	....	[1]1,624	3	5
8.5	....	....	....	[1]2,583	6	8
12.1	22	....	18	4,107	12	16
17.1	28	....	24	6,530	17	23
24.3	37	24	31	10,380	24	32
41.5	47	36	40	16,510	33	46
58.8	57	60	56	26,250	46	65
69.7	74	72	63	33,100	54	77
83.3	89	81	74	41,740	65	92
98.8	105	96	87	52,630	76	110
117.6	119	120	99	66,370	90	131
140.0	145	143	120	83,690	107	156
169.8	168	178	140	105,500	127	185
201.5	196	220	162	133,100	150	220
240.2	227	272	188	167,800	177	262
274.5	263	310	215	200,000	200	300
286.0	270	331	221	211,600	210	312
324.6	306	390	252	250,000	235	350
373.0	343	450	285	300,000	270	400
419.0	381	510	315	350,000	300	450
463.0	416	560	347	400,000	330	500
549.0	487	660	403	500,000	390	590
631.0	557	770	455	600,000	450	680
708.0	621	870	515	700,000	500	760
781.0	677	970	....	800,000	550	840
852.0	735	1,060	....	900,000	600	920
922.0	792	1,150	....	1,000,000	650	1,000
991.0	854	1,230	....	1,100,000	690	1,080
1,058.0	908	1,300	....	1,200,000	730	1,150
1,123.0	960	1,370	....	1,300,000	770	1,220
1,187.0	1,010	1,440	....	1,400,000	810	1,290
1,250.0	1,060	1,500	....	1,500,000	850	1,360
1,312.0	1,110	1,560	....	1,600,000	890	1,430
1,373.0	1,158	1,605	....	1,700,000	930	1,490
1,433.0	1,200	1,650	....	1,800,000	970	1,550
1,492.0	1,248	1,700	....	1,900,000	1,010	1,610
1,550.0	1,290	1,750	....	2,000,000	1,050	1,670

for fixture and signal wiring and pendant cords.

where the voltage does not exceed 550. They are particularly applicable for hot, dry places wherein ordinary insulations would soon perish. The outer braid is finished like that for slow-burning weather-proof conductors and has the same properties. See 177.

172. **Weather-proof slow-burning conductors** have a fire-resisting coating next to the conductor and a weather-proof coating on the outside. They are approved by the N.E.C.

173. Properties of Rubber-insulated Wire and Cable.

(Standard Underground Cable Co. See

Size B. & S.	Area cir. mils	*A* Dia. bare mils	*B* Insulation 64th in.	Solid wire				Stranded or cable	
				Single braid		Double braid		Single braid	
				C Dia. mils	Lb. per 1,000 ft.	*D* Dia. mils	Lb. per 1,000 ft.	Dia. mils	Lb. per. 1,000 ft.
.....	....	.....	.....	.....	....	.....	....	.....	....
18	1,624	40	2	143	14.5	185	19.1	.....	....
16	2,582	51	2	155	18.9	197	23.9	.....	....
14	4,106	64	3	208	33.0	258	40.0	216	34.3
12	6,530	81	3	225	43.1	275	51.5	235	44.9
10	10,381	102	3	246	58.1	296	67.2	260	60.6
9	13,094	114	3	258	68.4	308	78.2	274	70.0
8	16,509	128	3	273	82.1	322	92.2	290	85.5
6	26,251	162	4	337	130.0	387	142.0	360	136.0
5	33,102	182	4	357	154.0	407	167.0	396	166.0
4	41,742	204	4	393	190.0	457	208.0	422	198.0
3	52,634	229	4	418	228.0	482	247.0	451	238.0
2	66,373	258	4	447	276.0	511	297.0	504	293.0
1	83,694	289	5	530	363.0	614	395.0	571	377.0
0	105,593	325	5	565	439.0	649	474.0	613	457.0
00	133,100	365	5	605	528.0	689	564.0	659	556.0
000	167,805	410	5	650	646.0	734	685.0	709	675.0
0000	211,600	460	5	700	793.0	784	835.0	767	833.0

174. Rubber-covered or rubber-insulated wires and cables (see Fig. 93), when protected with one braid over the insulation, are known as single-braid, and when two braids are used, to insure against injury by abrasion, they are known as double-braid rubber-covered wire or cable. Rubber-covered conductors are used for inside wiring where concealed or in damp places and throughout where the voltage exceeds 550. Conductors insulated with less expensive materials (see following paragraphs) can be used out-of-doors, on pole lines and inside in dry places where the wires are exposed. The use of single-braid rubber-covered wires is permissible for exposed interior wiring in damp places and in wooden and metal moulding in dry places and in iron conduit, provided the wire is smaller than No. 6. Double braid wires should be used in all cases where the wire is larger than No. 6. Table 173 gives the principal properties of rubber-covered conductors, for pressures not exceeding 600 volts.

National Electrical Code Standard, 0-600 Volts

illustration below for key to reference letters)

Size B. & S.	Stranded or cable		Stranded or cable						
	Double braid					Single braid		Double braid	
	Dia. mils	Lb. per 1,000 ft.	*E* Size cir. mils	*B* Insulation 64th in.	Dia. bare mils	*F* Dia. mils	Lb. per 1,000 ft.	*G* Dia. mils	Lb. per 1,000 ft.
....	......	....	250,000	6	575	845	997	929	1,047
18	......	....	300,000	6	630	902	1,173	986	1,226
16	......	....	350,000	6	681	952	1,343	1,036	1,399
14	268	42.4	400,000	6	729	1,001	1,514	1,085	1,573
12	285	53.8	450,000	6	773	1,044	1,685	1,128	1,746
10	310	70.1	500,000	6	815	1,087	1,842	1,171	1,906
9	324	80.0	550,000	7	855	1,157	2,053	1,241	2,121
8	340	96.3	600,000	7	893	1,194	2,220	1,278	2,290
6	410	149.0	650,000	7	929	1,231	2,389	1,315	2,461
5	460	184.0	700,000	7	964	1,266	2,557	1,350	2,631
4	486	218.0	750,000	7	998	1,300	2,723	1,384	2,798
3	515	260.0	800,000	7	1,031	1,333	2,891	1,417	2,968
2	588	324.0	850,000	7	1,062	1,365	3,056	1,449	3,135
1	655	412.0	900,000	7	1,093	1,395	3,223	1,479	3,304
0	697	494.0	950,000	7	1,123	1,425	3,388	1,509	3,470
00	743	595.0	1,000,000	7	1,152	1,455	3,553	1,539	3,637
000	793	719.0	1,250,000	8	1,289	1,623	4,506	1,707	4,599
0000	851	879.0	1,500,000	8	1,413	1,747	5,344	1,831	5,445
....	......	....	1,750,000	8	1,526	1,860	6,177	1,944	6,284
....	......	....	2,000,000	8	1,631	1,965	7,006	2,049	7,119

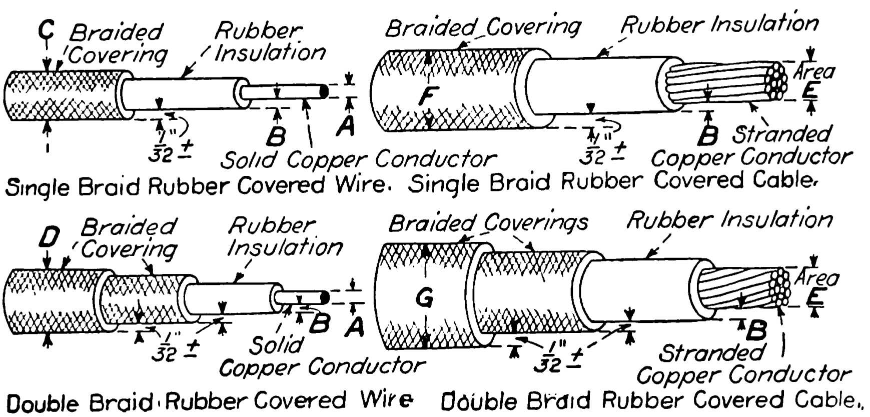


FIG. 93.—National electrical code, rubber-insulated, wire and cable (See Table 173)

175. Physical and Electrical Properties of Pure Copper Stranded Cable (*Standard Underground Cable Co.*)

Size, B. & S. gage and area cir. mils	No. of wires in strand	Dia. of wires in strand, mils	Diameter of bare cable		Approx. weight in lbs.		Approx. ft. per lb.	Approx. ft. per ohm	Approx. resistance international ohms at 68 deg. fahr.	
			Mils	In 64th of inch	Per 1,000 ft.	Per mile			Per 1,000 ft.	Per lb.
14	7	24.2	73	5	13	69	77	397	2.52	0.194
12	7	30.5	92	6	20	106	50	632	1.59	0.0795
10	7	38.5	116	8	32	169	31	1,005	0.997	0.0312
8	7	48.6	146	10	50	264	20	1,598	0.627	0.0125
6	**7**	**61.2**	**184**	**12**	**80**	**422**	**12.5**	**2,540**	**0.394**	0.00493
5	7	68.8	206	14	101	533	9.90	3,203	0.313	0.00310
4	7	77.2	232	15	127	670	7.87	4,031	0.248	0.00195
3	7	86.7	260	17	160	845	6.25	5,084	0.197	0.00123
2	7	97.4	292	19	202	1,067	4.95	6,410	0.156	0.000772
1	**19**	**66.4**	**328**	**22**	**255**	**1,346**	**3.92**	**8,083**	**0.124**	**0.000486**
1/0	19	74.5	373	24	322	1,700	3.11	10,190	0.098	0.000304
2/0	19	83.7	419	27	406	2,144	2.46	12,850	0.078	0.000192
3/0	19	94.0	470	31	512	2,704	1.95	16,210	0.062	0.000121
4/0	19	105.5	528	33	646	3,405	1.55	20,440	0.049	0.0000759
250,000	**37**	**82.2**	**575**	**37**	**764**	**4,023**	**1.34**	**24,150**	**0.041**	**0.0000550**
300,000	37	90.1	630	41	917	4,842	1.09	28,980	0.035	0.0000382
350,000	37	97.3	681	44	1,070	5,650	0.935	33,800	0.030	0.0000280
400,000	37	104.0	729	47	1,223	6,457	0.818	38,630	0.026	0.0000213
450,000	37	110.3	773	50	1,377	7,271	0.726	43,460	0.023	0.0000167
500,000	**61**	**90.5**	**815**	**53**	**1,530**	**8,078**	**0.653**	**48,290**	**0.021**	**0.0000137**
550,000	61	95.0	855	55	1,684	8,891	0.594	53,100	0.019	0.0000113
600,000	61	99.2	893	58	1,837	9,700	0.544	58,000	0.017	0.00000925
650,000	61	103.2	929	60	1,991	10,810	0.502	62,800	0.016	0.00000804
700,000	61	107.1	964	62	2,145	11,330	0.466	67,600	0.015	0.00000700
750,000	**61**	**110.9**	**998**	**64**	**2,299**	**12,140**	**0.435**	**72,400**	**0.014**	**0.00000609**
800,000	61	114.5	1,031	67	2,453	12,950	0.408	77,300	0.013	0.00000530
900,000	61	121.5	1,093	71	2,762	14,580	0.362	86,900	0.012	0.00000435
1,000,000	61	128.0	1,152	74	3,070	16,210	0.326	96,600	0.010	0.00000359
1,250,000	91	117.2	1,289	83	3,882	20,500	0.258	120,800	0.0083	0.00000214
1,500,000	**91**	**128.4**	**1,413**	**91**	**4,631**	**24,450**	**0.216**	**144,900**	**0.0069**	**0.00000149**
1,750,000	127	117.4	1,526	98	5,428	28,660	0.184	169,000	0.0059	0.00000111
2,000,000	127	125.5	1,631	105	6,200	32,740	0.161	193,200	0.0052	0.000000839

176. Properties of National Code Standard, Rubber-covered, Solid and Stranded Wire and Cable For Voltages of 600 to 1,500.

Standard Underground Cable Co.

Size		No. of wires in cond.	Diam. of wires comprising cable, mils	Thickness of rubber in inches	Diameter over all				Approx. weight per 1,000 ft., tape and braid
					Single braid		Double braid		
B. & S. gage	Cir. mils				Mils	64ths	Mils	64ths	
				Solid					
14	4,107	.....	....	$\frac{1}{16}$	239	15.3	289	18.5	46
12	6,530	.....	....	$\frac{1}{16}$	256	16.4	306	19.6	58
10	10,380	.....	....	$\frac{1}{16}$	277	17.75	327	20.9	75
8	16,510	.....	....	$\frac{1}{16}$	304	19.45	354	22.6	100
6	26,250	.....	....	$\frac{5}{64}$	382	24.2	446	28.5	153
4	41,740	.....	....	$\frac{5}{64}$	425	27.2	489	31.3	212
2	66,370	.....	....	$\frac{5}{64}$	498	31.9	582	37.2	310
1	83,690	.....	....	$\frac{3}{32}$	561	35.9	645	41.25	394
1/0	105,500	.....	....	$\frac{3}{32}$	596	38.2	680	43.5	475
2/0	133,100	.....	....	$\frac{3}{32}$	636	40.65	720	46.1	595
3/0	167,800	.....	....	$\frac{3}{32}$	681	43.5	765	48.96	700
4/0	211,600	.....	....	$\frac{3}{32}$	732	46.8	816	52.2	850
				Stranded					
8	16,510	7	48.6	$\frac{1}{16}$	321	20.5	371	23.75	106
6	26,250	7	61.2	$\frac{5}{64}$	404	25.8	468	30.0	160
4	41,740	7	77.2	$\frac{5}{64}$	453	29.0	517	33.1	225
2	66,370	7	97.4	$\frac{5}{64}$	532	34.1	616	39.4	320
1	83,690	19	66.4	$\frac{3}{32}$	604	38.65	688	44.0	405
1/0	105,500	19	74.5	$\frac{3}{32}$	645	41.25	729	46.6	490
2/0	133,100	19	83.7	$\frac{3}{32}$	691	44.25	775	49.6	595
3/0	167,800	19	94.0	$\frac{3}{32}$	742	47.5	826	52.8	715
4/0	211,600	19	105.5	$\frac{3}{32}$	800	51.2	884	56.5	875
....	250,000	37	82.2	$\frac{7}{64}$	878	56.2	962	61.5	1,040
....	300,000	37	90.1	$\frac{7}{64}$	933	59.7	1,017	65.2	1,220
....	350,000	37	97.3	$\frac{7}{64}$	984	63.0	1,068	68.5	1,390
....	400,000	37	104.0	$\frac{7}{64}$	1,032	66.0	1,116	71.4	1,570
....	450,000	37	110.3	$\frac{7}{64}$	1,076	68.9	1,160	74.3	1,745
....	500,000	61	90.6	$\frac{7}{64}$	1,118	71.5	1,202	76.9	1,915
....	600,000	61	99.2	$\frac{1}{8}$	1,227	78.5	1,311	83.9	2,300
....	650,000	61	103.2	$\frac{1}{8}$	1,263	80.9	1,347	86.3	2,470
....	700,000	61	107.1	$\frac{1}{8}$	1,298	83.1	1,382	88.5	2,640
....	750,000	61	110.9	$\frac{1}{8}$	1,332	85.3	1,416	90.6	2,810
....	800,000	61	114.5	$\frac{1}{8}$	1,365	87.4	1,449	92.8	2,930
....	900,000	61	121.5	$\frac{1}{8}$	1,327	91.5	1,511	96.75	3,330
....	1,000,000	61	128.0	$\frac{1}{8}$	1,486	95.2	1,570	100.5	3,670

177. Properties of Weather-proof and Slow-burning

Size, B. & S. and cir. mils	Weather-proof				Slow-burning
	Approx. wts. per 1,000 ft.		Approx. overall diameters, in.		Approx. wts. per 1,000 ft.
	Triple braid	Double braid	Triple braid	Double braid	Weather-proof white finish
			Solid wire		
0000	765	710	0.660	0.610	870
000	625	570	0.595	0.560	720
00	490	448	0.550	0.515	568
0	400	360	0.505	0.470	470
1	310	290	0.445	0.405	350
2	255	232	0.400	0.374	290
4	164	146	0.346	0.320	200
6	112	97	0.303	0.278	140
8	75	64	0.264	0.245	95
10	53	46	0.221	0.197	70
12	35	27	0.200	0.172	52
14	25	20	0.182	0.155	40
16	19	15	0.169	0.142	30
18	16	12	....	....	24
20	12	9	....	....	....
			Stranded Wire or Cable		
2,000,000	6,700	6,540	1.930	1.844	....
1,750,000	5 894	5,739	1.820	1.740	....
1,500,000	5,090	4,940	1.712	1.624	....
1,250,000	4,287	4,153	1.580	1.500	....
1,000,000	3,478	3,360	1.451	1.365	3,880
900,000	3,290	3,045	1.390	1.310	3,540
800,000	2,778	2,700	1.331	1.243	3,200
750,000	2,615	2,551	1.300	1.210	3,020
700,000	2,439	2,380	1.265	1.177	2,840
600,000	2,113	2,060	1.190	1.105	2,370
500,000	1,781	1,740	1.108	1.027	2,010
450,000	1,630	1,598	1.070	0.984	1,840
400,000	1,445	1,405	1.020	0.940	1,670
350,000	1,277	1,240	0.978	0.894	1,460
300,000	1,126	1,090	0.930	0.846	1,290
250,000	937	905	0.862	0.780	1,080
0000	806	753	0.785	0.708	910
000	655	610	0.728	0.648	745
00	515	470	0.662	0.599	590
0	420	382	0.605	0.555	485
1	328	300	0.518	0.470	360
2	267	251	0.440	0.415	300
4	173	153	0.379	0.353	205
6	117	103	0.327	0.305	145
8	75	69	0.290	0.270	97

For number of wires in strand see 183.

Solid Copper Wire and Cable. (*General Electric Co.*)

Slow-burning					Size, B. & S. and cir. mils.
Approx. weights per 1,000 ft.		Approx. overall diameters, inches			
Weather-proof black finish	Under-writers	Weather-proof or white	Weather-proof or black	Under-writers	
Solid wire					
862	780	0.660	0.660	0.660	0000
710	640	0.595	0.595	0.595	000
562	510	0.550	0.550	0.550	00
462	420	0.505	0.505	0.505	0
340	330	0.445	0.445	0.445	1
280	280	0.400	0.400	0.400	2
190	180	0.346	0.346	0.346	4
127	125	0.303	0.303	0.303	6
85	90	0.264	0.264	0.264	8
60	65	0.221	0.221	0.221	10
42	40	0.200	0.200	0.200	12
30	30	0.182	0.182	0.182	14
24	22	0.169	0.169	0.169	16
19	....	....	....	....	18
....	....	....	....	....	20
Stranded Wire or Cable					
7,540	....	1.930	1.930	1.930	2,000,00
6,700	....	1.820	1.820	1.820	1,750,00
5,830	....	1.712	1.712	1.712	1,500,000
4,940	....	1.580	1.580	1.580	1,250,000
3,980	3,578	1.451	1.451	1.451	1,000,000
3,640	3,250	1.390	1.390	1.390	900,000
3,280	2,894	1.331	1.331	1.331	800,000
3,100	2,720	1.300	1.300	1.300	750,000
2,920	2,540	1.265	1.265	1.265	700,000
2,460	2,204	1.190	1.190	1.190	600,000
2,080	1,858	1.108	1.108	1.108	500,000
1,900	1,700	1.070	1.070	1.070	450,000
1,700	1,509	1.020	1.020	1.020	400,000
1,500	1,329	0.978	0.987	0.978	350,000
1,310	1,170	0.930	0.930	0.930	300,000
1,120	981	0.862	0.862	0.862	250,000
960	844	0.785	0.785	0.785	0000
785	686	0.728	0.728	0.728	000
625	550	0.662	0.662	0.662	00
510	449	0.605	0.605	0.605	0
380	360	0.518	0.518	0.518	1
335	294	0.440	0.440	0.440	2
230	196	0.379	0.379	0.379	4
165	135	0.327	0.327	0.327	6
105	94	0.290	0.290	0.290	8

178. Properties of National Code Standard, Rubber-covered, Solid and Stranded Wire and Cable For Voltages of 1,500 to 2,500.

Standard Underground Cable Co.

Size		No. of wires in cond.	Diam. of wires compris-ing cable, mils	Thick-ness of rubber in inches	Diameter over all				Approx. weight per 1,000 ft., tape and braid
					Single braid		Double braid		
B.&S. gage	Cir. mils				Mils	64ths	Mils	64ths	
				Solid					
14	4,107	.....	....	3/32	302	19.3	352	22.5	70
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
1/0	105,500	.....	....	7/64	628	40.2	712	45.5	500
2/0	133,100	.....	....	7/64	668	42.75	752	48.1	600
3/0	167,800	.....	....	7/64	712	45.5	796	50.1	725
4/0	211,600	.....	....	7/64	763	48.8	847	54.25	875
				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
1/0	105,500	19	74.5	7/64	676	43.25	760	48.6	520
2/0	133,100	19	83.7	7/64	721	46.1	805	51.5	620
3/0	167,800	19	94.0	7/64	773	49.5	857	54.8	745
4/0	211,600	19	105.5	7/64	831	53.2	915	58.5	905
....	250,000	37	82.2	1/8	909	58.1	993	63.5	1,080
....	300,000	37	90.1	1/8	964	61.7	1,048	67.1	1,255
....	350,000	37	97.3	1/8	1,015	65.0	1,099	70.4	1,430
....	400,000	37	104.0	1/8	1,063	68.0	1,147	73.4	1,610
....	450,000	37	110.3	1/8	1,107	70.9	1,191	76.3	1,785
....	500,000	61	90.6	1/8	1,149	73.5	1,233	78.9	1,990
....	600,000	61	99.2	9/64	1,258	80.6	1,342	85.9	2,350
....	650,000	61	103.2	9/64	1,294	82.9	1,378	88.2	2,525
....	700,000	61	107.1	9/64	1,329	85.1	1,413	90.45	2,710
....	750,000	61	110.9	9/64	1,363	87.25	1,447	92.7	2,875
....	800,000	61	114.5	9/64	1,396	89.4	1,480	94.8	3,050
....	900,000	61	121.5	9/64	1,458	93.4	1,542	98.8	3,490
....	1,000,000	61	128.0	9/64	1,517	97.25	1,601	102.4	3,730

179. Duplex or twin wires or cables (sometimes called "conduit wire") are shown in Fig. 94. They are used where they are to be drawn into conduit and should never be used except in conduit. Each wire is rubber-insulated to the thickness indicated in Table

180 and then is served with a braid or with a tape. The two conductors are finally bound together with a tenacious braid at least $\frac{1}{32}$ in. thick for wires larger than No. 10 B. & S. gage and

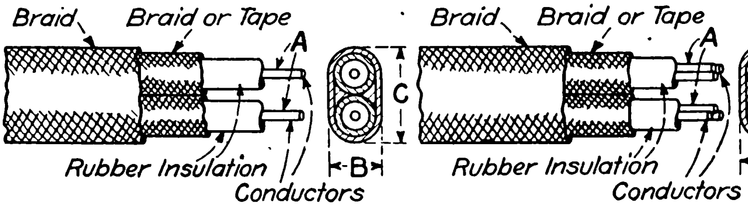


FIG. 94.—Duplex wire and cable.

$\frac{1}{64}$ in. for No. 10 B. & S. gage or less in size. This construction is considered in the N.E.C. as equivalent to that of double-braid, rubber-covered wire. Twin conductors larger than No. 0000 should not be used because of their tendency to kink.

180. National Electric Code Standard, Duplex (Flat), Two-conductor Wire and Cable, 0-600 Volts

(*General Electric Co.*)

A Size of each conductor B. & S. gage	Solid			Stranded		
	Weight in lbs. per 1,000 ft.	Dimensions in inches		Weight in lbs. per 1,000 ft.	Dimensions in inches	
		B	*C*		*D*	*E*
8	214	0.33	×0.57	214	0.35	×0.61
10	162	0.30	×0.52	162	0.32	×0.55
12	126	0.28	×0.46	126	0.29	×0.48
14	100	0.26	×0.42	100	0.27	×0.44

181. **Weather-proof wire or Cable** (Fig. 95) is used for out-of-door conductors and should be supported on porcelain or glass insulators and not on knobs, cleats or rubber hooks.* Weather-proof wire is not approved for inside wiring (N.E.C.) except where exposed to corrosive vapors. The so-called "weather-proof" insulation becomes a reasonably good conductor when moist. **Triple-braid** weather-proof conductors have three braids, saturated with a so-called moisture-proof compound served around them, and **double-braid** conductors have two such braids. Triple-braid conductors are approved by the N.E.C. for outside construction, but double-braid conductors are not approved at all. See Table 177 for properties.

182. **Safe Current-carrying Capacity of Large Fiber-cored Cables on A.-C. Circuits.**—See Fig. 96 for reference letters. Alternating current flowing in large cables has greater density on the surface of the conductor than in the center (so-called skin effect) therefore an ordinary cable will not carry as much alternating current as direct current with the same temperature rise. In order to overcome this it is advisable, on single-conductor cables 700,000 cm. and larger for 60-cycle circuits, and 1,250,000 cm. and larger

for 25-cycle circuits, to make the cable with a fiber core and strand the copper around it. The weight of copper in this type of cable is the same per foot as in an ordinary cable, but owing to its annular

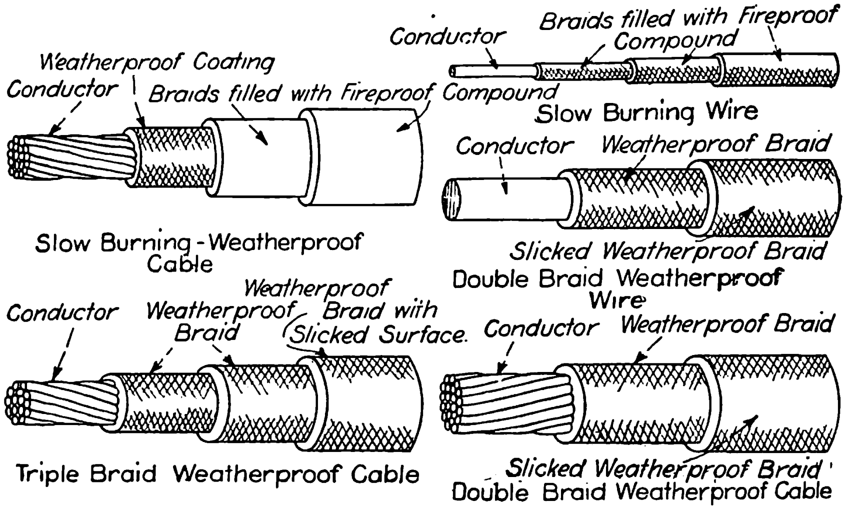


FIG. 95.—Weather-proof and slow-burning conductors.

cross-section the cable is much more efficient in carrying alternating current and also has a somewhat greater current-carrying capacity due to the larger radiating surface. These copper strands can be insulated with any desired type of insulation. (*General Electric Co.*)

182A. Fiber cord cables.

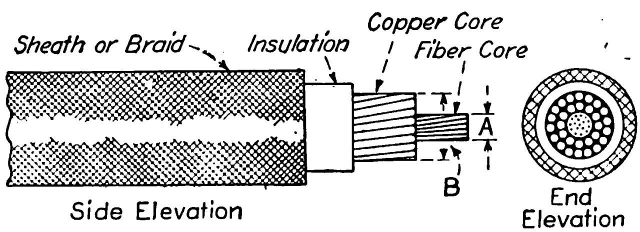


FIG. 96.—Cable with fiber core.

Size	*A* Dia. fiber core in in.	No. of wires in strand	Size wire in strand in in.	*B* Overall dia. copper core in in.	Ampere capacity 30 deg. cent. rise.	Ampere capacity 60 deg. cent. rise.
2,000,000	$\frac{7}{8}$	210	0.099	2.065	1,400	1,750
1,750,000	$\frac{25}{32}$	210	0.091	1.87	1,300	1,625
1,500,000	$\frac{11}{16}$	182	0.091	1.78	1,200	1,500
1,250,000	$\frac{9}{16}$	168	0.086	1.59	1,150	1,400
1,000,000	$\frac{15}{32}$	98	0.102	1.28	900	1,150
800,000	$\frac{11}{32}$	51	0.125	1.1	775	925
750,000	$\frac{10}{32}$	48	0.125	1.060	750	900
700,000	$\frac{9}{32}$	51	0.117	0.99	700	830
50,000	$\frac{1}{4}$	45	0.1056	0.890	550	660

183. Special Stranding Table for Weather-proof Slow-burning and Bare Cables.—*General Electric Co.* The price of any weather-proof, slow-burning or bare cable depends upon the size wire used in the strand. The finer the individual wires the more expensive the cable. The following table of strands insures a minimum price for the cable. Strands or cables from finer wires can be manufactured.

Size B. & S. and cir. mils	No. wires in strand	Diam. of individual wires in inches	Approximate diam. of bare cable in inches	Approximate weight of copper per 1,000 ft. in lb.
8	7	0.0485	0.1455	51
6	7	0.0613	0.1839	81
5	7	0.0688	0.2064	103
4	7	0.0773	0.2319	129
3	7	0.0868	0.2604	164
2	7	0.0974	0.2922	206
1	7	0.1110	0.3330	259
0	7	0.1250	0.3750	328
00	7	0.1400	0.4190	414
000	7	0.1560	0.4700	520
0000	19	0.1056	0.5280	658
250,000	19	0.1160	0.5754	775
300,000	19	0.1270	0.6342	943
350,000	19	0.1370	0.6818	1087
400,000	37	0.1040	0.7280	1242
450,000	37	0.1110	0.7770	1415
500,000	37	0.1170	0.8154	1554
550,000	37	0.1220	0.8550	1709
600,000	37	0.1280	0.8928	1864
650,000	37	0.1330	0.9297	2020
700,000	37	0.1380	0.9648	2177
750,000	61	0.1110	0.9990	2333
800,000	61	0.1146	1.0314	2487
900,000	61	0.1216	1.0944	2813
1,000,000	61	0.1281	1.1529	3110
1,250,000	61	0.1440	1.2903	3888
1,500,000	91	0.1284	1.4124	4660
1,750,000	91	0.1390	1.5262	5435
2,000,000	127	0.1255	1.6315	6212

184. Splices in bare copper line wire can be made as indicated in Fig. 97 and should be mechanically and electrically secure before solder is applied. There should be at least 5 turns in the neck (Fig. 97) of a splice to insure that the unsoldered splice will be as strong as the wire of which it is made. All splices in wires

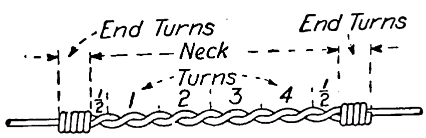


FIG. 97.—Bare copper, line wire splice.

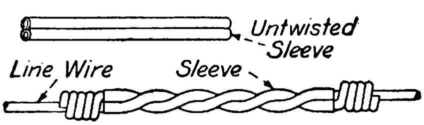


FIG. 98.—Splice made with McIntire sleeve.

for conveying electricity should be soldered in the neck. It is not always necessary to solder the end turns. McIntire sleeves are very satisfactory and are used to a great extent for splicing aerial line wires. (See Fig. 98.) Solder is not necessary where sleeves are used. For further information in regard to splices in bare wire see *Electrical World*, Nov. 17, 1910, "Some Tests on Splices in Galvanized Iron Wire," By C. T. Rashman.

184A. Splices in insulated aerial line wires are made similarly to that shown in Fig. 97 except tape is served around the splice for insulation. (See Fig. 99.) If the line wire has only weatherproof insulation, friction tape is sufficient but if the inner insulation is rubber, rubber tape to the thickness of the inner insulation should be applied before the friction tape is served. All splices in wires for conveying electricity should be soldered in the neck.

185. Instructions for Making a Joint in Pure Rubber Insulated Wire (*Okonite Co.*). (See Fig. 100.) 1. *Preparing the Conductor Ends.*—Bare and clean about 1 in. of each end of the conductor; then, with a very sharp thin-bladed knife, bevel the insulation for about 1 in. as one would sharpen a lead pencil. 2. Preferably

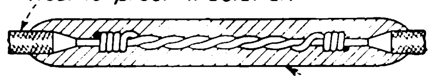


FIG. 99.—Splices and taps in insulated line wire.

make the conductor joint with a copper sleeve, sweating the latter on, being careful to clean off all surplus solder or, if the connection is made by twisting the two ends together, see that the ends do not protrude. 3. Now cover the bevels and conductor with a thin coat of a pure rubber cement and allow this to "set" (which takes about 1 min.).

4. *Insulating the Joint.*—Take a strip of $\frac{3}{4}$-in. pure rubber tape 6 to 8 in. long, and beginning at the bevel on a level with the insulation *A* in Fig. 100, wrap spirally (making sure that the turns overlap) to the other side of the joint as far as the high point of the bevel on that side, *B*. Continue to wrap to and fro until the insulation is built up slightly thicker than the regular wall. The tape must be put on under tension—say stretched to about half its width. Care must be taken to have everything perfectly clean.

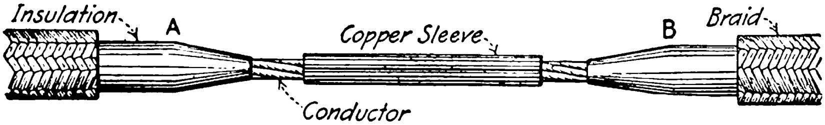


FIG. 100.—Splicing rubber-insulated conductor with copper sleeve.

5. *To Partially Vulcanize the Joint.*—Apply heat from a spirit lamp, a lighted match or the heat of the hand evenly around the joint. Do this for about 1 min. (be careful not to burn the insulation) and then wrap the joint with two layers of $\frac{3}{4}$-in. friction tape. If the wire is braided or taped, be sure that the braid or tape is cut well back so that there are no loose threads overhanging to interfere with the proper insulating of the joint.

This is the method of making a joint *properly*, and, with slight modifications, it is applicable to all sizes of conductors.

Should the friction tape become slightly set, as it sometimes does in extreme cold weather, warming will restore it perfectly.

186. Splices in Interior Wires (Fig. 101).—Not as many turns are necessary in the neck as for aerial line wires. All splices must be soldered unless made with some form of approved splicing device. Rubber tape to the thickness of the rubber insulation must be used on rubber-covered wires and friction tape must be served over the rubber to hold it in place. The so-called "Fixture Splice" (Fig. 101) is used largely by telephone men and in wiring fixtures. It can be conveniently used sometimes in splicing two wires that must be drawn taut in the splicing. A splice in wires is often made at a point between two supports, cleats, or knobs in this way. The duplex wire splice (Fig. 101) is often used by telephone men. The joints should always be "broken," that is, they should not be opposite one another.

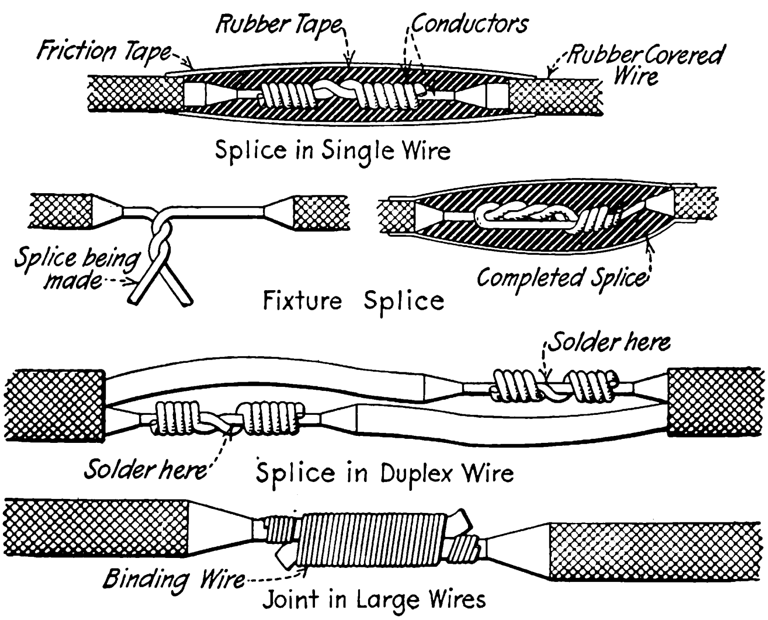


FIG. 101.—Splices in interior wires.

In conduit work, for which duplex wire is frequently used, joints are not permissible except in junction boxes, but nevertheless they are occasionally made as indicated and pulled into conduit. Rubber and friction tape is applied to each in the same way as to the joint in a single wire and then the pair of wires should be served with friction tape. Joints should always be taped so that the insulation over the joint equals that over the rest of the conductor.

187. Taps in copper wires are made as shown in Fig. 102. The "knotted" tap has the advantage that the tap wire cannot untwist from the main wire. Tape should be applied as with splices. The tap for small aerial wires, Fig. 102, is made by giving the tap wire one long complete wrap around the main wire and then four short turns. The long wrap gives the joint a certain amount of flexibility which is necessary for aerial work where wires are moved

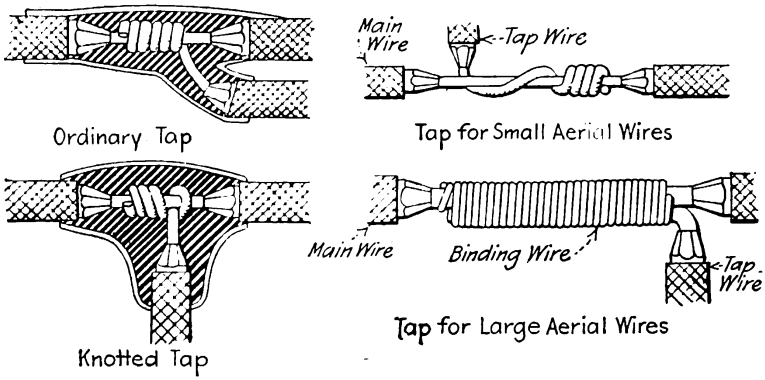


FIG. 102.—Methods of making taps from copper conductors.

by the wind. The tap for large wires is made by serving a binding wire about bared portions of the tap and main wires and then soldering the whole.

188. Joints in cables are made as shown in Fig. 103. The

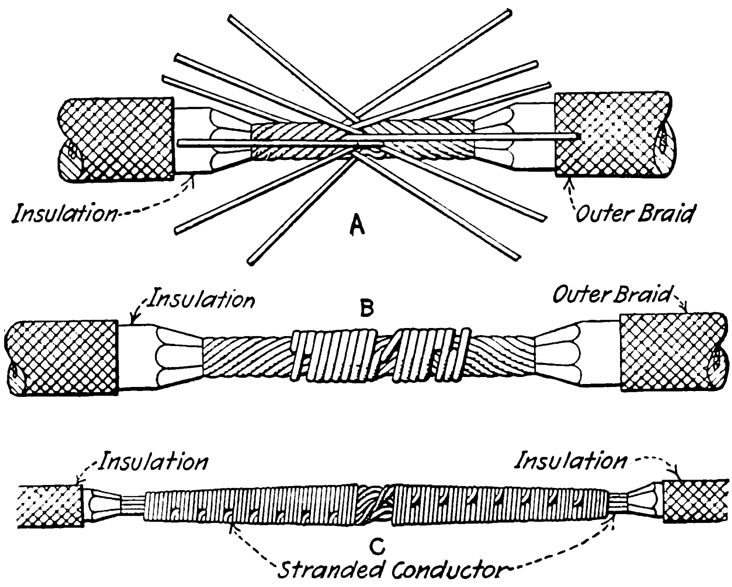


FIG. 103.—Methods of joining cables.

wires composing the cable should be spread and each pulled out straight and the core or a few inner wires cut away so that the splice will not be bulky. Then the two cable ends are abutted as shown in *A* (Fig. 103) and the wires are interwoven in groups of two each and served along the cable. The joint is soldered by pouring, with a ladle, molten solder through and over it, the solder pot being meanwhile held under the joint so as to catch any solder that does not adhere. For interior work a short joint like that of *B* is frequently used, but in aerial work a longer one like that of *C* is preferred. For an aerial joint (*C*) a length of about 16 to 20 in. is bared at the end of each cable in order to make a splice. All of these joints should be thoroughly soldered.

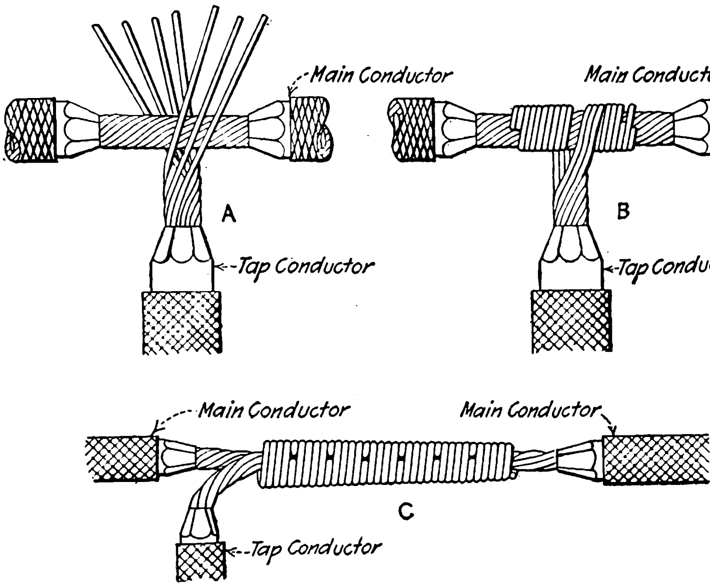


FIG. 104.—Tap joints in cables.

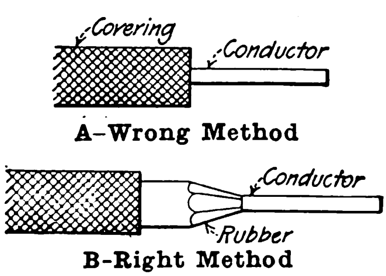


FIG. 105.—Methods of "skinning" wire.

189. Tap joints in Cables are made as suggested in Fig. 104. "*A*" shows how the tap wires are "fanned" out before being served about the main conductor and *B* shows a completed tap joint for interior work. *C* shows a completed tap joint in an aerial cable. Tap joints in cables can be made with a binding wire similarly to the method of Fig. 102.

190. In making any joint the wire ends should be scraped bright with the back of a knife blade, sand paper or emery paper so that the solder will adhere readily. Insulation should be cut away as shown at *B* (Fig. 105) rather than as shown at *A*. When cut as at *A* the wire is likely to be nicked and with the *B* method the tape can be served more neatly about the joint. The outer braid should be cut well back from the joint so that stray strands from it cannot be taped into the joint and, by capillary attraction, conduct moisture thereto.

191. **For soldering joints** the non-corrosive fluid of **201** is recommended.

192. Circular Millage and Carrying Capacity in Amperes of Flat Bus-bar Copper (*Electrical Engineer's Equipment Co.*)

	Circular mils	1,000 C. M. per ampere or 1,273 amp. per sq. in.	1,200 C. M. per ampere or 1,061 amp. per sq. in.	1,600 C. M. per ampere or 795 amp. per sq. in.
⅛ in. bar copper				
By 1 in.	159154	159	133	99
By 1½ in.	238731	239	199	149
By 2 in.	318309	318	265	199
By 2½ in.	397886	398	332	249
By 3 in.	477463	477	398	298
By 3½ in.	557040	557	464	348
By 4 in.	636618	637	531	398
By 5 in.	795772	796	663	497
By 6 in.	954927	955	796	597
¼ in. bar copper				
By 1 in.	318309	318	265	199
By 1½ in.	477463	477	398	298
By 2 in.	636618	637	531	398
By 2½ in.	795772	796	663	497
By 3 in.	954927	955	796	597
By 3½ in.	1114081	1,114	928	696
By 4 in.	1273236	1,273	1,061	796
By 5 in.	1591545	1,592	1,326	995
By 6 in.	1909854	1,910	1,592	1,194
⅜ in. bar copper				
By 1 in.	477463	477	398	298
By 1½ in.	716194	716	597	448
By 2 in.	954927	955	796	597
By 2½ in.	1193658	1,194	995	746
By 3 in.	1432390	1,432	1,194	895
By 3½ in.	1671122	1,671	1,393	1,044
By 4 in.	1909854	1,910	1,592	1,194
By 5 in.	2387317	2,387	1,989	1,492
By 6 in.	2864781	2,865	2,387	1,790
½ in. bar copper				
By 1 in.	636618	637	531	398
By 1½ in.	954927	955	796	597
By 2 in.	1273236	1,273	1,061	796
By 2½ in.	1591545	1,592	1,326	995
By 3 in.	1909854	1,910	1,592	1,194
By 3½ in.	2228163	2,228	1,857	1,393
By 4 in.	2546472	2,546	2,122	1,592
By 5 in.	3183090	3,183	2,653	1,989
By 6 in.	3819708	3,820	3,183	2,387

193. **Bus-bars** are usually made up of rolled copper bar from 0.25 to 0.375 in. thick and from 1 in. in width up. When more than one bar is needed to give the required current-carrying capacity the bars are separated by means of spacing blocks so as to give a maximum radiating surface. Copper bars are designed on the basis of a **current density** of about 800 to 1,000 amp. per sq. in. of cross-section. They are mounted on insulators, the type of insulator depending upon the voltage of the system. Occasionally aluminum bus-bars, employing a maximum current density of about 750 amp. per sq. in., have been installed. For medium size plants, operating at a potential of 2,300 volts, the bus-bars are made up of insulated wires, varnished cambric being preferred as the insulating material, and these are mounted on insulators attached to the framework which supports the panels. **Contact surfaces** between bus-bars should allow between 100 and 200 amp. per sq. in. of surface, and **terminals and leads** taken from the bars should allow 100 amp. per sq. in. Brass castings for **connections and terminals** have a conductivity between 12 and 18 per cent., and, therefore, it is best to use copper where large current-carrying capacity is desired.

194. **Aluminum.**—The weight of aluminum is 0.000,000,915 (or 91.5×10^{-8}) lb. per cir. mil-ft. or 0.000,000,808 (or 80.8×10^{-8}) lb. per sq. mil-ft. (*Standard Handbook*). See additional values giving properties of aluminum in adjacent comparative table. The following data is from the *Westinghouse Diary:*

	Copper	Aluminum
Area for equal conductivity	100.0	160.0
Diameter for equal conductivity	100.0	126.0

It will be noted from the relative diameters that an aluminum wire to be of equal conductivity to a copper wire is almost exactly two sizes larger by B. & S. Gage.

The conductivity of aluminum wire is 63 per cent. of that of copper; but an aluminum wire of equivalent conductivity will have 48 per cent. of the weight and 160 per cent. of the strength.

195. **Commercial galvanized-iron wire** is known in the market by the following terms: **Extra Best Best** (E.B.B.).—This is made by improved continuous processes from the very best iron. It has the best conductivity of any commercial iron wire. Its weight per mile-ohm is from 4,600 to 5,100 lbs. It is very uniform in quality, pure, tough and pliable. **Best Best** (B.B.).—This is less uniform and tough than the above (E.B.B.), but stands a good mechanical test. Its weight per mile-ohm is 5,500 to 5,800 lbs. It is largely used by telephone and telegraph companies and in railway telegraph service. **Best** (B.) is a term applied almost indiscriminately to the lower grades of iron wire for electric service. It is a harder and a less pliable wire than the two above grades. Its weight per mile-ohm is about 6,500 lbs. **Steel** is a stiff wire of high tensile strength and low conductivity. It is very difficult to work, but is used on short lines that must be erected at low cost, where conductivity is of little importance. Its weight per mile-ohm is 6,000 to 7,000 lbs.

196. Properties of Galvanized Telephone and Telegraph Wires

Based on Standard Specifications (*American Steel & Wire Co.*)

Size B. W. G.	Diameter in mils = d	Area in circular mils = d^2	Approximate weight in pounds		Approximate breaking strain in pounds			Resistance per mile (international ohms) at 68 deg. fahr. or 20 deg. cent.		
			Per 1,000 ft.	Per mile	Ex. B.B.	B.B.	Steel	Ex. B.B.	B.B.	Steel
0	340	115,600	313	1,655	4,138	4,634	4,965	2.84	3.38	3.93
1	300	90,000	244	1,289	3,223	3,609	3,867	3.65	4.34	5.04
2	284	80,656	218	1,155	2,888	3,234	3,465	4.07	4.85	5.63
3	259	67,081	182	960	2,400	2,688	2,880	4.90	5.83	6.77
4	238	56,644	153	811	2,028	2,271	2,433	5.80	6.91	8.01
5	220	48,400	131	693	1,732	1,940	2,079	6.78	8.08	9.38
6	203	41,209	112	590	1,475	1,652	1,770	7.97	9.49	11.02
7	180	32,400	87	463	1,158	1,296	1,389	10.15	12.10	14.04
8	165	27,225	74	390	975	1,092	1,170	12.05	14.36	16.71
9	148	21,904	60	314	785	879	942	14.97	17.84	20.70
10	134	17,956	49	258	645	722	774	18.22	21.71	25.29
11	120	14,400	39	206	515	577	618	22.82	27.19	31.55
12	109	11,881	32	170	425	476	510	27.65	32.94	38.23
13	95	9,025	25	129	310	347	372	37.90	45.16	52.41
14	83	6,889	19	99	247	277	297	47.48	56.56	65.66
15	72	5,184	14	74	185	207	222	63.52	75.68	87.84
16	65	4,225	11	61	152	171	183	77.05	91.80	106.55

197. The so-called galvanized-steel strand (Fig. 106) is really seven-strand cable composed of galvanized steel wires. It is used for guying and for **messenger cable** to support cables that have not themselves much mechanical strength. It is also used for **long spans in transmission lines** which (*American Steel & Wire Co.*)

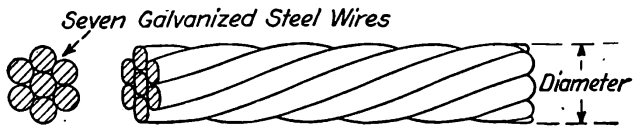


FIG. 106.—Galvanized steel strand.

cannot always be made with copper cables, because hard-drawn copper has a strength of only 65,000 lbs. per square inch. Where it is necessary to cross rivers with transmission lines, the energy may be conducted by one of the galvanized-steel cables tabulated, which should be of such size and strength that it will show a safety factor of at least five. It is not necessary to suspend bare copper cables beneath a steel strand, as the steel strand itself serves as the conductor. The ordinary or Bessemer steel cable is commonly used for guying and for supporting single suspension trolley wires, while the other grades are commonly used for messenger wires and for long transmission-spans.

198. Galvanized Steel Strand or Cable (*American Steel & Wire Co.*)

All of these are seven-strand cables

Ordinary or Bessemer steel				Extra galvanized Siemens-Martin					Extra galvanized high-strength or crucible steel					Extra galvanized extra high or plow steel				
Diam., in.	Approx. weight per 1,000 ft., pounds	Approx. strength, pounds	List prices per 100 ft.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.
$\frac{5}{8}$	...	...	...	..	19,000	$4.35	50	10.0	..	25,000	$6.25	55	6	..	42,500	$8.75	60	4
$\frac{1}{2}$	510	8,500	$4.50	..	11,000	2.80	50	10.0	..	18,000	3.95	55	6	..	27,000	5.50	60	4
$\frac{7}{16}$	415	6,500	3.75	..	9,000	2.30	50	10.0	..	15,000	3.45	55	6	..	22,500	4.60	60	4
$\frac{3}{8}$	295	5,000	2.75	..	6,800	1.80	50	10.0	..	11,500	2.70	55	6	..	17,250	3.55	60	4
$\frac{5}{16}$	210	3,800	2.25	..	4,860	1.35	50	10.0	..	8,100	2.10	55	6	..	12,100	2.70	60	4
$\frac{9}{32}$	...	...	...	..	4,380	1.10	50	10.0	..	7,300	1.75	55	6	..	10,900	2.10	60	4
$\frac{1}{4}$	125	2,300	1.75	..	3,060	1.00	50	10.0	..	5,100	1.50	55	6	..	7,600	1.90	60	4
$\frac{7}{32}$	95	1,800	1.50	..	...	...	...	...	..	...	...	...	...	..	...	...	...	...
$\frac{3}{16}$	75	1,400	1.25	..	2,000	0.85	50	10.0	..	3,300	1.30	55	6	..	4,900	1.60	60	4
$\frac{5}{32}$	55	900	1.15	..	...	...	...	...	..	...	...	...	...	..	...	...	...	...
$\frac{1}{8}$	32	500	1.00	..	900	0.55	50	10.0	..	1,500	0.80	55	6	..	2,250	1.05	60	4
$\frac{3}{32}$	20	400	0.80	..	...	...	...	...	..	...	...	...	...	..	...	...	...	...

199. Galvanized iron or steel wires are spliced as shown in Fig. 97 and 5 turns are necessary in the neck of the splice to insure that the splice will be as strong as the wire. The strength of an unsoldered joint is determined by the number of turns in the neck. The end turns have but little holding power. Small **galvanized steel cables are joined** in the same way as are wires, as shown in Fig. 107. There should be 5 turns in the neck, as with wires, and a few end turns to finish off the joint. Soldering is unnecessary for guy

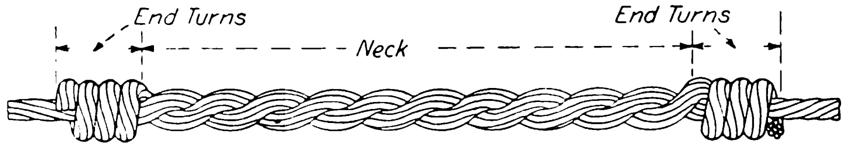


FIG. 107.—Joint in small steel cable.

wires. Larger cables can be spliced as shown in Fig. 103, or mechanical clamps can be used instead as shown in Fig. 108. Sometimes it is necessary to use several clamps, instead of one as the figure shows, in order that the joint will be as strong as the wire.

200. Methods of Soldering Wires in Terminal Lugs.—Where many terminal lugs are to be soldered to conductors a convenient and time-saving method of making the connections is to melt a pot of solder over a plumbers' furnace, heat the lug in the solder, pour the solder in the hole in the lug and then plunge the bared end of the conductor into it, as shown in Fig. 109. The insides of the holes of all commercial lugs are "tinned" so the solder adheres to them read-

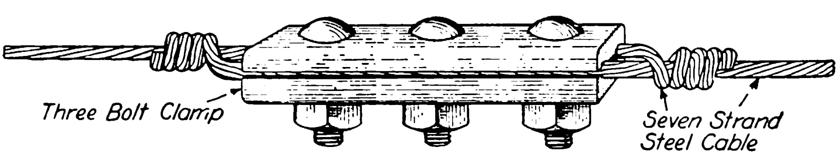


FIG. 108.—Steel cable joined with clamp.

ily, and the bared end of the conductor should also first be tinned. This may be done as follows: The end of the wire is carefully scraped with a knife or with a piece of fine sandpaper (the sandpaper is best because it cannot nick the wire) and then smeared with soldering flux and thrust into the solder pot. If a soldering stick is used the wire must be heated in the solder before the stick compound will melt and adhere. It requires but a short time to "tin" the wire end in the pot.

Immediately after the tinned end is pushed into the hole in the lug the lug should be soused with a piece of wet waste to cool it rapidly. Scrape or file off any shreds or globules of solder that adhered to the exposed surfaces of the lug and brighten it with fine sandpaper if necessary.

The insulation from the conductor ends should be cut back just far enough so that it will abut against the shoulder of the lug, as suggested in Fig. 110, *I*. The appearance is very unsightly and indicates careless work if there is a gap between the shoulder and the insulation, as at *II*. If because of some mishap a connection

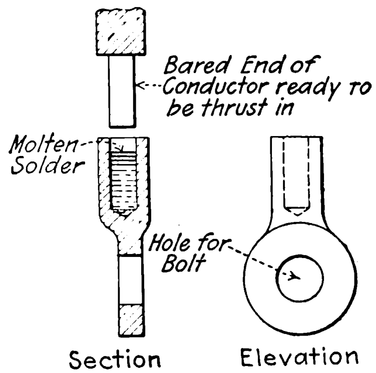


FIG. 109.—Soldering wire in lug.

results, having the appearance of *II*, a partial correction can be made by filling the gap with servings of tape, as shown at *III*. The tape of the standard $\frac{7}{8}$-in. width should be torn into strips about $\frac{1}{4}$ in. wide before applying.

Only enough molten solder should be poured into the hole in the lug to fill it almost to the brim when the conductor is in position.

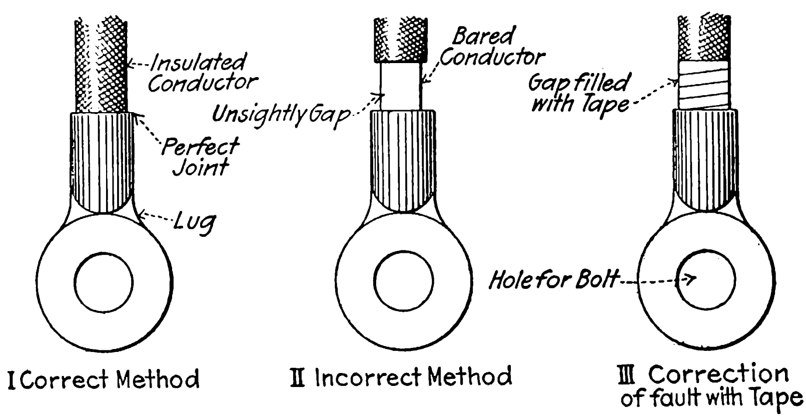


FIG. 110.—Finished connections.

If too much is poured in it will be squeezed out by the wire and will flow over the lug. It must then be removed at a sacrifice of time.

To secure proper adhesion between wire, solder and lug the temperature of all three must be above the melting-point of solder at the instant of contact. If this condition does not exist nothing more than a good friction fit of all three parts will be secured. To secure maximum mechanical strength and electrical conductivity, it is absolutely essential that the solder be maintained at the melting-point until it has thoroughly permeated the interstices of the conductor.

The wire terminal and lug should be held in the molten solder until they acquire the temperature of the solder. To prevent adhesion of solder to the outside of the lug it should first be dipped in a light oil of high flash-point. Be careful to see that no oil is permitted to reach the inside of the lug. It will be found advisable when holding the bared ends of heavy conductors in the solder pot to wrap the insulation well with a rag previously wrung out in cold water to prevent as far as possible the melting of the insulating compound and the consequent smearing of the terminal. Any such drip will not impair the joint if properly made, though it will detract from the appearance of the finished job. (*F. P. Kenny, Electrical World.*)

Another method of soldering wires in lugs is to heat the lug with a blow-torch flame. When the lug is sufficiently hot, wire solder is fed into the hole. The solder melts and the bared conductor end is then thrust into it, as above described. However, the use of a blow torch in this way should be avoided if possible, as it blackens the exposed surfaces of the lug. A cleaning with fine sandpaper is then necessary, and it requires considerable time.

201. **A soldering flux** removes and prevents the formation of an oxide during the operation of soldering, so that the solder will flow readily and unite firmly the members to be joined. For copper wires the following solution of zinc chloride is recommended by the Underwriters, and is good:

Saturated solution of zinc chloride ..	5 parts
Alcohol	4 parts
Glycerine	1 part

Solutions made with acids should be avoided as there is usually more or less corrosion in joints made with them. The commercial soldering pastes and sticks give good satisfaction in cleaning joints to be soldered.

202. **Soldering paste or stick can be made** as follows: Melt 1 lb. of tallow and add 1 lb. of common olive oil; stir in 8 oz. of powdered rosin; let this boil up and when partially cool, add, stirring constantly, ¼ pint of water that has been saturated with powdered sal ammoniac. Stir constantly until cool. By adding more rosin to make it harder, it can be cast into sticks.

203. **In soldering commutator wires and connections** around electrical machines, an acid solution should never be used, because of the ensuing corrosive action. A good flux is an alcoholic solution of rosin.

204. **Soldering with Blow Torch and Iron.**—When soldering connections between wires smaller than No. 8 many wiremen use a blow torch for heating the joint. While a joint can be made in this way, it is much better to use a soldering copper for small wires. Where a blow torch is used the insulation on the conductors is nearly always ignited and burns with a thick smoke and blackens

any object on which it deposits. It is probable also that the excessive heat of the blow torch injures the adjacent insulation on the conductors. Furthermore, the blow torch is difficult to manipulate in restricted locations. A small alcohol torch is often satisfactorily used instead of a blow torch and is better adapted for the work, but it is probably not as good as a soldering iron.

In using a soldering copper it is heated in the flame of a blow torch. To solder the joint the hot tool is placed under and in close contact with it and wire solder is fed into the turns of the joint. After the solder has flowed over the entire surface of the joint the iron is removed and the joint is shaken to throw off surplus solder. There is no ignition of insulation and no sooty smoke. The soldering copper can be used in confined spaces where the use of a torch would be out of the question. Wires to be soldered must be scraped clean and bright before the tool is applied. Any of the commercial soldering pastes can be used as a flux.

205. **Pointers in Blow Torch Manipulation** (*W. N. Matthews & Bros. Notebook*).—Only the very best grade of gasoline (74 deg.) should be used, and it must be clean and kept in a clean can, otherwise the burner will become clogged. Never try to fill a torch from a big can. A pint or quart receptacle should be used for this purpose. If this is done, the torch can be held in one hand and filled with the other without danger of overfilling or spilling. The torch should be a little more than two-thirds full, so that there will be room for sufficient air to prevent the necessity of frequent repumping to maintain the pressure.

See that the filler plug is closed tight, to prevent the escape of air from tank. The fiber washer under the plug must be replaced when worn out. Common washing soap rubbed into threads and joints will stop all leaks. The pump should be in good working order; a few drops of lubricating oil well rubbed in will soften the pump washer. Do not turn needle valve too tight, as there is danger of enlarging the orifice of the burner. See that the burner is sufficiently heated when starting. One filling of the drip cup is generally sufficient if the flame is shielded from draft while heating the burner; if it is not, fill the cup again and light the gasoline as before. A long or yellow flame or raw gasoline shooting from the burner shows that the burner is not hot enough to properly generate gas.

Ordinarily when a gasoline torch is used, 90 per cent. of the heat is dissipated, without doing any work whatever. When performing most blow torch operations a great part of this heat may be readily saved by making a shield of sheet iron or asbestos, to direct the heat to the object to be heated.

RESISTORS

206. **A cheap and good, heavy current resistor can be made by folding wire netting** up and down over iron rods supported by insulators. (*Standard Handbook.*) Galvanized iron wire (No. 19 B. & S.) netting of 1 in. mesh and 12 in. wide has a resistance of approximately 0.005 ohm per yard and will carry 100 amp.

207. **A design for a water-cooled resistor** is shown in Fig. 111. It consists of a number of pipes fitted into couplings and supplied with brass sliding bridge pieces. With all bridge pieces at the top the resistor is practically short-circuited, but when it is desired to cut out all the resistance the terminals of the rheostat should be short-circuited through the switch. With all the bridge pieces at the bottom the resistance of the circuit becomes a maximum. The pipe connections are so made that water can be circulated through the rheostat. The connections to the water mains and outlet should be made through rubber hose. The heat capacity will depend upon the amount and temperature of the water circulated.

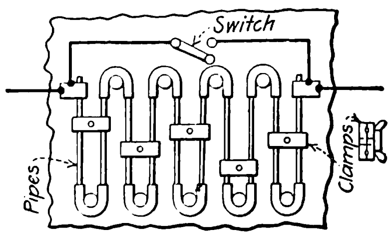


FIG. 111.—Water-cooled resistor made of pipe.

208. **Rheostats made up of galvanized-iron wire mounted on wooden frames and submerged in running water** are often used to absorb energy when making acceptance tests of large apparatus in the power house. In this case the power dissipated can be assumed as directly proportional to the surface of the resistor, and, therefore, the formula I $kd^{\frac{3}{2}}$ can be used with good results. Mr. P. M. Brown gives the following values of k as the results of extensive experiments:

Rheostat in barrel or tank, no flow of water.....	k = 540 to 700
Rheostat in flowing water (river or tail race)	k = 700 to 950
Rheostat in rapidly flowing water (river or tail race)	k = 950 to 1,250

A barrel should not be used to dissipate more than 5 kw. Values of $d^{\frac{3}{2}}$ can be taken from Table 215.

209. **Liquid rheostats are especially adapted to the absorption of large amounts of power** and are often used as an artificial load in testing dynamos or as starting rheostats for large motors starting under load. The adjustment is perfectly continuous, but unless there is a provision for short-circuiting the electrodes outside the solution it is impossible to cut out the resistance entirely. The material of which the electrodes are made is not important so long as it is a good conductor and is not attacked by the liquid. Lead or carbon plates are used with sulphuric acid, copper with copper sulphate and iron in most other cases. The current density should not exceed 1 amp. per square inch.

210. **The solution in a liquid rheostat** depends upon the voltage and quantity necessary to radiate the heat. Pure water is seldom used for pressures under 1,000 volts. For voltages below this sulphuric acid or some salt is added to the water to increase its conductivity. Fig. 112 shows the relative conductivity of various solutions expressed in inches between the plates with a current density of 1 amp. per square inch. Ordinary water gives a drop from 2,500 to 3,000 volts per inch gap at this current density.

211. **The radiation capacity of a liquid rheostat** depends upon the volume of the solution used and not upon the area of the surface.

It is also affected by the conductivity of the material of which the tank is made; the amount of radiating surface of the tank; the temperature, pressure and dampness of the surrounding air; and the counter e.m.f. generated by chemical action (at low pressures a large proportion of the power may be absorbed chemically without the evolution of heat). Fig. 113 is constructed from experiments made by H. W. W. Dix and shows the allowable watts per cubic inch for different values of temperature rise.

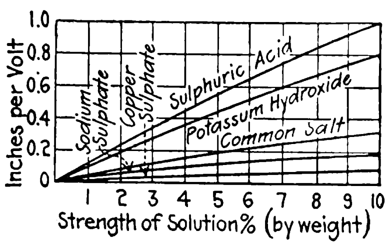


FIG. 112.—Curves showing conductivity of various solutions.

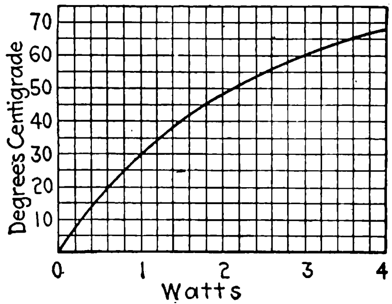


FIG. 113.—Allowable watts per cubic inch for a liquid rheostat.

As a general rule take 400 to 800 cu. in. of solution per horse-power absorbed continuously. For motors, about 20 cu. in. per horse-power capacity should be allowed for starting and 60 cu. in. per horse-power for running.

212. **A good design for a liquid rheostat,** which can be easily constructed, is shown in Fig. 114. It is arranged so as to short-cir-

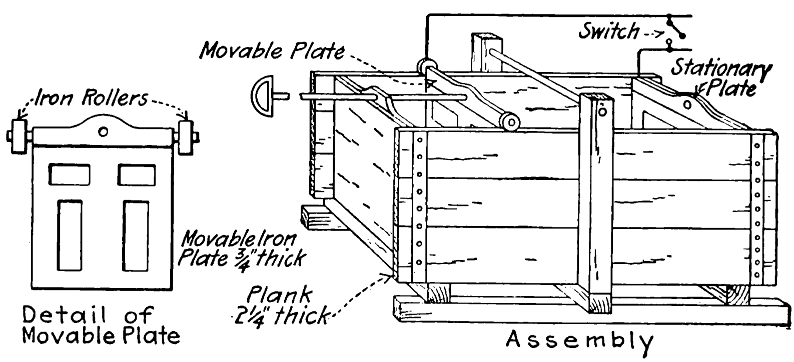


FIG. 114.—Water rheostat.

cuit the electrodes with the switch when all resistance is out. The size of the tank is determined by the size of the electrodes (roughly the area of the electrodes in square inches equals number of amperes) and the volume of the liquid necessary to radiate the heat liberated by the absorption of the given amount of power (Fig. 112). Knowing the size of the tank and the voltage, the solution and materials for the electrodes and tank can easily be chosen.

213. **Water rheostats can be worked at higher densities** than those given in Fig. 114 by allowing cool water to circulate through the tank. It will require $\frac{86.5}{t}$ kg. or $\frac{190}{t}$ lb. of water per hour to dissipate the heat liberated by the absorption of 1 kw. with a temperature rise of t deg. cent. This formula also applies to the cooling of metallic resistors submerged in running water.

214. **Where high voltage is used the water must be conducted to and from the tank in rubber hose.** For potentials up to 2,500 volts a length of 15 to 20 ft. is sufficient to prevent grounding, providing the diameter does not exceed 1 in. For larger diameters a correspondingly longer hose must be used.

215. **Values for Galvanized-iron Wire of $d^{\frac{3}{2}}$ in $I = kd^{\frac{3}{2}}$.**
(*Standard Handbook*)

Size B. & S.	Solid		Stranded		Size cir. mils.	Stranded	
	d-inch	$d^{\frac{3}{2}}$	d-inch	$d^{\frac{3}{2}}$		d-inch	$d^{\frac{3}{2}}$
20	0.0320	0.00571	....	....	250,000	0.575	0.437
18	0.0403	0.00809	....	....	300,000	0.634	0.505
16	0.0508	0.01145	....	....	350,000	0.682	0.563
14	0.0641	0.01622	0.073	0.0197	400,000	0.728	0.621
12	0.0808	0.02298	0.092	0.0278	450,000	0.777	0.685
10	0.102	0.03254	0.116	0.0394	500,000	0.815	0.736
8	0.128	0.04620	0.145	0.0555	550,000	0.855	0.791
6	0.162	0.06520	0.184	0.0788	600,000	0.893	0.844
5	0.181	0.07760	0.206	0.0940	650,000	0.930	0.896
4	0.204	0.09240	0.232	0.112	700,000	0.965	0.947
3	0.229	0.1098	0.260	0.133	750,000	0.999	0.998
2	0.258	0.1306	0.292	0.158	800,000	1.031	1.047
1	0.289	0.1555	0.332	0.911	900,000	1.094	1.145
0	0.325	0.1852	0.375	0.230	1,000,000	1.153	1.238
00	0.365	0.2203	0.419	0.271	1,250,000	1.290	1.465
000	0.410	0.2620	0.470	0.322	1,500,000	1.412	1.679
0000	0.460	0.3120	0.528	0.384	1,750,000	1.526	1.885
....	....	....	....	....	2,000,000	1.631	2.083

NOTE.—Formula $I = kd^{\frac{3}{2}}$ is used in calculation of wire for rheostats with forced cooling (208).

CIRCUITS AND ELECTRICAL DISTRIBUTION

216. **A series circuit** is one in which all components are connected in tandem as in Figs. 115 and 116. The current at every point of a series circuit is the same. Series circuits find their most important commercial application in series arc and incandescent lighting. They are seldom if ever used in this country for the transmission of power.

217. **Multiple, parallel or shunt circuits** are those in which the components are so arranged that the current divides between them (Figs. 116A and 117). Commercially, the distinction between

multiple and series circuits is that, in series lighting circuits, the current is maintained constant and the generated e.m.f. varies with the load, whereas, with multiple circuits, the current through the

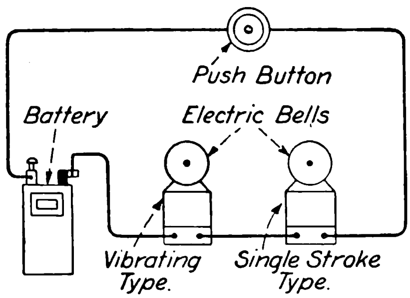


FIG. 115.—Series electric-bell circuit.

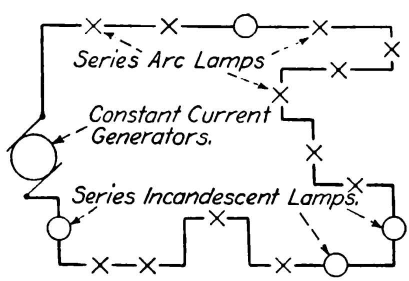


FIG. 116.—Series street-lighting circuit.

generator varies with the load and the generator e.m.f. is maintained practically constant.

218. **Adding receivers in parallel** on multiple circuits is really

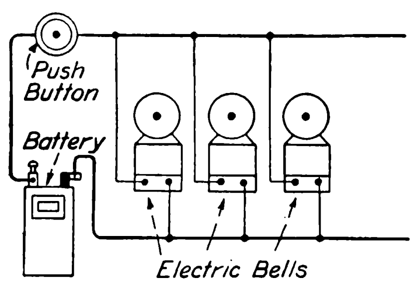


FIG. 116A.—Electric bells in parallel.

equivalent to increasing the cross-section of the imaginary conductor formed by all the receivers in parallel between the + and the − sides of the circuit.

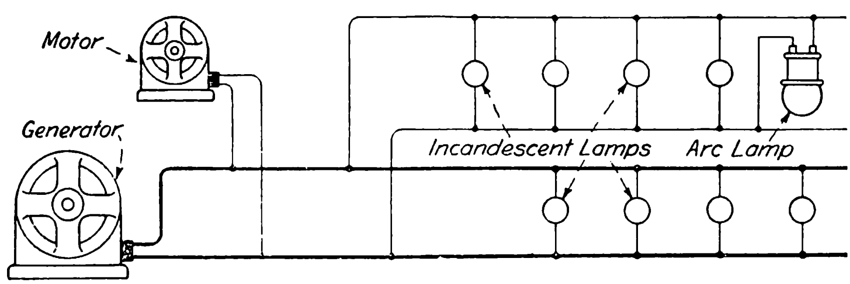


FIG. 117.—A multiple circuit for light and power.

219. **The distribution of current in a multiple circuit** is shown in Fig. 118. Motors, heating devices or other equipment requiring electricity for their operation could be substituted for the incan-

descent lamps if the proper current values were substituted for those shown. Note that the current in the main conductors decreases toward the end of the run and that the current supplied by the source—the generator—is equal to the sum of the currents

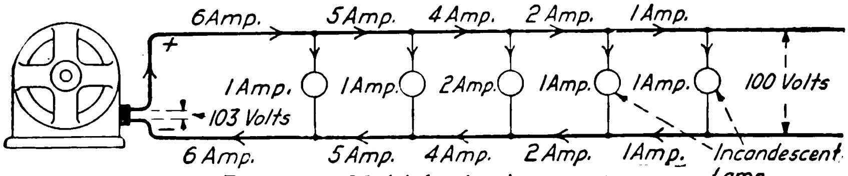


FIG. 118.—Multiple circuit currents.

required by all of the components. The voltage at the end of the run is less than that at the generator.

220. **A multiple-series or parallel-series circuit** consists of a number of minor circuits in series with each other and with several of

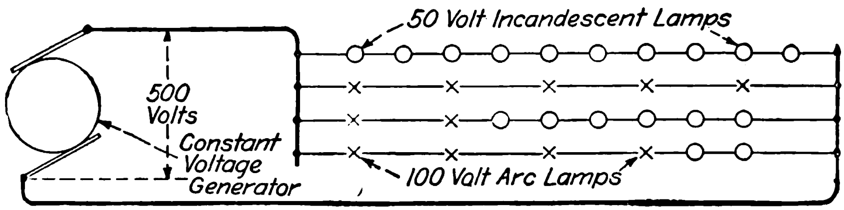


FIG. 119.—A parallel-series or multiple-series circuit.

these series then connected in parallel, as shown in Fig. 119. Arc lamps designed for such connection and incandescent lamps are sometimes arranged in this way. For example, 5 arc lamps each requiring 100 volts or 10 incandescent lamps requiring 50 volts

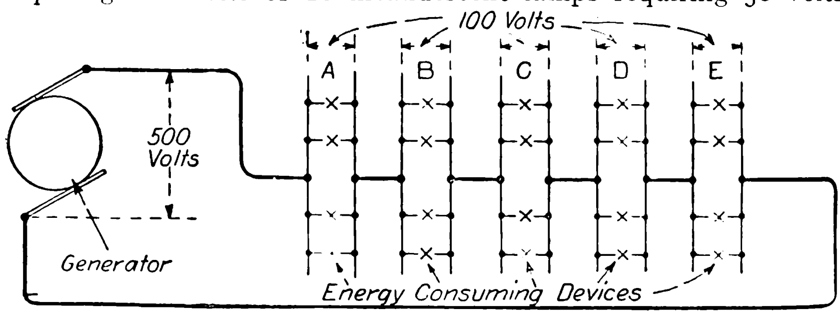


FIG. 120.—A series-parallel or series-multiple circuit.

are respectively connected in series and then these series groups are connected across a 500-volt railway circuit.

221. **A series-multiple or series-parallel circuit** is one wherein a number of minor circuits are first connected in parallel, and then several of the parallel-connected minor circuits are connected in series across a source of e.m.f. as in Fig. 120. This method of connection is seldom used. (There appears to be a difference of opinion as to what constitutes a "*series-multiple*" and what a "*multiple-series*" circuit. The definitions of Pars. 220 and 221 are in accordance with the practice of the General Electric and Westinghouse companies.)

222. A divided circuit (Fig. 121) is really one form of a multiple or parallel circuit. The distinction between the two sorts appears to be that, as ordinarily used, the term "divided" refers to an isolated group of a few conductors in parallel rather than to a group of a large number of conductors in parallel.

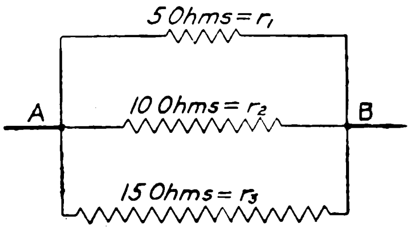


FIG. 121.—A divided circuit.

223. The joint resistance of a number of conductors in parallel can be computed with the following formula. There should be as many terms in the denominator of the formula as there are conductors in parallel:

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4}}, \text{ etc.}$$

Example—What is the joint resistance of the conductors in the divided circuit shown in Fig. 121? In other words, what is the resistance from *A* to *B*? *Solution.*—Substitute in the formula:

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}} = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{15}} = \frac{1}{\frac{6}{30} + \frac{3}{30} + \frac{2}{30}} = \frac{1}{\frac{11}{30}} = 1 \times \frac{30}{11} = 2.73 \text{ ohms.}$$

224. A feeder (or feeder circuit) is (Figs. 122 to 124) a set of conductors in a distributing system extending from the original source of energy in the installation to a distributing center and having nothing connected to it between the source and the center. The source may be a generating or a sub-station or, in the case of building or house wiring a connection to the service conductors from the street. (See Figs. 122, 123 and 124.)

225. A main. (Figs. 122 to 124.) There are really two rather distinct classes of mains thus:

(1) A main is an extension of a feeder extending from one distribution center to another distribution center having nothing connected to it between the two distribution centers. Frequently a main of this character is called a *sub-feeder.* (Fig. 122.)

(2) A main is any supply circuit to which other circuits (submains or branches) connect *through automatic cut-outs*—fuses or circuit breakers—at different points along its length. Where a main is supplied by a feeder the main is usually of smaller wire than the feeder which serves it. An energy-consuming device is never connected directly to a main, a cut-out always being interposed between the device and the main.

225A. A sub-main (Fig. 122) is a subsidiary main, fed through a cut-out from a main or another sub-main, to which branches are connected through cut-outs. A sub-main is usually of smaller wire than the main or other sub-main which serves it. Ordinarily submains are referred to as merely "mains." The term sub-main has not been used very extensively.

226. **A branch or branch circuit** (Fig. 122) is a set of **conductors** (feeding, through an automatic cut-out, from a distribution center, main or sub-main) to which one or more energy-consuming devices are connected directly—without the interposition of cutouts. The only cut-out associated with a branch is that through which the branch is fed at the main, sub-main or distribution center.

227. **A tap or tap circuit** (Fig. 122) is a circuit, serving a single energy-consuming device, connecting directly to a branch without the interposition of a cut-out.

228. **A distributing or distribution center** is an arrangement or group of fittings whereby two or more minor circuits are connected at a common point to another, larger circuit. A **panel box** is one form of a distribution center. (See Figs. 122 to 124.)

229. **A service** (or a service connection) is a set of conductors constituting an underground or an overhead connection between conductors (a **main** belonging to a public service corporation) in a thoroughfare and those of an interior or isolated wiring system. A "service" serves the wiring system with energy.

230. **A loop circuit** (see Fig. 125) is one wherein all receivers,

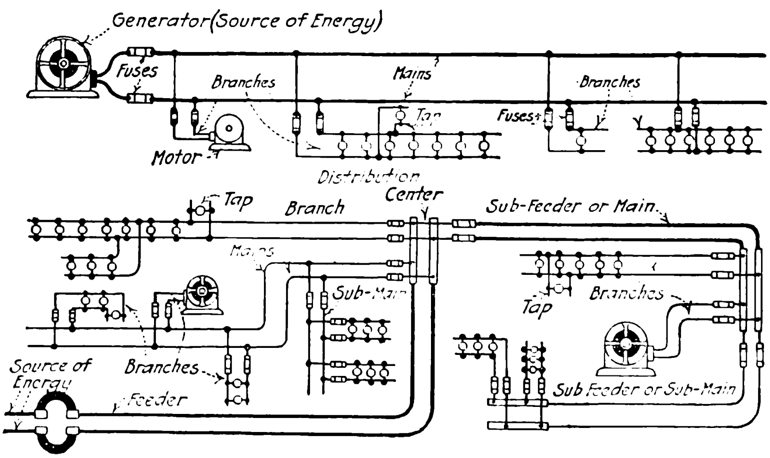


FIG. 122.—Diagram illustrating circuit nomenclature.

lamps or motors for example, are at the same electrical distance from the source of electricity. By tracing paths from one terminal back to the other through any receiver it will be found that the length of line is the same in every case. It is sometimes supposed (*Crocker's Electric Lighting*) that this arrangement of conductors must give the same pressure at all of the receivers since the sum of the distances of each receiver from the feeding points measured on the mains is constant. Actually the middle receiver (see Fig. 125) will receive a lower voltage than those at the ends as shown in the diagram. This is due to the fact that the middle receivers are supplied through the portions of the main conductors which carry heavy currents and in which the drop is greatest. For example, the drop on the mains in the case of the central receiver

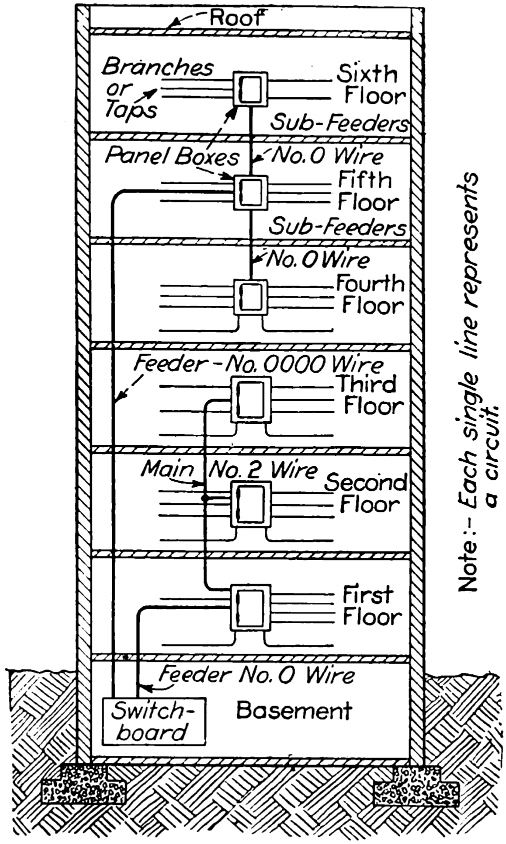


FIG. 123.—Examples of feeders, mains and branches.

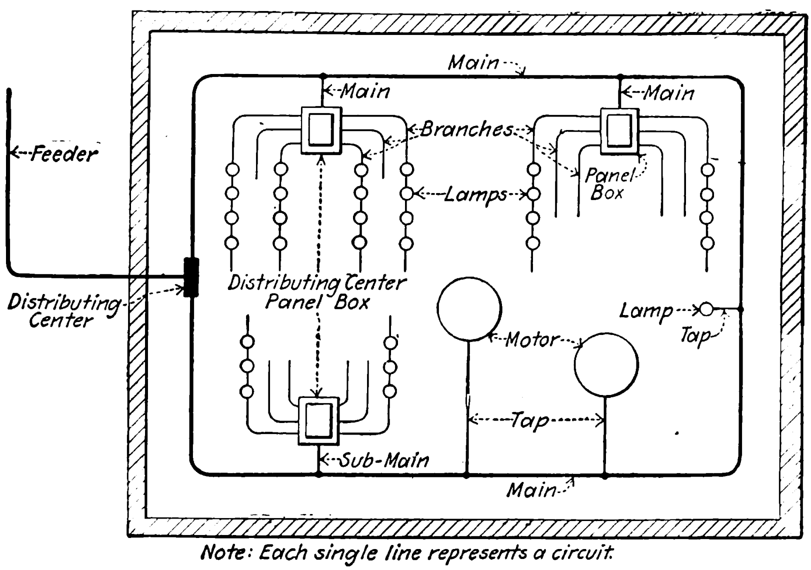


FIG. 124.—Diagram showing "closed-loop-main."

is, $2+1.5+1.5+2=7$ volts, while for the end receiver it is but $2+1.5+1+0.5=5$ volts.

Loop circuits are seldom used in modern installations. They provide close voltage regulation but more conducting material is required than for some of the other forms of circuits which provide sufficiently good results.

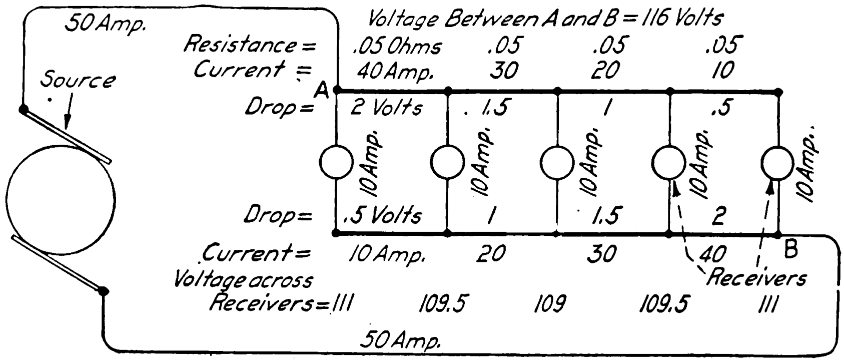


FIG. 125.—Loop circuit.

231. **A tree circuit** (Fig. 126) is so called because its main conductors resemble a tree trunk and the branch conductors limbs. Tree circuits of considerable length and feeding many receivers are usually undesirable and uneconomical because it is impossible to maintain a reasonable voltage regulation on them without using very large main conductors. Short tree circuits consisting of mains and branches are often and advantageously used in both interior and out-of-door distribution.

232. **Main-and-feeder circuits** are widely used in modern electrical distributions. This is not only because the feeder and main method is, for a given voltage regulation at the receivers, the least costly to install but also because it is the most reliable, in that it divides the load into sections so that short-circuits or trouble in one section is not apt to affect the rest of the load. This method of distribution is usually adopted by the central station companies in the construction of their out-of-door wire plants to distribute electricity to their subscribers. Practically the same system, on a smaller scale, is nearly always used within buildings to distribute electricity to lighting equipment and motors. (See Figs. 122 to 124.) The feeder in an interior feeder and main system may connect to the service of an out-of-door feeder and main system.

233. **A ring circuit** (Fig. 124) is one wherein a main (or possibly a branch) forms a closed ring. It is usually a special case of a feeder-and-main circuit. In out-of-door distributions ring mains are sometimes carried around a city block or around a certain district and branch mains or services are fed by the ring main. One feeder or several may serve a ring main each connecting at a different point. In interior electrical distributions, ring mains are seldom

used except in industrial plants, but for this service they can often be applied to advantage.

234. **The three-wire system is used because it saves copper.** (See Fig. 127.) Incandescent lamps for about 100 volts are more economical than those for higher or lower voltages. A system of any consequence operating at 110 volts would require very large conductors to maintain the line drop within reasonable limits. With the three-wire system, a low voltage, say 110, is impressed on the receivers while one twice as great, say 220, is used for transmission. Since the weight of conductors for a given loss varies inversely as the square of the voltage (see **242**) it is evident that a considerable saving is possible with the three-wire system. In this country the three-wire system is of most importance as applied to 110–220 volt lighting systems.

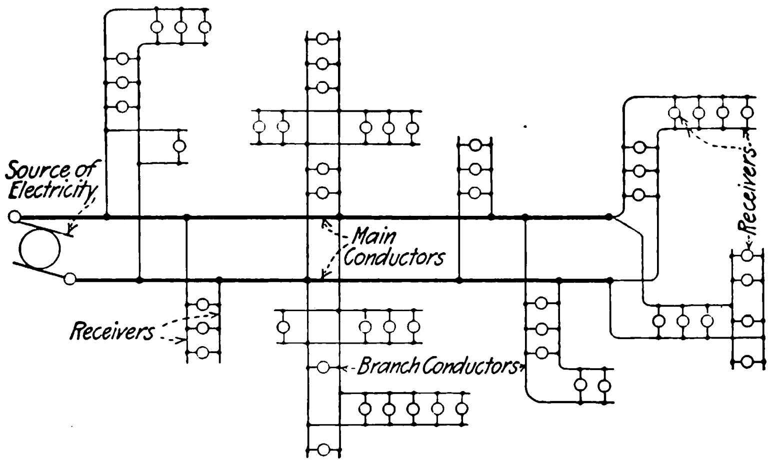


FIG. 126.—Tree circuit.

235. **The principle of the three-wire system is illustrated** in Fig. 127. Incandescent lamps for 110 volts could be connected two in series across 220 volts as shown at *I* and while each lamp would operate at 110 volts, the energy to the group would be transmitted at 220 volts and the outside conductor could, with equal loss, be one-fourth the size that would be necessary if the energy was transmitted at 110 volts. This arrangement (Fig. 127, *I*) while it would operate, is not commercially feasible because each lamp of each pair of lamps in series must be of the same size and if one lamp goes out its partner is also extinguished. These disadvantages might be partially corrected by running a third wire as at Fig. 127, *II*. Then one lamp might be turned off and the others would burn and a single lamp might be added to either side of the system between the third wire and either of the outside wires. But unless the total resistance of all of the lamps connected to one side was practically equal to that of all of the lamps connected to the other side, the voltage across one side would be higher than that across the other. On the high side the lamps

would burn bright and on the low side dim. Obviously, it is not feasible in practice to so arrange or "balance" the sides that they will have the same resistance. Hence some other method must be used in practicable three-wire systems whereby the electricity will be transmitted at, say, 220 volts and the pressure across the lamps will be, say, 110 volts.

236. **Commercial three-wire systems** consist (Fig. 127, *III* and *IV*) of two outer conductors, having (for lighting installations) a pressure of 220 volts impressed across them and a neutral wire so connected to sources of voltage that the pressure between it and either of the outside wires is 110 volts. In Fig. 127, *III*, generators are the sources of voltage. The neutral wire joins at the

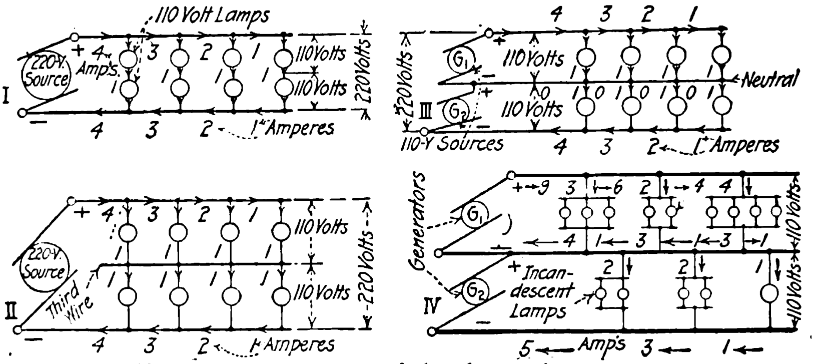


FIG. 127.—Elements of the three-wire system.

point where the generators are connected together. When the system is perfectly balanced, the neutral wire carries no current and the system is in effect a 220-volt system. Perfect balance seldom obtains in practice. When the balance is not perfect, the neutral wire conveys a current equal to the difference between the current taken by one side and that taken by the other side. Note from Fig. 127, *IV*, that the current in different parts of the neutral wire may be different and that it is not necessarily in the same direction in all parts of the neutral wire. Each incandescent lamp in Fig. 127, *IV*, is assumed to take 1 amp. and the small figures indicate the currents in different parts of the circuit.

237. **The Size of the Neutral Wire of Three-wire Systems.**—Where the balance is and always will be perfect no neutral wire is necessary. In out-of-door distribution systems the neutral is often one-half the size of the outer wires. For interior wiring, the neutral is frequently made the same size as the outside wires. However, a neutral conductor having two-thirds—or even one-half—the cross-sectional area of each of the outers will usually be satisfactory if it is protected in accordance with *Code* requirements. Some engineers specify thus: Where the outers are No. 6 or smaller, the neutral shall have the same area as each of the outers and where the outers are larger than No. 6 the neutral shall have two-thirds the area of each of the outers.

238. **The amount of unbalance that may come on a three-wire system** depends on local conditions. In ordinary three-wire lighting systems the unbalanced load seldom exceeds 10 per cent. of the total load. Probably 5 per cent. is a fair average for a well-

laid-out system. Balancer sets for interior three-wire systems are frequently specified of sufficient capacity to take care of a 10 per cent. unbalance. Sometimes the unbalance on a poorly laid out system may be 20, 30 per cent. or even more.

239. Application of Alternating Current and of Direct Current for Distribution.—The following suggestions are general and cannot be expected to apply to every special case. Where electricity is to be distributed for lighting only and not at a greater distance than about a mile from the generating station, direct current will probably be most satisfactory and economical. If many adjustable speed motors are to be served by a distribution, direct current should be used at the motors even if it is necessary to convert alternating into direct current, at the using point, with a motor generator or rotary converter. There is no satisfactory alternating current, adjustable speed motor that has the general characteristics of the direct-current shunt or compound wound motor.

Where electricity is to be distributed to points more than a mile distant from the station, alternating current will usually be most economical and satisfactory. It may be generated at a reasonably high voltage and transmitted to the points where it is to be used at that voltage and there "stepped down" with transformers to the voltage required by the receivers. Transmitting at a high voltage makes possible the use of small feeder conductors. Where many constant-speed motors are to be used, polyphase alternating current is always preferable for either short or long distribution distances because polyphase constant-speed motors are simpler and more reliable than direct current. Furthermore, alternating-current motors can be operated on higher voltages than can direct current, so it is not necessary to step down for them unless the voltage of the generator is quite high. Two-wire (single-phase) electric lighting can always be arranged from single-phase or polyphase alternating-current circuits.

Alternating current is always used where it is necessary to transform from one voltage to another without the use of moving apparatus and offers a very flexible system in this respect. But where transformers are used there are slight losses in them even when they are not loaded. An alternating-current system also has the disadvantages that its inherent voltage regulation and its efficiency are not so good as those of a direct-current system. This is particularly true if much inductive equipment, that containing coils wound on iron such as motors and arc lamps, is connected to the circuits. Despite these disadvantages experience has shown that alternating is preferable to direct current for the applications outlined above. Polyphase constant-speed motors are preferable to direct-current constant-speed motors because they are simpler, in that they have no commutator and they cost less to maintain than do direct-current motors. Direct current is nearly always used in office buildings served by isolated plants because such loads are mainly lighting.

240. Selection of a Frequency.—There are two frequencies now standard in this country, 25 cycles and 60 cycles. All other things being equal, 25 cycles would seem at first sight preferable because there is less inductive effect with it than with a higher frequency. It therefore follows that the inherent voltage regulation of a 25-cycle system is better than that of a 60-cycle system and also that the 25-cycle system is a trifle more efficient. For transmission distances of less than a few miles neither of these factors is of much consequence one way or the other. Alternating current at 25 cycles is not particularly well adapted for electric lighting because arc lamps do not operate well on it and, under some conditions, with certain generator waves, a flickering due to 25-cycle current alternations is visible in incandescent lamps. With frequencies lower than 25 the flickering is quite perceptible, while with 60 cycles no flickering is noticeable. However, some large lighting systems are successfully operated at 25 cycles. The advent of metallic filament lamps of high candle-power renders the matter of operation of multiple arc lamps of little importance and series arc lamps are now usually operated on direct current.

Several years ago a frequency of 25 cycles was often considered necessary for the operation of rotary converters but modern converters operate as well on 60 cycles as on 25.

It is often wise for an isolated plant to adopt the frequency of the local central station so that, in emergencies, energy or apparatus can be interchanged. Transformers and most other apparatus, except very slow speed motors, is as cheap or cheaper for 60 cycles as for 25 and the delivery on 60-cycle apparatus is better. A great proportion, probably over 85 per cent., of the equipment sold in this country is for 60 cycles and it is probable that the average isolated plant, central station or industrial plant which supplies electricity for light or power or for both should adopt a frequency of 60 cycles. However, where the power load is important and very slow speed motors must be used 25 cycles is adopted as it is not feasible to economically build 60-cycle motors for very slow speeds. For example, steel mills and cement plants often adopt 25 cycles.

241. Selection of a Voltage for a Distribution System.—The standard voltages for which American manufacturers build electrical apparatus are 110, 220, 440, 550, 1,100, 2,200 and higher ones, the treatment of which is not within the scope of this book. These are nominal voltages and it is seldom that apparatus is operated at exactly any one of them. It may be operated at some one voltage within a range extending from, possibly, 5 per cent. below to 5 per cent. above the nominal voltage.

Incandescent lamps for 220 volts, in the 50- to 60-watt sizes, are 10 to 15 per cent. less efficient and cost more than do corresponding 110-volt lamps. This is an inherent condition due to the relatively great length and smaller diameter of the 220-volt filament and it cannot be corrected. Steinmetz says: "The 220-volt lamp has no right to existence." It follows that a nominal voltage of 110 (an actual voltage of something between 105 and 120 volts) should be used at the terminals of incandescent lamps where feasible. Sometimes (Fig. 128) it is desirable to use 220-volt lamps where the load is largely a 220-volt motor load. In such a case the use of 220-volt lamps may be justified because of the simplicity of the method.

Branches serving incandescent lamps (Fig. 128, *II*) must always be two-wire and should be 110-volt, but the mains, even in residence wiring, are often, and profitably, three-wire because of the economy in copper of the three-wire system.

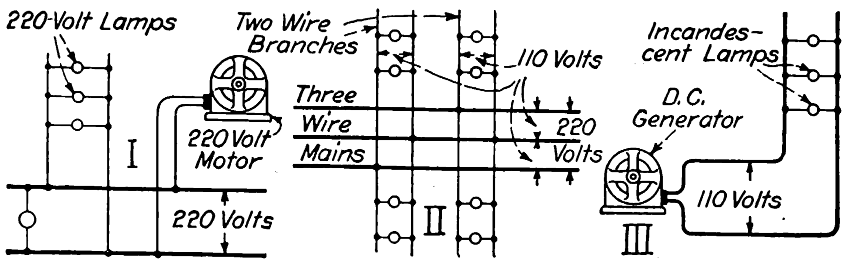


FIG. 128.—Methods of connection.

For incandescent lighting alone, in a town, industrial plant or building, for distribution distances not exceeding about 1,000 ft. a two-wire, direct-current circuit (Fig. 128, *III*) with a nominal voltage of 110 can be used with fair satisfaction. But a three-wire circuit having 220 volts across the outside wires will usually cost

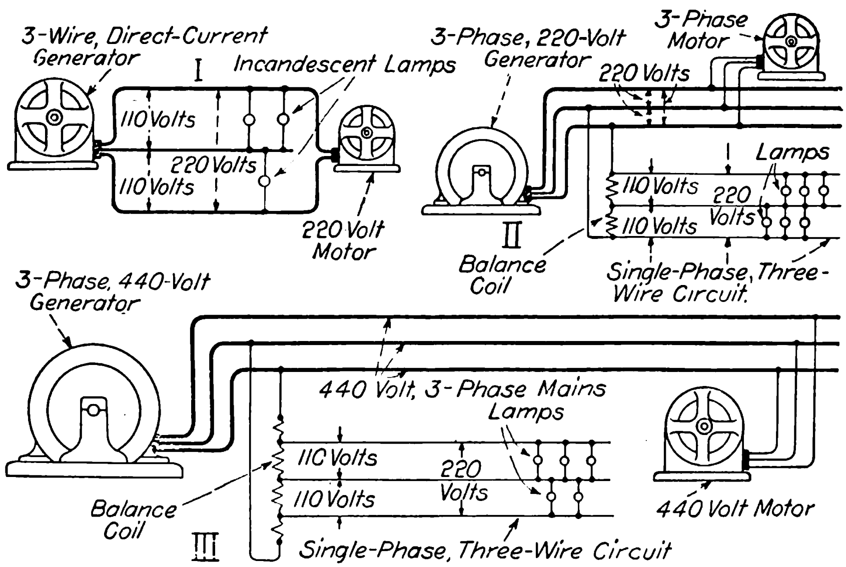


FIG. 129.—Distribution circuits.

less to install and it can be used with fair economy for distances up to possibly a mile. If the load is almost entirely lighting or adjustable speed motors, the distribution (Fig. 129, *I*) should be direct-current 110–220 volt, three-wire, and motors should be operated at 220 volts. But if there is a considerable constant-speed motor load, a 220-volt, three-phase distribution (Fig. 129, *II*) should, probably, be used. The motors can be operated three-

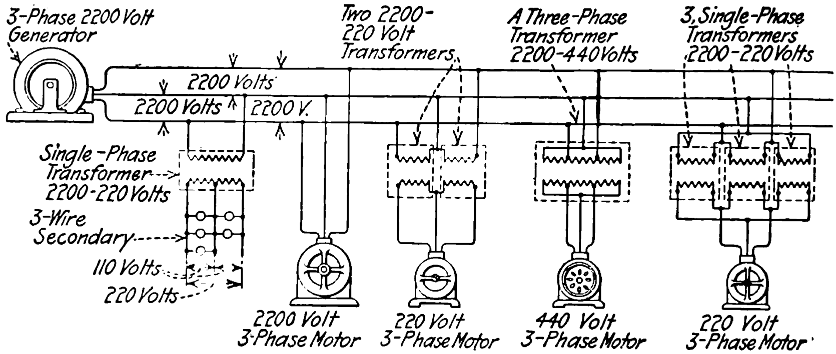
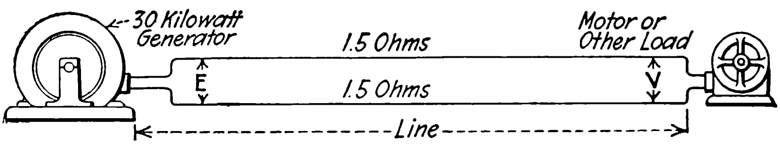


FIG. 130.—A 2200-volt distribution.

phase, and then three-wire, single-phase, 110–220-volt lighting circuits can be arranged from one or all of the phases with balance coils. (See Fig. 129, *II*.)



Note: This table is strictly correct for direct-current and is very nearly correct for alternating-current

30 Kilowatts Generated at E Volts
(Timbie's Elements of Electricity)

Volts E	Amperes I	Line Drop in Volts R=3 Ohms IR	Line Loss in Watts I^2R	Volts Left for Motor V	Watts Transmitted to Motor	Efficiency of Line Per Cent
100	300	900	Impossible Case		——	——
200	150	450	Impossible Case		——	——
300	100	300	30,000	0	0	0
400	75	225	16,875	175	13.125	43.8
500	60	180	10,800	320	19.200	63.3
600	50	150	7,500	450	22.500	75.
800	37.5	112.5	4,219	687.5	25.780	86.
1000	30	90	2,700	910	27.300	91.
1200	25	75	1,875	1,125	28.125	93.8
1500	20	60	1,200	1,440	28.800	96.
2000	15	45	675	1,955	29.325	97.8
3000	10	30	300	2.970	29.700	99.
5000	6	18	108	4.982	29.964	99.8
10,000	3	9	27	9.991	29.973	99.9

FIG. 131.—Illustrating relation of voltage to efficiency of transmission.

Either a 440- or a 550-volt, three-phase, distribution using (Fig. 129, *III*) 440- or 550-volt motors might profitably be used instead of the 220-volt and a saving of about three-fourths the copper would result. Balance coils could be used to provide 110–220-volt, three-wire, lighting circuits. However, a voltage exceeding 300 is quite apt to kill a man that crosses it, while persons are very seldom killed on the voltages lower than 300. So, as a rule, 440 volts or greater should not be installed in any plant where the electrical apparatus cannot have expert supervision. Yet 440 or 550 volts is low enough that motors can be conveniently operated at those pressures and in practice the insulation used on

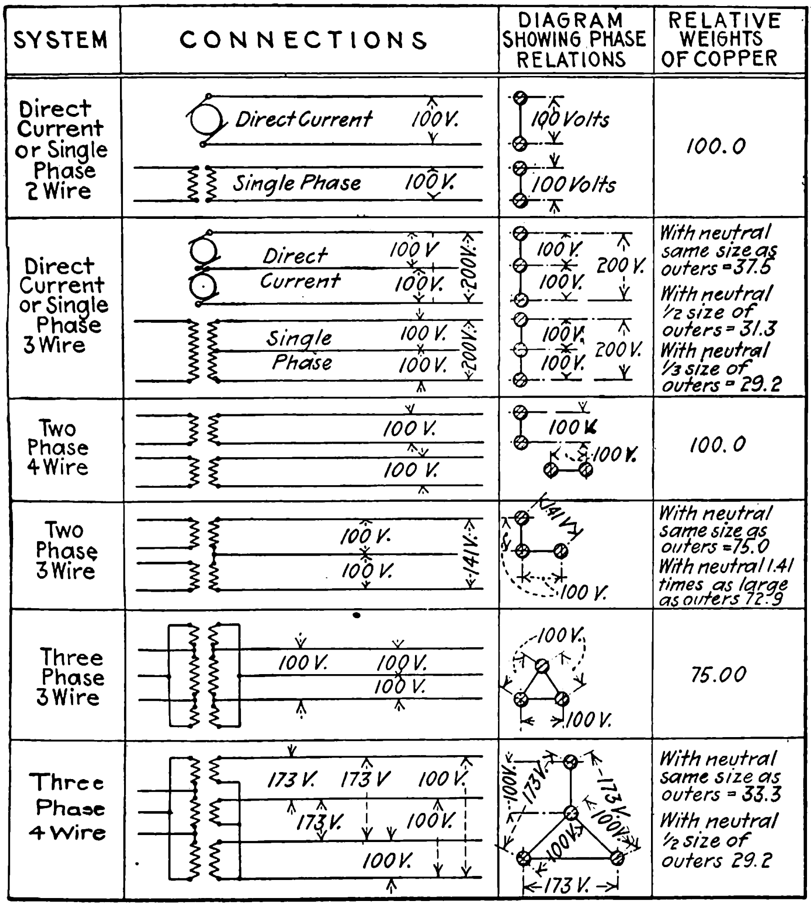


FIG. 132.—Copper economies of different distribution systems.

them is the same as for 220-volt machines. Voltages of 440 or 550 find their widest applications in industrial plants and are seldom used in central-station distributions. Direct-current voltages of 400 to 550 are now seldom used except in street railway work.

A voltage of 1,000 is practically never used in commercial work in this country except for railways.

For central stations or industrial plants distributing to distances up to a few miles from the station, a nominal alternating current voltage of 2,200 is often adopted. Higher voltages, the treatment of which is not within the scope of this book, are also frequently used. (See Fig. 130.) The generators are three-phase in modern installations and each or one of the phases is used for single-phase lighting. Power service is supplied by all three phases. Transformers stepping down from 2,200, single-phase, to 110 volts single-phase or to 110-220 volts, single-phase, three-wire, are used for lighting. Three-phase transformers, stepping from 2,200 to 220, 440 or 550 volts are used for three-phase constant-speed motors or, in special cases, 2,200-volt motors are used. If adjustable-speed motors are required, a motor generator set can be installed which will deliver direct current at 220 volts.

242. **A high distribution voltage is desirable from the standpoint of cost of line conductors** because: *The power lost in a given line, transmitting a given watts load, varies inversely as the square of the impressed voltage.* It follows that: *The weight of a conductor for transmitting a given watts load with a given power loss is inversely proportional to the square of the voltage.* If the voltage is doubled, only one-fourth the copper will be required to transmit the power with the same energy loss in the line. Requirements of safety and utility compel the use of relatively low voltages for ordinary electrical distribution.

Example.—Fig. 131 illustrates the economy of high line voltages by giving values for the transmission of a certain amount of power at different voltages.

243. **Relative Weights of Copper Conductors Required for Different Systems of Distribution.**—The values given in Fig. 132 are true ones assuming for all systems: equal voltages on the lamps or other receivers, equal amounts of power transmitted, equal line losses and balanced circuits. The weight of the conductors of a two-wire, direct-current circuit is assumed, for convenience, to be 100 per cent. For the derivation of the values see *Crocker's Electric Lighting*, Vol. II.

BATTERIES

244. **The Theory of the Electric Battery** (*Standard Handbook*).—When two different metals come in contact with each other there is generated an e.m.f. the value of which depends upon the kind of metal, the character of the contact surfaces, the medium in which the contact takes place, the conditions existing in the medium, etc.

If a circuit made up of various substances and including no source of energy is closed on itself the various contact e.m.fs. will just compensate and the resultant e.m.f. of the circuit will be zero. However, if the circuit includes a source of energy as heat (thermocouple), or chemical reaction, an unbalance of e.m.f. will be produced and a current established, this current tending to reduce the e.m.f. of the source and restore the static balance of the system. **Polarization** is the action of the current in reducing the e.m.f. of the cell and it is overcome by the use of certain substances called depolarizers.

245. The materials consumed in a battery represent a given quantity of energy. Since the internal e.m.f. is a constant, the total electrical energy output of the chemical reaction is directly proportional to the quantity of electricity produced.

246. The e.m.f. of a given cell is the contact e.m.f. and is therefore independent of the dimensions of the battery. The energy and power of the battery, however, are directly affected by the dimensions. For a given battery the energy stands in a direct ratio to the weight of active material. The power for a given number of cells in series (given e.m.f.) is determined by the area of the plates. The e.m.f., of course, depends only on the number of cells in series.

247. The standard Daniell cell has an e.m.f. which is practically 1 volt when delivering a constant current. There are many forms of Daniell cell; each of which is particularly adapted to certain service, but all having very nearly the same e.m.f. (1.07+volts). The e.m.f. is not changed appreciably by the degree of concentration of the solutions; by the temperature; by the resistance; by the purity of the zinc or copper, etc. In short, it makes a very good rough and ready standard.

A very good model is that used by the British Post-office. The jar is made with two compartments; one containing the porous cup immersed in water, in which are placed a copper plate and crystals of copper sulphate. The other compartment contains the zinc plate and the 50 per cent. saturated solution of zinc sulphate. The zinc plate is fastened so as to be just clear of the solution, and a pencil of zinc is placed in the bottom. When in use, the porous cup is placed in the second compartment, thus raising the level of the zinc solution so as to immerse the zinc. Under working conditions the e.m.f. is about 1.07 volt; when new it is about 1.079 volts.

248. The gravity type cell, which is used in telegraph work, is suitable for closed-circuit work, but should not be used for applications where it is liable to stand for a long time on open-circuit.

249. In setting up the gravity cell place the copper electrode (−) in the bottom of the jar and pour in about 3 lb. of copper sulphate crystals. Next place the zinc electrode (+) and fill with water to cover the zinc; to the water add a tablespoonful of sulphuric acid. Cover the electrolyte with a layer of pure mineral oil, which should be free from naphtha or acid and have a flash point above 400 deg. fahr. If the oil is not used the creeping can be stopped by dipping the edge of the jar in hot paraffin. When the cell is thus set up it should be short-circuited for a day or two to form zinc sulphate which will protect the zinc electrode; this preliminary run also reduces the internal resistance. The temperature of the cell should be kept above 70 deg. fahr., since the resistance increases very fast with a decrease in temperature.

The internal resistance of the gravity cell is ordinarily from 2 to 3 ohms. A blue color in the bottom of the cell denotes a good condition, but a brown color shows that the zinc is deteriorating. When renewing the copper sulphate it is best to empty the cell and set it up with a completely new electrolyte. The blue line, which marks the boundary between the copper sulphate and the zinc sulphate, should stand about half way between the electrodes. If it comes too close to the zinc, some of the copper sulphate can be siphoned out or the cell can be short-circuited so as to produce more zinc sulphate. If the blue line goes too low some water and crystals of copper sulphate should be added.

250. **The Fuller cell** is well adapted to telephone work or any intermittent work. It can stand on open-circuit for several months at a time without any appreciable deterioration.

251. **The Fuller cell is set up** as follows: Mix the electrolyte by adding 6 oz. of potassium bichromate and 17 oz. of sulphuric acid to 56 oz. of soft water; pour this mixture into the glass jar. Into the porous cup put one teaspoonful of mercury and two teaspoonfuls of salt; place the cup and zinc electrode in the glass jar and fill to within 2 in. of the top with soft water. Put on the cover, insert the carbon electrode, and the cell is ready for use.

The color of the solution is orange when in working order. The resistance varies from 0.5 to 4 ohms depending upon the condition and dimensions of the porous cup and upon the concentration of the solution.

252. **The Edison-Lalande or Edison cell** is suitable for either open or closed-circuit work. The mechanical construction of this cell is especially good. The positive pole is a plate of compressed oxide of copper, the surfaces of which are reduced to metallic copper to improve the conductivity. This form of plate also acts as a depolarizer. The negative pole is of pure zinc amalgamated throughout by adding mercury when the casting is made. The electrolyte is a solution of caustic soda. The top of the solution is covered with a heavy mineral oil to prevent the solution from evaporating.

These cells have an initial e.m.f. of 0.95 volt, which drops to 0.70 volt when the circuit is closed. The internal resistance is very low, varying from 0.020 to 0.089 ohm, depending upon the type of cell. The Edison Manufacturing Co. have kindly submitted the following data:

Continuous capacity, amp.	1.5	2.5	4.0	6.0	7.0
Max. capacity, amp.	7.49	9.53	15.51	26.68	33.35
Capacity, amp-hr.	100	150	300	300	600
Internal resistance, ohm.	0.089	0.070	0.043	0.025	0.020

253. **The Leclanché cell** is adapted only to intermittent work such as bells, telephones, etc. It is cheap and easy to maintain.

254. **The Leclanché cell is set up** as follows: Put 3 or 4 oz. of salammoniac in the jar; pour about one-third full of water and stir until the salammoniac is all dissolved; place the carbon electrode in the porous cup and pack it around with manganese dioxide and crumbled carbon; then, inserting the porous cup and the zinc electrode into the jar, the cell is ready for use.

Practically the only attendance consists in renewing the evaporated water. The zinc is replaced when worn out. When it becomes necessary to add salammoniac the solution should be thrown out and a new one made. If the porous cell becomes clogged, soaking in warm water will improve it.

The resistance depends upon the dimensions of the electrodes, the state of the porous cup and the condition of the cell. Under proper working conditions and with a carbon-electrode having about 8 sq. in. surface, the resistance will be about 1.5 ohm.

255. **The dry cell** is a very popular form, and does not require any attendance. It is simply thrown away when exhausted. The jar, generally of zinc, forms one electrode. The carbon electrode is suspended in the center of the zinc vessel, care being taken not to allow it to touch the zinc. The zinc is protected by several thicknesses of blotting paper and the chamber filled with a mixture of carbon, manganese dioxide and sawdust (or some absorbent substance), the mixture being saturated with a solution of salammoniac. The top is sealed with wax and the whole cell slipped into a pasteboard box.

Oftentimes the life can be extended slightly by punching a hole in the top and pouring in water.

256. **A storage battery, secondary battery, or accumulator** (*Standard Handbook*) is an electrical device in which chemical action is first caused by the passage of electric current, after which the device is capable of giving off electric current by means of secondary reversed chemical action. Any voltaic couple that is reversible in its action is a storage battery. The process of storing electric energy by the passage of current from an external source, is called *charging* the battery; when the battery is giving off current, it is said to be *discharging*. A storage-battery cell has two elements, or plates, and an electrolyte. The two plates are usually made of the same material, though they may be of two different materials.

257. **The unit of capacity of any storage cell is the ampere-hour** and is generally based on the 8-hr. rate of discharge. Thus a 100 amp-hr. battery will give a continuous discharge of $12\frac{1}{2}$ amp. for 8 hr. Theoretically it should give a discharge of 25 amp. continuously for 4 hr. or 50 amp. for 2 hr. As a matter of fact, however, the ampere-hour capacity decreases with an increase of discharge rate.

258. **The capacity of a cell** is proportional to the exposed area of the plates to which the electrolyte has access, and depends on the quantity of the active material on these plates.

259. **The capacity of batteries** depends, therefore, on the size and number of plates in parallel, their character, the rate of discharge and also on the temperature. Taking the 8-hr. rate of discharge and temperature of 60 deg. fahr. as standard, the capacities which obtain in American practice are from 40 to 60 amp-hr. per

square foot of *positive* plate surface (= no. of positive plates in parallel × length × breadth × 2).

260. The voltage of any storage cell depends only on the character of the electrodes, the electrolyte density and the condition of the cell, and is independent of the size of the cell.

261. The voltage of the lead sulphuric-acid cell, when being charged is from 2 to 2.5 volts, while on discharge it varies from 2.0 down to 1.7 volts. (See Fig. 133.)

262. High battery voltages are obtained by joining the required number of cells in series. Thus for 100-volt circuits, approximately 50 cells in series are required.

263. The lead storage battery of commerce is made up with electrodes having their active materials of lead peroxide and sponge lead as the positive and negative electrodes respectively, immersed in a dilute solution of sulphuric acid.

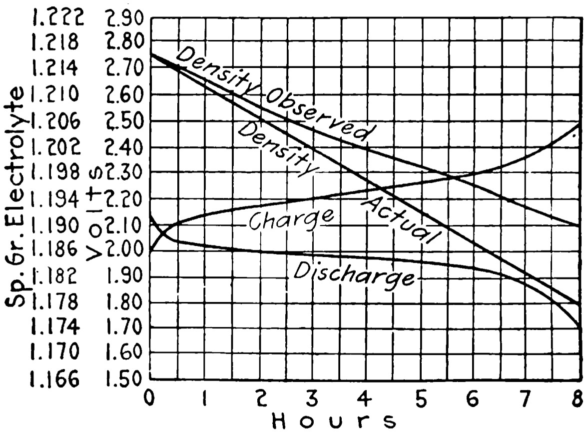


FIG. 133.—Characteristic curves of the lead storage battery.

264. There are two general types of plates, for lead storage batteries, namely, the Planté and the pasted, and numerous variations of each of these types. In the Planté type of plate the active materials are formed out of and on the lead surface of the plate itself. Pasted plates are made up by applying the active material by some mechanical process, such as mixing in a paste and spreading on the surface of a grid or plate. The pasted active material has some substance added to it to cause it to set or harden.

265. The essential differences between the Planté and the pasted plates are: For a given output Planté plates are more costly, more bulky and heavier than the equivalent pasted plates. They also are more easily injured by impurities in the electrolyte. They are, however, capable of standing more rapid charging and discharging rates without injury. They are less liable to lose their active material and be injured by the accumulation of sediment in the bottom of the cells. They are more durable, and have longer life, and in general they are a more dependable type of plate than the pasted. The pasted, however, for a given output, are cheap, light and occupy a smaller space. They also are not so badly damaged by impurities in the electrolyte. The efficiency of pasted batteries is lower at high current rates than the Planté type.

Each of these types has its particular place in the art. For work such as motor-car propulsion the pasted battery is better adapted than the Planté, owing to its lightness and low cost. For power-station work the Planté battery is more suitable. There are certain classes of work for which each type is fairly well suited, such as train-lighting, railway-signal and telephone work. In every case all the conditions, commercial as well as technical, must be considered before definitely fixing on the type which is most suitable to meet the requirements.

266. **The electrolyte for lead storage batteries** must be of dilute sulphuric acid made of sulphur and not from pyrites. Pyrite contains iron, and acid made from it must necessarily contain some iron. The presence of this metal in the electrolyte is injurious to the battery plates. An electrolyte need not necessarily be chemically pure, but it must be free from chlorine, nitrates, copper, mercury, arsenic, acetic acid, iron and platinum. It should be tested by a competent chemist or supplied by some reliable company guaranteeing its character and freedom from injurious impurities. It is usually purchased of the desired specific gravity, ready for use, but in cases where it is desirable to save freight, or for other reasons, to make the electrolyte at the point of installation, either distilled water (usually purchasable from a local ice factory) or rain water must be used to dilute the acid. *The acid should be poured into the water—never pour water into acid.* A chemical combination between the water and acid takes place, generating heat, and the solution, which becomes hot, must be allowed to cool before using and before attempting to determine its specific gravity, as the specific gravity changes markedly with the temperature of the liquid. The specific gravity required depends on the character of the cell, its rate of discharge, and its ampere hour capacity. The density is usually specified by the makers of the battery. Experience shows that density should be as low as possible for satisfactory operation, but should not be less than 1.100.

267. **Rules for operation of lead storage batteries** (*Standard Handbook*).

1. Be sure the ELECTROLYTE is free from injurious IMPURITIES.
2. Keep ELECTROLYTE well above tops of PLATES.
3. Maintain the SPECIFIC GRAVITY of the electrolyte at the density specified by the manufacturers of the battery.
4. Do not let the DENSITY of the electrolyte in any cell differ from the standand density more than 0.005. Thus a cell having normal density of 1.200 should register above 1.205 and below 1.195 when fully charged. Test each cell with hydrometer once a week at least.
5. Keep CELLS CLEANED out and remove sediment when it has deposited metal near the lower edges of the plates.
6. Be sure SEPARATORS are all in place and in good order.
7. Note any evidences of TANK LEAKAGE and correct at once.
8. Maintain INSULATION of cells from ground and from each other.
9. Begin CHARGE IMMEDIATELY after the end of discharge or as soon thereafter as practicable.

10. DO NOT CONTINUE CHARGE AFTER the negative plates begin to give off gas, except the occasional "boiling" to be mentioned later.

11. NEVER LET CHARGING CURRENT FALL BELOW the 8-hr. rate except toward the end of charge, and

12. STOP DISCHARGE WHEN the battery potential falls to 1.75 volts per cell with the normal current; 1.70 volts per cell discharging at the 4-hr. or 1.60 volts per cell discharging at the 1-hr. rate.

13. Watch the COLORS OF THE PLATES AND IF they begin to grow lighter treat at once for removal of sulphate.

14. Give the battery a PROLONGED OVER-CHARGE ABOUT ONCE A MONTH. This over-charge should continue at about 60 per cent. of the 8-hr. rate until free gassing of the negative plates has continued for 1 hr.

15. Never let the BATTERY TEMPERATURE rise above 110 deg. fahr. and, if possible, keep below 100 deg. fahr.

16. TEST EACH CELL ONCE A WEEK WITH A CADMIUM ELECTRODE and a low-reading voltmeter to determine the condition of the negative plates.

17. TEST the cells OCCASIONALLY FOR DROP ON DISCHARGE; excessive drop indicates the presence of sulphate, and if the drop increases the amount of sulphation is also increasing.

18. WHEN ONE OF A SERIES OF CELLS IS SULPHATED, charge it as usual in series with the others; on discharge cut the cell out, connecting the opened circuit by a heavy wire joining the two cells adjacent to the sulphated one. Be careful not to short-circuit the latter cell. When discharge is ended, remove connector and switch in the sulphated cell so that it again receives charge. Repeat this process until the cell has had its sulphate fully reduced. A double-pole, double-throw switch is conveniently used to switch the cell and the connector alternately into and out of the circuit. With it the cell may be allowed to discharge a short time before cutting out, which improves the treatment.

19. CELLS WHICH STAND A CONSIDERABLE TIME UNUSED—say as long as 45 days—should work in low density electrolyte not exceeding 1.210 specific gravity and be over-charged as directed in 18. It is better to give them a slight discharge and charge about once a week if practicable.

20. CELLS WHICH ARE TO BE IDLE TWO MONTHS OR MORE should be taken out of commission by first fully charging and then discharging for two hours at the normal rate. Then draw off the electrolyte and fill the cells with pure water, preferably distilled. Begin discharge again at the normal rate. The cells will have to be practically short-circuited to produce this discharge in the water. When the discharge has been carried to a point at which the voltage is about 0.5 volt per cell, the water is poured out of the jars and the plates washed thoroughly by putting a hose in the jar and flowing the water over the plates. Allow the water which fills the jars at the end of the washing to remain 24 hr.; then pour out and allow the electrodes to dry. When the battery is to be used again pour in electrolyte and give a prolonged over-charge.

268. Installation of Lead Storage Batteries.—It is necessary that these cells be insulated from each other. For small glass cells make a shallow wooden box, an inch deep, having a length and breadth greater than the corresponding cell dimensions. Set this box on four glass insulators and fill it with clean sand. On this sand the cell is set. The sand affords a uniform bedding and support for the glass cell and catches and absorbs moisture which may drip down from the sides of the cell.

With lead-lined, wooden tanks, the cells themselves are set directly on glass insulators, there being four insulators under ordinary size cells and six where cells are so long as to require middle supports. It is customary now to set large cells with double insulation, that is, the cells are set on insulators, these insulators rest on a wooden framework, and the wooden framework rests in turn on a set of insulators.

The insulators used are generally of a special form, and are made of both glass and porcelain. Many years of experience have indicated that porcelain is not a proper material, as it is liable to crack and expose its porous mass so that any electrolyte spray is absorbed into it when it ceases to be an insulator and becomes a fairly good conductor.

269. The Edison Storage Battery (*data furnished by the Edison Storage Battery Co.*) is the result of an effort to avoid many of the disadvantages of the lead sulphuric-acid combination and is a radical departure therefrom in every detail of construction. The positive plate consists of hollow, perforated, sheet-steel tubes filled with alternate layers of nickel hydrate and metallic nickel. The hydrate is the active material; and the metal, which is made in the form of microscopically thin flakes, is added to provide good conductivity between the walls of the tube and the remotest active material. The negative plate is made up of perforated, flat, sheet steel boxes or pockets loaded with iron oxide and a small amount of mercury oxide, the latter also for the sake of conductivity. The grids which support these tubes and pockets are punchings of sheet steel. The cell terminals and container are likewise of steel and all metallic parts are heavily nickel plated. The electrolyte is a 21 per cent. solution of caustic potash containing also a small amount of lithium hydrate. All separators and insulating parts are made of rubber.

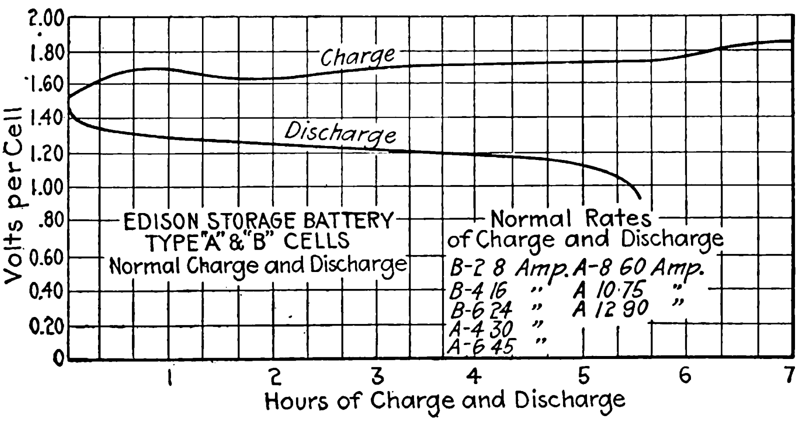


FIG. 134.—Charge and discharge curves of the Edison battery.

The current used in charging causes an oxidation of the positive plate and a reduction of the negative, and these operations on discharge are reversed. The electrolyte acts merely as a medium and does not enter into combination with any of the active material as it does in the acid battery. Its specific gravity remains practically constant throughout the complete cycle of charge and discharge. The charge and discharge curves are shown in Fig. 134.

The chief characteristics of the battery are ruggedness, due to its solid, steel construction; low weight, because of its stronger and lighter supporting metal; long life, because of the complete reversibility of the chemical reactions and the absence of shedding active material; and low cost of maintenance, due to its freedom from the diseases, such as sulphation, so commonly met with in storage battery practice, and from the necessity of internal cleaning and plate renewals. The arguments against it are high first cost and high internal resistance. The importance of these must, of course, be weighed with the advantages and the resultant considered in each proposed installation. The battery has attained its chief prominence in vehicle propulsion, but its characteristics also recommend it for many other purposes.

The attention required by this battery is of the simplest character. It is chiefly important that the electrolyte be replenished from time to time with distilled water so that the plates will be entirely immersed, and that the outside of the cells be kept clean and dry, for if this is not done leakage of current will occur with consequent corrosion of containers by electrolysis.

270. Efficiency of the Edison Storage Battery (*Standard Handbook*).—The Edison battery is not as efficient from the energy standpoint as are some of the other types, 60 per cent. being the efficiency usually attained in practice. The advantages of the cell lie largely in its mechanical construction and its freedom from deterioration due to rough usage. It is compact and extremely light and strong.

271. Directions for Charging Small Storage Batteries.—Alternating current cannot be used directly. When this only is

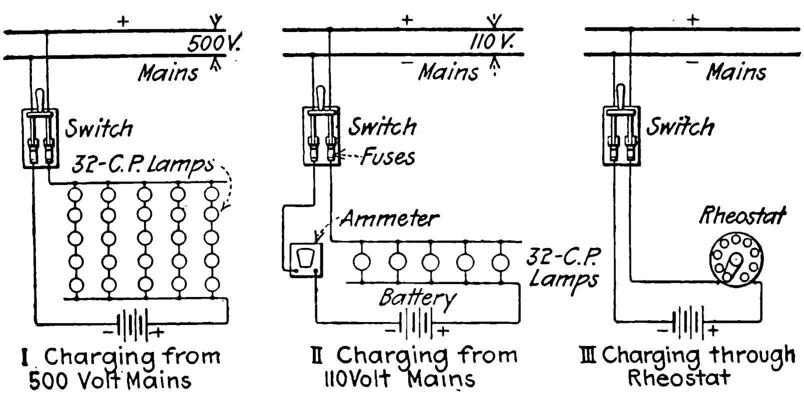


FIG. 135.—Connections for charging storage batteries.

available it must be converted to direct current by means of motor-generators, rotary converters, or mercury-vapor converters. Connections are shown in Fig. 135 for charging small storage batteries from direct-current mains. An ammeter in the circuit is convenient but not absolutely necessary and lamps or a rheostat (Fig. 135, *III*) are used to vary the current. A 16 c-p., 110-volt, carbon-filament lamp has about 220 ohms resistance and will carry 0.5 ampere; a similar lamp of 32 c-p. rating has about 110 ohms resistance and will carry 1 amp. Therefore, the charging current from 110-volt mains (Fig. 135, *II*) can be limited to, say, 5 amp. by connecting five 32 c-p. lamps in parallel, or from 500-

volt mains (Fig. 135, *I*) by connecting in parallel five series of lamps, each series containing five 32 c-p. lamps. In both cases, two 16 c-p. lamps in parallel can be used in place of each 32 c-p. lamp. Charging current must always flow through the battery from the positive pole to the negative pole. See directions elsewhere in this section for determining polarity.

CIRCUIT CALCULATIONS

(The material on Circuit Calculation Considerations that follows was prepared by the compiler of this book and was first printed in *Electrical Review*, March 8, 1913, under the pen name of Anthony Gorman.)

272. **There are three factors that should be considered** when determining the sizes of wires for the distribution of electricity. A wire should be of such size that: (1) It will carry the electricity to the point where it will be used without an excessive drop or loss of voltage; (2) the current will not heat it to a temperature that would spoil the insulation or cause a fire (see Table 170 of *safe carrying capacities*); and (3) the cost of energy lost—the I^2R loss—due to the current overcoming the resistance will not be excessive. A conductor may satisfy one of the three conditions and may not satisfy the other two.

273. **The Voltage Drop Allowable in Lamp Circuits.**—For a 110-volt incandescent lamp load the conductors should be of such size that the pressure at the lamps can never vary more than 3 volts. Sometimes 4 and even 5 volts variation is allowed on 110-volt lamp circuits. This is not good practice. Expressed in percentages, a 1 per cent. to a 3 per cent. drop represents good practice; a $4\frac{1}{2}$ per cent. drop is the upper limit. These are percentages of the receiver or normal lamp voltage. If the values above suggested are exceeded the life of the lamps may be shortened or they may burn dimly when the circuits are loaded.

274. **The Voltage Drop Allowable in Motor Circuits.**—A drop of 5 per cent. is very good practice and a 10 per cent. drop is often permitted. If motors are on the same circuits with lamps a 3 per cent. drop should not be exceeded. The question of voltage drop in conductors is closely associated with that of conductor economy. In important work particularly where the cost of energy is high, the cost of the energy lost in a conductor as well as the volts lost in it should be considered.

275. **Per cent. line drop or voltage loss** may be figured as either a percentage of the voltage required at the receiver or as a percentage of the voltage impressed by the generator or other energy source on the line. For instance, in Fig. 136, the voltage impressed on the receivers—lamps and motor—is 220. The line loss is 11 volts, hence, the pressure impressed on the line $= 220 + 11 = 231$ volts. The voltage loss as a percentage of the voltage at the receiver $= \frac{11}{220} = 0.05 = 5$ per cent. The voltage loss as a percentage of the voltage impressed on the line is $\frac{11}{231} = 0.048 = 4.8$

per cent. In practical work the percentage loss or drop is usually taken as a percentage of the voltage required at the receivers because this is the most convenient and direct method. In this book the term "percentage drop" refers to a percentage of the voltage required at the receivers unless otherwise noted.

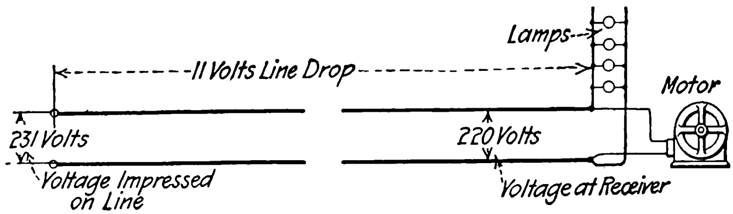


FIG. 136.—Illustrating percentage line drop.

276. To ascertain the volts drop as a percentage of the volts impressed on the line, use the following formula:

$$V = \frac{E \times p}{100 - p} \qquad \text{(volts)}$$

wherein V = volts drop or loss in line, p = percentage drop of the voltage impressed on the line and E = voltage at the receiver.

Example.—What will be the voltage drop in a circuit where 110 volts is to be impressed on the receivers—lamps, motors or other equipment—and the allowable drop is 4 per cent. of the voltage impressed on the circuit.

Solution.—Substitute in the above formula:

$$V = \frac{E \times p}{100 - p} = \frac{110 \times 4}{100 - 4} = \frac{440}{96} = 4.58 \textit{ volts.}$$

Table **277** gives actual line drops for different percentages of voltages impressed on the line.

277. Volts Lost at Different Per cent. (of Voltage Impressed On Circuit) Drop (*Standard Handbook*)

Per cent. drop	Voltage impressed on receivers		Per cent. drop	Voltage impressed on receivers	
	110	220		110	220
0.5	0.552	1.10	8	9.56	19.13
1	1.11	2.22	9	10.87	21.75
1.5	1.67	3.35	10	12.22	24.44
2	2.24	4.48	11	13.59	27.19
2.5	2.82	5.64	12	14.99	29.99
3	3.40	6.80	13	16.43	32.87
4	4.58	9.16	14	17.90	35.81
5	5.78	11.57	15	19.41	38.82
6	7.02	14.04	20	27.50	55.00
7	8.27	16.55	25	36.66	73.33

278. Distribution of Drop in Wiring Systems.—It is necessary in designing circuits to apportion the total allowable drop between the components of a wiring system, the feeders, mains and branches. The Table **279** indicates good practice for lighting circuits at 110 volts.

279. Distribution of Drop in 110-volt Lighting Circuits

Part of circuit	Proportion	4 volts total drop		3 volts total drop	
		Actual drop	Per cent. drop	Actual drop	Per cent. drop
Branches........	1 volt.......	1 volt..	0.91	1 volt	0.91
Mains..........	⅓ remainder.	1 volt..	0.91	⅔ volt	0.60
Feeders.........	⅔ remainder.	2 volts	1.82	1⅓ volt	1.21
Total...........	....	4 volts	3.64	3 volts	2.72

In incandescent lamp electric lighting most of the drop should be confined to the feeders so that all of the lamps on mains and branches served by the same feeder will burn at about the same brilliancy. If most of the drop is in the mains and branches, lamps located close together but served by different mains may burn at decidedly different brilliancies and may attract attention and cause comment. Fig. 137 illustrates drop distribution.

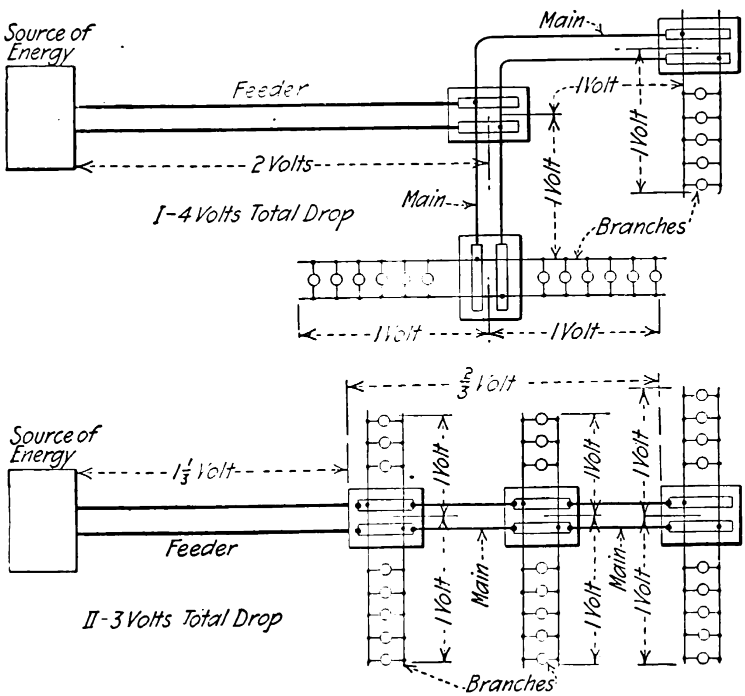


FIG. 137.—Distribution of drop in lighting circuits.

With motor circuits it is desirable to confine most of the drop to the mains so that a variation in the load on one motor or group of motors will affect the speeds of the others as little as possible. If most of the drop is in the feeder, a heavy overload on one motor might cause a very appreciable drop in the feeder and the voltages impressed on all the motors, served by the feeder, would be correspondingly decreased. The speeds of all of the motors served by the feeder would be lowered accordingly. In general, on low-voltage motor circuits, 1 volt drop can be allowed in the branches, two-thirds of the remaining allowance in the mains and one-third of the remaining allowance in the feeder. See Fig. 138 which

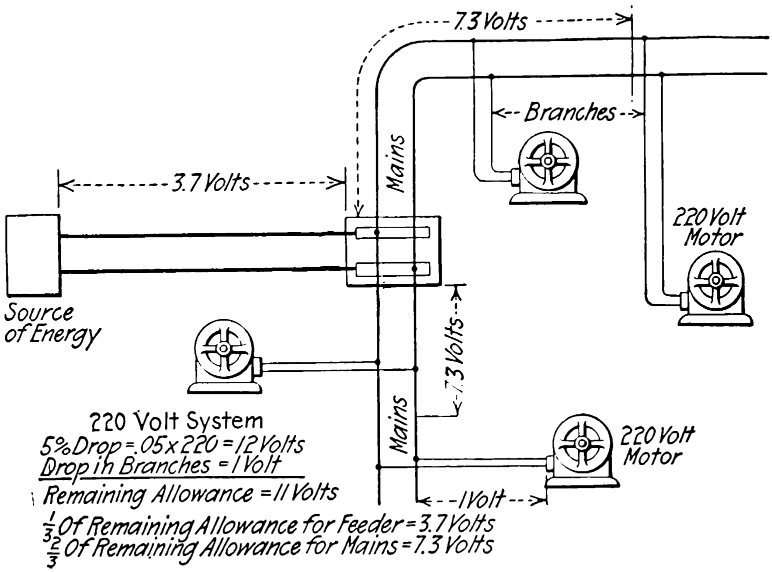


FIG. 138.—Distribution of drop in feeder-and-main 220-volt motor circuit.

shows the drop distribution for a system wherein the total allowable drop is 5 per cent.

Where a wiring system is not laid out in accordance with a feeder and main system, the drop must be apportioned among the conductors in accordance with the judgment of the designer, but

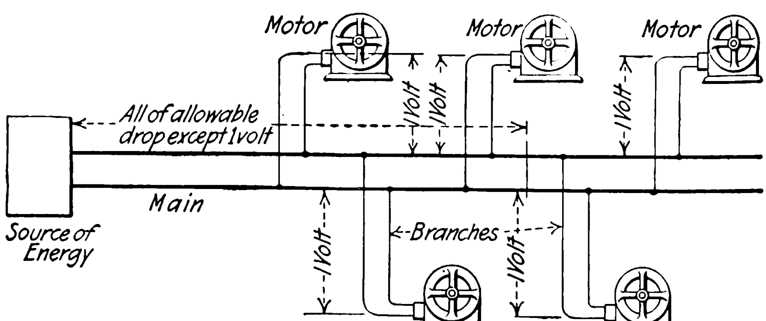


FIG. 139.—Distribution of drop in main-and-branch motor circuit.

the principles outlined above should be considered. Where a motor circuit consists only of a main and branches (Fig. 139) one method is to allot 1 volt drop to the branches and the balance of the permissible drop to the main. Where motor branches are not very long the drop in them (because they must be large enough to carry full-load current without overheating) is frequently not far from 1 volt with full-load current. It may, in practice, be often assumed that it is 1 volt. Motor branches must be large enough to safely carry a current 25 per cent. greater than the full-load current because of *N.E.C.* regulations.

280. Safe current carrying capacity should always be considered when designing circuits. A wire may be large enough to carry a given current a given distance without undue drop, but yet so small that the current will overheat it. After a conductor size has been selected with reference to drop, Table 170 of safe current-carrying capacities should be consulted. If the wire first selected is not large enough to safely carry the current one that is large enough should be used. The matter of safe current-carrying capacity must be watched very closely in circuits that are short.

281. The resistance of a circular mill-foot of commercial copper, that is, a wire 1 ft. long and having an area of one cir. mil, at a temperature of 75 deg. fahr., is usually given as from 10.6 to 10.8 ohms. For wiring calculations 11 ohms is sufficiently accurate. (*Standard Handbook.*) In wiring calculations it is useless to exercise refinement, especially as the purity of the copper is unknown, the circuit lengths are often not measurable to within many per cent. of accuracy, and the difference between the successive sizes of wire available on the market, that is, the even numbered sizes, is about 60 per cent. There are other undeterminate factors.

282. How to Proceed in Determining Wire Sizes for Circuits.—Nearly every wiring problem involves the finding of the size wire that will carry a given current a given distance with a given drop in volts. The steps to be taken in finding the wire size in any such problem are as follows.

A. Determine the load in amperes that will come on the circuit. This ampere load value will be used in taking the wire size from a table or will be substituted for the letter *I* in a formula. See 284.

B. Find the distance to the load center of the circuit. See 285. This distance will be the actual length if the load is concentrated at the end or it will be the distance to the load center if the load is distributed. When found, this distance is used as the length of the circuit and is substituted for the letter *L* in a formula.

C. Decide what voltage drop or volts drop is allowable. See 273 and 274.

D. Determine the wire size that will give the voltage drop decided on in *C* by using one of the formulas that follow, using the values for distance and volts drop of *B* and *C*.

E. Check the wire size determined in *D* to see that it is large enough to safely carry the current by Table 170. See 280. If the size first selected is not large enough, one that is big enough to safely carry the current must be used.

F. Where economy of operation is a factor, check the size conductor as determined by *D* and *E* to be sure that the cost of the energy wasted in it in overcoming its resistance will not be excessive. See 286 and 287.

283. **In determining circuit lengths from drawings or blue prints** a long piece of tough paper divided (see Fig. 140) into the same measure as the drawing can be effectively used in scaling distances. Always allow for rises or drops for wall outlets. The

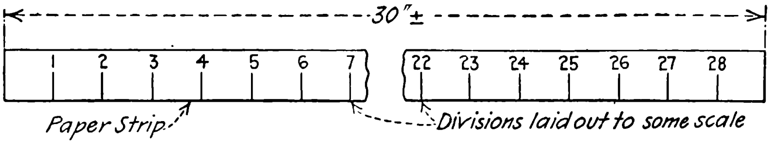


FIG. 140.—Paper scale for measuring circuit lengths.

rotometer (Fig. 141), is a convenient tool for scaling distances. The little wheel is run over the course of the circuit. The pointer indicates feet direct for drawings of certain scales. For other scales the dial reading must be multiplied by a constant to obtain actual lengths. A rotometer costs $2.00 or $3.00.

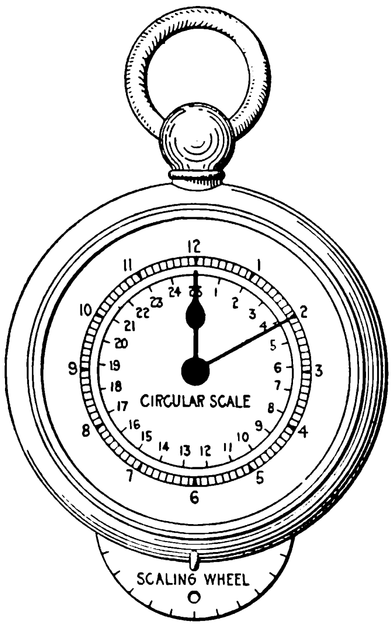


FIG. 141.—A rotometer.

284. **Determination of Loads That Will Come on Conductors.**—It is necessary to determine the load in amperes that will come on each conductor in a wiring system for figuring the wire sizes and so that one may be sure that the wire will safely carry the current. Where drawings are available note the ampere loads on the sheet in pencil as shown in Fig. 142. The figures opposite the receivers indicate the currents they take. The total load on each branch main and feeder is indicated within a circle. Motor branch circuits must be large enough to safely carry 25 per cent. more

than full-load current. It is convenient to note a current 25 per cent. greater than full-load current in a square near each motor branch, as in Fig. 142, so that the wire for the branch can be checked for carrying capacity. The numbers of amperes required by lamps, motors and other devices are given in tables elsewhere in this book.

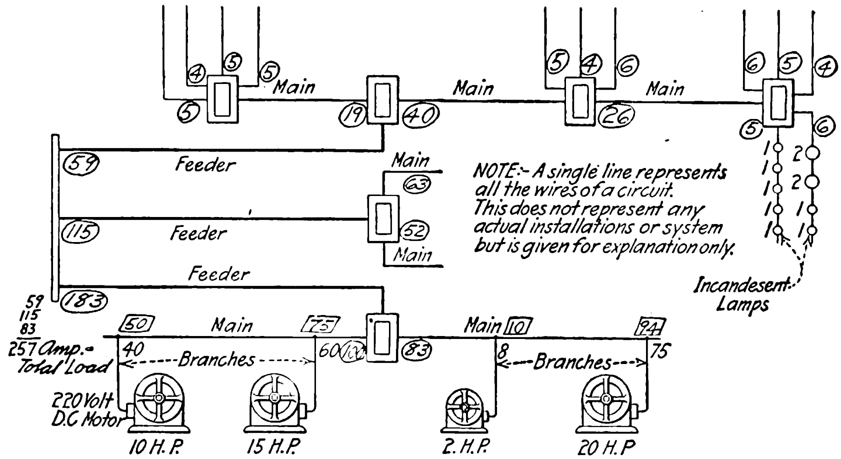


FIG. 142.—Determination of loads on conductors.

285. The location of the load center of a circuit is that point at which the total load can be assumed to be concentrated when making wiring calculations. The letter L in the wiring formulas in this book stands for the distance to the load center. The load center of a group of receivers, symmetrically arranged (Fig. 143)

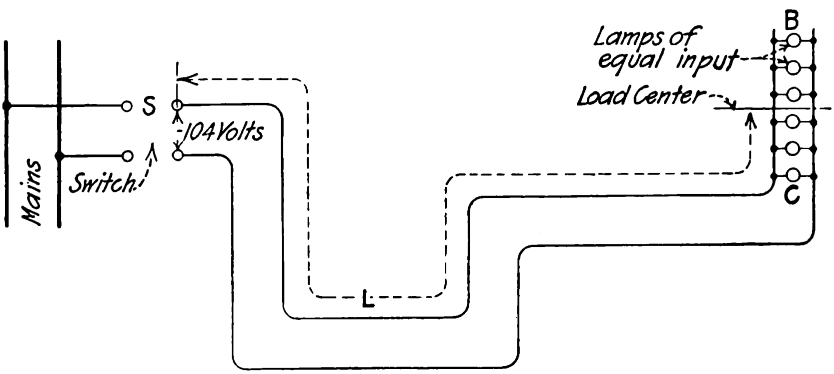


FIG. 143.—Illustrating location of load center.

and all of the same input will be in the middle of the group. Always take the distance along the circuit as L, Fig. 143.

The distance to the load center (Fig. 143) denoted by L would be used for L in the wiring formula cir. mils $= 22IL \div V$. The drop of voltage, V in the formula, would be the drop from the switch S to the last lamp, B. The current, I in the formula, would be the total current taken by all 6 lamps. If the conductors were calculated for a drop of 5 volts, the drop between S and B would be 5 volts. If 110 volts was impressed at S, the voltage at B would be $110-5=105$ volts. The other 5 lamps in the group

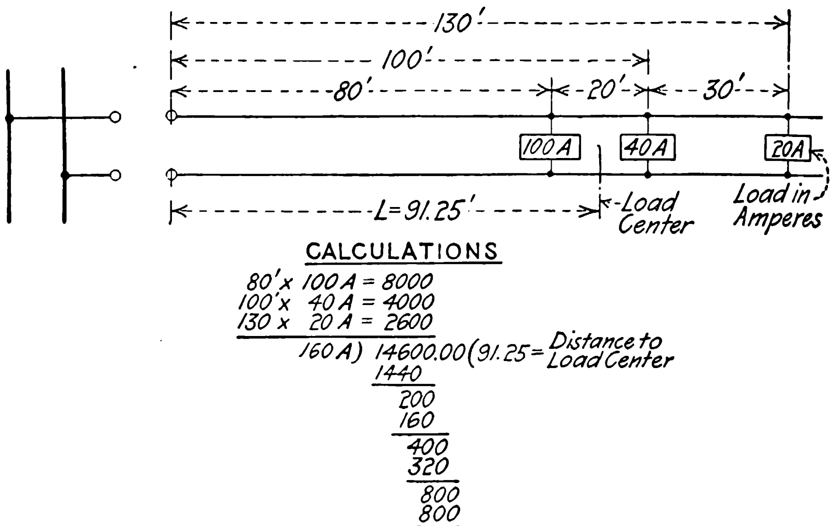


FIG. 144.—Method of computing location of load center.

would receive something greater than 105 volts, the pressure increasing slightly along the circuit toward the switch. The lamp C would receive the highest pressure of all.

The load center of a group of receivers unsymmetrically located or of unequal capacities or of both is found by: (first) multiplying

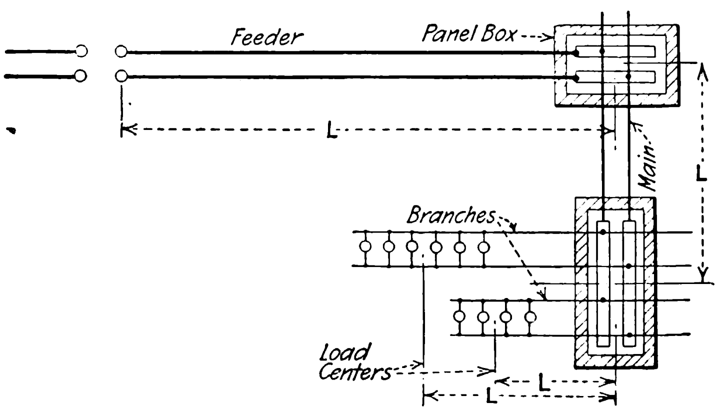


FIG. 145.—Illustrating the distance "L" to a load center.

the normal ampere capacity of each receiver by its distance from the starting point of the circuit, (second) adding together all the products thus found, and (third) dividing this sum by the total current of the circuit. See solution of example in Fig. 144.

Where no energy is taken from a circuit except at its end, the distance L for the formula is, as shown in Fig. 145, the entire length of the circuit. Always measure L along the circuit. In practice the load center is usually determined by inspection because great accuracy is not essential. A beginner should calculate a few examples until he is familiar with the principles involved.

286. **For calculating direct-current two-wire circuits** the following formula is used: (The material on Wiring Calculations that follows was prepared by the compiler of this book and was first printed in *Electrical Review*, June 14, 1913, under the pen name of N. V. Dunne.)

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein V = drop in volts in the circuit, I = the current in amperes in the circuit, L = the length one way or single distance of the circuit in feet and *cir. mils* is the area of the conductor in circular mils. Other forms of the formula are:

$$V = \frac{22 \times I \times L}{\text{cir. mils}} \qquad I = \frac{\text{cir. mils} \times V}{22 \times L} \qquad L = \frac{\text{cir. mils} \times V}{22 \times I}$$

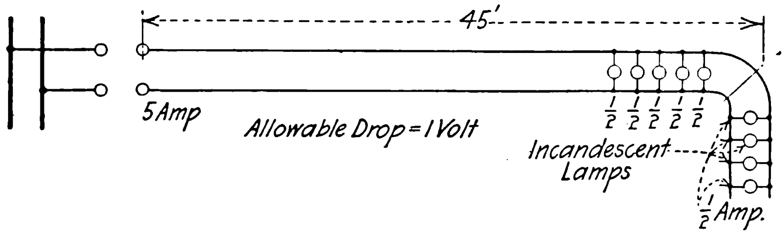


FIG. 146.—An example in wire size determination.

Example.—What size wire should be used for the branch circuit of Fig. 146? Allowable drop to the furthest lamp is 1 volt. Load consists of 10 incandescent lamps each taking ½ amp. Distance from starting point of circuit to load center is 45 ft.

Solution.—Substitute in the formula:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 5 \times 45}{1} = 4{,}950 \text{ cir. mils.}$$

Referring to Table 170, the standard size wire next larger than 4,950 cir. mils is No. 12 which has an area of 6,530 cir. mils. No. 12 wire, rubber insulated (for concealed work), safely carries, as given in the National Code column of the table, 20 amp., hence it will readily carry the 5 amp. of the circuit in question.

Example.—What size wire should be used for the 220-volt motor main of Fig. 147? The motors, so the table of motor currents (see index) shows, take approximately the currents indicated. The total load is (114 amp. + 40 amp.) 154 amp. Allowable drop is 5 per cent. or 11 volts to the furthest motor. Distance to load center is 120 ft.

Solution.—Substitute in the formula thus:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 154 \times 120}{11} = \frac{406{,}560}{11} = 36{,}960 \text{ cir. mils.}$$

Referring to Table 170, No. 4 wire, which has an area of 41,740 cir. mils, is the next largest standard size wire and would keep the drop within the 11 volts allowed. But a No. 4 rubber insulated wire has a safe carrying capacity of but 70 amp. The circuit under consideration carries 154 amp; hence the smallest rubber insulated wire (Code rules) that can be safely used is a No. 000 which has a safe capacity of 175 amp. No. 00, which safely carries 150 amp., could be probably safely used if the wiring inspector would pass it.

Branch leads to motors must (National Electrical Code) have a carrying capacity of 25 per cent. in excess of the full-load current ratings of the motors they serve. With a main serving several motors, the 25 per cent. excess capacity is not required.

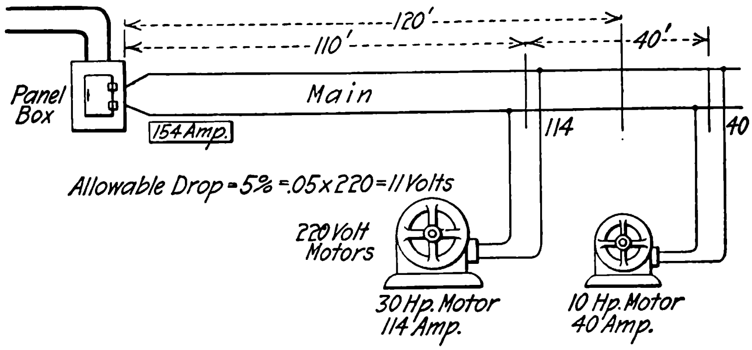


FIG. 147.—Determining wire size for main.

287. Calculations of three-wire, direct-current circuits are made in essentially the same manner as those for direct-current, two-wire circuits. With a balanced three-wire circuit, no current flows in the neutral wire. In practice the circuits should be very nearly balanced and in making wiring calculations it is usually assumed that they are balanced unless there is obviously great unbalance. The first step is to ascertain the current that will flow in the outside wires. This is obtained in practice by adding together the currents taken by all of the receivers connected between the neutral and the outside wires and dividing the sum by 2. (See Fig. 148.) Then to this value are added the currents taken by receivers, if there are any, that are connected across the outside wires. The sum is taken as the total current. The calculation is then made in the same way as for any two-wire circuit. The neutral wire is disregarded in the calculation as it is assumed that it carries no current. The neutral is frequently made smaller than the outside wires. (See Par. 237, Sect. I.)

The drop in voltage, V in the formulas, is the drop in the outside wires and is two times the drop to each receiver between neutral and outside wires. Two-wire branch circuits feeding from three-wire mains or feeders are computed in the same manner as for any two-wire circuit.

Example.—What size wire should be used for the three-wire main of Fig. 148? Allowable drop is 3 volts and the distance to the load center is 40 ft. The circuit is loaded with two groups of receivers each taking 60 amp., connected between the neutral and the outside wires, and one group of receivers taking 20 amp. connected across the outside wires.

Solution.—Load $= \frac{60+60}{2} + 20 = 80$ amp. Substitute in the formula:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 80 \times 40}{3} = \frac{70{,}400}{3} = 23{,}470 \text{ cir. mils.}$$

Referring to Table 170, 23,470 cir. mils correspond most nearly to No. 6 wire which has an area of 26,250 cir. mils. This size wire would satisfy the voltage drop requirements but, for concealed wiring, rubber insulated wire must be used and rubber insulated No. 6 (see Table 170) has a safe carrying capacity of but 50 amp. The current in the circuit is 80 amp. Therefore, with rubber insulated wire No. 3 should be used which will safely carry 80 amp. The neutral wire may be made the same size as the outside wires or it may be smaller (see Par. 237, Sect. I). For exposed wiring with slow-burning or weather-proof insulation, three No. 5 wires each of which safely carries 80 amp. could be used.

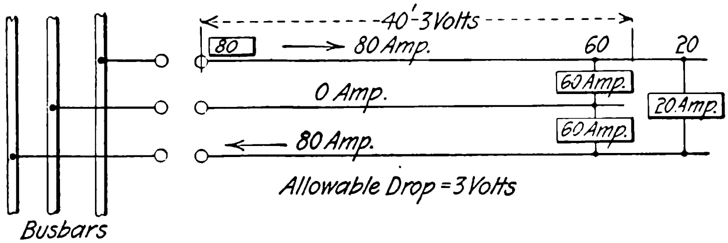


FIG. 148.—A three-wire circuit problem.

288. **In calculating alternating-current circuits** there are certain phenomena that must be considered that do not exist with direct-current circuits. Among these are the effects of power factor and of induction which creates reactance. Where circuits are short these effects need not always be considered, but where circuits are long they may be of considerable consequence. Capacity seldom need be considered with circuits operating at the voltages discussed in this book, namely, those of pressures below 2,200 volts. Skin effect is usually of so little consequence that it can be neglected.

There is no simple method of calculating alternating-current circuits, that takes into account the effects of power factor and reactance, that is reasonably accurate under all conditions. The methods described in following paragraphs, in which the effect of line reactance is not considered, give approximate results, but experience has shown them to be quite accurate enough for many wiring calculations. The results from these approximate formulas are usually subject to less error than other factors entering into ordinary wiring calculations. The results from the Mershon diagram method are quite accurate.

289. **Large Conductors Should not be Used for Alternating-current Circuits.**—If conductors are too large, the skin effect becomes so great that but a small proportion of the total area of the conductor is effective. Some engineers will use no conductor larger than 300,000 cir. mils for interior wiring, but 700,000 cir. mil conductors can be used economically for interior work if they are made upon a fiber core as described in 182. As a general proposition, conductors larger than 700,000 cir. mils are very difficult to install. If, for instance, a carrying capacity equivalent to 800,000 cir. mils is required, use two 400,000 cir. mil conductors in parallel or a similar equivalent arrangement.

290. **Power factors of the load apparatus or equipment** must often be known before alternating-current wiring calculations can

be made. If the exact power factor of the load is not known or cannot be readily obtained the approximate values of Par. 57 can be used. Or for ordinary wiring calculations, it can be assumed that power factors of loads will be as follows: Incandescent lighting load, from 100 per cent. to 95 per cent.; incandescent lighting and motors, 85 per cent.; motors only 80 per cent. The power factor of the load, if it be other than 100 per cent., may affect the volts loss in the line considerably. See examples in the following paragraphs.

291. **Effect of Line Reactance.**—Practically all alternating-current circuits have some line reactance. The effect of reactance is to cause a drop in voltage somewhat similar to that caused by resistance. Where all of the wires of a circuit, two wires for a single-phase, four wires for a two-phase and three wires for a three-phase circuit, are carried in the same conduit or where the wires are separated less than an inch between centers, the effect of line (inductive) reactance may ordinarily be neglected. Where circuit conductors are large and widely separated from one another and the circuits are long, the effect of inductive reactance may increase the volts line loss considerably over that due to resistance alone. Every such case should be investigated with the Mershon diagram (Fig. 158). With aerial circuits on pole lines, where the wires are widely separated, the effect of inductive reactance is apt to be large. Line reactance increases somewhat as the size of wire decreases, and decreases as the distance between wires decreases. (See Table 306.)

292. **Line or circuit reactance with a conductor of given area can be reduced in two ways.** One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of a span. In inside wiring, knob or cleat work, it is limited by the separation distances required by the underwriters. In conduit work the conductors lie so close together that there is very little effect from inductive reactance under ordinary conditions. The other way of reducing reactance is to divide the copper into a greater number of circuits. Voltage drop in lines due to inductive reactance is best diminished (Mershon) by subdividing the copper or by bringing the conductors closer together. It is little affected by changing the size of conductor. See 301 for a problem illustrating this and its solution.

293. **Calculation of alternating-current incandescent lighting installations.** The following method, though not strictly accurate, can be used for ordinary house and building single-phase wiring where the power factor of the load is nearly 100 per cent., as with incandescent lamps: *Treat the circuits as if they were direct-current circuits using the formula of* **286.** *See the example following that paragraph.* If the circuits are very long and the wires widely separated use the method of **299.**

294. **Three-wire, single-phase, alternating-current circuits can be calculated,** provided they are of moderate length, with the three-wire direct-current formula of **287.** If the circuit is quite

long and the wires widely separated use the method of **300.** Treat the circuit as a single-phase circuit of the voltage between the two outside wires of the three-wire system, disregarding the neutral wire. Then make the neutral wire the same size as is found for the two outside wires.

295. Calculation of Single-phase Alternating-current Circuits where Line Reactance Can be Neglected.—This method, although not strictly accurate, can be safely used for computing short branch circuits and also feeders and mains where the circuits are carried in conduit or are not very long. Where circuits are of considerable length, the method of **300** should be used. If the current is not known it must be found, using this formula:

$$I = \frac{kw. \times 1000}{E \times p.f.}$$

Wherein, I = current in amperes, $kw.$ = kilowatts input of load, E = voltage of circuit and $p.f.$ = power factor of load. The current being known, use this formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein, cir. mils = area of conductor, I = current in amperes, L = single distance or length one way of the circuit, in feet, and V = volts drop allowable.

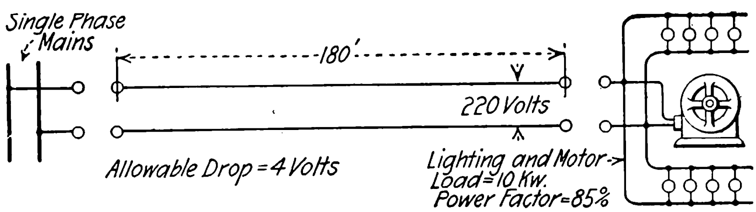


FIG. 149.—Single-phase circuit problem.

Example.—See Fig. 149. Load = 10 kw., voltage of circuit = 220, power factor = 0.85, distance is 180 ft., allowable drop = 4 volts. What size wire should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 1000}{E \times pf.} = \frac{10 \times 1000}{220 \times 0.85} = \frac{10,000}{187} = 53.5 \text{ amp.}$$

Then to find the size conductor:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 53.5 \times 180}{4} = \frac{211,860}{4} = 52,965 \text{ cir. mils.}$$

Referring to Table **170**: The next larger standard size wire is No. 2 (66,370 cir. mils). It safely carries 90 amp. so is ample for the 53.5 amp. of this problem.

296. Calculation of Two-phase, Four-wire, Alternating-current Circuits where Line Reactance can be Neglected.—The following method, although not strictly accurate, can be safely used for computing short branch circuits and also feeders and mains where the circuits are carried in conduit or are not very long. Where circuits are of considerable length, the method of **301** should be used. If the current is not known, it must be found using this formula:

$$I = \frac{kw. \times 1000}{E \times p.f. \times 2} = \frac{kw. \times 500}{E \times p.f.}$$

Wherein, I is the current in amperes in each of the four wires, $kw.$ = kilowatts input to load, E is the voltage across each of the two phases and $p.f.$ = the power factor of the load. The current being known:

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein, cir. mils = area of required conductor, I = current in amperes in each of the four wires, L = the length or single distance of the circuit in feet, and V = volts drop to be allowed in the circuit.

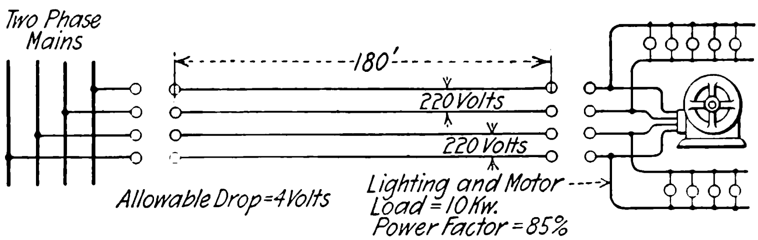


FIG. 150.—Two-phase circuit problem.

Example.—See Fig. 150. Load = 10 kw., voltage of circuit = 220, power factor = 0.85, distance is 180 ft., allowable drop is 4 volts. What size wire should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 500}{E \times p.f.} = \frac{10 \times 500}{220 \times 0.85} = \frac{5{,}000}{187} = 26.8 \text{ amp.}$$

Then to find the size conductor:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 26.8 \times 180}{4} = \frac{106{,}128}{4} = 26{,}532 \text{ cir. mils.}$$

Referring to Table 170: The next larger standard size wire is No. 5 which has an area of 33,100 cir. mils and which will safely carry, with rubber insulation, 55 amp. and with other insulations, 80 amp. It will, therefore, with either insulation, readily carry the 26.8 amp. in this circuit. Four No. 5 conductors would be used.

297. Calculation of Three-phase, Three-wire, Alternating-current Circuits where Line Reactance can be Neglected.—This method, although not strictly accurate, can be safely used for computing ordinary branch circuits and also for computing feeders and mains where the circuits are carried in conduit or are not very long. Where circuits are of considerable length, the method of 302 should be used. If the current is not known, it must be found, using this formula:

$$I = \frac{kw. \times 1{,}000}{E \times p.f. \times 1.73} = \frac{kw. \times 580}{E \times p.f.}$$

Wherein, I = current in amperes in each of the three wires, E = voltage between wires, $kw.$ = kilowatts input to load, and $p.f.$ = power factor of load. The current being known, the wire size can be calculated thus:

$$\text{cir. mils} = \frac{11 \times I \times L \times 1.73}{V} = \frac{19 \times I \times L}{V}$$

Wherein, cir. mils = area for each of the three wires, I = current in each of the three wires in amperes, L = single distance or length one way of the circuit in feet, and V = allowable volts drop in line.

Example.—See Fig. 151. Load = 10 kw., voltage of circuit = 220, power factor = 0.85, distance is 180 ft., allowable drop = 4 volts. What size wire should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 580}{E \times p.f.} = \frac{10 \times 580}{220 \times 0.85} = \frac{5{,}800}{187} = 31 \text{ amp.}$$

Then to find the conduction size:

$$\text{Cir. mils} = \frac{19 \times I \times L}{V} = \frac{19 \times 31 \times 180}{4} = \frac{106{,}000}{4} = 26{,}500 \text{ cir. mils.}$$

Referring to Table 170: The next larger standard size wire is No. 5 which has an area of 33,100 cir. mils. It will safely carry with rubber insulation 55 amp., and with other insulations 80 amp. It is therefore ample in section for the 31 amp. of this problem. Three No. 5 wires would be used for the circuit.

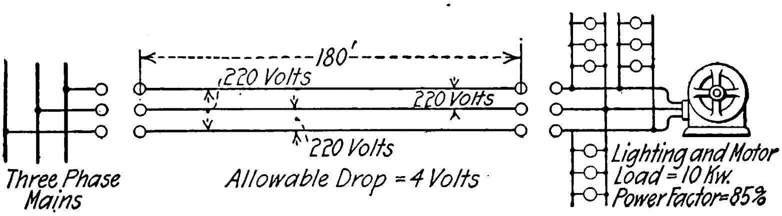


FIG. 151.—Three-phase circuit problem.

298. Single-phase branches from three-phase circuits are calculated the same as any single-phase circuit. If the two-branch conductors are tapped from two of the conductors of a three-wire, three-phase circuit, the voltage across the branch wires will be the same as that across two of the wires of the three-phase circuit. If the branch is connected between one of the three wires and neutral, the voltage across the branch wires will be 0.58 × the three-phase voltage between wires. See paragraphs on the three-phase system under "Alternating Currents."

299. Calculation of Circuits where Line Reactance must be Considered.—The Mershon diagram (Fig. 158) is recommended for making such calculations. Other and apparently simpler methods are available, but all simple methods are inaccurate under certain conditions and are apt to get their user into trouble unless he is quite familiar with the principles of alternating currents. The Mershon diagram does not offer a direct method of ascertaining drop. It is rather a "cut-and-try" method. The distance between wires and the frequency of the circuit being known, a conductor of a size that appears to be about right is selected for trial. With the known current flowing, the volts line loss in this conductor can be determined with the diagram. If the volts line loss with this conductor is found to be excessive a different size conductor is tried. Trials are made until a size conductor is found that will bring the drop within the specified limit. It is seldom that more than two trials are necessary. The method is a little tedious, but not difficult. It is accurate under all ordinary conditions. See the examples that follow.

300. Calculation of Single-phase Alternating-current Circuits where Line Reactance must be Considered.—The use of the **Mershon diagram** in computing such circuits can best be explained by examples.

Example.—What size wire should be used for the branch to the 50-h.p., 60-cycle, 250-volt, single-phase induction motor of Fig. 152? The name-plate current rating of the motor is 195 amp. and its full-load power factor is 85 per cent. The wires are run open and separated 4 in. Length of circuit is 600 ft. The volts line loss must not exceed 7 per cent. or $0.07 \times 250 = 17.5$ volts.

Solution.—To ascertain approximately what size the conductor must be, use the simple single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 195 \times 600}{17.5} = 147{,}000$$

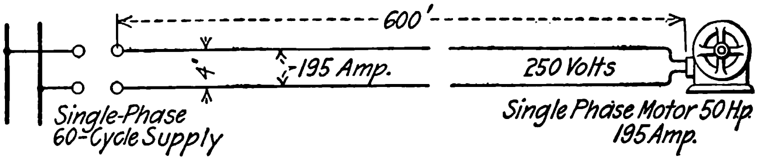


FIG. 152.—Another single-phase circuit problem.

Referring to Table 306: The next larger standard size wire is No. 000 or 167,800 cir. mils. This size would be ample if there were no line reactance, but as it is known that there is line reactance we will select a larger conductor and find what the volts loss with it will be, using the Mershon diagram (Fig. 153). Try a 250,000 cir. mil conductor.

Find the resistance and reactance drops in the line using the values from Table 306 for a 250,000 cir. mil conductor for 60 cycles and a 4 in. separation. From the table *resistance volts* = 0.085 and *reactance volts* = 0.139.

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1{,}000} = \frac{195 \times 0.085 \times 600}{1{,}000} = 9.9 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{\text{resistance drop}}{\text{receiver volts}} = \frac{9.9}{250} = 3.96 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1{,}000} = \frac{195 \times 0.139 \times 600}{1{,}000} = 16.3 \text{ volts.}$$

$$\text{Per cent. of reactance drop} = \frac{\text{reactance drop}}{\text{receiver volts}} = \frac{16.3}{250} = 6.5 \text{ per cent.}$$

Refer to the Mershon diagram (Fig. 158). Follow the vertical line corresponding to the power factor, 0.85, upward until it intersects the smallest circle marked *O* as illustrated in Fig. 153. From this point lay off horizontally the percentage resistance drop, 3.96. From this last point lay off vertically the percentage reactance drop, 6.5. (See Fig. 153.) This last point lies about on the 7 per cent. circle indicating that the volts line loss in this circuit with 195 amp. flowing will be $0.07 \times 250 = 17.5$ volts. The conditions of the example are satisfied by a 250,000 cir. mil conductor. Actually the line loss will be somewhat less than 7 per cent. as the last point does not quite touch the 7 per cent. circle.

Inasmuch as this is a motor branch, the code rules require that its safe carrying capacity be sufficient for a 25 per cent. over-load. Therefore the conductor should be capable of safely carrying $195 \times 1.25 = 244$ amp. Referring to Table 306, a 300,000 cir. mil conductor, rubber insulated cable would be required to safely carry this 244 amp. In a problem in practice one would, therefore, immediately try a 300,000 conductor for volts line loss. The preliminary calculations were given in the above problem to illustrate the method.

301. Calculation of Two-phase, Four-wire, Alternating-current Circuits where Line Reactance must be Considered.—Use the Mershon diagram (Fig. 158). Calculate the single-phase circuit required to transmit one-half the power at the same voltage. The two-phase transmission will require two such circuits.

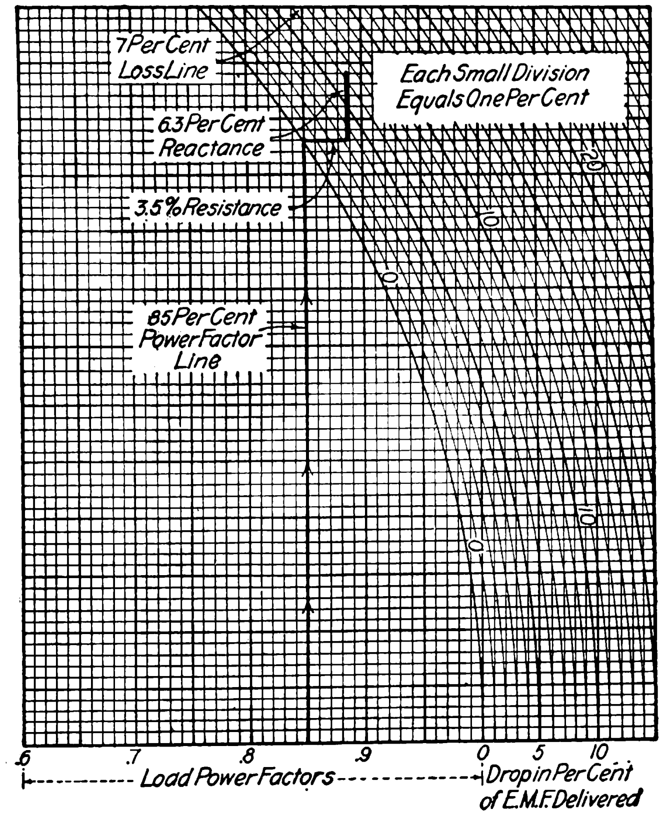


FIG. 153.—Illustrating the application of the Mershon diagram for computing a single-phase circuit.

Example.—What size wire should be used for the two-phase circuit of Fig. 154? Load = 120 kw.; receiver voltage = 220; load power factor = 80 per cent.; frequency = 60 cycles; length of circuit = 400 ft.; distance between wires = 6 in. Allowable loss (voltage drop) is 5 per cent.

Solution.—Find one-half of the total load on the circuit and then proceed with this one-half total load as if it were the entire load on a single-phase circuit.

$$\tfrac{1}{2} \text{ total load } = \frac{120\ kw.}{2} = \frac{120{,}000 \text{ watts}}{2} = 60{,}000, \text{ watts}$$

$$\text{line current } = \frac{P}{E \times p.f.} = \frac{60{,}000}{220 \times 0.80} = \frac{60{,}000}{176} = 341 \text{ amp.}$$

To ascertain approximately what size wire should be installed, use the approximate single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 341 \times 400}{12} = 250{,}066 \text{ cir. mils.}$$

The next larger standard size wire is 300,000 cir. mils, which will safely carry the current 341 amp. (see Table 306) if the wires are run open. (If they are concealed—rubber insulated—at least a 500,000 cir. mil conductor must be used.)

Referring to Table 306 for a 300,000 cir. mil conductor, 6 in. separation and 60 cycles: *Resistance volts per amp.* = 0.075 and *Reactance volts per amp.* = 0.153, therefore

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1{,}000} = \frac{341 \times 0.075 \times 400}{1{,}000} = 10.23 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{10.23}{220} = 4.65 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1{,}000} = \frac{341 \times 0.153 \times 400}{1{,}000} = 20.9$$

$$\text{Per cent. of reactance drop} = \frac{20.9}{220} = 9.5 \text{ per cent.}$$

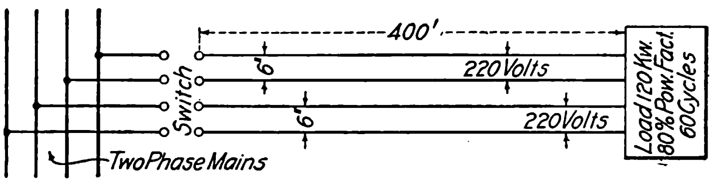


FIG. 154.—Two-phase circuit problem.

Lay out the per cent. resistance and reactance drops on the Mershon diagram (Fig. 158) for 0.80 power factor, as suggested in the single-phase problem above and as illustrated in Fig. 155. The last point on the lay out is between the 9 per cent. and the 10 per cent. volts loss circles in the diagram indicating that the volts loss with 300,000 cir. mil conductors would be about 9½ per cent. The allowable loss is but 5 per cent., so a different size conductor must be selected.

A conductor larger than 300,000 cir. mils might be selected that would bring the volts line loss within the 5 per cent. limit, but it is probably better to install two two-phase transmissions of smaller wire in multiple as shown in Fig. 156, making the aggregate area of the two conductors in multiple equal to about 300,000 cir. mils. (See Paragraph 292.)

Therefore try two transmissions of No. 00 wire. Take values for No. 00 wire from Table 306 in the manner as before, for 60 cycles and a 6 in. separation, remembering that half the former current will flow in the conductors of the subdivided transmission. Then for each two-phase, two-wire circuit the current will be $\frac{1}{2} \times 341 = 170.5$ amp. Therefore:

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1{,}000} = \frac{170.5 \times 0.156 \times 400}{1{,}000} = 10.7 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{10.7}{220} = 4.8 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1{,}000} = \frac{170.5 \times 0.172 \times 400}{1{,}000} = 11.7 \text{ volts}$$

$$\text{Per cent. of reactance drop} = \frac{11.7}{220} = 5.3 \text{ per cent.}$$

Laying the per cent. resistance and per cent. reactance drops out on the Mershon diagram at 0.80 power factor it will be found that for this No. 00

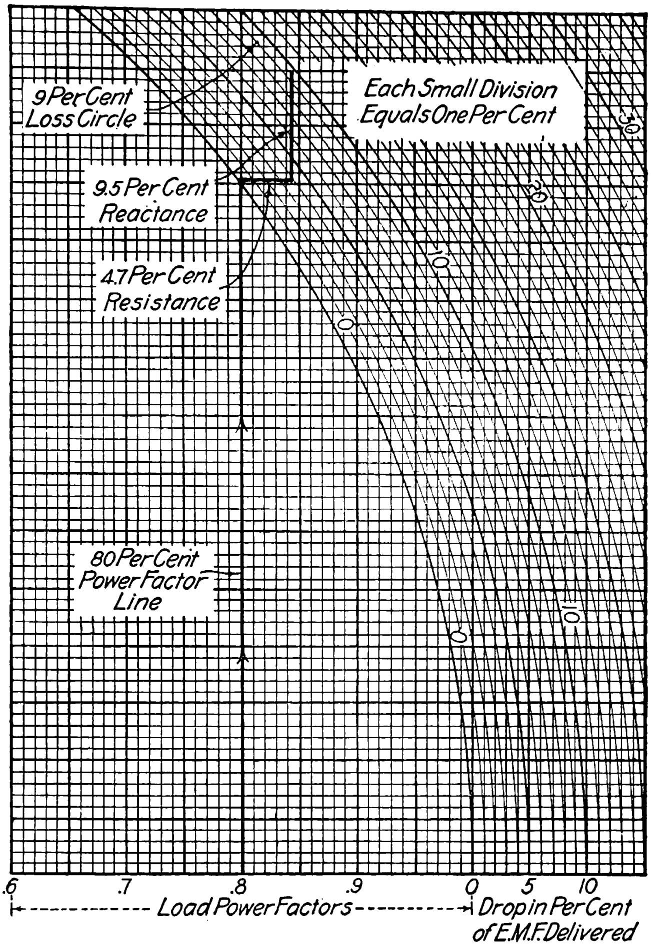


FIG. 155.—Illustrating the application of the Mershon diagram for computing a two-phase, four-wire alternating-current circuit.

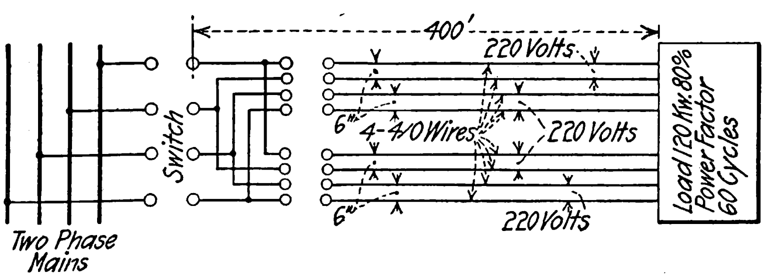


FIG. 156.—Divided two-phase circuit.

wire the per cent. volts line loss will be about 7 per cent., which is excessive.

Making another trial, considering this time two two-phase transmissions of No. 0000 wire in parallel, it will be found that the per cent. volts line loss will be about just a trifle over 5 per cent. So two two-phase circuits in parallel of No. 0000 wire would be used as shown in Fig. 156.

This is an unusually tedious problem and was selected to indicate the method of dividing a given transmission into two transmissions of smaller wire to decrease the effect of line reactance. In practice it might not be the most economical method to install the transmission as indicated in Fig. 156.

302. Calculation of a Three-phase, Three-wire Alternating-current Circuit where Line Reactance must be Considered.—Use the Mershon diagram (Fig. 158). Calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase circuit. See paragraph 300 for the calculation of a single-phase circuit.

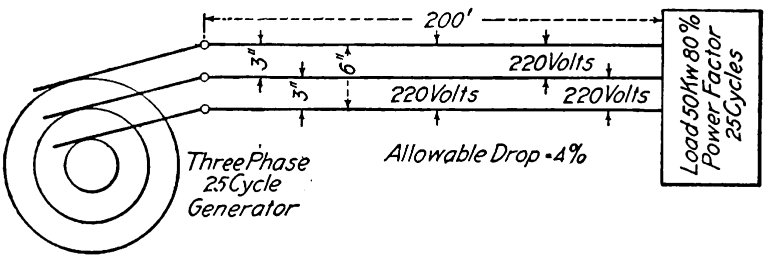


FIG. 157.—Three-phase circuit.

Example.—What size conductor should be used for the open-wire transmission shown in Fig. 157, the allowable volts loss in the line being 4 per cent. or $0.04 \times 220 = 8.8$ volts? Receiver voltage = 220; load = 50 kw.; power factor = 0.80; distance = 200 ft.; distance between wires = 3 in. Frequency is 25 cycles.

Solution.—The actual current in each wire must be known to insure that a conductor large enough to carry it will be selected. (See Par. 69.)

$$\text{actual current} = \frac{0.58 \times P}{E \times p.f.} = \frac{0.58 \times 50{,}000}{220 \times 0.8} = \frac{29{,}000}{176} = 0.165 \text{ amp.}$$

Now find one-half of the total load and proceed with this load as for a single-phase transmission which will be called the imaginary transmission.

$$\tfrac{1}{2} \text{ total load} = \frac{\text{watts}}{2} = \frac{50{,}000}{2} = 25{,}000 \text{ watts}$$

The current in the imaginary transmission would be:

$$I = \frac{P}{E \times p.f.} = \frac{25{,}000}{220 \times 0.80} = \frac{25{,}000}{176} = 142 \text{ amp. in the imaginary transmission.}$$

To approximate the size of wire, use the single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 142 \times 200}{8.8} = \frac{624{,}800}{8.8} = 71{,}000 \text{ cir. mils.}$$

The next larger standard size wire is No. 1—83,690 cir. mils.—which will safely carry, when exposed, 150 amp. The actual current is 165 amp. No. 1 is therefore not satisfactory from a current-carrying standpoint. Therefore, it will be necessary to use at least the next larger size wire, No. 0, which will safely carry, when exposed, 200 amp. Now check this No. 0 wire for volts line drop (volts line loss).

The average distance between the three wires $= \dfrac{3 \text{ in.} + 3 \text{ in.} + 6 \text{ in.}}{3} = \dfrac{12 \text{ in.}}{3} = 4$ in.

Refer to Table 307 under 25 cycles and opposite No. 0 wire and find: Resistance volts per 1,000 ft. = 0.196 and (under 4 in. separation) reactance volts per 1,000 ft. = 0.066. Then

$$\text{Resist. drop} = \frac{\text{current} \times \text{resist. volts} \times \text{dist.}}{1{,}000} = \frac{142 \times 0.196 \times 200}{1{,}000} = 5.57 \text{ volts.}$$

$$\text{Per cent. resistance drop} = \frac{5.57}{220} = 2.5 \text{ per cent.}$$

$$\text{React. drop} = \frac{\text{current} \times \text{react. volts} \times \text{dist.}}{1{,}000} = \frac{142 \times 0.066 \times 200}{1{,}000} = 1.87 \text{ volts.}$$

$$\text{Per cent. reactance drop} = \frac{1.87}{220} = 0.85 \text{ per cent.}$$

Laying out the per cent. resistance drop and the per cent. reactance drop on the Mershon diagram (Fig. 158) at the upper end of the 80 per cent. power factor line as described under the single-phase problem of 300 the last point of the lay out comes just under the 3 per cent. volts loss circle. Therefore the true volts loss in the line will be somewhat less than 3 per cent. with No. 0 wire. Therefore use three No. 0 wires for the transmission as shown in Fig. 157. Study the examples of 300 and 301 for other features of the Mershon diagram method.

303. How to Use the Mershon Diagram (*Westinghouse Electric Co.*).—By means of tables **306** and **307** calculate the resistance-volts and the reactance-volts in the line, and find what per cent. each is of the e.m.f. delivered at the end of the line. Starting from the point on the chart (Fig. 158) where the vertical line corresponding with power factor of the load intersects the smallest circle, lay off in per cent. the resistance e.m.f. horizontally and to the right; from the point thus obtained lay off upward in per cent. the reactance e.m.f. The circle on which the last point falls gives the drop in per cent. of the e.m.f. delivered at the end of the line. Every tenth circle arc is marked with the per cent. drop to which it corresponds.

304. Power Loss in Any Conductor.—Taking 11 ohms as the resistance of a circular mil-foot of commercial copper wire at 75 deg. fahr. the power loss in any conductor may be found thus:

$$P = \frac{11 \times I^2 \times L}{\text{cir. mils}}$$

Wherein, P = power lost in the conductor in watts; I = the current in amperes in the conductor; L = length of the conductor in feet, and cir. mils = area of the conductor in circular mils.

305. Power Loss in a Circuit.—It follows from the above formula that: For a two-wire, direct-current or a single-phase circuit:

$$P = \frac{2 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{22 \times I^2 \times L}{\text{cir. mils}}$$

For a balanced four-wire, two-phase circuit:

$$P = \frac{4 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{44 \times I^2 \times L}{\text{cir. mils}}$$

For a balanced three-wire, three-phase circuit:

$$P = \frac{3 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{33 \times I^2 \times L}{\text{cir. mils}}$$

Wherein, P = the power, in watts, lost in the line; I = the current in amperes which flows in each of the wires of the line; L = the length or single distance of the circuit and cir. mils = area in circular mils of each of the wires of the line. The above formulas can be used only when all of the wires of the line are the same size.

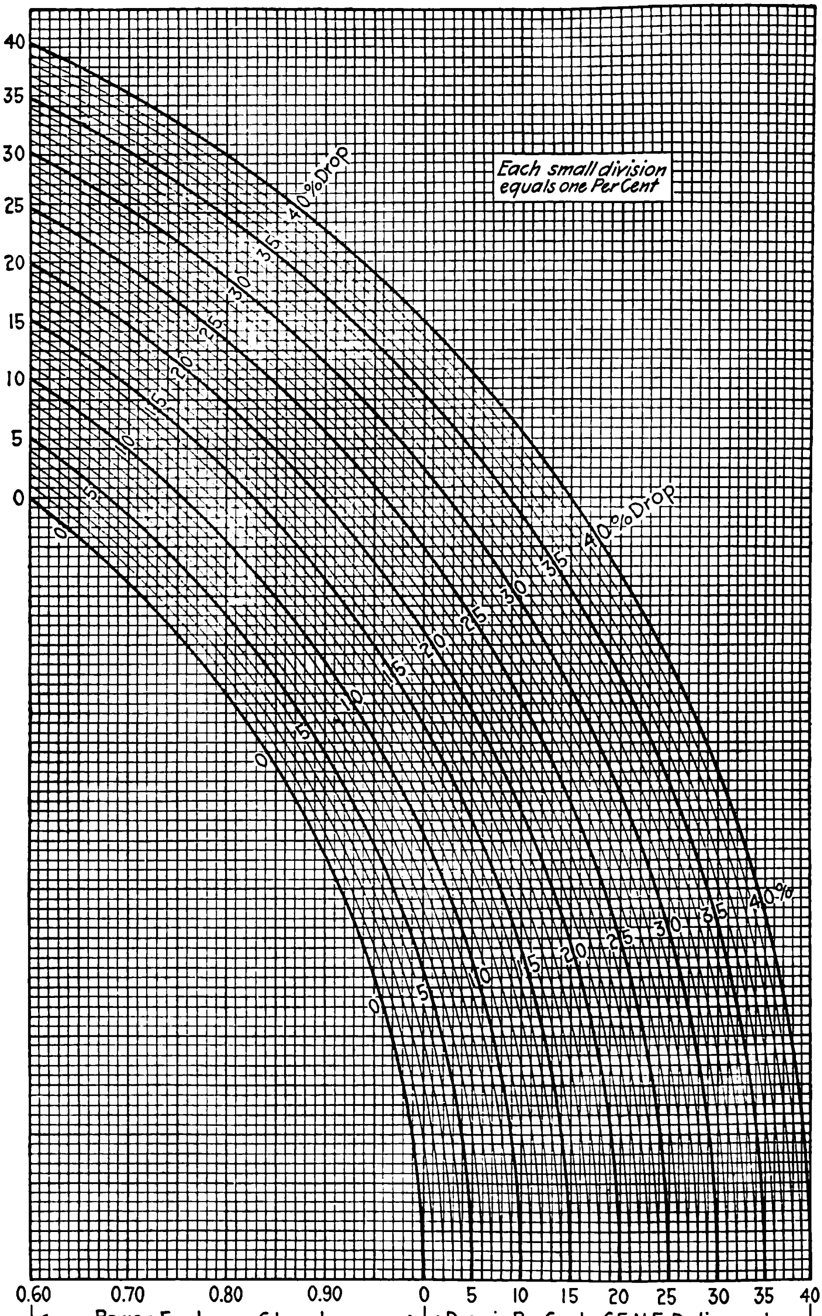


FIG. 158.—The Mershon diagram. See Par. 303 for directions as to its use and application.

306. Table for Calculating Drop in Alternating-current Lines with the Mershon Diagram—60 Cycles

Size of wire (cir. mils) and B. & S. gage	Safe carrying capacity, N.E.C. 1915 Rules		Resistance-volts in 1,000 ft. of copper line (2,000 ft. of wire) for 1 amp. (The values in this column are really the resistances of 2,000 ft. of conductor at 75 deg. fahr.)	[1]Frequency = 60 cycles Reactance-volts in 1,000 ft. of line (2,000 ft. of wire) for 1 amp. at 7,200 alternations per minute (60 cycles per second) for the distance given in inches between centers of conductors. (The values in these columns are really the reactances of 2,000 ft. of conductor)										
	Rubber ins., amp., Table A	Other ins., amp., Table B		½	1	2	3	4	5	6	9	12	18	24
14– 4,107	15	20	5.06	0.138	0.178	0.218	0.220	0.233	0.244	0.252	0.271	0.284	0.302	.....
12– 6,530	20	25	3.18	0.127	0.159	0.190	0.210	0.223	0.233	0.241	0.260	0.273	0.292	.....
10–10,380	25	30	2.00	0.116	0.148	0.180	0.199	0.212	0.223	0.221	0.249	0.262	0.281	.....
8–16,510	35	50	1.26	0.106	0.138	0.169	0.188	0.201	0.212	0.220	0.238	0.252	0.270	0.284
6–26,250	50	70	0.790	0.095	0.127	0.158	0.178	0.190	0.210	0.209	0.228	0.241	0.260	0.272
4–41,740	70	90	0.498	0.085	0.117	0.149	0.167	0.180	0.190	0.199	0.217	0.230	0.249	0.262
2–66,370	90	125	0.312	0.074	0.106	0.138	0.156	0.169	0.180	0.188	0.206	0.220	0.238	0.252
1–83,690	100	150	0.248	0.068	0.101	0.132	0.151	0.164	0.174	0.183	0.201	0.214	0.233	0.246
0–105,500	125	200	0.196	0.063	0.095	0.127	0.145	0.159	0.169	0.177	0.196	0.209	0.228	0.241
2/0–133,100	150	225	0.156	0.057	0.090	0.121	0.140	0.153	0.164	0.172	0.190	0.204	0.222	0.236
3/0–167,800	175	275	0.122	0.052	0.085	0.116	0.135	0.148	0.158	0.167	0.185	0.199	0.217	0.230
4/0–211,600	225	325	0.098	0.046	0.079	0.111	0.130	0.143	0.153	0.161	0.180	0.193	0.212	0.225
250,000	240	350	0.085	.....	0.075	0.10[illegible]	0.125	0.139	0.148	0.157	0.175	0.189	0.207	0.220
300,000	275	400	0.075	.....	0.071	0.103	0.120	0.134	0.144	0.153	0.171	0.185	0.203	0.217
350,000	300	450	0.061	.....	0.067	0.099	0.118	0.128	0.141	0.149	0.168	0.182	0.200	0.213
400,000	325	500	0.052	.....	0.064	0.096	0.114	0.127	0.138	0.146	0.165	0.178	0.197	0.209
500,000	400	600	0.042	.....	.....	0.090	0.109	0.122	0.133	0.141	0.160	0.172	0.192	0.202
600,000	450	680	0.035	.....	.....	0.087	0.106	0.118	0.128	0.137	0.155	0.169	0.187	0.200
700,000	500	760	0.030	.....	.....	0.083	0.102	0.114	0.125	0.133	0.152	0.165	0.184	0.197
800,000	550	840	0.026	.....	.....	0.080	0.099	0.112	0.122	0.130	0.148	0.162	0.181	0.194
900,000	600	920	0.024	.....	.....	0.077	0.096	0.109	0.119	0.127	0.146	0.159	0.178	0.191
1,000,000	650	1,000	0.022	.....	.....	0.075	0.094	0.106	0.117	0.125	0.144	0.158	0.176	0.188

[1] For other frequencies the reactance will be in direct proportion to the frequency.

307. Table for Calculating Drop in Alternating-current Lines with the Mershon Diagram—25 Cycles

Size of wire (cir. mils) and B. & S. gage	Safe carrying capacity, N.E.C. 1915 Rules		Resistance-volts in 1,000 ft. of copper line (2,000 ft. of wire) for 1 amp. (The values in this column are really the resistances of 2,000 ft. of conductor at 75 deg. fahr.)	[1]Frequency = 25 cycles Reactance-volts in 1,000 ft. of line (2,000 ft. of wire) for 1 amp. at 3,000 alternations per minute (25 cycles per second) for the distance given in inches between centers of conductors. (The values in these columns are really the reactances of 2,000 ft. of conductor)										
	Rubber ins., amp., Table A	Other ins., amp., Table B		½	1	2	3	4	5	6	9	12	18	24
14– 4,107	15	20	5.06	0.057	0.071	0.08[illegible]	0.093	0.097	0.102	0.105	0.113	0.118	0.126	.....
12– 6,530	20	25	3.18	0.053	0.066	0.080	0.087	0.094	0.097	0.101	0.108	0.113	0.122	.....
10–10,380	25	30	2.00	0.049	0.062	0.075	0.083	0.088	0.092	0.096	0.104	0.110	0.117	.....
8–16,510	35	50	1.26	0.044	0.057	0.071	0.078	0.084	0.088	0.092	0.099	0.105	0.113	.....
6–26,250	50	70	0.790	0.040	0.053	0.066	0.074	0.079	0.084	0.087	0.095	0.100	0.108	.....
4–41,740	70	90	0.498	0.035	0.049	0.062	0.070	0.075	0.079	0.083	0.091	0.096	0.104	.....
2–66,370	90	125	0.312	0.031	0.044	0.057	0.065	0.071	0.075	0.078	0.086	0.092	0.099	.....
1–83,690	100	150	0.248	0.028	0.042	0.055	0.063	0.068	0.073	0.076	0.083	0.089	0.097	.....
0–105,500	125	200	0.196	0.026	0.040	0.053	0.061	0.066	0.070	0.073	0.082	0.087	0.095	.....
2/0–133,100	150	225	0.156	0.024	0.037	0.051	0.058	0.064	0.068	0.072	0.079	0.085	0.093	.....
3/0–167,800	175	275	0.122	0.022	0.035	0.048	0.056	0.062	0.066	0.070	0.077	0.083	0.091	.....
4/0–211,600	225	325	0.098	0.019	0.033	0.046	0.053	0.059	0.064	0.067	0.075	0.081	0.088	.....
250,000	240	350	0.085	.....	0.031	0.044	0.051	0.058	0.062	0.065	0.073	0.079	0.086	0.002
300,000	275	400	0.075	.....	0.030	0.043	0.050	0.056	0.060	0.064	0.071	0.077	0.084	0.000
350,000	300	450	0.061	.....	0.028	0.041	0.049	0.054	0.059	0.062	0.070	0.076	0.083	0.089
400,000	325	500	0.052	.....	0.027	0.040	0.048	0.053	0.057	0.061	0.069	0.075	0.082	0.087
500,000	400	600	0.042	.....	.....	0.038	0.046	0.051	0.055	0.059	0.067	0.072	0.080	0.085
600,000	450	680	0.035	.....	.....	0.036	0.044	0.049	0.053	0.057	0.065	0.070	0.078	0.083
700,000	500	760	0.030	.....	.....	0.035	0.042	0.048	0.052	0.056	0.063	0.069	0.077	0.082
800,000	550	840	0.026	.....	.....	0.033	0.041	0.047	0.050	0.054	0.062	0.068	0.075	0.081
900,000	600	920	0.024	.....	.....	0.032	0.040	0.046	0.050	0.053	0.061	0.066	0.074	0.080
1,000,000	650	1,000	0.022	.....	.....	0.031	0.039	0.044	0.049	0.052	0.060	0.065	0.073	0.079

[1] For other frequencies the reactance will be in direct proportion to the frequency.

308. The Question of Energy Loss in a Circuit should not be Slighted in Circuit Calculations (*Standard Handbook*).—It is well known that in overcoming resistance, electrical energy is wasted; and as it costs money to develop or buy electrical energy, it is evident that in any commercial system such waste must be kept to a minimum. This may be done by decreasing the resistance of the conductors or what amounts to the same thing, of increasing the size of the conductors. Inasmuch as this is also an expensive matter, care must be exercised that the additional sum added to the expenditure in copper is not so excessive as to more than counterbalance the cost of the energy continually saved. It has been laid down as a general rule that for the transmission of any given energy, the most economical conductor is one having such a resistance that the value of the energy wasted in heat annually is equal to the interest per annum on the original outlay upon the conductor.

Knowing the average amount of energy to be transmitted, it becomes an easy matter to find the average kilowatt-hours wasted in a conductor of a given resistance. The question of energy loss in conductors increases in importance as the price of the energy increases, and decreases as the price of energy decreases, so that where the energy costs or may be purchased for very little, the loss may be more than offset by the additional investment in copper necessary to avoid it. With regard to the conductors themselves, in interior wiring work, it is merely a question of the additional cost of the copper, as the price of the installation, etc., is usually about the same for any size conductor that is apt to be used. So many considerations enter into the question of the best size of wire to employ consistent with strict economy, that the matter cannot be discussed at length here. A few illustrations may suffice to show what an important bearing the question has in wiring work.

Example.—A two-wire direct-current feeder system supplies a current of 50 amp. at a distance of 200 ft. from the meter. The drop allowed is 5 per cent. and the voltage of the circuit is 110. What size of wire should be installed?

Solution.—Substituting the value given above in the cir. mil. formula, the size of wire is found to be

$$A = \frac{22 \times 50 \times 200}{110 \times 0.05} = 40{,}000 \text{ cir. mils, or a No. 4 wire.}$$

If this energy were used 10 hr. a day for 300 days, and the cost of the energy were 8 cents per kilowatt-hour, the total yearly cost would be

$$\frac{50 \times 110 \times 10 \times 300 \times 0.08}{1{,}000} = \$1{,}320.$$

Of this 5 per cent., or $66, would be lost yearly due to the drop. The cost of 400 ft., No. 4, double-braid, rubber-covered wire would be about $22.50. The interest at 5 per cent. on this $22.50 would be $1.13. Since the yearly cost of energy lost is $66.00, it would cost each year $1.13 + $66.00 = $67.13 to operate this No. 4 conductor, assuming that the use of money costs 5 per cent. a year. It is evident, since the interest charge is so much smaller than the energy cost charge, that a No. 4 conductor is not nearly large enough and that it is not by any means the most economical one for the condition of the problem.

Table 310 shows the total annual charges or costs for conductors of several sizes worked out for the conditions of this problem, it being assumed that, in each case, the current of 50 amp. flows 10 hr. a day, 300 days a year over a conductor length of 400 ft., the energy cost being 8 cents a kw-hr. and the costs of the conductors being those indicated. As above noted the voltage drop for the No. 4 conductor is 5 per cent. For the No. 6 conductor (which will safely carry only 46 amp. and which therefore would be too small for the 50 amp. of this problem) it will be greater than 5 per cent. For conductors larger than No. 4 the drop will be less than 5 per cent.

It is evident from Table 310 that, for the conditions of this problem and with wire at the prices assumed, a 400,000 c. m. conductor is the most economical, that is, it has the least *total annual cost*, although a 300,000 c. m. conductor is almost as economical.

The market price of copper has a bearing on the matter of conductor economy. Where the energy cost is very low, the conductor that would be theoretically the most economical might be too small to safely carry the current. In such a case, the most economical conductor that can be used is the smallest one that has ample carrying capacity.

Example.—A two-wire feeder system 100 ft. long supplies a device requiring a current of 500 amp. The voltage of the supply is 110 and a drop of 1 per cent. is permitted. Required the size of wire (slow-burning weatherproof wire being permitted) used.

Solution.—Calculating the size of wire as in the preceding case shows that a 1,100,000-cir. mil cable is required.

If the energy in this case costs 2 cents per kilowatt-hour and the device were used 24 hr. a day and 300 days a year, what size of wire should be installed to obtain the best economy?

With the above data the yearly cost of the energy used is found to be

$$\frac{24 \times 300 \times 500 \times 110 \times 0.02}{1,000} = \$7,920.$$

If a 2,500,000-cir. mil cable be used, the drop according to the formula would be approximately 0.44 volt or 0.4 per cent. ($\frac{4}{10}$ per cent). The weight of 200 ft. of cable equivalent to 2,500,000 cir. mils would be approximately 1,900 lb., and assuming the cost to be 30 cents per pound, the copper investment would be $570. The interest on this investment at 5 per cent. would be $28.50. Now a loss of 0.4 per cent. on $7,920 would be $32 per year and since the interest on the copper investment is less than that amount, the 2,500,000-cir. mil cable should be installed. A 3,000,000-cir. mil cable would be found to be a trifle too costly. The substitution of the 2,500,000-cir. mil cable for the 1,000,000-cir. mil cable results therefore in a saving of $47 yearly. These results are figured on the ground that all other costs remain the same, which may or may not be the case. If copper were cheaper than specified, a larger cable could be substituted with a still further saving. It may readily be seen therefore that the question of drop alone should not determine the size of wire.

The preceding remarks deal with the question of energy loss from a purely financial basis. There are electrical considerations which must be taken into account in determining the maximum drop and energy loss allowable. The variation in the life and candle-power of incandescent lamps and the performance of motors and other equipment as affected by voltage and therefore energy loss should be considered.

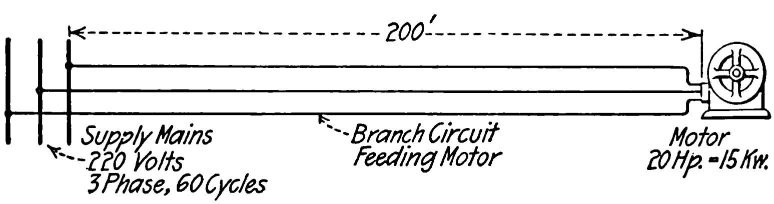


FIG. 159.—Three-phase motor circuit.

309. Use of Constants in Circuit Calculations.—Wiring and many other calculations that involve the use of several constants can be much simplified by resolving the constants into a factor which is itself a constant. It frequently occurs in central-station work that the permissible voltage drop and the power factor remain the same for many wiring computations. These and other constants can be effectively incorporated into a multiplier. An example will best explain the method.

Example.—Consider the problem suggested in Fig. 159. A three-phase 220-volt, 60-cycle, 20-h.p. motor is to be installed. It is assumed that the power factor is 70 per cent. What is the current in the line wires?

The following formula gives the current in each of the wires of a balanced three-phase circuit: $I = P \div 1.73 \times E \times p.f.$ where I is the current in amperes, P is the power transmitted in watts, 1.73 is a constant, E is the voltage of the supply circuit and $p.f.$ is the power factor of the circuit. For wiring calculations it may often be assumed that the factors 1.73, E and $p.f.$ are always of the same value in many computations. These three factors can therefore be resolved into a constant thus: $I = P \div 1.73 \times 220 \times 0.7 = 0.003{,}754 \times P$ watts or approximately: $I = 3.8$ kw.

It is apparent, then, that by multiplying the kilowatt capacity of the motor by the factor 3.8 the approximate full-load current in amperes flowing to the motor will result. The current for the motor of Fig. 159 will be $3.8 \times 15 = 57$ amp. Other problems may be much simplified by resolving constants into a factor.

309A. Allowable Amperes for 1-volt Drop (*National Lamp Works*)

Size wire, B. & S. or A.W.G.	Length of circuit in feet (length of wire twice as great)																
	15	20	30	40	60	80	100	125	150	175	200	250	300	350	400	450	500
16	8.3	6.2	4.2	3.1	2.1	1.6	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2
14	13	9.9	6.6	5.0	3.3	2.5	2.0	1.6	1.3	1.1	1.0	0.8	0.7	0.6	0.5	0.4	0.4
12	21	16	10	7.9	5.3	3.9	3.1	2.5	2.1	1.8	1.6	1.3	1.1	0.9	0.8	0.7	0.6
10	33	24	17	13	8.3	6.3	5.0	4.0	3.3	2.9	2.5	2.0	1.7	1.4	1.3	1.1	1.0
8	53	40	27	20	13	10	8.0	6.4	5.3	4.6	4.0	3.2	2.7	2.3	2.0	1.8	1.6
6	84	63	42	32	21	16	13	10	8.5	7.2	6.3	5.1	4.2	3.6	3.2	2.8	2.5
4	134	101	67	50	34	25	20	16	13	12	10	8.1	6.7	5.8	5.0	4.5	4.0
3	169	127	84	63	42	32	25	20	17	15	13	10	8.5	7.2	6.3	5.6	5.1
2	216	160	107	80	53	40	32	26	21	18	16	13	11	9.2	8.0	7.1	6.4
1	268	201	134	101	67	50	40	32	27	23	20	16	13	12	10	9.0	8.1
0	340	254	167	128	85	64	51	41	34	29	25	20	17	15	13	11	10

C Not prohibited

A Prohibited by "allowable" current-carrying capacity" rule.

B Prohibited by "660 watts per circuit" rule. (See Sec. 4, Par. **248**.)

Explanation.—Values in Section *A* of table are greater than those permitted by the *Code* (Par. **167**) in rubber-insulated copper wires of the sizes shown. Values in both Sections *A* and *B* are all such that, in any circuit operating at 110 volts or more, they will constitute a load greater than 660 watts, which is prohibited on ordinary incandescent-lamp branch circuits (Sec. 4, Par. **248**). Values in Section *C* are not prohibitive.

Example.—It is desired to install a circuit 80 ft. in length (160 ft. of wire). Reading down column headed "80," a current of 2.5 amp. causes a drop of 1 volt in an 80-ft. circuit of No. 14 wire. In an 80-ft. circuit of No. 12 wire, 3.9 amp. would cause 1 volt drop; with No. 10 wire, 6.3 amp. would cause 1 volt drop. For a current of 6 amp.—the max. current permitted on a 110-v., incandescent-lamp, branch circuit—a No. 10 wire should be used to keep the drop in this 80-ft. circuit within a 1-volt limit.

310. Table Showing Relative Economies of Conductors of Different Sizes.

(*This table applies only to the first example in paragraph* 308)

	No. 6 wire	No. 4 wire	250,000 c. m.	300,000 c. m.	400,000 c. m.	500,000 c. m.	600,000 c. m.	700,000 c. m.
Cost of 400 ft. of conductor....................	$16.80	$22.50	$102.40	$118.40	$150.40	$184.00	$218.20	$248.00
Interest on above cost at 5 per cent............	$0.84	$1.13	$5.12	$5.92	$7.52	$9.20	$10.91	$12.40
Cost of energy lost in conductor at 8 cents per kw-hr.	$101.64	$66.00	$10.56	$8.84	$6.60	$5.28	$4.49	$3.96
Total annual cost of conductor.................	$102.48	$67.13	$15.68	$14.76	$14.12	$14.48	$15.40	$16.36

311. Table for Three-phase Transmission (*General Electric Co.*)

(Approximate distances over which 100 kw., three-phase current, can be transmitted with different sizes of wires at different voltages, assuming an energy loss of 10 per cent. and a power factor of 85 per cent.)

American or B. & S.	Area in circular mils	Distance of transmission for various voltages at receiving end—miles				
		2,000 v	3,000 v	4,000 v	5,000 v	6,000 v
6	26,250	1.32	2.98	5.28	8.27	11.92
5	33,100	1.66	3.75	6.64	10.40	15.00
4	41,740	2.10	4.74	8.40	13.15	18.96
3	52,630	2.54	5.96	10.16	16.55	23.84
2	66,370	3.33	7.51	13.32	20.85	30.04
1	83,690	4.21	9.48	16.84	26.32	37.92
0	105,500	5.29	11.92	21.16	33.10	47.68
00	133,100	6.71	15.11	26.84	41.97	60.44
000	167,800	8.45	19.04	33.80	52.85	76.16
0000	211,600	10.62	23.92	42.48	66.42	95.68
	250 000	12.58	28.33	50.32	78.67	113.32
	500,000	25.17	56.66	100.68	157.35	226.64

Example.—What size wire is required to deliver 500 kw. at 6,000 volts a distance of 12 miles; energy loss, 10 per cent.; power factor, 85 per cent.?

Solution.—To transmit 100 kw. one would look in the 6,000-volt column for value nearest to 12 miles and use size of wire corresponding. To transmit five times this power or 500 kw., find the value corresponding most closely to $5 \times 12 = 60$ miles in the 6,000-volt column. Nearest value is 60.44 miles, which corresponds to No. 00 wire. No. 00 is the size required. To ascertain wire size to give a 5 per cent. loss—one-half the loss for which table is computed—multiply the distance of transmission by 2 before finding wire size.

SECTION II

GENERATORS AND MOTORS

PRINCIPLES, CHARACTERISTICS AND MANAGEMENT OF DIRECT-CURRENT MOTORS AND GENERATORS

1. **Direct-current generators** develop a direct or continuous e.m.f., that is, one that is always in the same direction. Commercial direct-current generators have commutators and may thereby be distinguished from alternating-current machines. The function of the commutator and the elementary ideas of generation of e.m.f. and of commutation are discussed in the First Section. See Index. Additional information in regard to commutation as applied to direct-current motors, which is in general true for direct-current generators, is given hereinafter.

2. **Excitation of Generator Fields.**—To generate an e.m.f. conductors must cut a magnetic field which in commercial machines must be relatively strong. A permanent magnet can be used for producing such a field in a generator of small output, such as a telephone magneto or a generator for sparking for an automobile; but for generators for light and power the field is produced by electro-magnets, which may be excited by the machine itself or "separately excited" from another source.

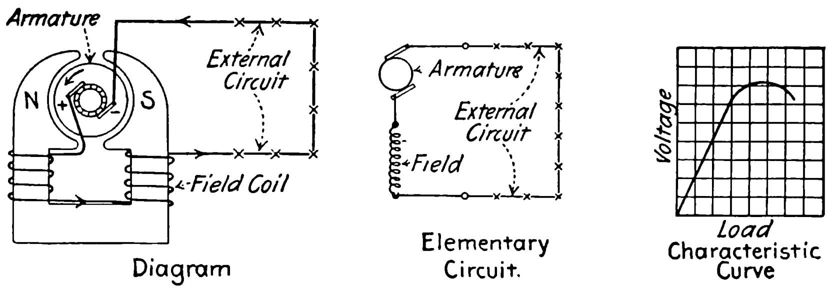


FIG. 1.—Series generator diagrams.

3. **Series-wound or constant-current generators** have their armature coils, field coils and external circuits in series with one another. (See Fig. 1.) Series generators are now used commercially only for series arc-lighting circuits and are equipped with automatic regulators to maintain the current constant irrespective of the resistance of the external circuit, *i.e.*, the number of lamps in service. The same current passes through each lamp in the series and the generator. The voltage at the brushes of a series machine is equal to (neglecting a small line loss) the voltage per lamp times the number of lamps. Thus on a circuit of 100 lamps each requiring 50 volts the brush pressure would be $100 \times 50 = 5{,}000$ volts. As shown by the curve of Fig. 1 up to a certain maximum value with an increase in load—resistance in this case—the voltage of the generator increases, tending to keep the current

constant. Automatic regulation to maintain constant current is usually effected, commercially, by either shifting the brushes or by cutting in and out portions of the field winding or by a combination of the two methods.

In Fig. 2 are shown the essentials of an arrangement for regulation by brush shifting. The course of the main current is indicated by the heavy line. When the current is at normal value the *contactor* is held midway between the contacts C_1 and C_2 by the spring. If the current increases slightly the core is pulled down into *solenoid* and brings the *contactor* with it, which makes contact with C_2. This permits a small current in shunt with the solenoid to flow through the *clutch B*, the mechanical details of which are not shown. This *clutch* pulls the *shifting rod* down and so shifts the brushes as to tend to maintain the current at a constant value. A decrease in current allows the spring to pull the *contactor* against C_1; *clutch A* operates and the brushes are shifted in the opposite direction. The principle of an arc-light (constant current) machine that is regulated by field variation is illustrated in Fig. 3. The *lever L* is shifted automatically and cuts in or out turns of the field magnet so as to maintain a constant current in the external circuit.

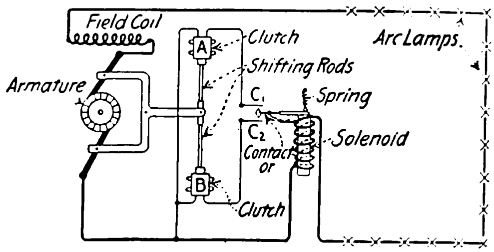


FIG. 2.—Essentials of brush-shifting mechanism for a constant-current generator.

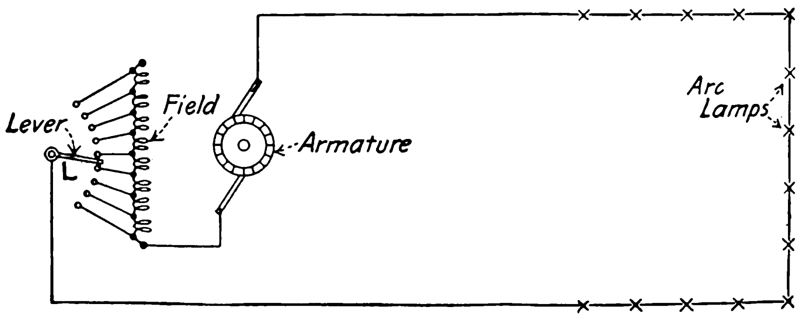


FIG. 3.—Regulation of an arc-lamp machine by field variation.

4. Separately excited generators are used for electro-plating and for other electrolytic work where it is essential that the polarity of a machine be not reversed. Self-excited machines may change their polarities. The essential diagrams are shown in Fig. 4. The fields may be excited from any direct-current constant potential source, such as a storage battery or lighting circuit.

The field magnets can be wound for any voltage because they have no electrical connection with the armature. With a constant field excitation, the voltage will drop slightly from no-load to full-load because of armature drop and armature reaction.

5. **The shunt-wound generator** is shown diagrammatically in Fig. 5. Shunt generators are now seldom used. They have been superseded by compound-wound machines. A small part of the total current, the exciting current, is shunted through the fields. The exciting current varies from possibly 5 per cent. of the total current in small machines to 1 per cent. in large ones. The exciting current is determined by the voltage at the brushes and

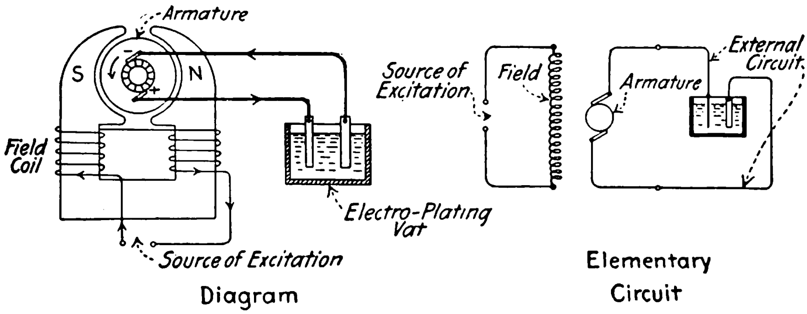


FIG. 4.—Separately excited generator diagrams.

the resistance of the field winding. Residual magnetism in the field cores permits a shunt-generator to "build up." This small amount of magnetism that is retained in the field cores induces a voltage in the armature (Timbie's *Elements of Electricity*). This voltage sends a slight current through the field coils which increases the magnetization. Thus, the induced voltage in the armature is increased. This in turn increases the current in the fields, which still further increases the magnetization, and so on, until the satu-

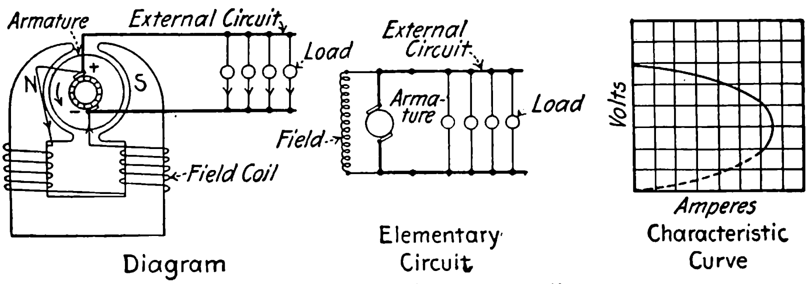


FIG. 5.—Shunt-wound generator diagrams.

ration point and normal voltage of the machine are reached. This "building up" action is the same for any self-excited generator and often requires 20 to 30 sec.

If a shunt generator (Timbie) runs at constant speed, as more and more current is drawn from the generator, the voltage across the brushes falls slightly. This fall is due to the fact that it requires more and more of the generated voltage to force this increasing current through the windings of the armature. That is, the armature *IR* drop increases. This leaves a smaller part of

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the total e.m.f. for brush e.m.f., and then when the brush pressure falls, there is a slight decrease in the field current which is determined by the brush pressure. This causes the total e.m.f. to drop a little, which still further lowers the brush potential. These two causes combine to gradually lower the brush pressure (voltage) especially at heavy overloads. The curve in Fig. 5 shows these characteristics. For small loads the curve is nearly horizontal, but at heavy overloads it shows a decided drop. The point where the output of a commercial machine drops off is beyond the operating range and is only of theoretical interest.

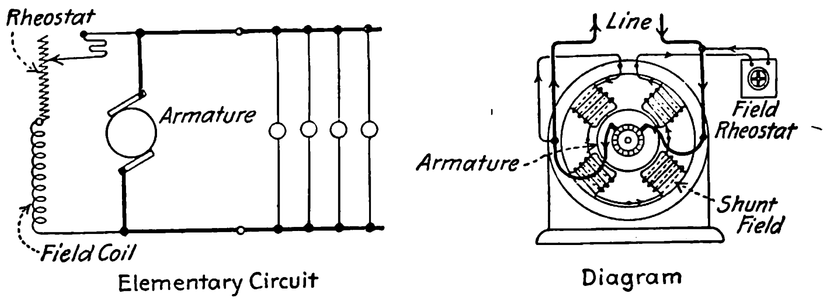

FIG. 6.—Shunt-wound generator with rheostat.

The voltage of a shunt machine may be kept fairly constant by providing extra resistance in the field circuit, see Fig. 6, which may be cut out as the brush potential falls. This will allow more current to flow through the field coils and increase the number of magnetic lines set up in the magnetic circuit. If the speed is kept constant, the armature conductors cut through the stronger magnetic field at the same speed, and thus induce a greater e.m.f. and restore the brush potential to its former value. This resistance may be cut out either automatically or by hand. See *Rheostat*, Index.

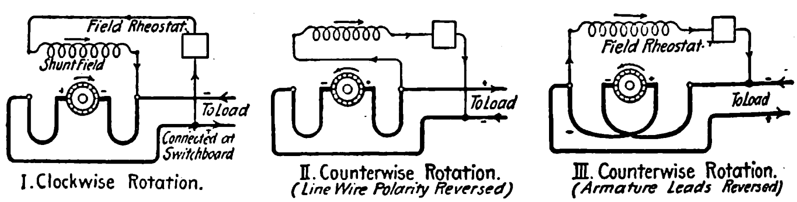

FIG. 7.—Changing rotation direction of shunt machine.

6. A shunt-wound generator gives a fairly constant voltage, even with varying loads, and can be used for incandescent lighting and other constant potential loads. These generators do not operate well in parallel, partially because the voltage of one machine may rise above that of the others and it will run them as motors. Shunt generators running in parallel do not "divide the load" well between themselves. They are seldom installed now, as compound-wound generators are more satisfactory for most purposes. Shunt generators may be bipolar (two poles) or multipolar (more than two poles) similarly to compound-wound generators. See the following paragraphs.

7. **How to reverse the direction of rotation** of a shunt-wound machine is indicated in Fig. 7. Rotation is *clockwise* when, facing the commutator end of a machine, the rotation is in the direction

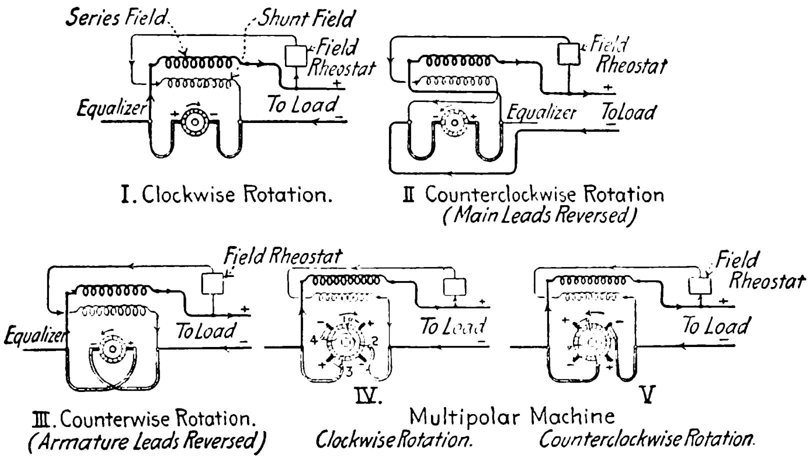

FIG. 8.—Changing rotation direction of compound machine.

of the hands of a clock. *Counter-clockwise* rotation is the reverse. It is desirable, when changing the direction of rotation, not to reverse the direction of current through the field windings. If it is reversed the magnetism developed by the windings on starting will oppose the residual magnetism and the machine may not "build-up." Connections for reversing compound machines are

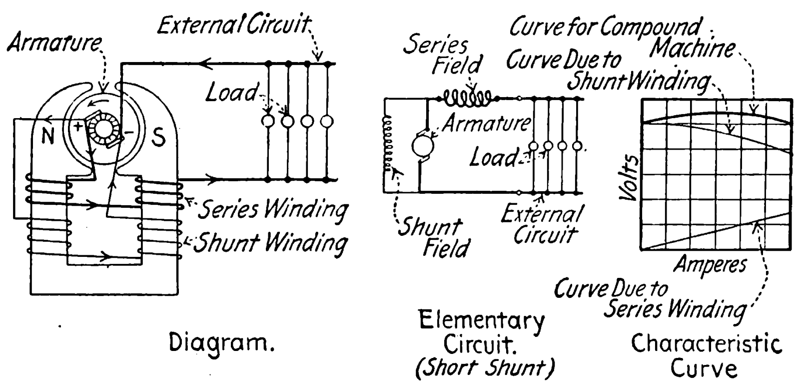

FIG. 9.—Compound-wound generator diagrams.

shown in Fig. 8. A multipolar machine can be reversed as shown by reversing the brushes on the studs and then re-locating them on the neutral points.

8. **The compound-wound generator** is shown diagrammatically in Fig. 9. If a series winding be added to a shunt generator

(Fig. 5), the two windings will tend to maintain a constant voltage as the load increases. The magnetization due to the series windings increases as the line current increases, which will cause the voltage generated by the armature to rise. The drop of voltage at the brushes that occurs in a shunt generator is thus compensated for. See also Figs. 15, 16 and 17.

9. **A flat-compounded generator** is one having its series coils so proportioned that the voltage remains practically constant at all loads within its range.

10. **An over-compounded generator** has its series windings so proportioned that its full-load voltage is greater than its no-load voltage. Over-compounding is necessary where it is desirable to maintain a practically constant voltage at some point out on the line distant from the generator. It compensates for line drop. The characteristic curve (Fig. 9) indicates how the terminal voltage of a compound-wound machine is due to the action of both shunt and series windings. The voltage of the compound generator at any load is equal to the sum of the voltage due to shunt winding plus that due to the series winding. Generators are usually over-compounded so that the full-load voltage is from 5 per cent. to 10 per cent. greater than the no-load voltage.

Although compound-wound generators are usually provided with a field rheostat, it is not intended for regulating voltage as the rheostat of a shunt-wound machine is. It is provided to permit of initial adjustment of voltage and to compensate for changes of the resistance of the shunt winding caused by heating. With a compound-wound generator, the voltage having been once adjusted, the series coils automatically strengthen the magnetic field as the load increases. For direct-current power and lighting work, compound-wound generators are used almost universally.

11. **If a compound-wound generator is short-circuited** the field strength due to the series windings will be greatly increased, but the field due to the shunt winding will lose its strength. For the instant or so that the shunt magnetization is diminishing a heavy current will flow. If the shunt magnetization is a considerable proportion of the total magnetization the current will decrease after the heavy rush and little harm will be done if the armature has successfully withstood the heavy rush. However, if the series magnetization is quite strong in proportion to the shunt, their combined effect may so magnetize the fields that the armature will be burnt out.

12. **A short-shunt compound-wound generator** has its shunt field connected directly across the brushes. (See Fig. 9.) Generators are usually connected in this way because it tends to maintain the shunt field current more nearly constant on variable loads, as the drop in the series winding does not directly affect the voltage on the shunt field with this arrangement.

13. **A long shunt generator** has its shunt field winding connected across the terminals of the generator. (See Fig. 10.)

14. **Three-wire direct-current generators** are discussed, as regards their application to three-wire systems, in the first section. See index. They are ordinary direct-current generators with the

modifications and additions described below. They are usually wound for 125–250 volt three-wire circuits. In commercial three-wire generators (*Westinghouse Electric & Manufacturing Co.*) four equidistant taps are made in the armature winding, and each pair of taps diametrically opposite each other is connected together through a balance coil. (See Fig. 11.) The middle points of the two balance coils (see Index) are connected together and this junction constitutes the neutral point to which the third or neutral wire of the system is connected. A constant voltage is maintained between the neutral and outside wires which, within narrow limits, is one-half the generator voltage. The generator shaft is extended at the commutator end for the collector rings. Four collector brushes and brush-holders are used in addition to the regular direct-current brushes and brush-holders.

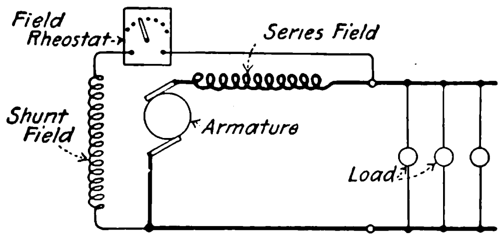

FIG. 10.—Long-shunt compound-wound generator.

15. The series coils of compound-wound three-wire generators are divided into halves (see Fig. 12), one of which is connected to the positive and one to the negative side. This is done to obtain compounding on either side of the system when operating on an unbalanced load. To understand this, consider a generator with the series field in the negative side only and with most of the load on the positive side of the system. The current flows from the positive brush through the load and back along the neutral wire without passing through the series field. The generator is then operating as an ordinary shunt machine. If most of the load be on the negative side, the current flows out the neutral wire and back through the series fields, boosting the voltage (on that side only). Such operation is evidently not satisfactory, and so the divided series fields are provided.

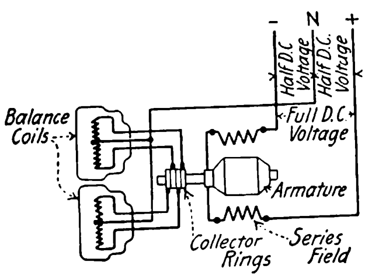

FIG. 11.—Diagram showing connections for three-wire generator.

16. As there are two series fields, two equalizer buses are required when several three-wire machines are installed (see Fig. 12) and are to be operated in multiple. The two equalizers serve to distribute the load equally between the machines and to prevent cross currents due to differences in voltage on the different generators. Because of the equalizer connections, two small terminal boards are supplied, one for each side of the generator. Arrangement is also made for ammeter shunts on the terminal boards.

An ammeter shunt is mounted directly on each of the contact boards of the machine. The total current output of the machine can thereby be read at the switchboard. As the shunts are at the machine, there is no chance for current to leak across between generator switchboard leads without causing a reading on the ammeters. Two ammeters must be provided for reading the current in the outside wires. It is important that the current be measured on both sides of the system, for with an ammeter in one side of the system only, it is possible for a large unmeasured current to flow in the other side with disastrous results.

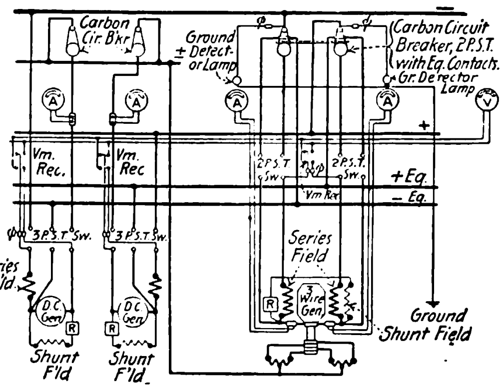

Fig. 12.—One three-wire direct-current generator, 125–250 volts, in parallel with two two-wire generators, 125 volts. Diagram of connections.

17. Wires connecting the balance coils to a three-wire generator must be short and of low resistance. Any considerable resistance in these will affect the voltage regulation. The unbalanced current flows along these connections; consequently, if they have much resistance, the resulting drop in voltage reduces the voltage on the heavily loaded side.

Switches are ordinarily not placed in the circuits connecting the four collector rings to the balance coils. When necessary, the coils may be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance-coil connections to the switchboard and back, requiring heavy leads to keep the drop low; or if heavy leads are not used, then poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them that will not be taken care of by the main circuit breakers. Complete switchboard connection diagrams are given in Figs. 12, 13 and 14.

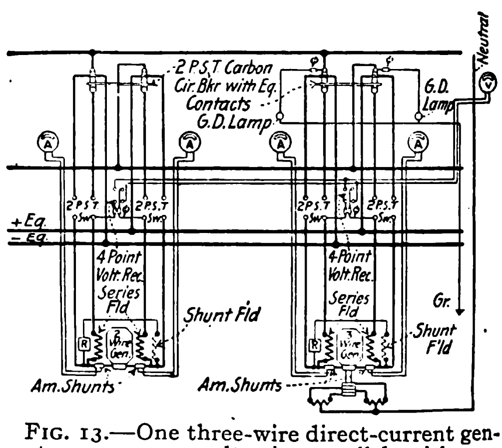

Fig. 13.—One three-wire direct-current generator, 125–250 volts, in parallel with one two-wire generator, 250 volts. Diagram of connections.

18. To Start a Shunt-wound Generator.—Note the directions in 21 concerning the oiling arrangements and bringing the machine up to speed. (1) See that the machine is entirely disconnected from the external circuit. This is not always necessary, but is safest. See that the field resistance is all in circuit. (2) Start the armature turning. (3) When the armature is up to speed, cut out field resistance until the voltage of the machine is normal or equal to that on the bus-bars. (4) Close the line switch, watching the ammeter and voltmeter and make further adjustment with the field rheostat if necessary.

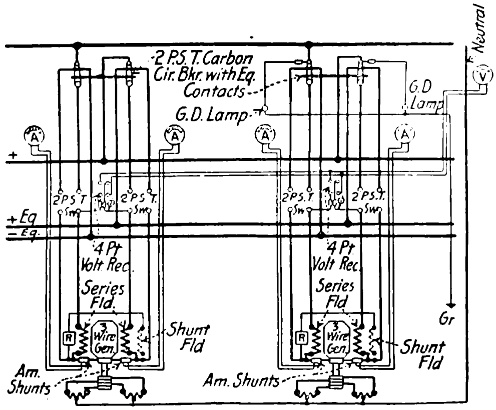

FIG. 14.—Diagram of connections of two three-wire direct-current generators operating in parallel, 125–250 volts.

19. Approximate Data on Standard, Compound-wound, Direct-current, Commutating-pole Generators

The efficiency of a generator depends on its design, and, to a certain extent, on its speed and voltage. Average values are given in the following table that are fairly representative of modern practice.

Kilowatts capacity	Output current, amperes			Efficiency, per cent.		
	125 volts	250 volts	500 volts	½ load	¾ load	Full-load
5	40	20	10	77.0	81.0	82.5
10	80	40	20	82.0	85.0	86.0
15	120	60	30	82.5	86.5	86.5
20	160	80	40	84.0	86.5	87.5
25	200	100	50	85.0	88.0	89.0
35	280	140	70	87.0	89.0	89.5
50	400	200	835	88.0	89.5	90.5
60	480	240	120	88.5	90.5	91.0
75	600	300	150	88.5	90.5	91.0
90	720	360	180	88.5	90.5	91.0
100	800	400	200	89.0	90.5	91.0
125	1,000	500	250	90.5	91.0	91.0
150	1,200	600	300	90.5	91.3	91.5
200	1,600	800	400	91.0	91.5	92.0
300	2,400	1,200	600	91.3	91.8	92.0
400	3,200	1,600	800	91.8	92.3	92.5
500	4,000	2,000	1,000	91.8	92.2	92.5
750	6,000	3,000	1,500	92.0	92.3	92.5
1,000	8,000	4,000	2,000	92.5	93.0	93.5

20. Nearly all commercial direct-current generators have more than two poles. In some of the preceding diagrams only two were shown so that the diagrams would be simple. A two-pole machine is a bipolar machine; one having more than two poles is a multipolar machine. Fig. 15 shows the connections and the direction of the magnetic flux of a four-pole machine. Diagrams for machines having more poles would be similar. In multipolar machines there is usually one set of brushes for each pair of poles, but with series-wound armatures, such as are used for railway

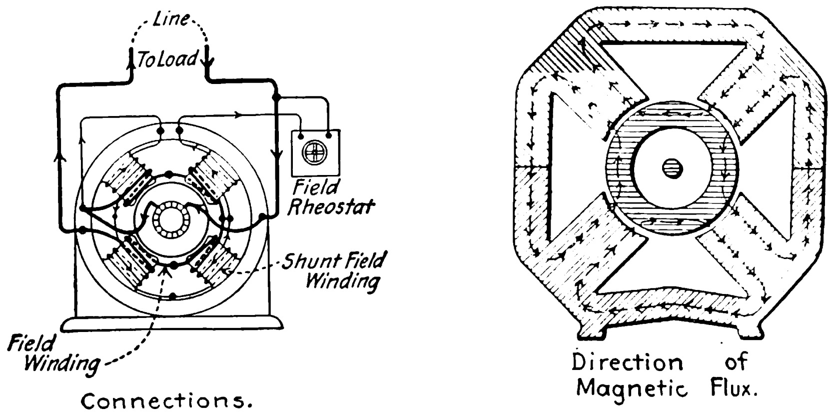

FIG. 15.—Diagrams for four-pole compound-wound generator.

motors, one set of brushes may suffice for a multipolar machine. The connections of different makes of machines vary in detail and the manufacturers will always furnish complete diagrams so no attempt will be made to give them here. The directions of the field windings on generator frames are given in Fig. 16. The directions of the windings on machines having more than four poles are similar in general to those of the four-pole machines.

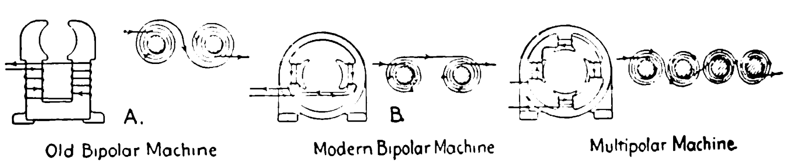

FIG. 16.—Direction of field windings on generator frames.

21. To Start a Compound-wound Generator.—(1) See that there is enough oil in the bearings, that the oil rings are working, and that all field resistance is cut in. (2) Start the prime mover slowly and permit it to come up to speed. See that the oil rings are working. (3) When machine is up to normal speed, cut out field resistance until voltage of the machine is normal or equal to or a trifle above that on the bus-bars. (4) Throw on the load. If three separate switches are used, as in Fig. 17, close the equalizer switch first, the series coil line switch second, and the other line switch third. If a three-pole switch is used, as in Fig. 18, all three poles are, of course, closed at the same time. (5) Watch the voltmeter and ammeter and adjust the field rheostat until the machine takes its share of the load. A machine generating the higher voltage will take more than its share of the load and if its voltage is too high it will run the other as a motor.

22. To Shut Down a Compound-wound Generator Operating in Parallel with Others.—(1) Reduce the load as much as possible by throwing in resistance with the field rheostat. (2) Throw off the load by opening the circuit-breaker, if one is used, otherwise open the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine and put it in good order for the next run.

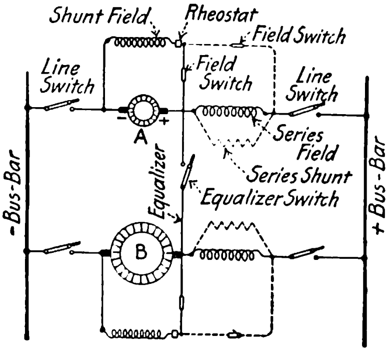

FIG. 17.—Elementary connections for parallel operation of compound-wound generators.

If the machine is operating independently and no motors are connected to the circuit, close the engine throttle valve and permit the engine and generator to come to rest. Turn all resistance in the field rheostat. Open the main switch. Where motors are served they must be disconnected first. If they are not, a loaded

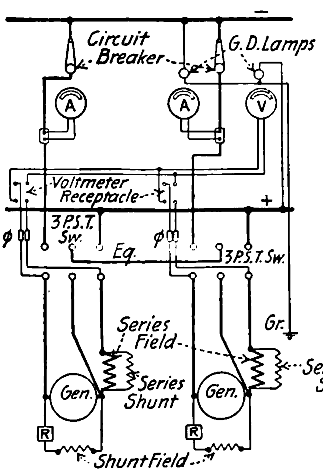

FIG. 18.—Diagram of connections of two compound-wound generators to switchboard (Westinghouse).

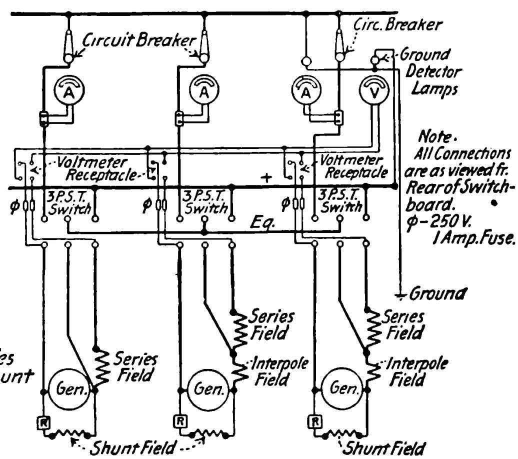

FIG. 18A.—Diagram of connections of two direct-current commutating-pole generators in parallel with one generator without commutating poles.

motor may stop when the impressed voltage decreases somewhat below normal. Then, since its armature is not turning, it is in effect a short-circuit and may blow fuses or make other trouble.

23. To Shut Down a Shunt-wound Generator.—(1) Reduce the load as much as possible by throwing in resistance with the field rheostat. (2) Throw off the load by opening the circuit-breaker, if one is used, otherwise open the feeder switches and finally the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine and put it in good order for the next run.

24. **Parallel Operation of Shunt Generators.**—As suggested in 6 shunt-wound generators do not operate very well in parallel because they do not divide the load well and the voltage of one is apt to rise above that of another and drive it as a motor. When it is running as a motor its direction of rotation will be the same as when it was generating, hence the operator must watch the ammeters closely for an indication of this trouble. Shunt generators are now seldom installed and are seldom operated in parallel, although they will work that way. Where there are several in

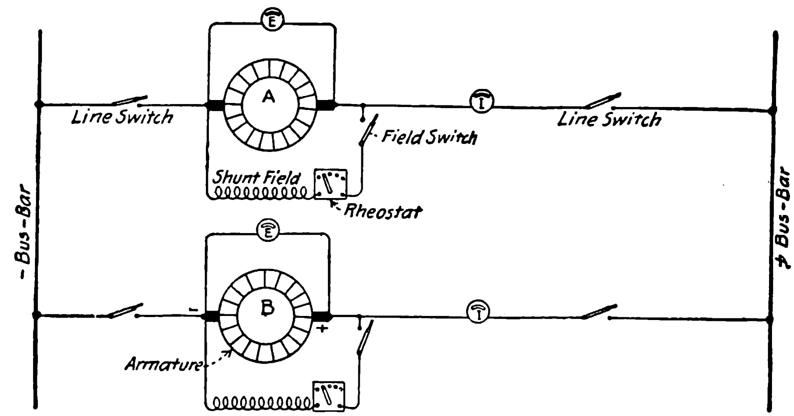

FIG. 19.—Connections for shunt generators for parallel operation.

a plant the best arrangement is to divide the total load between them, giving each its own distinct circuit. Fig. 19 shows the connections for shunt generators that are to be operated in parallel.

25. **Parallel operation of compound-wound generators** is readily effected if the machines are of the same make and voltage or are designed with similar electrical characteristics (*Westinghouse Co.*). The only change usually required is the addition of an equalizer connection between machines. If the generators have different compounding ratios it may be necessary to readjust the series field shunts to obtain uniform conditions.

26. **An equalizer, or equalizer connection,** connects two or more generators operating in parallel at a point where the armature and series field leads join (see Fig. 17), thus connecting the armatures in multiple and the series coils in multiple, in order that the load will divide between the generators in proportion to their capacities. The arrangement of connections to a switchboard (*Westinghouse*) is shown in Fig. 18. Consider, for example, two compound-wound machines operating in parallel without an equalizer. If, for some reason, there is a slight increase in the speed of one machine, it would take more than its share of load. The increased current

flowing through its series field would strengthen the magnetism, raise the voltage, and cause the machine to carry a still greater amount until it carried the entire load. Where equalizers are used, the current flowing through each series coil is proportional to the resistance of the series coil circuit and is independent of the load on any machine; consequently an increase of voltage on one machine builds up the voltage of the other at the same time, so that the first machine cannot take all the load but will continue to share it in proper proportion with the other generators.

27. **Operation of a shunt and a compound dynamo in parallel** is not successful because the compound machine will take more than its share of the load unless the shunt machine field rheostat is adjusted at each change in load.

28. **Three-wire direct-current generators can be operated in multiple** (*Westinghouse Publication*) with each other and in multiple with other machines on the three-wire system (see Figs. 12, 13 and 14). When operating a three-wire, 250-volt generator in multiple with two-wire, 125-volt generators, the series fields of the two two-wire generators must be connected, one in the positive side and one in the negative side of the system, and an equalizer must be run to each machine. Similarly, when operating a three-wire, 250-volt generator in multiple with a 250-volt, two-wire generator, the series field of the 250-volt, two-wire generator must be divided and one-half connected to each outside wire. The method of doing this is to disconnect the connectors between the series field coils and reconnect these coils so that all the N pole fields will be in series on one side of the three-wire system and all the S pole fields in series on the other side of the system.

29. **Switchboard Connections for Three-wire Generators.**—Fig. 12 is a diagrammatical representation of the switchboard connections for two three-wire generators operated in multiple (*Westinghouse Publication*). Two ammeters indicate the unbalanced load. The positive lead and equalizer are controlled by a double-pole circuit-breaker; the negative lead and equalizer likewise. Note that both the positive and negative equalizer connections as well as both the positive and negative leads are run to the circuit-breakers in addition to the main switches on the switchboard. It is necessary that this be done in all cases. Otherwise, when two or more machines are running in multiple and the breaker comes out, opening the main circuit to one of them but not breaking its equalizer leads, its ammeter is left connected to the equalizer bus-bars and current is fed into it from the other machines through the equalizer leads, either driving it as a motor or destroying the armature winding. (See also Figs. 13 and 14.)

30. **Commutating-pole machines will run in multiple** with each other and with non-commutating-pole machines provided correct connections are made. See illustrations. The series field windings on commutating-pole machines are usually less powerful than on non-commutating-pole; and particular attention should, therefore, be paid to getting the proper drop in accordance with instructions of **32.** A connection diagram is shown in Fig. 18, *A*.

31. **Testing for Polarity.**—When a machine that is to operate

in parallel with others is connected to the bus-bars for the first time it should be tested for polarity. The + lead of the machine should connect to the + bus-bar and the − lead to the − bus-bar (Fig. 20, *I*). The machine to be tested should be brought up to normal voltage, but not connected to the bars. The test can be made with two lamps (Fig. 20, *II*), each lamp of the voltage of the circuit. Each is temporarily connected between a machine terminal and bus terminal of the main switch. If the lamps do not burn, the polarity of the new machine is correct, but if they burn brightly its polarity is incorrect and should be reversed. A voltmeter can be used (Fig. 20, *III*). A temporary connection is

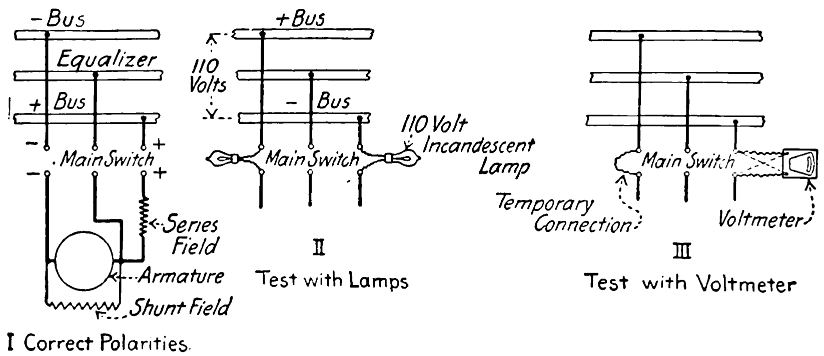

FIG. 20.—Tests for polarity.

made across one pair of outside terminals and the voltmeter is connected across the other pair. No or a small deflection indicates correct polarity. (Test with voltmeter leads one way and then reverse them, as indicated by the dotted lines.) A full-scale deflection indicates incorrect polarity. Use a voltmeter having a voltage range equal to twice the voltage on the bus-bars.

32. **To adjust the division of load between two compound-wound generators:** First adjust the series shunts of both machines so that, as nearly as possible, the voltages of both will be the same at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full-load. Then connect the machines in parallel, as suggested in Fig. 17, for trial. If upon loading, one machine takes more than its share of the load (amperes), increase the resistance of the path through its series-field coil path until the load divides between the machines proportionally to their capacities. Only a small increase in resistance is usually needed. The increase may be provided by inserting a longer conductor between the generator and the bus-bar, or iron or German-silver washers can be inserted under a connection lug. Inasmuch as (when machines are connected in parallel) adjustment of the series coil shunt affects both machines similarly, nothing can be accomplished through making such adjustment.

33. **A series shunt for a compound generator** consists of a low-resistance connection across the terminals of the series field (see Figs. 17 and 18) by means of which the compounding effect

of the series winding may be regulated by shunting more or less of the armature current past the series coils. It may be in the form of grids, on large machines, or of ribbon resistors. In the latter case it is usually insulated and folded into small compass.

34. Connecting Leads for Compound Generators.—See that all the cables that lead from the various machines to the bus-bars are of equal resistance. This means that if the machines are at different distances from the switchboard, different sizes of wire should be used, or resistance inserted in the low-resistance leads. See **32.**

With generators of small capacity the equalizer is usually carried to the switchboard, as suggested in Fig. 18A, but with larger ones it is carried under the floor directly between the machines (Fig. 21). In some installations the positive and the equalizer switch of each machine are mounted side by side on a pedestal near the generator (Fig. 21). The difference in potential between the two switches is only that due to the small drop in the series coil. The positive bus-bar is carried along under the floor near the machines. This permits of leads of minimum length. Leads of equal lengths should be used for generators of equal capacities. If the capacities are unequal (see **32**) it may be necessary to loop the leads. (See Fig. 21.)

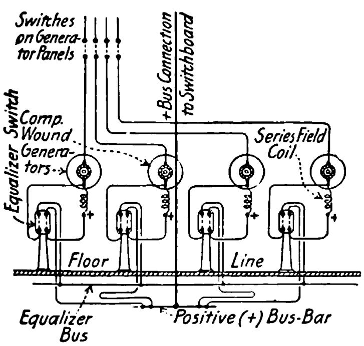

FIG. 21.—Equalizer carried directly between machines.

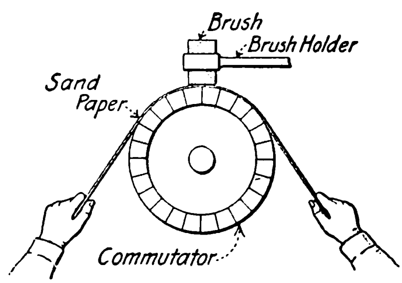

FIG. 22.—Sandpapering brushes.

35. Ammeters for compound generators should, as in Fig. 18, always be inserted in the lead not containing the compound winding. If cut in the compound winding lead the current indications will be inaccurate because current from this side of the machine can flow either through the equalizer or the compound-winding lead.

36. Brushes, their Adjustment and Care (*Westinghouse Instruction Book*).—The position of the brushes on a direct-current machine should be on or near the no-load neutral point of the commutator. This neutral point on most standard, non-commutating pole machines is in line with the center of the pole and the brushes should be set a little in advance of this neutral point. The brushes of non-commutating pole generators should be given a slight "forward lead" in the direction of rotation of the armature. Motor brushes should be set somewhat back of the neutral point, the "backward lead" in this case being approximately equal to the forward lead on generators. The exact position in either case is that which gives the best commutation at normal voltage for all loads. In no case should the brushes be set far enough from the neutral point to cause dangerous sparking at no-load.

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing faces. This can be most easily accomplished after the brush holders have been adjusted and the brushes inserted as follows: Lift a set of brushes sufficiently to permit a sheet of sandpaper to be inserted. Draw the sand-paper in one direction only, preferably in the direction of rotation, under the brushes (Fig. 22) being careful to keep the ends of the paper as close to the commutator surface as possible and thus avoid rounding the edges of the brushes, each set of brushes being similarly treated in turn. Start with coarse sand paper and finish with fine sand paper. If the brushes are copper plated, their edges should be slightly beveled, so that the copper does not contact with the commutator.

37. Current Taken by Direct-current Motors

Horse-power	Total amperes		
	110 volts	220 volts	500 volts
1	9	4.5	2.0
2	17	8.5	3.7
3	26	13	5.6
5	40	20	8.8
7.5	60	30	13
10.	76	38	17
15	112	56	25
20	150	75	33
25	188	94	41
30	226	113	50
40	302	151	66
50	368	184	81
75	552	276	122
100	736	368	162
150	1,110	555	244
200	1,474	737	324

38. Commutating-pole Generators and Motors, Fig. 23 (*Standard Handbook*).—The principal advantage of the commutating pole construction resides in the fact that with it the commutation can be rendered practically perfect under any condition of service.

39. The object in using the commutating-pole is to produce within the armature coil under commutation an e.m.f. of the proper value and sign to reverse the current in the coil while it is yet under the brush—a result that is essential to perfect commutation. The variation in the flux distribution in the air-gap of a commercial direct-current machine of the ordinary shunt-wound type, at no-load and under full-load, is shown in Fig. 24. Consider now the value and position of the flux in the coil under the brush when the machine is operating at full-load. The motion of the armature through this flux causes the generation within the coil of an e.m.f., and the sign of this e.m.f. is such as to tend to cause the current in the coil to continue in the direction which it had before the coil reached the brush, and hence it opposes the desired reversal of the current before the coil leaves the brush.

There is an additional detrimental influence which tends to retard the rapid reversal of the current even when all other influences are absent. This latter influence is due to the local magnetizing effect of the current in the coil under the brush. On account of this there

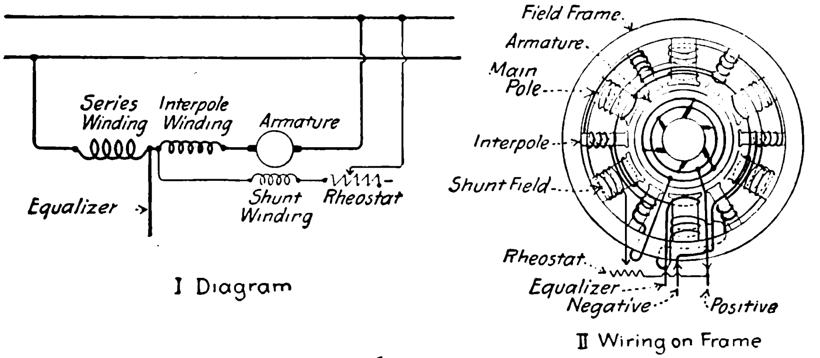

Fig. 23.—Diagram of compound-wound commutating-pole machines.

surround the conductor lines of force, the change in the value of which, with the fluctuations of the current as it tends to be reversed, generates in the coil an e.m.f. which opposes the change in the value of the current. This reactive e.m.f. is in the same direction as that due to the cutting of the flux by the coil under the brush and is likewise proportional to the speed.

It will be apparent that even were the field distortion completely neutralized, the detrimental reactive e.m.f. would yet remain.

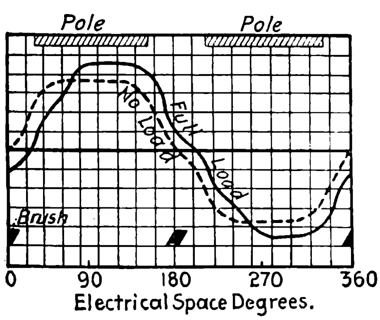

Fig. 24.—Distribution of magnetic flux at no load and at full load, without commutating poles.

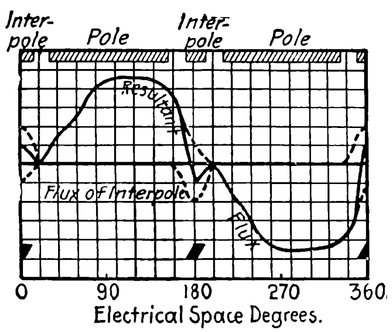

Fig. 25.—Distribution of magnetic flux at full load, with and without commutating poles.

The improved and practically perfect commutation of the commutating-pole motor is due to the fact that the flux, which is locally superposed upon the main field, not only counterbalances the undesirable main flux cut by the coil under the brush, but it causes to be generated within the coil an e.m.f. sufficient to equal and oppose the reactive e.m.f. just referred to. This effect will be appreciated from a study of Fig. 25, which represents the distorted flux of the motor of the usual design, as shown in Fig. 24, and indicates the results to be expected when the flux due to the auxiliary or commutating pole is given the relatively proper value.

It is worthy of note that this desirable effect is the more pronounced the weaker the main field; and that the commutation voltage, if correct for a low speed, is correct for a high speed; and that with increase of load-current and main-field distortion there is a proportional increase of counter-magnetizing field produced in the coil under the brush, up to the point of magnetic saturation of the auxiliary pole; and that sparkless operation is insured for all operating ranges both of speed and load.

40. **Commutating-pole, direct-current generators** are similar in construction and operation to commutating-pole motors. Ordinary generators (*Westinghouse Co.*) that operate under severe overloads and over a wide speed range are liable to spark under the brushes at the extreme overloads and at the higher speeds. This is because the field due to the armature current distorts the main field to such an extent that the coils being commutated under the brush are no longer in a magnetic field of the proper direction and strength. To overcome this, interpoles are placed between the main poles. (See Fig. 23.) These interpoles introduce a magnetic field of such direction and strength as to maintain the magnetic field, at the point where the coils are commutated, at the proper strength for perfect commutation. Commutating-poles are sometimes called interpoles but probably "*commutating-pole*" is the preferable term.

The winding in the interpoles is connected in series with the armature so that the strength of the corrective field is proportional to the load. The adjustment and operation of interpole generators is not materially different from that of non-interpole machines.

When the brush position of an interpole machine has once been properly fixed, no shifting is afterward required or should be made, and most interpole generators are shipped without any shifting device. An arrangement for securely clamping the brush-holder rings to the field frame is provided.

In interpole apparatus accurate adjustment of the brush position is necessary. The correct brush position is on the no-load neutral point, which is located by the manufacturer. A templet is furnished with each machine or some other provision is made whereby the brush location can be determined in the field. If the brushes are given a backward lead on an interpole generator, the machine will over-compound and will not commutate properly. With a forward lead of the brushes, a generator will under-compound and will not commutate properly.

41. **The action of the magnetic flux in a commutating-pole generator** is illustrated in Fig. 26. The direction of the main field flux is shown by the dashed line. The direction of the armature magnetization is shown by the dotted lines. The direction of the flux in the interpole is shown by the full line. It is evident that the interpole flux is in a direction opposite to that of the armature flux, and as the interpole coil is more powerful in its magnetizing

action than the armature coils, the flux of the armature coils is neutralized. With a less powerful magnetizing force from the interpole than from the armature, the armature would overpower the interpole and reverse the direction of the flux, which would result in a very bad commutating condition.

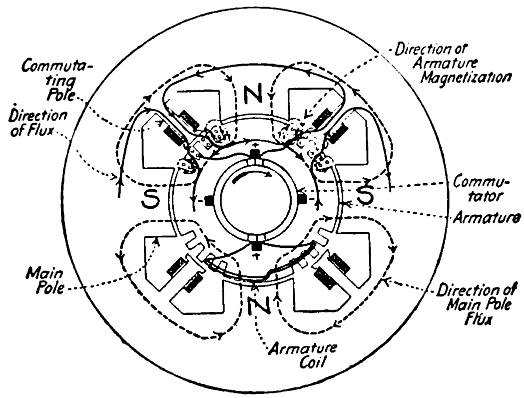

FIG. 26.—Distribution of flux in a commutating-pole generator.

42. **Commutating-pole, Three-wire Generators.**—On three-wire generators connections are so made that one-half of the interpole winding is in the positive side and the other half is in the negative side. This insures proper action of the interpoles at unbalanced load. (See Figs. 12, 13 and 14 and the text accompanying them.)

43. **To reverse the direction of rotation of a commutating-pole generator,** reverse the shunt and series fields as in an ordinary generator.

TROUBLES OF DIRECT-CURRENT MOTORS AND GENERATORS—THEIR LOCALIZATION AND CORRECTION

Table No. 44.—Pages 174 to 184 inclusive—troubles of direct-current motors and generators.

44. Direct-current Generator and Motor Defects

(From *Machinery* by special permission)

Sparking at the brushes.	Faults of	Brushes.	Not set diametrically opposite.	*A*. Should have been set properly at first, by counting bars, or by measurement on the commutator. *B*. Can be done if necessary while running; move rocker until brush on one side sparks least, then adjust other brushes so they do not spark.	1
			Not set at neutral points.	Move rocker back and forth slowly until sparking stops.	2
			Not properly trimmed.	*A*. Brushes should be properly trimmed before starting. If there are two or more brushes one may be removed and retrimmed. *B*. Clean with alcohol or ether, then grind and reset carefully. *See* lines 1, 4, 38.	3
			Not in line.	Adjust each brush until bearing is on line and square on commutator bar, bearing evenly the whole width. *See* line 13 *A*.	4
			Not in good contact.	*A*. Clean commutator of oil and grit. See that brushes touch. *B*. Adjust tension screws and springs to secure light, firm and even contact. *See* line 38 *C*.	5
		Commutator.	Rough; worn in grooves or ridges; out of round.	*A*. Grind with fine sandpaper on curved block, and polish with crocus cloth. Never use emery in any form.	6
				B. If too bad to grind down turn off true in a lathe or preferably in its own bearings, with a light tool and rest, a light cut; running slowly. *Note*.—Armature should have $\frac{1}{16}$ to $\frac{1}{8}$ in. end motion when running, to wear commutator evenly and smoothly. *See* line 31.	7
			High bars.	Set "high bar" down carefully with mallet or block of wood, then clamp tightly end nuts, or file, grind or turn true. A high bar may cause singing. *See* line 38.	8
			Low bars.	Grind or turn commutator true to the surface of the low bars.	9
			Weak magnetic field.	*A*. Broken circuit } in field coils { Repair if external. *B*. Short circuit } in field coils { Rewind if internal. *C*. Machine not properly wound, or without proper amount of iron—no remedy but to rebuild it.	10

Direct-current Generator and Motor Defects (*Continued*)

Sparking at the brushes.	Excessive current in armature.	Generator.	Excessive load.	*A.* Reduce number of lamps and load.	11
			Ground and leak from short-circuit on line.	*B.* Test out, locate, and repair.	
			Dead-short circuit on line.	*C.* *Note.*—Dead short-circuit will or should blow safety fuse. Shut down, locate fault and repair before starting again, and put in a new fuse.	
		Motor.	Excessive voltage.	*D.* Use proper current only, and with proper rheostat and controller and switch.	
			Excessive amperes on constant-current circuit.	*E.* See that controller, etc., are suitable with ample resistance.	
			Friction.	*F.* Reduce load on motor to its rated capacity or less. *See* 3 *B* and 35, 36.	
			Too great load on pulley.	*G.* See that there is no undue friction or mechanical resistance anywhere.	
	Armature faults.		Short-circuited coils.	*A.* Remove copper dust, solder or other metallic contact between commutator bars. *B.* See that clamping rings are perfectly free, and insulated from commutator bars; no copper dust, carbonized oil, etc., to cause an electrical leak. *C.* Test for cross connection or short-circuit, and if such is found rewind armature to correct. *D.* See that brush holders are perfectly insulated. No copper dust, carbon dust, oil or dust, to cause an electrical leak. *See* lines 1, 2, 60.	12
			Broken coils.	*A.* Bridge the break temporarily by staggering the brushes, until machine can be shut down (to save bad sparking) and then repair. *B.* Shut down machine if possible, and repair loose or broken connection to commutator bar. *C.* If coil is broken inside, rewinding is the only sure remedy. May be temporarily repaired by connecting to next coil, across mica. *D.* Solder commutator lugs together, or put in a "jumper," and cut out, and leave open the broken coil. Be careful not to short-circuit a good coil in doing this. *See* line 12.	13
			Cross connections.	Cross connections may have same effect as short-circuit, treat as such, *see* line 12. Each coil should test complete without cross and no ground.	14

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts.	Armature.	Overloaded.		Overload. Too many amperes, lights, or too much power being taken from machine. *See* 11, 12, 13, 14.	15
		Short-circuit.		Short-circuited. Generally dirt, etc., at commutator bars. *See* 11,12,13,14.	16
		Broken circuit.		Broken circuit. Often caused by a loose or broken band. *See* 11,12,13,14.	17
		Cross connection.		Cross connection. Often caused by a loose coil abrading on another coil or core. *See* 11, 12, 13, 14.	18
		Moisture in coils.		Dry out by gentle heat. May be done by sending a small current through, or causing machine to generate a small current itself, by running slowly.	19
		Eddy currents in core.		Iron of armature hotter than coils after a run. Faulty construction. Core should be made of finely laminated insulated sheets. No remedy but to rebuild.	20
		Friction.		Hot boxes or journals may affect armature. *See* 23, 33 below.	21
	Field coils.	Excessive current.	Shunt.	*A.* Decrease voltage at terminals by reducing speed . Increase field resistance by winding on more wire, finer wire, or putting resistance in series with fields.	22
			Series.	*B.* Decrease current through fields by shunt, removing some of field winding or rewind with coarser wire.	
				Note.—Excessive current may be from a short circuit, or from moisture in coils, causing a leakage. *See* 10, 24.	
		Eddy currents.		Pole pieces hotter than coils after short run, due to faulty construction, or fluctuating current, if latter, regulate, and steady current.	23
		Moisture in coils.		Coils show less than normal resistance, may cause short circuit or body contact to iron of dynamo. Dry out as in 19. *See also* 22 *note*.	24
	Bearings.	Not sufficient or poor oil.		*A.* See that plenty of good mineral oil, filtered clean, and free from grit, feeds; but be careful that it does not get on commutator or brush holder. *See* 12. *B.* Cylinder oil or vaseline may be used if necessary to complete run, mixed with sulphur or white lead, or hydrate of potash. Then clean up and put in good order.	25

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts.	Bearings.	Dirt or grit in bearings.	*A.* Wash out grit with oil while running, then clean up and put in order. Be careful about flooding commutator and brush holder. *B.* Remove caps and clean and polish journals and bearings perfectly, then replace. See that all parts are free and lubricate well. *C.* When shut down, if hot, then remove bearings and let them cool naturally, then clean, scrape and polish, assemble; see that all parts are free and lubricate well.	26
		Rough journals or bearings.	Smooth and polish in a lathe, removing all burrs, scratches, tool marks, etc., and rebabbitt old boxes and fit new ones.	27
		Journals too tight in bearings; bent shaft.	Slacken cap bolts, put in liners and retighten till run is over, then scrape, ream, etc., as may be needed, bend or turn true in lathe or grinder. Possibly a new box or shaft will be needed.	28 29
		Bearings out of line.	Loosen bearing bolts, line up and block, until armature is in center of pole pieces, ream out dowel and bolt holes and secure in new position.	30
		End pressure of pulley hub or shaft collars.	*A.* See that foundation is level and armature has free end motion. *B.* If there is no end motion, file or turn ends of boxes or shoulders on shaft to provide end motion. *C.* Then line up shaft and belt, so that there is no end thrust on shaft, but that the armature plays freely endways when running.	31
		Belt too tight.	*A.* Reduce load so that belt may be loosened and yet not slip. Avoid vertical belts if possible. *B.* Choose larger pulleys, wider and longer belts with slack side on top. Vibrating and flapping belts cause winking lamps.	32
		Armature out of center of pole pieces.	*A.* Bearings may be worn out and need replacing, throwing armature out of center. *See* 36. *B.* Center armature in polar space, and adjust bearings to suit. *See* 30. *C.* File out polar space to give equal space all round. *D.* Spring pole away from armature; this may be difficult or impossible in large machines.	33

Direct-current Generator and Motor Defects (*Continued*)

Noises.		Armature or pulley out of balance.	Faulty construction, armature and pulley should have been balanced when made. May be helped by balancing on knife edges now.	34
		Armature strikes or rubs pole pieces.	*A*. Bend or press down any projecting wires, and secure with tie bands. *B*. File out pole pieces where armature strikes. *See* 30, 33.	35
		Collars or shoulders on shaft strike or rub box.	Bearings may be loose or worn out. Perhaps new bearings are needed. *See* 30, 31.	36
		Loose bolt connection or screws.	See that all bolts and screws are tight, and examine daily to keep them so.	37
		Brushes sing or hiss.	*A*. Apply stearic acid (adamantine) candle, vaseline, or cylinder oil to commutator and wipe off; only a trace should be applied. *B*. Move brushes in and out of holder to get a firm, smooth, gentle pressure, free from hum or buzz. *See* 3, 6, 7, 8, 9, 31.	38
		Flapping of belt.	Use an endless belt if possible, if a laced belt must be used, have square ends neatly laced.	39
		Slipping of belt from overload.	Tighten belt or reduce load. *See* 32.	40
		Humming of armature lugs or teeth.	*A*. Slope end of pole piece so that armature does not pass edges all at once. *B*. Decrease magnetism of field, or increase magnetic capacity of tooth.	41
Speed.	Runs too fast.	Engine fails to regulate with varying load.	Adjust governor of engine to regulate properly, from no-load to full-load, or get a better engine.	42
		Series motor, too much current, and runs away.	*A*. Series motor on constant current—(1) Put in a shunt and regulate to proper current; (2) use regulator or governor to control magnetism of field for varying load. *B*. Series motor on constant potential—(1) Insert resistance and reduce current; (2) use a proper regulator or controlling switch; (3) change to automatic speed-regulating motor.	43

Direct-current Generator and Motor Defects (*Continued*)

Speed.	Runs too fast.	Shunt motor.	Field rheostat not properly set.	*A*. Adjust field rheostat to control motor.	44
			Not proper current.	*B*. Use current of proper voltage and no other, with a proper rheostat.	
			Motor not properly proportioned.	*C*. Get a better motor, one properly designed for the work.	
	Runs too slow.	*See note below table.*		45, same as 42; 46, *see* 11 *A*; 47, short circuit in armature, *see* 12; 48 rubbing armature, *see* 35; 49, friction, *see* 3 *B*; 50, weak magnetic field, *see* 10.	
Motor.	Stop or fail to start.		Great overload. *See* 11 *F* and *G*.	Open switch, find and repair trouble. Keep switch open and rheostat "off" to see if everything is right.	51
			Excessive friction. *See* 25, 33, 35.	Shunt motor on constant potential circuit, fuse may blow or armature burn out.	52
		Circuit open.	Fuse melted or switch open.	*A*. Find and repair trouble after opening switch, then put in fuse. *See* 11 *C*.	53
			Broken wire or connection.	*B*. Open switch, find and repair trouble. *See* 13.	
			Brushes not in contact.	*C*. Open switch and adjust. *See* 5.	
			Current fails or is shut off at station.	*D*. Open switch and return starting box lever to off position, wait for current.	
			Short-circuit of field.	Test for and repair if possible. Examine insulation of binding posts and brush holders.	54
			Short-circuit of armature.	Poor insulation, dirt, oil, and copper, or carbon dust often result in a short-circuit.	56
			Short-circuit of switch.		
	Runs backward. Wrong connections.			Connect up correctly per diagram; if no diagram is at hand, reverse connections to brushes or others until direction of rotation is satisfactory.	57

Note from line 50.—45, Engine fails to regulate. 46, Overload. 47, Short-circuit in armature. 48, Striking or rubbing of armature. 49, Friction. 50, Weak magnetic field.

Direct-current Generator and Motor Defects (*Continued*)

Dynamo or generator.	Reversed residual magnetism.	Reversed current through field coils. Reversed connections. Earth's magnetism. Proximity of another dynamo. Brushes not in right position. *See* 1, 2, 3.	*A*. Use current from another machine or a battery through field in proper direction to correct fault. Test polarity with a compass. *B*. If connections or winding are not known, try one way and test; if not correct reverse connections, try again and test. *C*. Connect up per diagram for desired rotation, see that connections to shunt and series coils are properly made. *See* 57. *D*. Shift brushes until they operate better. *See* 1, 2, 3.	58
		Too weak residual magnetism.	Same as 58 *A*.	59
		Short-circuit in machine.	*See* 12, 54, 56.	60
		Short-circuit in external circuit.	A lamp socket, etc., may be short-circuited or grounded, and prevent building up shunt or compound machines. Find and remedy before closing switch. *See* 54, 56.	61
		Field coils opposed to each other.	Reverse connections of one of field coils and test. Find polarity with compass; if necessary try 58 *A*, *C*, *D*. If necessary reverse connections and recharge in opposite directions.	62
	Open circuit.	Broken wire. Faulty connections. Brushes not in contact. Safety fuses melted or broken. Switch open. External circuit open.	*A*. Search out and repair. *See* 13. *B*. Search out and repair. *See* 37. *C*. Search out and repair. *See* 5. *D*. Search out and repair. *See* 53 *A*. *E*. Search out and repair. *See* 53 *D*. *F*. Search out and repair with dynamo switch open until repairs are completed.	63
		Too great load on dynamo.	Reduce load to pilot lamp on shunt and incandescent machines; after voltage is obtained close switches in succession slowly, and regulate voltage. *See* 11 *A* and 65.	64
		Too great resistance in field rheostat.	Bring up to voltage gradually with rheostat, and watch pilot lamp; regulate carefully.	65

45. Troubles of Direct-current Motors.—Much of the material under this heading is based on that in the book *Motor Troubles* by E. B. Raymond. For more-complete information relating to direct-current-motor-and-generator troubles, see the author's ELECTRICAL MACHINERY, published by the McGraw-Hill Book Company.

46. Measurement of the insulation resistance of generators will give an indication of the average condition of the insulation as regards moisture and dirt, but will not always detect weak spots (*Westinghouse Co.*). The higher the resistance, the better the general condition of the insulating material. The approximate figure of one megohm per thousand volts of rated e.m.f. when the machine is at its normal full-load temperature may be taken as indicating a fairly satisfactory condition of the armature insulation. The insulation resistance of the field will be much higher in proportion to the e.m.f. of the exciting current and will seldom give appreciable trouble. Since large armatures have much greater areas of insulation, their insulation resistance will be proportionally lower than that of small machines. Even though the material is in exactly the same condition, the insulation resistance of any machine will be much lower when hot than when cool, especially when the machine is rapidly heated.

The only feasible method of increasing the insulation resistance after the machine has been completed by its manufacturer is by "drying out." Armature winding and field coils are dried by heat;

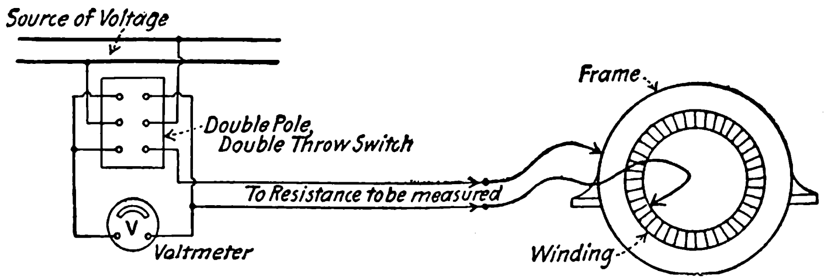

FIG. 27.—Measuring generator insulation resistance.

baking in an oven is to be preferred, but is often impracticable. They are usually heated by the passage of current. For an armature this may be done by short-circuiting the leads and running the generator with a low field charge, just sufficient to produce the proper current. (See 47.)

Insulation resistance may be conveniently measured with a high-resistance voltmeter specially designed for the purpose as directed in the first section (see Index). Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified. A double-pole switch arranged as indicated in Fig. 27 is convenient for changing the voltmeter connections. If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

47. **Drying Out a Generator or Motor.**—If a generator has been exposed to dampness, before being started in regular service it should be operated with its armature short-circuited beyond the ammeters and with the field current adjusted so as to raise temperature to about 70 deg. cent. The current should then be lowered and raised by means of the field adjustment until the coils become thoroughly dry. The temperature should not be allowed to drop to that of the surrounding atmosphere, as the moisture would then again be condensed on the coils, and the machine brought to the same condition as at the start.

There is always danger of overheating the windings of a machine when drying them with current, as the inner parts, which cannot quickly dissipate the heat generated in them and which cannot be examined, may get dangerously hot, while the more exposed and more easily cooled portions are still at a comparatively moderate temperature. The temperature of the hottest part accessible should always be observed while the machine is being dried out in this way, and should not be allowed to exceed the boiling-point of water. It may require several hours or even days to thoroughly dry out a machine, especially if it is of large capacity. Large field coils dry very slowly. Insulation is more easily injured by overheating when damp than when dry.

48. **When starting up, a generator may fail to excite itself** (*Westinghouse Instruction Book*). This may occur even when the generator operated perfectly during the preceding run. It will generally be found that this trouble is caused by a loose connection or break in the field circuit, by poor contact at the brushes due to a dirty commutator or perhaps to a fault in the starting box or rheostat, or incorrect position of brushes. Examine all connections; try a temporarily increased pressure on the brushes; look for a broken or burnt out resistance coil in the rheostat. An open circuit in the field winding may sometimes be traced with the aid of a magneto bell; but this is not an infallible test as some magnetos will not ring through a circuit of such high resistance and reactance even though it be intact. If no open circuit is found in the starting box or in the field winding, the trouble is probably in the armature. But if it be found that nothing is wrong with the connections or the winding it may be necessary to excite the field from another generator or some other outside source.

Calling the generator we desire to excite No. 1, and the other machine from which current is to be taken No. 2, the following procedure should be followed. Open all switches and remove all brushes from generator No. 1; connect the positive brush holder of generator No. 1 with the positive brush holder of generator No. 2; also connect the negative holders of the machines together (it is desirable to complete the circuit through a switch having a fuse of about 5 amp. capacity in series). Close the switch. Where the generator in trouble connects to bus-bars fed by other generators, the same result can be effected by insulating the brushes of the machine in trouble from their commutator and closing the main switch. (See Fig. 28.) If the shunt winding of generator No. 1 is all right, its field will show considerable magnetism. If possible, reduce the voltage of generator No. 2 before opening the exciting circuit; then break the connections. If this cannot be done, throw in all the rheostat resistance of generator No. 1; then open the switch very slowly, lengthening out the arc which will be formed until it breaks.

A simple means for getting a compound-wound machine to pick up is to short-circuit it through a fuse having approximately the current capacity of the generator. (See Fig. 29.) If sufficient current to melt this fuse is not generated, it is evident that there is something wrong with the armature, either a short-circuit or an open circuit. If, however, the fuse has blown, make one more

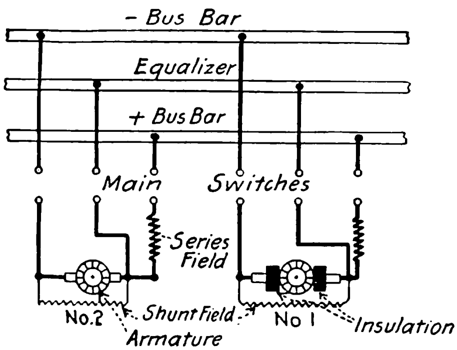

FIG. 28.—Exciting a generator.

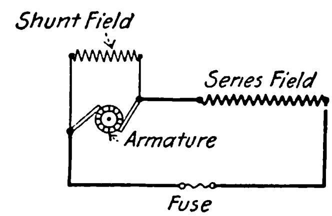

FIG. 29.—Another method of exciting a generator.

attempt to get the machine to excite itself. If it does not pick up, it is evident that something is wrong with the shunt winding or connections.

If a new machine refuses to excite and the connections seem to be all right, reverse the connections, *i.e.*, connect the wire which leads from the positive brush to the negative brush and the wire which leads from the negative brush to the positive brush. If this change of connections does no good, change back and locate the fault as previously suggested.

49. The proper connections for a shunt motor are as shown in Fig. 30. The field *B* is connected as shown, so that when the switch *D* is closed it becomes excited before the armature circuit through the switch *E* is closed. Thus when the motor armature has current admitted to it through switch *E* and starting resistance-box *A*, the field is already on, and the full torque of the motor is obtained. The torque of a motor is equal to the product of flux per pole, the ampere turns on the armature, and the number of poles. Hence, if the full field is not on the motor at starting, full torque will not be obtained.

50. If a motor will not start when the starting-box is operated and when current is flowing in the armature, an investigation should be made to see if the field flux is on, which can be done by holding a piece of iron, such as a key, against the pole-piece. If the flux exists the key will be drawn strongly against the pole-piece; if there is no flux there will be practically no attraction.

51. **Reversed Field-spool Connection.**—There may be cases where the manufacturer has shipped a motor with one or more field spools reversed. If such is the case no torque, or, perhaps, very weak torque, will be noticed. Under such conditions a trial

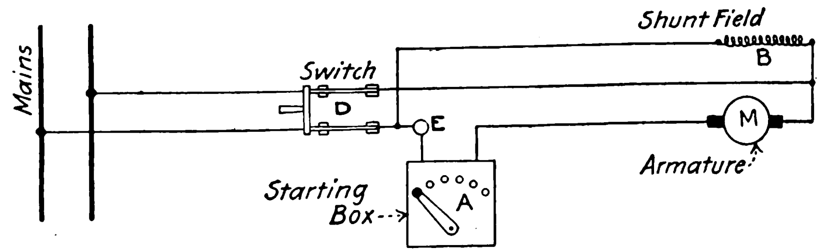

FIG. 30.—Control apparatus connections for a shunt motor.

with an iron key will show proper field magnetism, yet the weakness or total absence of torque will be present, and a trial of polarity should be made.

52. **Running in the Wrong Direction.**—Sometimes a motor when set up and started will run in the wrong direction. The only change necessary is to reverse the field connection. Thus Fig. 31, *I*, shows the connection for one direction of rotation and

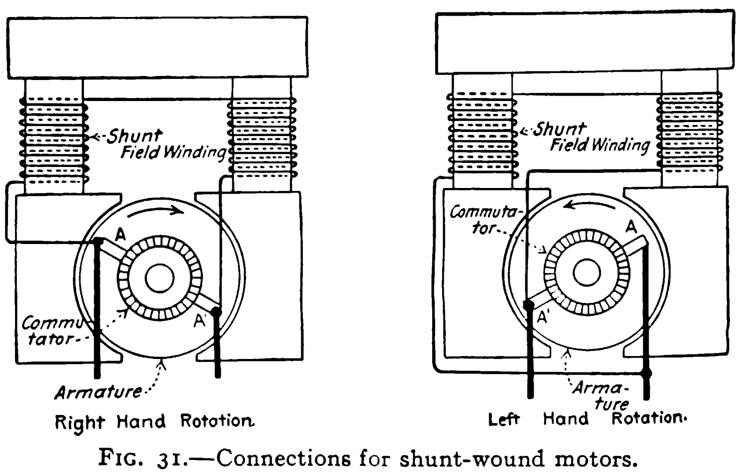

FIG. 31.—Connections for shunt-wound motors.

Fig. 31, *II*, that for the other. Note that in Fig. 31, *I*, the brushes *A* and A^1 are shifted backward against the direction of rotation. For the opposite rotation, a backward lead, as shown in Fig. 31, *II*, must be chosen.

53. **Testing Polarity of Field.**—This can be done in two ways: First, by using a compass, bringing it near the various poles and noting the direction of the deflection of the needle. Since in all motors the poles alternate in magnetic polarity, in one pole the

magnetism coming out and the next going in, it follows that a certain end of a compass needle will point toward one pole and away from the next when conditions are normal. If, however, two adjacent poles show similar magnetism, the trouble is located, and the offending spool should be reversed. This should be done "end for end," not by turning on the axis. The latter operation does not change the direction of magnetism, while the former does. Direction of magnetism is determined by the following rule:

"Looking at the face of an electromagnet (such as the field spool of a motor), a pole will be north if the current is flowing around it in a direction opposite to the motion of the hands of a watch," Fig. 32, and south if in the same direction as the motion of the hands of a watch. (See also the rules outlined in Sect. I of this book.)

Another method of determining whether the magnetism of the poles is correct is to use two ordinary nails, their lengths depending upon the distance between pole-tips. The point of one nail should touch one pole-tip, the point of the other nail the other pole-tip, and the heads of the nails should touch each other.

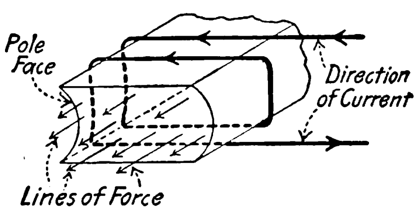

FIG. 32.—Direction of magnetism and current about a pole.

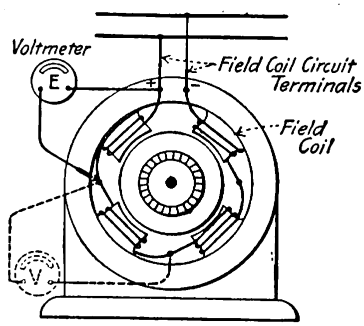

FIG. 33.—Locating field-coil troubles.

When the current flows around the field spools, the polarity between any two poles is properly related if the nails placed as suggested stick together by the magnetism. If there is no tendency to stick, the polarity of the two poles is alike and therefore wrong.

54. **Open Field Circuit.**—If, on closing the field switch, no magnetism is obtained by trial with an iron key, as suggested above, there is an open circuit within one of the spools or in the wires leading to these spools. The open circuit can be located by cutting out one spool at a time and allowing current to flow through the rest until the defective spool is discovered. On a two-pole motor try first one spool and then the other. For a very short time, say, 10 min., double voltage can be carried on a spool. On a motor having four or more poles, three spools can always be left in circuit during the open-circuit investigations.

55. **A method of locating an open-circuited field coil** is illustrated in Fig. 33. Connect one terminal of the voltmeter to one side of the field-coil circuit and with the bared end of a wire or a contactor, successively touch the junctions of the field-coil leads around the frame. When the open coil is bridged the voltmeter will show a full deflection. Another way: Connect the field-coil circuit ter-

minals to a source of voltage. Connect the voltmeter successively across each coil as indicated by the dotted lines in Fig. 33. There will be no deflection on the voltmeter until the open coil is bridged, when the full voltage of the circuit will be indicated.

56. **A grounded field coil can be located** (Fig. 34) by connecting a source of voltage to the machine terminals having first raised the brushes from the commutator, if it is a direct-current machine. Connect one terminal of the voltmeter to the frame and the other to a lead with a bared end. Tap with the bared end exposed parts of the field circuit. The voltmeter deflection will be least near the grounded coil.

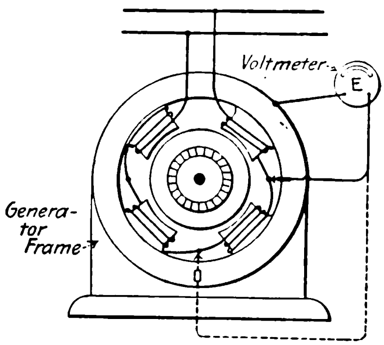

FIG. 34.—Locating grounded coil.

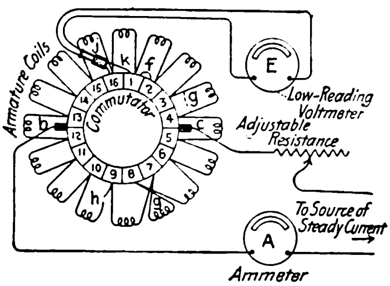

FIG. 35.—Method of testing an armature.

57. **Heating of Field Coils** (*Westinghouse Instruction Book*).—Heating of field coils may develop from any of the following causes: (a) Too low speed; (b) too high voltage; (c) too great forward or backward lead of brushes; (d) partial short-circuit of one coil; (e) overload.

58. **Direct-current armatures can be tested for the common troubles** with the arrangement of Fig. 35. Terminals *b* and *c* are clamped to the commutator at opposite sides and connected with a source of steady current through an adjustable resistance and an ammeter. The terminals of a low-reading voltmeter (a galvanometer can often be used) are connected to two bare metal points, which are separated by an insulating block, *j*. In use, the current is adjusted to produce a convenient deflection of the voltmeter when each of the points rests on an adjacent bar. The points are moved around the commutator and bridged across the insulation between every two bars. If the voltmeter deflection is the same for every pair of bars it indicates that there is no trouble in the armature.

59. **Sparking Due to Open Armature Circuit.**—A cause of a sparking commutator is an open circuit in the winding, either in the armature body or, more often, where the lead from the armature winding is soldered to the commutator. In the latter case resoldering is a ready remedy. If, however, the location of the point of open circuit cannot be found, the bars can be bridged over on the

commutator itself by fastening with solder, or otherwise, a strip of copper around the segments which indicate the break.

The indication of this trouble is very apparent, for, if an open circuit exists, the long heavy spark which accompanies it soon eats away the mica between the two segments which are on each side of the break. This shows positively where to bridge over. An open circuit also shows itself, when the machine is running, by the viciousness of the spark. It is unlike any other kind of commutator sparking, being heavy, long, and destructive in its action.

60. **A poor connection between a bar and coil leads** will cause a considerable deflection of the voltmeter (Fig. 35) when one of the points rests on the bar in trouble and the other rests on either of the adjacent bars.

61. **An open-circuited coil,** as *h*, Fig. 35, will prevent the flow of current through its half of the armature. There will be no deflection on that half of the armature until the "open" is bridged, when the voltage of the testing circuit will be indicated.

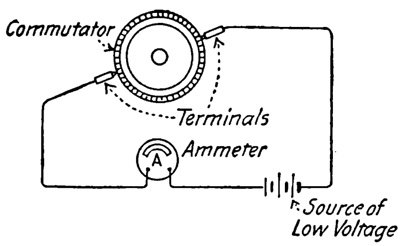

Fig. 36.—Testing for armature open-circuit with an ammeter.

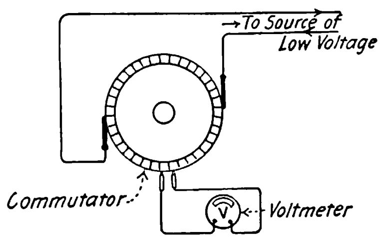

Fig. 37.—Testing for armature open-circuit with a voltmeter.

62. **Tests for Open Armature Circuits.**—Another method (Fig. 36) is to apply to the commutator, at two opposite points, a low voltage, say from a battery or a dynamo with its voltage kept low. Place an ammeter in circuit and clean the surface of the commutator so that it is bright and smooth.

The terminal ends leading the current into and out of the commutator should be small, so that each rests only on a single segment (Fig. 36). Note the ammeter reading and rotate the armature slowly. At the point where the open circuit exists the ammeter needle will go to zero if the leads to the commutator bar have become entirely open-circuited. This is because the segment is attached to the winding through the commutator leads.

If the armature does not show the above symptoms, try connecting a low-reading voltmeter or a galvanometer to two adjacent segments while the current is passing through the armature as described from some external low-voltage source (Fig. 37). Note the deflection. Pass from segment to segment in this manner, recording the drop between the successive pair of bars. This drop, if the current is held constant from the external source, should be the same between each pair of adjacent segments. If any pair shows a higher drop than the others near it, a higher resistance connection exists there, perhaps causing sparking and biting of commutator insulation, to a less degree, to be sure, than with an actual open circuit, but enough, perhaps, to cause the trouble requiring the investigation.

63. **The test for armature short-circuits,** described in the preceding paragraph, is called a "bar to bar" test. It is most valuable in locating faults in armatures. It is the method to use if a short-circuit from one segment to another is suspected. When the section in which the short-circuit, or partial short-circuit, exists comes under the contacts, a low or perhaps no deflection is shown on the galvanometer or voltmeter, thus locating the defective place. Such short-circuits, if they occur when running, owing to defective insulation, burn out the coil short-circuited. When the coil passes through the active field in front of the pole-piece, an immense current is induced in it, causing a destruction of the insulation. When this occurs the coil should be open-circuited if the burning has not already short-circuited it. If practical, it should be bridged over, as suggested in a preceding paragraph.

64. **If two bars or a coil is short-circuited** as at *f* and *g* (Fig. 35) respectively, there will be little or no voltmeter deflection when the two bars connecting to the "short-circuit" are bridged by the points.

65. **A grounded armature coil** can be detected in the same manner as indicated in Fig. 34 for a field coil. Impress full voltage on the terminals clamped to the commutator. Ground one side of the voltmeter on the shaft or spider and touch a lead connected to the other side to all the bars in succession. The minimum deflection will obtain when the bars connecting to the grounded coil are touched.

66. **Crossed coil leads** as at *g* (Fig. 35) are indicated by a twice normal deflection when the points bridge the bars to which the crossed coils should rightly connect. The crossing of the coil leads connects two coils in series, hence causes twice normal drop. Bridging the bars to which coil *h* connects will produce a normal deflection, but it will be reversed in direction.

67. **Reversed Armature Coil.**—Instead of the armature winding progressing uniformly around from bar to bar of the commutator, there may at some point be a coil connected in backward. Such a reversed coil often causes bad sparking. One way to locate such a trouble is to pass through the armature, at opposite points on the commutator, a current. Then with a compass explore around the armature the direction of magnetism from slot to slot. If a coil is reversed when the compass comes before it, the needle will reverse, giving a very definite indication of the improperly connected coil.

68. **Heating of Armature** (*Westinghouse Instruction Book*).—Heating of the armature may develop from any of the following causes: (a) Too great a load; (b) a partial short-circuit of two coils heating the two particular coils affected; (c) short-circuits or grounds on armature or commutator.

69. **Hot Armature Coils.**—Sometimes when a new machine is

started, local heating occurs in the armature, following the exact shape of the armature coil. This may be because, in receiving its final turning off, the commutator bars were bridged with copper from one segment to another by the action of the turning tool. An examination of the commutator surface will reveal this bridging. When it is removed, satisfactory operation will ensue if the trouble has not gone too far and seriously injured the insulation of the coil.

70. Care of Commutators.—They should be kept smooth by the occasional use of No. 00 sandpaper. A small quantity of high grade, light body oil should be used as a lubricant. The lubricant should be applied to high-voltage generators by aid of a piece of cloth attached to the end of a dry stick. If the commutator gets "out of true" it should be turned down. By using a special slide rest and tool this can be done while running the engine at a reduced speed without removing the rotating part from the bearings. Inspect the commutator surface carefully to see that the copper has not been burned over from segment to segment in the mica and remove by a scraper any particles of copper which may be found embedded in the mica. Keep oil away from the mica end-rings of the commutator as oily mica will soon burn out and ground the machine.

71. Process of Commutation and Correction of Glowing and Pitting.—The path of the current is as shown in Fig. 38. A is the carbon brush; C, C', C'' are the commutator segments; B, B', B'' are the windings of the armature. At the position shown, coil B is short-circuited by the carbon, the current passing into the face of the brush and out again as shown by the dotted line. This local current may be many times larger than the normal flow of current and is the one that causes pitting.

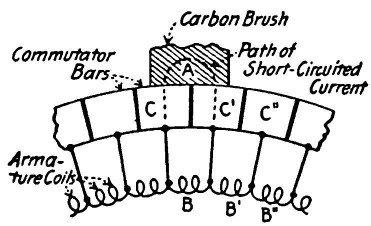

FIG. 38.—Armature coil short-circuited when commutating.

With perfect commutation, with no sparking or glowing, there should be created in the short-circuited coil under the brush, by means of the flux from that pole-tip away from which the armature is revolving, an electromotive force. This should be just large enough to reverse the current within the short-circuited coil and to render it equal to the current in the winding proper. Since on one side of the brush the current is in one direction and on the other side in the other direction, the act of commutation beneath the brush is to reverse this current and bring it up to the correct amount in the opposite direction.

With copper brushes this reversal of current must be very accurately effected. With carbon brushes there is a much smaller tendency to spark, hence they will stand a certain inexactness of commutation adjustment. Experiments indicate that the carbon can resist as much as 3 volts creating current in the wrong direction and still not spark or glow. This is the property that has caused the use of carbon brushes instead of copper on most apparatus. When, however, this potential, induced in the wrong direction, rises above 3 volts during the passage of the armature coil underneath the brush, trouble from sparking and glowing occurs.

This is the reason that, in a motor, the brushes are pulled backward as far as possible at no-load, so that the coil short-circuited by the brush may enter the fringe or flux from the pole-tip, thus creating the proper reversal of current during the time the coil is passing under the brush. Since adjacent poles are opposite in polarity, only one can provide the proper flux direction for this reversal. In a motor it is always the pole behind the brush and thus the brush requires a backward lead. In a generator it is the pole ahead of the brush in the direction of rotation. Hence generators require a forward lead.

If the motor gives trouble from glowing and pitting, the cause is probably this induced current, and the remedy is, first, to see that the lead of the brushes brings them in the most satisfactory position. If no change of lead or brush position can be found which will eliminate the trouble, the width of the brush must be changed. The wider the brush the longer does the coil suffer short-circuit, as described. Conversely the narrower the brush, the quicker must the current be reversed. There is, therefore, a width of brush which best satisfies both conditions.

Usually, however, where glowing occurs, the cause is too wide a brush, and often serious trouble from this cause can be entirely eliminated by varying the width of the brush perhaps only $\frac{1}{8}$ in.

72. **Sparking Due to Rough Commutator.**—First, the commutator surface may not be perfectly smooth after receiving its last turn off. The work may have been poorly done by the manufacturer, with the result that the commutator surface, instead of being left smooth, is somewhat rough. The result of this, especially with high-speed commutators, is that the brush does not make first-class contact with the commutator surface. It may chatter with attending noise, and thus with many motors (especially those of high voltage) the operation will be attended with sparking. As a result, the commutator surface, instead of becoming bright and smooth with time, becomes rough and dull or raw in appearance. Under these conditions the brushes do not make good contact, and, hence, the heat generated even under proper commutator conditions, owing to the resistance of brush contact, is multiplied several times, with consequent increase of temperature of the commutator. In addition, the friction of brush contact (which should give a coefficient of 0.2) is, with a rough commutator, much higher than it should be, which tends to increase the temperature.

73. **Heating of commutator** (*Westinghouse Instruction Book*) may develop from any of the following causes: (a) Overload; (b) sparking at the brushes; (c) too high brush pressure; (d) lack of lubrication on commutator.

74. **Hot Commutator.**—All this (see above) trouble is cumulative. The result is that finally the temperature will rise to a point where the solder in the commutator will melt, perhaps short-circuiting or open-circuiting the winding. A commutator will stand very slight sparking, but where it is noticeable and where

it is continued for long periods of time, trouble is liable to result. Where the load is usually very light on a motor, and where full-load or overload are infrequent, a smoothing of the commutator occurs during the light-load period which averts trouble. This is the reason that certain railway motors, which sometimes show sparking under their normal hour rating load, give satisfaction as to commutation. The coasting of the car smooths up the imperceptible damage done by the sparking during the heavy load.

75. Loose Commutator Segments.—A further and more serious cause of sparking and commutator trouble is due to the fact that the commutator may not be "settled" when shipped by the manufacturer. A commutator is made of many parts (Fig. 39), insu-

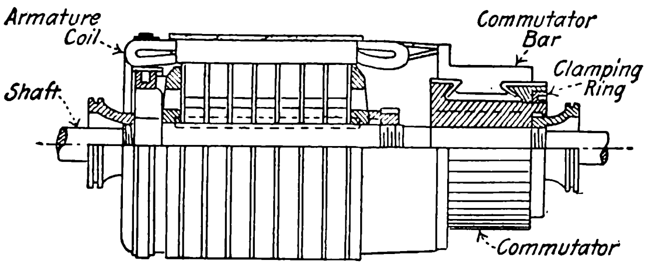

FIG. 39.—Section of direct-current motor armature.

lated one from another, and all bound together by mechanical clamping arrangements. The segments themselves are held by a clamp-ring on each end, which must be insulated from them and which should hold each segment individually from any movement relative to another.

Since the clamp must touch and hold down all segments, a failure to do so in any case results in a loose bar, which moves relatively to the next bar and causes roughness and thus sparking, with all its attendant accumulative troubles. The roughness of commutators due to poor turning or to poor design is shown uniformly over all the surface of the commutator on which brushes rest. A roughness due to a high or loose bar is shown by local trouble near the bad bar and its corresponding bars around the commutator. The jump of the brush occurs at the high bar and is the cause of the sparking. See also Pars. 77 and 78.

76. Blackening of the Commutator.—Sparking due to a loose or high bar causes a local blackening instead of a uniform blackening, which occurs in case of poor design or poor commutator surface resulting from poor turning. Also, if the speed of the commutator is low enough, there will be a spark at the time the bad segment passes the brush. At ordinary speeds, or where there are several loose bars, the sparking in appearance will not be different from that due to poor design or poor turning. In such a case an examination of the commutator surface must be made to identify the cause.

It must be remembered that the slightest movement of a bar, especially with the higher voltage and high-commutator-speed machines, may cause the trouble. A splendidly designed motor may show very poor operation, due to a commutator fault.

77. Correcting Commutator Roughness.—The proper way to correct a rough surface due to poor turning is to grind the surface with a piece of ordinary grindstone (Fig. 40). It should be cut to convenient size and held by the hand against the commutator. If possible it should be rounded out to the shape of the commutator, though the rounding is not absolutely necessary except when the surface is exceedingly irregular. A commutator can be ground on low-voltage machines without removing the brushes from the commutator and during the ordinary operation of the motor under load. When sparking is due to poor turning, grinding causes the sparking to entirely disappear. This is also a good method of cleaning the surface of brushes which have become coated with copper from the use of sandpaper in fitting them to the commutator surface.

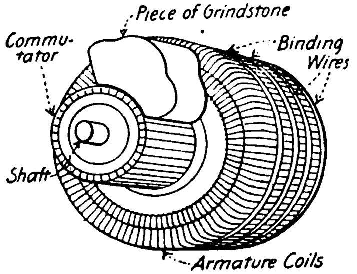

FIG. 40.—Smoothing commutator with grindstone.

Some kinds of sandpaper, if used to give a brush surface or to smooth a commutator with the brushes down, imbed in the face of the brush hard material which sticks there, cutting the commutator and thus collecting about itself copper from the commutator. An examination of the face of the brush after running a time will show these collections either in spots or all over the face of the brush. The sandstone, used as suggested, removes all this.

Where roughness and sparking are due to a loose bar, grinding will do no particular good. Then a different process for correction must be used. It consists first in tightening the clamp-rings which hold down the segments so that they touch and hold, each one preventing any relative movement of the bars. After this is done, produce a smooth surface by turning, if the bar is much displaced, or by grinding if it is but slightly displaced. The process of correcting a loose commutator therefore is as follows:

78. Loose Commutator. Clamp-rings.—First, draw the clamps of the commutator down firm, so that when the commutator is at normal temperature the clamping rings cannot be screwed down further without excessive effort. This is necessary so that all the bars may have a direct pressure from the clamp, rendering any movement, up or down, impossible. Second, after having drawn the clamps down, smooth off the surface of the commutator.

To get the clamps down firm run the motor; if roughness appears, shut down at a convenient time, and, while hot, tighten the clamping rings. If it is found that the tightening bolts can be screwed up somewhat, the machine should again be put in service for at least 4 hr., at the end of which time shut it down again and make another trial on the tightening bolts. If, now, no more can be taken up on the tightening bolts, the commutator should be surfaced, either by turning with a tool or by grinding. If the clamps are down tight and the surface of the commutator has been properly smoothed, there will be no further trouble.

79. **The Slotting of Commutators** (*Alan Bennett, American Machinist*, Sept. 26, 1912).—There seems to be a prevalent idea that slotting should cure all commutator troubles, irrespective of their causes. This is not true, but slotting is a cure for certain specific troubles. Where the peripheral speed of the commutator is so slow that the dirt which may collect in the slots between commutator bars will not be thrown out by centrifugal force, slotting may aggravate rather than correct commutation difficulties. See also 84.

80. **The principal reason for slotting commutators** is to relieve the commutators of high mica, that is, mica that projects above the surface. High mica is generally due to one of two causes: Either the mica is too hard and does not wear down at an equal rate with the copper, or the commutator does not hold the mica securely between the segments, allowing it to work out by the combined action of centrifugal force and the heating and cooling of the commutator.

It is evident that a commutator with a surface made irregular by projecting mica rotating at high speed under a brush, must impart to the brush a vibratory action, and thus impair the close contact that should exist between the brush and commutator. The result is that sparking takes place more or less violently, depending on the condition of the commutator surface and the rate of speed.

This condition generally manifests itself after the machine has been running for some time, and in many cases will account for the development of sparking which did not occur at the time of installation. Often a case of this kind is aggravated by increasing the brush tension, causing a still faster rate of wear of copper over mica, with an attendant increased heating of the commutator.

81. **What is Accomplished by Slotting.**—A harder brush may at times be used, with the idea of grinding off the mica and thus bringing it down to the commutator surface. Instead of curing the trouble, the commutator will, in the majority of cases, assume the raw appearance of being freshly sandpapered, instead of the glossy surface it should have, and both brush and commutator will wear rapidly.

This condition can be restored to normal and the commutator kept to a true surface by slotting, after which, with proper care and the use of proper brushes, commutator troubles will generally cease, provided the electrical design of the machine is not at fault. Even then there are cases that may be benefited to a certain extent by slotting, by reason of the good brush contact obtained. The majority of cases that show improvement are the ones in which the trouble is not inherent in the design of the machine, but is due to mechanical causes.

With a slotted commutator it is possible to use a brush of fine grain and soft texture, inasmuch as there is not the same tendency to wear away the brush as with an unslotted commutator. The commutator will then take on the much-desired polish that is generally not possible with the harder brush. The life of both brush and commutator will be increased, and friction and the consequent heating will be reduced. These advantages will effect a saving that will more than offset the cost of slotting.

82. **Various Methods of Slotting.**—There is a variety of slotting devices on the market. Some are designed to operate with the armature swung between the centers of a lathe; others use a special tool in a shaper, with the armature secured to its bed. Still others are used by hand with the armature resting on blocks. In all cases the full width of the mica should be removed, and the resulting slot carefully cleaned from burrs and rough edges. It is not necessary that the slotting be carried deeply in the commutator. One-sixteenth of an inch is generally considered sufficient. See also Par. 84.

83. **A slotted commutator should have proper and frequent care,** as there is a chance of small particles of copper being dragged across from bar to bar, and for dirt, oil and carbon dust to accumulate in the slots and short-circuit the commutator.

84. **High Mica in Commutators.**—Some motors, under certain conditions, roughen up their commutators after a short term of service, although there seems to be no excessive sparking under or at the edges of the brushes. This may occur even though the commutator has been well "settled." The commutator acts as if the mica used between bars to insulate the various segments, one from another, had protruded upward, causing roughness and excessive sparking.

Actual raising of the mica is a very rare occurrence, and, if it occurs, does so at certain spots and is easily and positively identified. An actual uniform protruding of mica, all over a commutatoɪ, as described, is practically an unknown phenomenon. What actually does occur is an eating away of the copper surface of the commutator, leaving the high mica between the bars. A good machine will not spark enough to cause this condition. A poor machine will.

The phenomenon is easily identified, as the commutator surface looks raw all over instead of smooth and bright with a good brown gloss. If allowed to continue, a general roughness appears, accompanied by sparking, until finally the sparking and heating will increase so much that the machine may flash over from brush to brush, blowing the fuses or opening the circuit-breakers. The trouble is aggravated if the motor operates continuously under heavy load. If there are periods of light load, the commutator has an opportunity to be smoothed down by the brushes. This condition is appreciated by railway motor designers. A railway motor coasts a considerable portion of the time. Thus the commutator is smoothed, neutralizing the roughening occurring under load.

To remedy a roughened, high-mica commutator: (1) Use it on work where the load is somewhat intermittent; (2) replace it altogether; or (3) slot the commutator. Then, as there are no longer two different materials to wear down or to be worn away by sparking, an unequal surface will not result. The mica need be cut down only $\frac{1}{16}$-in. and a narrow, sharp chisel will do the work satisfactorily. No trouble will result from short-circuiting in this case, since centrifugal force keeps the slots clean. Some manufacturers ship machines with slotted commutators.

85. Brush Troubles.—When there is an excessive drop in speed from no-load to full-load, the position of the brushes on the commutator should first be investigated as elsewhere suggested. No brush position that causes sparking should be chosen. The following paragraphs outline the more important brush troubles and their remedies.

86. Sparking of the brushes may be due to one of the following causes (*Westinghouse Instruction Book*). (See also Dynamo-defects Table.) (a) The machine may be overloaded; (b) the brushes may not be set exactly at the point of commutation—a position can always be found where there is no perceptible sparking, and at this point the brushes should be set and secured; (c) the brushes may be wedged in the holders; (d) the brushes may not be fitted to the circumference of the commutator; (e) the brushes may not bear on the commutator with sufficient pressure; (f) the brushes may be burnt on the ends; (g) the commutator may be rough; if so, it should be smoothed off; (h) a commutator bar may be loose or may project above the others; (i) the commutator may be dirty, oily or worn out; (j) the carbon in the brushes may be unsuitable; (k) the brushes may not be equally spaced around the periphery of the commutator; (l) some brushes may have extra pressure and may be taking more than their share of the current; (m) high mica; (n) vibration of the brushes.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator, and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken it will draw a bright spark as the break passes the brush position. This trouble can be readily located, as the insulation on each side of the disconnected bar will be more or less pitted. The commutator should run smoothly and true, with a dark, glossy surface.

87. Glowing and Pitting of Carbon Brushes.—This may be due to either of two causes, poor design or a wrong position of the brushes on the commutator. The error of design may be only in the choice of width of carbon brush used. The pitting is due to glowing. If the glowing is at the edge of the carbon it is plainly visible and easily located. It may, however, occur underneath the carbon so that only with difficulty can it be seen. Such glowing pits the carbon face by heat disintegration. With some machines three-fourths of the brush face may be eaten away and the pits may be, perhaps, $\frac{1}{4}$ in. to $\frac{1}{2}$ in. deep when discovered. A usual (incorrect) decision is that the current per sq. in. of contact is too great, the calculation being made by dividing the *line amp.* by *the sq. in. cross-section of either the positive or the negative brushes.* If this calculation gives a value under 45 or

50, it is certain that the cause of the trouble has not been judged correctly.

The real cause of the glowing is, to be sure, excessive current through the carbon, but this is not the line current if the calculation, as stated, shows a brush-face density below 50 amp. per square inch. It is a local current caused by the short-circuiting of two or more segments of the commutator by the brush resting upon them. The usual overlap of a carbon brush is about two segments, and while these two segments are under the brush, the armature coils connected to them are short-circuited. If the design of the machine is such that the coil so short-circuited encloses stray flux from the pole-tip, this flux will create in the short-circuited coil a current, perhaps many times larger than the brush is capable of carrying, with the result that the glowing and pitting occurs.

88. Chattering of brushes is sometimes experienced on direct-current machines. Chattering under certain conditions may become so prominent as to not only be of annoyance, but as to actually break the carbons. An examination of the commutator will reveal no roughness, the surface being, perhaps, perfectly smooth and bright. This trouble occurs principally with the type of brush holder which has a box guide for the carbon. The spring which forces the brush into contact rests on top of the carbon which has fairly free play in the box guide. Chattering usually occurs with high-speed commutators, running at 4,000 to 5,000 ft. per min., peripheral speed.

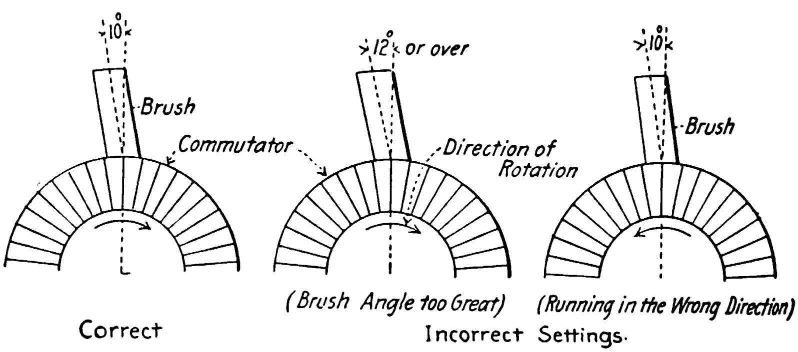

FIG. 41.—Methods of setting brushes.

Such brush holders are necessary on commutators which, like those on engine-driven machines, may run out of true on account of the shaft play in the bearings caused by the reciprocating motion of the engine. The clamped type of holder is usually free from bad chattering but rocks on a commutator that runs out, causing poor contact and perhaps sparking.

Lubricating the commutator causes the chattering to immediately disappear, but there is no commutator compound which gives a lubricating effect lasting over possibly a half hour. Thus it is not practical to lubricate often enough to prevent the chattering. There will be no chattering if the angle of the brush with the radial line, passing through the center of the carbon and the center of the commutator, is less than 10 deg. and if the carbon trails on the commutator instead of leads. Fig. 41, *I*, shows the setting which will stop all serious chattering and Fig. 41, *II* and *III*, show settings which may give trouble.

89. Low Speed.—The fault may be in the winding of the armature or field, in which case a remedy is a serious matter. On the other hand, considerable range of speed can be obtained by the choice of brush position on the commutator. Many motors will run without sparking with a range or brush shift on the commutator giving a range of speed of 15 per cent. Therefore, if the discrepancy of speed is within this amount, the brushes should be moved to counteract it. A backward shift of brush gives increased speed and a forward shift decreased speed. At any brush position, however, there must be practically no sparking. Sparking is a very serious matter, causing all sorts of trouble. A first-class motor should run at full-load within 4 per cent. (up or down) of the name-plate speed if the voltage is as specified on the name-plate. The speed at no-load should not be more than 5 per cent. higher than this, also the speed at full-load, hot, should not be over 5 per cent. greater than the speed at full-load, cold.

90. Bearing Troubles of Direct-current Motors and Generators.—See paragraphs under this same heading under "Troubles of Alternating-current Motors and Generators."

PRINCIPLES, CHARACTERISTICS AND MANAGEMENT OF ALTERNATING-CURRENT MOTORS AND GENERATORS

91. Alternating-current generators are discussed in an elementary way in the preceding section. See Index. Modern

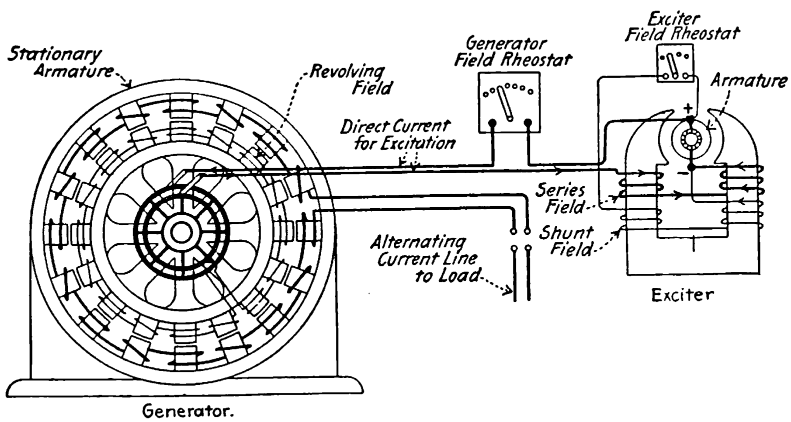

FIG. 42.—Elementary diagram of alternator and exciter.

commercial alternating-current generators usually are arranged as suggested diagrammatically in Fig. 42. Electromagnets, excited by a small direct-current generator or exciter, are mounted on a wheel-like structure which revolves within a circular stationary frame in the inner surface of which are armature coils. The revolving part is the revolving field; the stationary part is the armature. The direct current is fed to the field coils through collector rings. Armature coils are, in practice, arranged in slots in the inner circumference of the armature structure. Alternating e.m.fs. are induced in the armature by the lines of force from the field magnets cutting the armature coils. The alternating voltage can be varied, within limits, by adjusting the field rheostats.

92. **There are several types of alternators** or alternating-current generators. They are: (1) Revolving armature alternators wherein the armature revolves and the field magnets are stationary; (2) revolving field alternators, wherein the field magnets revolve and the armature is stationary; (3) inductor alternators, wherein both field magnets and armature are stationary and iron cores revolve between the armature core and the field-magnet poles. Modern alternators are practically all of the revolving field type because the stationary armature offers better opportunity for insulation and a high voltage is not necessary on the collector rings.

93. **The electromotive force in an alternator is generated as suggested in Fig. 43.** As each field coil, *D* for instance, sweeps past the armature coils the lines of force from the field coil cut the armature coils. As coil *D* passes from *A* to *C* an alternating e.m.f. represented by the curve *ABC* will be generated in the armature. It should be understood that in commercial alternators the armature coils are set in slots and differently arranged than in Fig. 43, which only illustrates a principle.

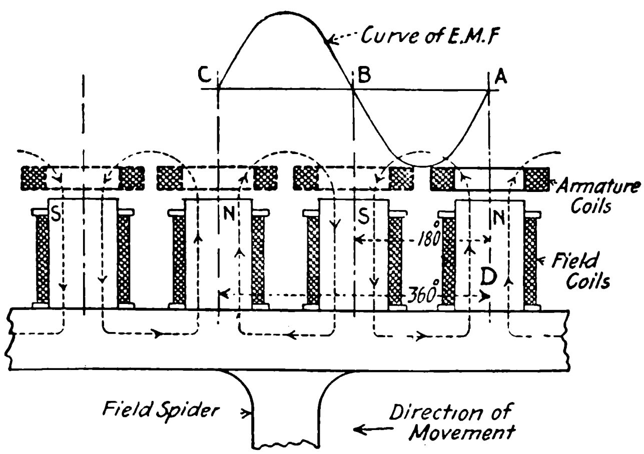

FIG. 43.—Armature and field structure developed.

94. **The speed and number of poles of an alternator or an alternating-current motor determine its frequency and vice versa.** (See Table 97.)

$$f = \frac{p \times \text{r.p.m.}}{120};\ \text{or}\ p = \frac{120 f}{\text{r.p.m.}};\ \text{or r.p.m.} = \frac{120 f}{p}$$

Wherein f = frequency in cycles per second, r.p.m. = revolutions per minute of rotor and p = the number of field poles.

Example.—What is the frequency of a two-pole alternator running at 3,600 r.p.m.?

Solution.—Substitute in the formula:

$$f = \frac{p \times \text{r.p.m.}}{120} = \frac{2 \times 3{,}600}{120} = \frac{7{,}200}{120} = 60 \text{ cycles per second.}$$

Example.—How many poles has a 25-cycle alternator running at 500 r.p.m.?

Solution.—Substitute in the formula:

$$p = \frac{120\,f}{\text{r.p.m.}} = \frac{120 \times 25}{500} = \frac{3{,}000}{500} = 6 \text{ poles.}$$

95. Single-phase Alternators.—The circumferential distance from the center line of one pole to the center line of the next pole of the same polarity constitutes 360 magnetic degrees. See Fig. 43, which shows how a single-phase e.m.f. is generated. Fig. 42 is a diagrammatic illustration of a single-phase alternator and Fig. 44 shows, diagrammatically, two different kinds of single-phase windings. Single-phase alternators are seldom made now. The

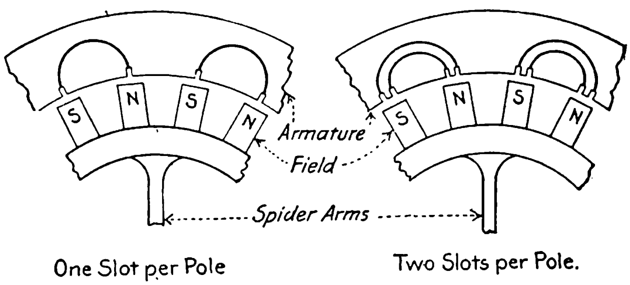

FIG. 44.—Single-phase armature windings.

manufacturers furnish three-phase machines instead and give them a single-phase rating equal to about 70 per cent. of the three-phase rating. The single-phase load is carried on any two of the three leads of the three-phase generator. See "Three-phase Alternator."

96. Approximate Performance Values

220, 440, 600, 1,100, 2,200 and 2,400

It should be understood that values will vary somewhat with mate only and do not apply to any particular manufacturers' line.

A slow-speed machine is assumed to be one turning at from 100 200 r.p.m. to 300 r.p.m., and a high-speed machine, one turning slow speed; "M" medium speed, and "H" high speed.

Kva output		Current							
		Three-phase						Two-phase	
		240 volts	480 volts	600 volts	1,200 volts	2,200 volts	2,400 volts	240 volts	480 volts
50	S M H	120.3	60.1	48.0	24.0	13.2	12.0	104.2	52.1
75	S M H	180.4	90.2	72.2	36.1	19.7	18.0	156.3	78.1
100	S M H	240.6	120.3	96.2	48.1	26.3	24.1	208.3	104.2
125	S M H	301.0	150.0	120.0	60.1	32.8	30.1	261.0	130.0
150	S M H	360.8	180.4	144.3	72.2	39.4	36.1	312.5	156.3
200	S M H	481.1	241.6	192.4	96.2	52.5	48.1	416.7	208.3
300	S M H	723.0	362.0	289.0	145.0	79.2	72.0	625.0	313.0
400	S M H	962.0	481.0	385.0	192.0	105.0	96.2	833.0	417.0
500	S M H	1203.0	602.0	481.0	241.0	132.0	120.0	1042.0	521.0
600	S M H	1450.0	722.0	578.0	289.0	158.0	144.0	1250.0	625.0
700	S M H	1690.0	841.0	673.0	337.0	184.0	168.0	1460.0	729.0
800	S M H	1930.0	977.0	773.0	387.0	211.0	193.0	1670.0	834.0
1,000	S M H	2406.0	1203.0	962.0	481.0	263.0	241.0	2083.0	1042.0
1,250	S M H	3000.0	1500.0	1200.0	600.0	328.0	300.0	2600.0	1300.0
1,500	S M H	3640.0	1804.0	1443.0	722.0	394.0	361.0	3130.0	1563.0
2,000	S M H	4850.0	2420.0	1924.0	962.0	526.0	481.0	4170.0	2080.0

of Alternating-current Generators
volts. Two-phase and three-phase.
speed and other conditions. Those given are general and approxi-

r.p.m. to 200 r.p.m.; a medium-speed machine, one turning at from at from 300 r.p.m. to 1,200 r.p.m. In the table, "S" indicates

Current				Efficiency			Exciter capacity required
Two-phase							
600 volts	1,200 volts	2,200 volts	2,400 volts	½ load	¾ load	Full-load	
41.7	20.8	11.3	10.4	...... [1]85.5 86.6	...... [1]88.0 89.8	...... [1]89.0 90.8	...... 7.0 2.0
62.5	31.3	17.2	15.6	...... [1]88.0 87.1	...... [1]90.0 89.7	...... [1]91.3 90.8	...... 8.0 3.0
83.3	41.7	22.8	20.8	...... [1]89.0 87.7	...... [1]91.0 90.2	...... [1]92.0 91.3	...... 9.0 3.0
104.0	52.1	28.4	26.1	...... [1]91.0 90.1	...... [1]92.0 91.7	...... [1]92.5 92.7	...... 9.0 5.0
125.0	62.5	34.1	31.3	[1]90.5 [1]91.0 90.2	[1]91.7 [1]92.0 91.8	[1]92.2 [1]93.0 92.8	14.0 9.0 4.5
166.7	83.3	45.5	41.7	[1]90.7 [1]91.0 90.1	[1]92.3 [1]93.0 92.7	[1]93.4 [1]93.5 93.5	12.0 11.0 6.0
250.0	125.0	68.1	63.0	[1]91.0 [1]92.0 89.2	[1]93.0 [1]93.5 92.1	[1]93.5 [1]94.2 93.2	20.0 15.0 12.0
333.0	167.0	91.0	83.3	[1]92.0 [1]92.0 90.2	[1]93.0 [1]94.0 92.3	[1]94.0 [1]94.5 93.8	23.0 14.0 12.0
417.0	208.0	113.0	104.0	[1]92.5 91.8 90.8	[1]94.0 93.5 93.5	[1]94.5 94.4 94.5	23.0 16.0 13.0
500.0	250.0	136.0	125.0	[1]92.5 92.4 90.0	[1]94.0 94.1 92.4	[1]94.5 94.8 93.8	28.0 22.0 20.0
583.0	292.0	159.0	146.0	[1]93.0 91.8 90.0	[1]94.0 94.1 92.5	[1]94.6 95.0 94.0	35.0 24.0 20.0
667.0	333.0	185.0	167.0	[1]92.8 92.1 91.5	[1]94.5 94.0 93.0	[1]95.3 95.0 94.0	32.0 23.0 17.0
833.0	417.0	228.0	208.0	[1]93.0 92.3 92.5	[1]94.0 94.2 94.0	[1]94.8 95.0 94.6	35.0 29.0 25.0
1040.0	520.0	384.0	260.0	[1]93.5 92.5 92.0	[1]94.5 94.6 94.2	[1]95.7 95.5 95.3	38.0 30.0 26.0
1250.0	625.0	341.0	313.0	[1]93.6 92.2 93.0	[1]94.7 94.4 95.1	[1]95.4 95.5 95.9	42.0 38.0 22.0
1667.0	833.0	455.0	417.0	[1]94.0 92.6 92.3	[1]95.0 94.8 94.7	[1]95.8 95.8 95.7	50.0 42.0 38.0

[1] **Engine type machines—efficiencies do not include friction of bearings.**

97. Synchronous Speeds—Alternating-current Generators and Motors

Application to Generators.—The table shows the speeds at which the rotor of an alternator which has a given number of field poles must turn to generate currents at given frequencies.

Application to Motors.—The table indicates the synchronous speed or the speed of the rotary magnetic field of an induction motor having a given number of poles and taking current at a given frequency.

The table also shows the speeds of synchronous motors having a given number of field poles and taking currents at given frequencies.

Number of poles	Revolutions per minute when frequency is											
	25	30	33⅓	40	50	60	66⅔	80	100	120	125	133⅓
2	1,500	1,800	2,000	2,400	3,000	3,600	4,000	4,800	6,000	7,200	7,500	8,000
4	750	900	1,000	1,200	1,500	1,800	2,000	2,400	3,000	3,600	3,750	4,000
6	500	600	667	800	1,000	1,200	1,333	1,600	2,000	2,400	2,500	2,667
8	375	450	500	600	750	900	1,000	1,200	1,500	1,800	1,875	2,000
10	300	360	400	480	600	720	800	960	1,200	1,440	1,500	1,600
12	250	300	333	400	500	600	667	800	1,000	1,200	1,250	1,333
14	214	257	286	343	428	514	571	686	857	1,029	1,071	1,143
16	188	225	250	300	375	450	500	600	750	900	938	1,000
18	167	200	222	267	333	400	444	533	667	800	833	889
20	150	180	200	240	300	360	400	480	600	720	750	800
22	136	164	182	217	273	327	364	436	545	655	682	720
24	125	150	167	200	250	300	333	400	500	600	625	667
26	115	138	154	185	231	280	308	370	423	554	577	615
28	107	128	143	171	214	257	286	343	429	514	536	571
30	100	120	133	160	200	240	267	320	400	480	500	533
32	94	113	125	150	188	225	250	300	375	450	487	500
36	83	100	111	133	166	200	222	266	333	400	417	444
44	79	82	91	109	136	164	182	218	273	327	341	363
48	63	75	83	100	125	150	167	200	250	300	312	333
54	56	66	74	90	111	133	148	178	222	266	278	296
60	50	60	67	80	100	120	133	160	200	240	250	266
68	44	53	59	71	88	106	118	141	176	212	221	235
72	42	50	55	67	83	100	111	133	166	200	208	222
96	31	38	42	50	64	75	82	100	125	150	156	167
100	30	36	40	48	60	72	80	96	120	120	150	160

98. Two-phase Alternator.—In a generator of the type indicated in Fig. 45 the centers of the two component coils *I* and *II* are situated 90 deg. apart and the single-phase electromotive forces generated in coils *I* and *II* by the passage of the field system past them, differ in phase by 90 deg. This property has given rise to the term quarter-phase for this type of machine, but it is more frequently called a two-phase machine. The electromotive force in coil *I* is zero when that in coil *II* is a maximum, and vice versa. The curves of electromotive force in coils *I* and *II* may be plotted as indicated in Fig. 46. Fig. 47 shows two methods of connecting

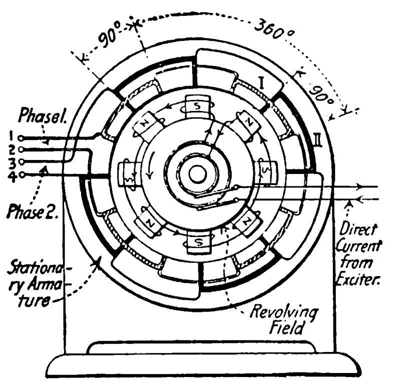

FIG. 45.—Diagram for two-phase alternator.

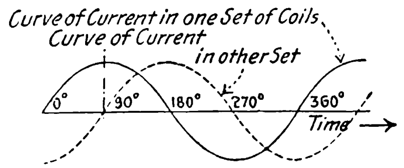

FIG. 46.—Curves of two-phase current.

the armature windings of two-phase alternators. The armature coils can be arranged in one or more slots per pole as diagrammatically suggested in Fig. 48. In commercial machines the windings are almost always arranged in more than one slot per pole. See first section for further information in regard to two-phase currents.

99. Three-phase alternator coils are arranged as illustrated diagrammatically by coils *I*, *III* and *II* of Fig. 49, and the curves of

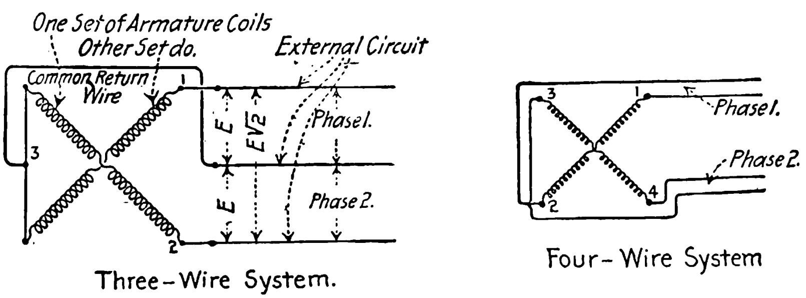

FIG. 47.—Methods of connecting two-phase generator armature windings.

instantaneous electromotive force are displaced from one another by 60 deg. as indicated in Fig. 51. This arrangement of coils is really a six-phase grouping, and in connecting the winding for three-phase, the coils of one of the phases must be connected in the reverse sense from the other two. This will give the true three-phase arrangement in which the e.m.f. curves are as in Fig. 52. These curves also represent the e.m.fs. for the winding in Fig. 50 with the three phases connected up in the same sense. Here

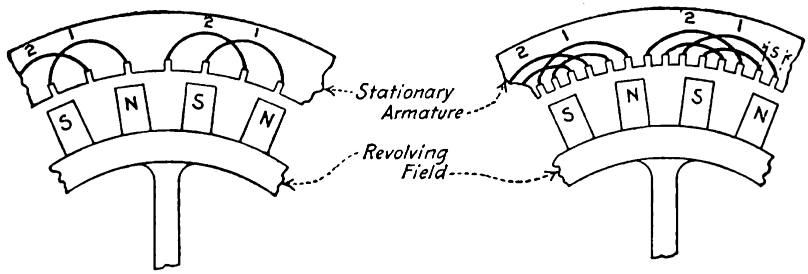

FIG. 48.—Two-phase armature windings.

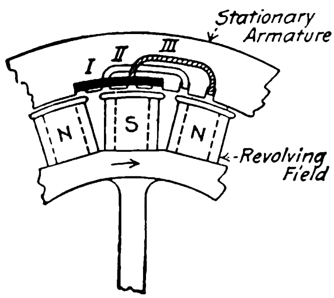

FIG. 49.—Six-phase grouping.

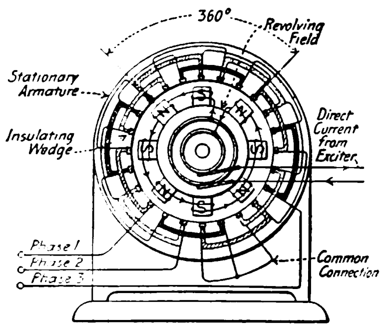

FIG. 50.—Diagram for three-phase, Y-connected alternator.

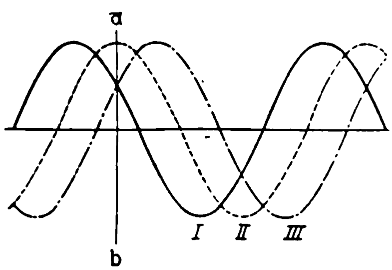

FIG. 51.—Curves of instantaneous electromotive forces.

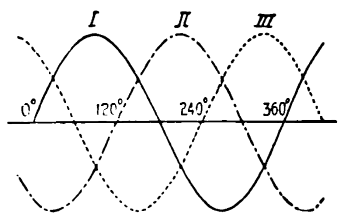

FIG. 52.—Curves of three-phase currents.

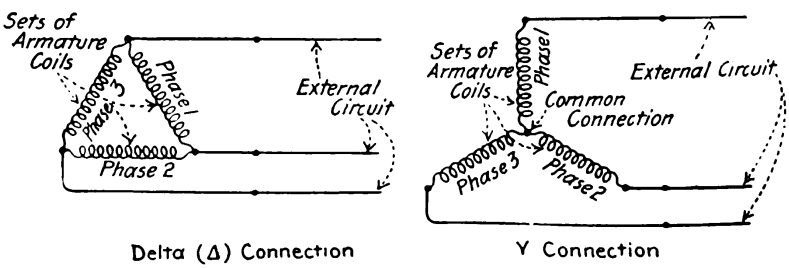

FIG. 53.—Methods of connecting three-phase armature coils.

three coils are distributed over a double pole pitch, and the phase displacement between the e.m.fs. is 120 deg.

The two methods of connecting three-phase armature windings are shown in Fig. 53. These methods are discussed in more detail in the first section. Armature windings can be arranged in one or more slots per pole (Fig. 54). The Y method of connection is almost always used for three-phase generators.

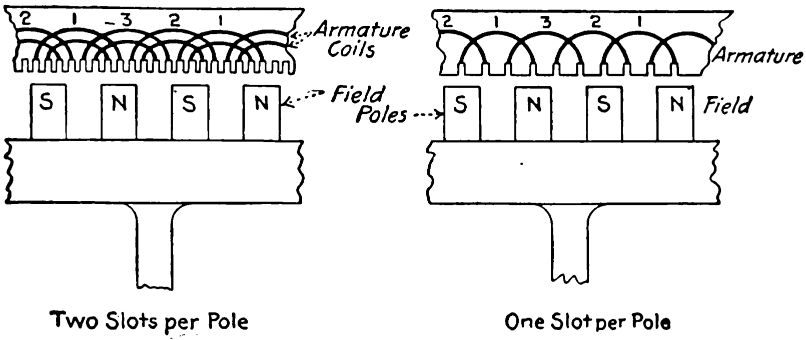

FIG. 54.—Three-phase armature windings.

100. Exciters for alternating-current generators (*Standard Handbook*) are usually compound-wound, flat-compounded, and rated at 125 or 250 volts. It is especially desirable that they be "stable," if direct-connected to the shaft of the alternators, as is sometimes done. By a stable generator is meant one that does not have an excessive rise or fall in potential with a corresponding change in speed. Standard direct-current machines of good design and of the desired rating are used where the exciters are separately driven, and separately driven exciters are preferable for most plants on account of the fact that the system is made much more flexible; any drop in the speed of the alternator does not cause a corresponding drop in the exciter voltage, and the regulation of the plant as a whole is improved. Furthermore, if the exciter is not direct-connected, an accident to it will not necessitate shutting down the generator, assuming that there is a duplicate exciter set.

In all cases it is necessary that the exciter capacity be ample and that there be sufficient reserve capacity. In order to make the exciter plant as reliable as possible, storage batteries are being installed in connection with the exciting generators in many plants in such a way that current may be furnished to the field circuits of the alternators, even though all rotating apparatus be at a standstill. As an example of the amount of reserve capacity that is sometimes installed: in the first power plant of the Niagara Falls Power Company four exciters are installed, each one having sufficient capacity to excite the entire plant, and each driven by its own turbine, fed by a separate penstock.

It is apparent that where separately driven exciters are used, the prime movers should be such that the exciters may be started independently of the current furnished by the alternators. Steam-water-, or gas-driven units are necessary unless a storage battery or power from an external source is available for excitation of the plant when first starting up. With the bus-bars excited, motor-driven units may be operated and they are preferable in many cases. General figures for the capacity of an exciter for any machine run from 2.5 per cent. of the capacity of the alternator for moderate speeds and small sizes, to 0.5 per cent. of the alternator capacity, or a trifle less, for large, high-speed, turbine units. Two per cent. is a figure very commonly used in the absence of definite data. This is too low in a very few cases, but more often in error on the safe side.

101. Synchronizing.—(For a complete discussion of the various methods, and for diagrams of all synchronizing circuits in common use, for both lamps and synchroscopes, see *Electric Journal* articles by *Harold Brown*, May, 1912, and July, 1912.) Two or more alternating-current generators will not operate in parallel unless (1) their voltages, as registered by a voltmeter, are the same; (2) their frequencies are the same; and (3) their voltages in phase. If the machines are not in phase, even if their indicated voltages and their frequencies are the same the voltage of one will, at given instants, be different from that of the other and there will be an interchange of current between the machines. When two or more generators all satisfy the three above requirements they are in synchronism. Synchronizing is the operation of getting machines into synchronism. Incandescent lamps or instruments are, as described in other paragraphs used for indicating when machines are in synchronism.

102. Synchronizing a Single-phase Circuit with Lamps.—The elementary principle involved in determining synchronism is indicated in Fig. 55. If the voltage and frequency of generators A and B are the same and the machines are in phase, point a will be at the same potential at every instant as will point a'. Hence the lamps between a and a' will not light so long as the three conditions are satisfied. So long as the conditions are not satisfied there will be a fluctuating cross current from a to a' and a constant fluctuating of the brilliancy of the incandescent lamps. When the lamps become dark and remain so, the generators are in synchronism and may be thrown together. Had the connection at a' been made to the b' generator lead, the lamps would be bright when the generators were in synchronism, but for reasons outlined in another paragraph the connection shown which provides the "dark lamp" method of synchronizing is preferred. The second pair of lamps between b and b' is provided to insure against accident in case the a—a' set were broken. The same conditions occur in the a—a' set as in the b—b'

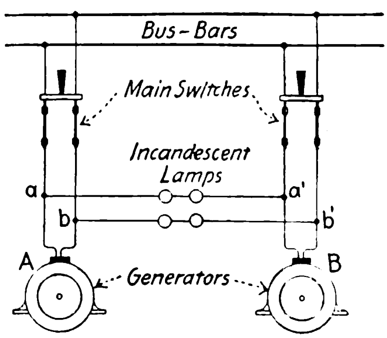

FIG. 55.—Circuits for synchronizing with lamps.

set. A voltmeter of proper rating can be substituted for the lamps.

Where the voltage generated is so high that it is not desirable to connect a sufficient number of lamps in series for it, a single lamp fed through voltage transformers can be used for synchronizing, as suggested in Fig. 56.

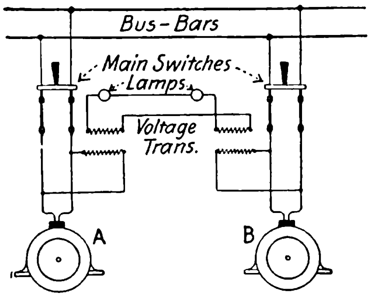

FIG. 56.—Circuits for synchronizing high-voltage circuits with lamps.

103. Phasing Out Three-phase Circuits.—Prior to connecting the leads from a polyphase generator, that is to operate in parallel with others, to the generator switch, the circuits must be "phased out." That is, the leads must be so arranged that each lead from the generator will, when the generator switch is thrown, connect to the corresponding lead of the other generator. If this is not arranged there may be considerable damage done due to an interchange of current when the two machines are paralleled. After once phasing out it is necessary to synchronize but one phase of the machine with the corresponding phase of the other machine.

Connections for phasing out three-phase circuits are shown in Fig. 57. If voltage transformers are not used the sum of the vol-

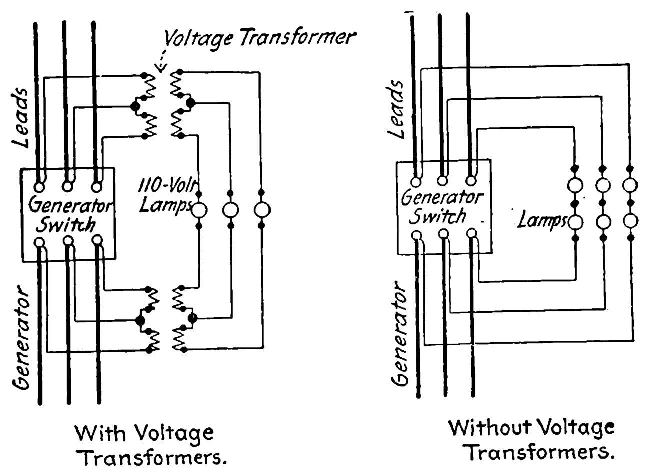

FIG. 57.—Connections for phasing out three-phase circuits.

tages of the lamps in each line should be approximately the same as the voltage of the circuits. On 440-volt circuits, two 220-volt or four 110-volt lamps should be used in each phasing-out lead.

To phase out, run the two machines at about synchronous speed. If the lamps do not all become bright and dark together, interchange any two of the main leads on one side of the switch, leaving the lamps connected to the same switch terminals, after which the lamps should all fluctuate together and the connections are correct. The machines are in phase when all the lamps are dark.

104. The synchronizing connections for three-phase generators are shown in Fig. 58. A synchronizing plug may be used instead of the single-pole synchronizing switch shown. The illustration indicates the connections used where machines are to be synchronized to a bus. Where only two machines are to be synchronized, the connections are the same as shown in Fig. 58, except that the bus transformer and the corresponding lamp are omitted and one plug is required instead of two.

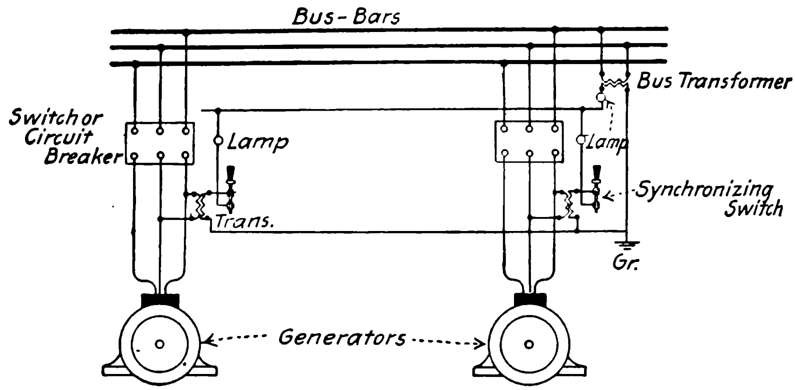

FIG. 58.—Connections for synchronizing three-phase circuits where transformers are required.

105. Synchronizing Dark or Light.—Synchronizing dark appears to be the preferable method. All the connections shown are for "synchronizing dark." When the lamps are "dark" the machines are in phase and it is necessary to close the switch when the pulsation is the slowest obtainable or ceases altogether, that is, at or just before the middle of the longest dark period.

Should a filament break the synchronizing lamps would remain dark and thus apparently indicate synchronism and possibly cause an accident. Therefore it is considered desirable by some to reverse the synchronizing circuit connections and thereby synchronize "light." Synchronizing light eliminates the danger due to the breaking of a filament, but has the disadvantage that the time of greatest brilliancy is difficult of determination. The "light" period is relatively long compared with the dark period so that synchronizing light is usually considered the more difficult and were it not that with the "synchronizing light" method the danger due to filament breakage is eliminated, the method would never be used.

The probability of a filament breaking just at the time of approaching synchronism and when the machines are not in phase is remote. If it occurs at any other time in the operation it will be noticed. As a protection against accidents due to breakage, two synchronizing lamps should always be placed in multiple.

106. **The number of lamps to use in a group to indicate synchronism** is determined by the voltage of the generators. With high voltage circuits it is not feasible to use a sufficient number of lamps, so a transformer is employed that has a voltage sufficient for a 110-volt lamp. See the diagrams. The greatest voltage impressed on the lamps is double that of the voltage transformers or generators. Thus the maximum voltage on the lamps where two 220-volt generators are being synchronized is 440 volts. The dark period may be shortened by impressing a voltage higher than their normal on the lamps. For two 220-volt machines, for example, three 110-volt lamps might be used.

107. **Synchroscopes** are instruments that indicate the difference in phase between two electromotive forces at every instant. They show whether the machine to be synchronized is running fast or slow and indicate the exact instant when the machines are in synchronism. The companies that manufacture the instruments furnish literature describing the theory involved and that gives complete circuit diagrams.

108. **While for successful parallel operation,** it is not necessary that alternating-current generators be of the same type, output, and speed, it is universally conceded that the question of wave shape is important, since if the waves are of different shapes, cross currents will always be present. Similar wave shapes are more readily obtained with machines of similar type. Satisfactory parallel operation, the previously mentioned conditions being fulfilled, consists in obtaining:

(1) Correct division of the load amongst the machines; and

(2) Freedom from hunting.

109. **Division of Load.**—Machines with similar characteristics tend to divide the common load uniformly. Such a proportional load division may be disturbed if the steam supply to the engines is defective or variable from any cause. The steam supply is regulated by the engine governors, and defects in one or more of these governors will give rise to poor load division. It is essential that the governors of all the engines shall have similar speed-regulation characteristics so that a sudden change in the load shall cause the same amount of regulation on each engine. Correct load division is therefore essentially a problem for the engine governors. It is sometimes arranged to govern all the engines from a common throttle valve, but this plan is not often employed. A more usual plan consists in running all the machines except one, with their stop valves full open and their governors fixed, so that the remaining engine may take up any variations in the common load.

Varying the voltage of an alternator running in parallel with others by adjusting its field rheostat will not vary the load on it as with a direct-current generator. To increase the energy delivered by an alternator it is necessary that the prime mover be caused to do more work. An engine should be given more steam or a waterwheel more water.

110. **Adjustment of Field Current.**—When the rheostats of two alternators running in parallel at normal speed are not adjusted to give a proper excitation, a cross current will flow between the

armatures. The intensity of this current depends only upon the difference in field charges of the machines. It may vary over a wide range, from a minimum of zero when both field charges are normal, to more than full-load current when they differ greatly. The effect of this cross current is to increase the temperature of the armatures and, consequently, to decrease the output of the generators. It is important that the rheostats be so adjusted as to reduce it to a minimum. This cross current registers on the ammeters of both generators and usually increases both readings. The sum of the ammeter readings will be a minimum when the idle or cross current is zero.

In general, the proper field current for a machine running in parallel with others is that which it would have if running alone and delivering its load at the same voltage. In order to determine the proper position of the rheostats it is necessary to make trial adjustments after the alternators are paralleled, until that position is found at which the sum of the ammeter readings is a minimum.

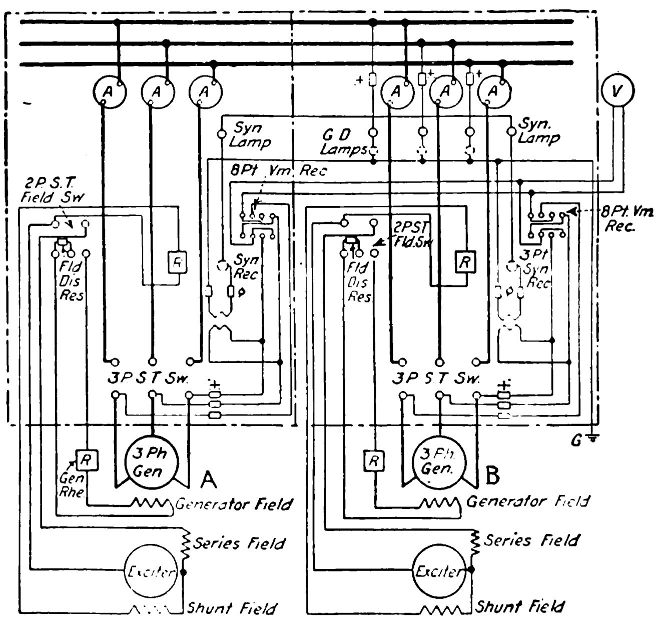

FIG. 59.—Two three-phase alternators of similar characteristics operating in parallel.

To illustrate this method let us consider two similar alternators, *A* and *B*, Fig. 59, operating in parallel. When the generator field rheostats of both are properly adjusted no cross currents will flow through the armatures and the main ammeters will show equal readings if each machine is receiving the same amount of power from its prime mover. If the rheostat of *A* be partly cut in so as to reduce its field current, a cross current, lagging in *B* and leading in *A*, will flow between the armatures, the effect of which will be to strengthen *A's* magnetization and weaken *B's* until they are approximately equal. The resultant e.m.f. of the system will thereby be lowered.

On the other hand, if the rheostat of B be partly cut out so as to increase its field current, a cross current leading in A and lagging in B will flow between the armatures, strengthening A's magnetization and weakening B's magnetization until they are again equal. The resultant e.m.f. of the system will thereby be raised. A cross current of the same character is therefore produced by decreasing one field current or increasing the other, *i.e.*, in both cases it will lead in the first machine and lag in the second machine. The e.m.f. of the system will, however, be decreased in one case and increased in the other.

It is obvious that by simultaneously adjusting the two rheostats, the strength of the cross current may be varied considerably and the e.m.f. of the system maintained constant.

For the first trial adjustment cut in A's rheostat several notches and cut out B's the same amount, so as not to vary the e.m.f. of the system. If this reduces the sum of the main ammeter readings, continue the adjustment in the same direction until the result is a minimum. After this point is reached a further adjustment of the rheostat in either direction will increase the ammeter readings. If the first adjustment increases the sum of the ammeter readings it is being made in the wrong direction, in which case move the rheostats back to the original positions and then cut out A's rheostat and cut in B's. If both adjustments increase the sum of the ammeter readings the original positions of the rheostats are the proper ones.

In making these adjustments of the rheostats it may be found difficult to locate the exact points at which the cross current is a minimum, as it may be possible to move the rheostats over a considerable range when near the correct positions without materially changing the ammeter readings. When the adjustment is carried this far, it is close enough for practical operation. If the generators are provided with power factor meters, the same result may be obtained by adjusting all these to read the same.

111. **Hunting** (*Standard Handbook*) is a term employed to describe the oscillations of the revolving masses of the machines when they are accelerated and retarded above and below the normal average speed. If this hunting or swinging be allowed to exceed a certain amount, the regulation of the machines becomes unstable and they may break out of step. Freedom from cumulative hunting is consequently essential. The swinging action is set up primarily by variations in the rotative speed resulting from irregularity in the turning force. A perfectly uniform turning moment or turning force cannot be obtained with reciprocating engines. The irregularity in the turning moment during a revolution results from the following causes:

Defective distribution of steam in cylinders.

Short connecting rod.

Inertia of moving parts.

If one of two machines running in parallel momentarily lags behind the other, its armature receives a current which tends to pull the machine into phase and accelerate it so that at the instant it reaches the correct phase position its speed is a little greater than that of the other machine, which is now in turn accelerated. The machines are now alternately lagging and leading with relation to one another. In other words, hunting is set up.

Whichever engine is, for the instant, accelerating, will have its steam supply cut down by the governor. If the governor is too sensitive, it will over-govern, cutting down the steam and the speed too far. An instant later, the over-governing will be in the opposite sense, and this process will repeat itself. Similar occurrences will simultaneously be taking place on the other engine, and thus we have a case of hunting governors. By this hunting, the steam supply is rendered periodic and varies between two limits.

112. **Surging** is the term used in connection with the current variations during the hunting, the latter term applying to the mechanical phenomenon of periodic speed variations. The case described is an instance of hunting in the governors due to change of load and to over sensitiveness of the governors. If, however, the governors are sluggish, a time interval elapses between an accidental acceleration and its correction by the governor. This lag will, in response, tend to set up hunting.

113. **Prevention of Hunting.**—The variations in turning moment and angular speed may be greatly reduced by the use of a heavy flywheel, as this tends to keep the rate of revolution uniform by virtue of storing energy and giving it out again during the course of each revolution. The flywheel, however, must not have too great a moment (that is, it must not be too big) as it adds to the inertia of the moving parts and may prolong hunting if once started. Hunting may sometimes be overcome by damping the governor so that it shall not respond to small and quick variations in speed such as occur during one revolution, but shall only respond to steady and continued changes in speed. This result is obtained by fitting each governor with a suitable dash-pot so that it is rendered more sluggish and will make no alteration in the steam supply except when the force acting on the governor is continued for some length of time.

Liability to hunt may sometimes be prevented by synchronizing the engines so that the cranks on all the engines are in step, and the variations in turning moment are coincident in all the engines. This plan is sometimes effective, so far as the prevention of hunting in the generating station is concerned, but it cannot always be utilized owing to the time taken to get the cranks in step, especially as an engine must be run up in a few minutes when the load is coming on quickly. It also is apt to intensify the hunting of the apparatus in distant sub-stations.

With steam turbine-driven generators, this hunting difficulty is much more rare—practically unknown—and the use of high and uniform speeds facilitates the problem of parallel running.

The tendency of generators to hunt may be minimized by surrounding the pole pieces of the field magnets with copper bands in which eddy currents are induced by the shifting and distortion of the field. These currents react on the field and oppose the shifting and thus damp the oscillations. A more suitable construction consists of a grid of copper embedded in the pole face. It is very seldom necessary to provide such "dampers" on pole pieces of generators for modern steam-engine or waterwheel drive. They are usually necessary for gas-engine driven generators.

114. **To Start a Single Alternator.**—(1) See that there is plenty of oil in the bearings and that the oil rings are free to turn and that all switches are open. (2) Start exciter and adjust for normal voltage. Start generator slowly. See that the oil rings are turning. (3) Permit the machine to reach normal speed. Turn the generator field rheostat so that all of its resistance is in the field circuit. Close the field switch. (4) Adjust the rheostat of the exciter for the normal exciting voltage. Slowly increase the alternator voltage to normal by cutting out the resistance of the field rheostat. (5) Close the main switch.

115. **To Start an Alternator to Run in Parallel with Others.**—(1) Bring the exciter and generator to speed as described in the above paragraph. Adjust the exciter voltage and close the field switch, the generator field resistance being all in. (2) Adjust the generator field resistance so that the generator voltage will be the same as the bus-bar voltage. (3) Synchronize, as outlined in one of the above paragraphs. Close the main switch. (4) Adjust the field rheostat until cross currents are a minimum and adjust the governors of the prime movers so that the load will be properly distributed between the operating units in proportion to their capacities.

116. **To Cut Out a Generator Which is Running in Parallel with Others** (*Westinghouse Instruction Book*).—(1) Preferably cut down the driving power until it is just sufficient to run the generator empty. This will reduce the load on the generator. (2) Adjust the resistance in the field circuit until the armature current is a minimum. (3) Open the main switch. It is usually sufficient, however, to simply disconnect the machine from the bus-bars, thereby throwing all the load on the remaining machine without having made any previous adjustment of the load or of the field current.

Caution.—The field circuit of a generator to be disconnected from the bus-bars must not be opened before the main switch has been opened; for, if the field circuit be opened first, a heavy current will flow between the armatures.

117. **The principle of operation of the induction motor** is illustrated in Fig. 60, which indicates diagrammatically a two-phase revolving field generator and a two-phase induction motor having a rotor that is simply a bar of iron. The induction motor depends for its operation on a rotating magnetic field. There is no electrical connection between the revolving and stationary parts of an induction motor.

Windings of the types shown in the illustration are not used in commercial machines, but the general theory involved is the same as with commercial windings. The revolving field (see illustration) of the generator, in turning in the direction shown by the arrow, generates a two-phase current which is transmitted to the motor.

The current, in conductors of one phase, magnetizes poles *A* and *B* and that in the other phase the poles *C* and *D*. The winding is so arranged that a current entering at *A* will produce a south pole at *A* and a north pole at *B*. At the instant shown at *I*, the motor poles *A* and *B* are magnetized while poles *C* and *D* are not, because it is a property of a two-phase circuit that when the current in one of the phases is at a maximum value, the current in the other phase is at a zero value. Hence, the bar iron rotor will assume the vertical position shown.

At another later instant, represented at *II*, the currents in both of the phases are equal and in the same direction; the motor poles will be magnetized as shown and the rotor will be drawn into the position indicated. At the instant illustrated at *III*, because of the properties of two-phase currents, there is no current in the phase the conductors of which are wound on poles *A* and *B*, but the current in the phase the conductors of which magnetize poles *C* and *D*, is a maximum. Hence the rotor is now drawn into a horizontal position. Similar action occurs during successive instants and the rotor will be caused to rotate in the same direction within the motor frame so long as the two-phase current is applied to the motor terminals. Considering it in one way, the rotating magnetic field rotates within the motor frame and drags the rotor around with it.

The magnetic attraction or drag exerted on the rotor in a simple motor built as illustrated would be pulsating in effect, hence the torque exerted by such a motor would not be uniform.

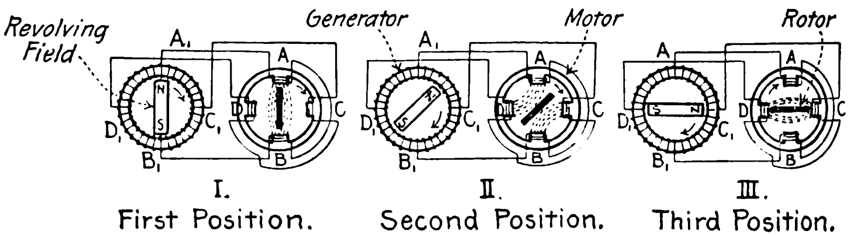

FIG. 60.—Illustrating the principle of the induction motor.

118. Commercial induction motors operate because of the principles outlined in **117**, but their construction is considerably different from that shown in Fig. 60. In commercial induction motors the stator or primary winding is distributed over the entire inner surface of that portion of the stator structure which is of laminated iron and which conducts the magnetic flux. The rotor consists of a laminated iron cylinder which has a winding of insulated wire or of copper rods or bars embedded in slots uniformly spaced around the periphery of the core. Where bars or rods are used they are short-circuited at both ends by heavy copper conductors forming a completely short-circuited rotor.

In the commercial induction motor the magnetic field of the rotor which reacts on the magnetic field of the stator is produced by currents in the rotor conductors. These currents are generated by the rotor conductors being cut by the lines of force of the rotating field which was described in a preceding paragraph. Consider a polyphase induction motor with its rotor at rest. Now connect a source of the proper polyphase current to the motor terminals thereby energizing the stator winding. A rotating magnetic field will be produced by the stator winding. As this magnetic field swings around within the stator structure it will cut the copper bars imbedded in the surface of the rotor. Currents will thereby be induced in the bars and these currents will generate magnetic fields around and within the rotor. Due to the interaction between the rotor and stator magnetic fields, rotation of the rotor will be produced.

It is therefore evident that the turning speed (revolutions per minute) of the rotor can never be quite equal to that of the rotating magnetic field as there must always be a sufficient difference in speed or "slip" that the rotor conductors will be cut by the lines of force of the rotating field. Obviously, if the rotor speed were the same as that of the revolving field, no lines of force could be cut by rotor conductors and there would not be sufficient magnetic interaction between the stator and rotor fields to produce rotation of the rotor and pull a load.

The intensity of the current induced in the rotor and therefore the torque is determined by the amount of "slip" between the rotor and the rotating magnetic field. The greater the torque required, the greater will be the slip.

119. General Characteristics of Polyphase Squirrel-cage Induction Motors.—Their speed is practically constant at all loads. Hence they are used for constant-speed service where starting and reversing are infrequent. The starting torque is relatively small and a large starting current 2 to 6 times full-load current, depending on the design of the motor, is drawn from the line if the motor must start full-load torque.

Simple and rugged construction is a feature of these motors, the bearings being the only parts subject to wear. Since there are no sliding electrical contacts there can be no sparking and the motors are therefore particularly suitable for operation in places where there are inflammable gases or dust.

If the resistance of the rotor be increased the motors can be built, in the smaller capacities, for high starting torque, rapid acceleration, and frequent starting. Motors built thus can be profitably used for operating punches, shears and the like, where simplicity of control is desirable, as with them a large drop in speed produces but a slight increase in torque, permitting the stored energy in the flywheel to be delivered to the machine when a heavy load occurs. In this respect such an induction motor resembles a compound-wound direct-current motor.

If the torque imposed on any induction motor reaches 2 to 4 times full-load torque the motor will stop or "pull out." (See Par. 126.)

The output and torque of an induction motor varies as the square of the applied voltage, hence it is desirable to maintain the voltage at normal value.

120. Approximate Data on

220, 440 and 2,200 volts,[1]

The values given are general and approximate, but are fairly represen-

H.p.	Poles	Synchronous speed		Approx. full-load slip, per cent.		Approximate full-load speed		[2]Starting current for full-load torque
		25 cycles	60 cycles	25 cycles	60 cycles	25 cycles	60 cycles	
½	4	750	1,800	8	6	690	1,700	2.7-3
1	4	750	1,800	8	6	690	1,700	2.7-3
1½	6	500	1,200	8	7	460	1,120	2.7-3
2	4	750	1,800	8	6	690	1,700	2.7-3
2	6	500	1,200	8	7	460	1,120	2.7-3
3	4	750	1,800	8	6	690	1,700	2.7-3
3	6	500	1,200	8	7	460	1,120	2.7-3
4	8	375	900	8	6	345	850	2.7-3
5	4	750	1,800	8	6	690	1,700	2.7-3
5	6	500	1,200	8	7	460	1,120	2.7-3
5½	8	375	900	8	6	345	850	2.7-3
7½	4	750	1,800	7	4	700	1,720	2.7-3
7½	6	500	1,200	7	5	465	1,135	2.7-3
7½	8	375	900	7	6	349	850	2.7-3
10	6	500	1,200	7	5	465	1,135	2.7-3
10	8	375	900	7	6	349	850	2.7-3
12	10	300	720	6	6	282	680	2.7-3
15	6	500	1,200	6	5	470	1,135	2.7-3
15	10	300	720	6	6	282	680	2.7-3
20	6	500	1,200	6	5	470	1,135	2.7-3
20	8	375	900	6	6	353	850	2.7-3
25	6	500	1,200	6	5	470	1,135	2.7-3
25	12	250	600	5	6	237	565	2.7-3
30	8	375	900	5	6	355	850	2.7-3
35	8	375	900	5	6	355	850	2.7-3
35	12	250	600	5	6	237	565	2.7-3
40	8	375	900	4	6	360	850	2.7-3
50	8	375	900	4	6	360	850	2.7-3
75	10	300	720	4	6	288	680	3-3.5
75	14	214	514	4	4	205	495	3-3.5
100	10	300	720	4	4	288	690	3-3.5
110	16	....	450	....	4	......	430	3-3.5
150	12	....	600	....	4	......	575	3-3.5
150	16	....	450	....	3	......	435	3.5
200	12	....	600	....	4	......	575	3.5

[1] 2,200-volt motors are seldom if ever made for capacities of less than 20 to 30 h.p.

[2] Starting current for full-load torque in terms of full-load current.

[3] Starting torque in terms of full-load torque.

121. Characteristics of Polyphase Induction Motors Having Wound Rotors and Internal Starting Resistance.—Motors of this type of the ordinary design give about 1½ times full-load torque with approximately 1½ times full-load current, making them suitable for use on lighting circuits and for other applications where a minimum starting current is desirable. In general, motors of this type are not built in capacities exceeding 200 h.p. because of the mechanical difficulties encountered in arranging the internal resistance.

Standard Induction Motors

two-phase and three-phase.

tative of what may be expected from commercial induction motors.

[3]Starting torque at rated voltage	[4]Pull out torque	[5]Efficiency, per cent.				Power factor, per cent.				H.p.
		½ load	¾ load	Full-load	1¼ load	½ load	¾ load	Full-load	1¼ load	
1.3	2.3	65	70	72	73	52	63	70	72	½
1.3	2.3	74	77	77	76	60	72	80	83	1
1.3	2.3	82	84	84	83	60	72	78	80	1½
1.2	2.3	82	84	85	85	64	75	80	83	2
1.3	2.3	82	84	84	83	60	72	78	80	2
1.3	2.3	82	85	85	84	74	83	86	88	3
1.3	2.3	81	83	84	84	65	75	81	83	3
1.5	2.5	82	85	85	84	74	83	86	88	4
1.5	2.5	83	85	85	84	78	85	88	89	5
1.3	2.5	84	86	86	85	78	84	86	87	5
1.5	2.5	82	85	85	84	74	83	86	88	5½
2	3	83	85	85	84	79	88	90	92	7½
1.5	2.5	83	85	84	84	73	82	85	87	7½
1.5	2.5	83	85	85	85	70	78	83	85	7½
1.5	2.5	85	86	85	84	80	86	89	90	10
1.5	2.5	84	86	85	84	75	82	86	88	10
1.5	2.5	85	86.5	86	86	70	80	85	88	12
1.5	2.5	85	86	86	85	79	86	89	90	15
1.5	2.5	85	86.5	86	86	70	80	85	88	15
1.5	2.5	87	88	87.5	87	82	89	91	90	20
1.5	2.5	84	85	85	85	71	81	85	87	20
1.5	2.5	86	87	87	86	82	89	91	91	25
1.5	2.5	86	87	87	87	64	75	81	83	25
1.5	2.5	86	86.5	86	85	72	82	86	88	30
1.5	2.5	87	88	88	87	72	82	86	88	35
1.5	2.5	86	87	87	86	75	83	85	86	35
1.5	2.5	87	88	87	86	76	84	89	90	40
1.75	2.75	87	88	88	88	78	86	89	90	50
1.75	2.75	86	87.5	87	86.5	76	84	88	90	75
1.75	2.75	86	88	89	89	74	83	87.5	89	75
1.75	3	89	90	90	90	83	89	91	91	100
1.75	3	87	89	92	91	85	91	92	91	110
1.75	3	89	90	90	89	82	89	91	90	150
1.5	2.5	87	89	89	88	80	87	89	90	150
1.5	2.5	91	92.5	92	91	85	91	92	91	200

[4] Pull-out torque in terms of full-load current.

[5] Efficiencies of 25-cycle motors slightly lower than those of 60-cycle motors due to their lower speeds.

Compared with the squirrel cage motor, one with a wound rotor and internal resistance will develop a greater starting torque per ampere, but it should not be used for applications wherein there is great inertia or excessive static friction. If used for such applications full starting current may be required for a considerable period before the apparatus attains full speed. Since the capacity of the internal resistance is small, excessive temperatures may result and cause trouble.

122. Approximate Amperes per Terminal for Alternating-current Induction Motors

Horse-power	Single-phase			Two-phase (four wire)			Three-phase (three wire)					
	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	550 volts	1100 volts	2200 volts
0.5	6.6	3.4	1.8	3.3	1.7	0.9	3.7	1.8	1	....	....	....
1	14	7	3.5	6.4	3.2	1.6	7.4	3.7	1.9	....	....	....
2	24	12	6	11	5.7	2.9	13	6.6	3.3	2.5	....	....
3	34	17	8.5	16	8.1	4.1	19	9.3	4.7	3.5	....	....
5	52	26	13	26	13	6.5	30	15	7.5	6	....	....
7.5	74	37	18.5	38	19	9.5	44	22	11	9	....	....
10	94	47	23.5	44	22	11	50	25	12.5	11	....	....
15	....	....	....	66	33	16.5	76	38	19	16	....	....
20	....	....	....	88	44	22	102	51	25.5	22	....	....
25	....	....	....	111	55	28	129	64	32	25	....	....
30	....	....	....	134	67	33.5	154	77	38.5	32	16	8
40	....	....	....	178	89	44.5	204	107	53.5	44	21	11
50	....	....	....	204	102	51	236	118	59	52	27	13
75	....	....	....	308	154	77	356	178	89	77	39	20
100	....	....	....	408	204	102	472	236	118	100	50	25
150	....	....	....	616	308	154	710	355	178	147	80	40
200	....	....	....	818	409	204	940	470	235	192	98	49
250	....	....	....	.....	510	250	.....	590	290	237	125	62
300	....	....	....	.....	600	300	.....	700	350	285	150	74

123. Characteristics of Polyphase Slip-ring or Wound-rotor Induction Motors Having External Starting Resistance.—These motors have insulated wire or bar windings on the rotor and are provided with collector rings whereby an external resistance can be connected in the rotor circuit. The speed of the motor can be varied by varying the amount of external resistance in the rotor circuit. These motors are used in moderate and large capacities for nearly all variable speed applications. They are also used for constant speed applications where the starting current must be low.

The motors operate with characteristics similar to those of direct-current motors having resistance in the armature circuit. When the external resistance is short-circuited, the motors really become squirrel cage machines and operate with the characteristics of such machines.

124. Characteristic Curves of the Induction Motor.—The curves of Fig. 61 are fairly typical of the average commercial induction motor. It will be noted that the normal rating of the motor is taken at such a point that both the power factor and the efficiency are the highest possible. The motor could be so designed that either the power factor or the efficiency, but not both, could be higher than shown at normal load, but the design of an induction motor is a compromise between the leading factors resulting in the best efficiency and power factor obtainable with suitable overload and starting characteristics. Fig. 62 shows the curves of the same motor running single-phase.

125. The torque curves of an induction motor with a wound rotor, from rest to synchronism, running both three-phase and single-phase with resistance and without resistance, are shown in Fig. 63. Curve *A* shows the torque from rest to synchronism without resistance in the rotor circuit. If resistance is inserted, curve *B*

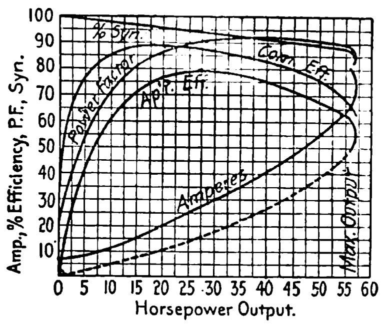

FIG. 61.—Typical performance curves of a 20-h.p., three-phase induction motor.

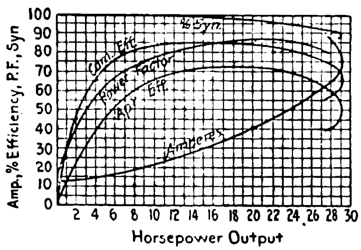

FIG. 62.—Performance curves of the motor shown in Fig. 63, when running single-phase.

is obtained and the starting torque is 440 lb. against 170 lb. without resistance. Curve *C* indicates the torque where too much resistance is used in the rotor. Curve *E* illustrates the torque single-phase, which is zero at starting. An induction motor starts as shown on curve *B* until it reaches the point *F*, when the resistance is cut out and the motor adjusts itself to its operating position at *G*. Thus, if the torque required of the motor for which the curve is shown,

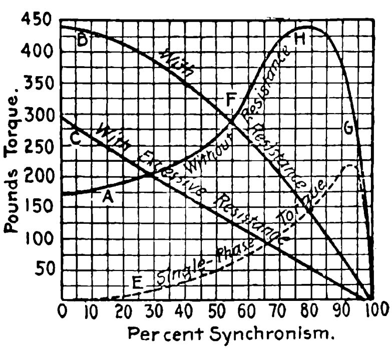

FIG. 63.—Torque curves of a 30-h.p. induction motor.

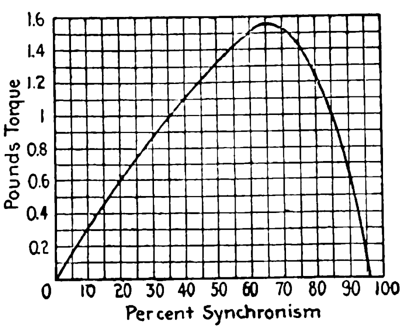

FIG. 64.—Torque curves of a 1-h.p., three-phase induction motor, running single phase.

is greater than 440 lb., shown at *H*, the motor will break down and come to rest. With the resistance in the rotor, a starting torque of 440 lb. is available, but this load cannot be brought up to normal speed. The motor can only bring the torque represented by the point *F*, in other words 290 lb., up to normal speed.

In Fig. 64 it will be noted that the torque of a three-phase motor running single-phase at starting is zero, rising to a maximum and reaching zero at synchronism. This means that an induction motor never runs at synchronous speed. The three-phase motor, Fig. 65, starts with a reasonable torque, reaches its maximum output and goes to zero again at synchronism.

Figs. 65 and 66 show the torque curves of squirrel cage motors without resistance in the rotor circuit. With resistance inserted in the armature, the torque is greater at starting and less later. This is the reason that it is advantageous to introduce resistance at starting and cut it out as synchronism is approached.

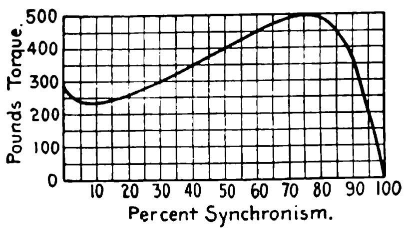

FIG. 65.—Torque curves of a 20-h.p., three-phase induction motor.

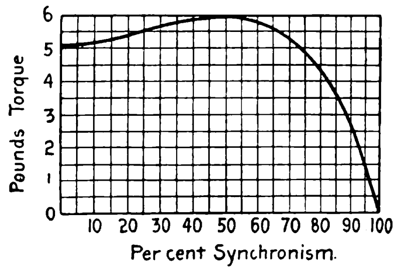

FIG. 66.—Torque curve of a 1-h.p., three-phase induction motor.

126. The Pull-out Torque of an Induction Motor.—All induction motors will "pull out" at some certain torque if they are overloaded. The "pull-out" limit—the maximum torque that can be developed—is that point at which further increase in torque will cause the motor speed to decrease rapidly and then to stop. This point is usually at between 2 and 4 times the full-load rated torque, depending on the design and the capacity of the motor. See the typical induction motor curve, Fig. 61.

127. Starting Torque and Starting Current of Alternating-current Motors (*F. D. Newbury, N.E.L.A. Convention Paper*, 1911). —In what follows the starting torque is expressed in terms of the full-load torque, and the starting current in terms of the full-load current. The smaller values given for synchronous motors cover the requirements of motor-generator sets and air compressors and pumps when the apparatus can be started without load. The larger values refer to motors for driving pumps and fans, which must be started under practically full-load conditions. The wide variation in the starting current comes from differences in construction of the motor or differences in the proportions of the motor, since, by increasing the size and cost of synchronous motors, the starting performances can be materially improved.

SINGLE-PHASE INDUCTION MOTORS, WITH CLUTCH, SPLIT-PHASE STARTER.—Starting torque, 1 to $1\frac{1}{4}$, starting current, $4\frac{1}{2}$ to 6.

SINGLE-PHASE INDUCTION MOTORS, WITHOUT CLUTCH, SPLIT-PHASE STARTER.—Starting torque, 2; starting current, $3\frac{1}{2}$ to $4\frac{1}{2}$.

POLYPHASE INDUCTION MOTORS, CAGE-WOUND TYPE, AUTO-TRANSFORMER STARTER.—Starting torque, 2; starting current, 7 to 8.

POLYPHASE INDUCTION MOTORS, WOUND-ROTOR TYPE, STEP-BY-STEP RESISTANCE STARTER.—Starting torque, 1; starting current, $1\frac{1}{4}$. Starting torque, 2; starting current, $2\frac{1}{2}$.

SYNCHRONOUS MOTORS, AUTO-TRANSFORMER STARTER.—Starting torque, 0.3 to 0.5; starting current, $1\frac{1}{2}$ to $2\frac{1}{2}$. Starting torque, 0.7 to 1; starting current, 4 to 8.

ROTARY CONVERTERS, AUTO-TRANSFORMER STARTER.—Starting torque, 0.2; starting current, $1\frac{1}{2}$. Starting torque, sufficient to start itself.

128. **Speed Regulation of Induction Motors. Slip.**—The speed regulation is the percentage drop in speed between no-load and full-load based on the maximum speed; it is usually called the "slip." The "slip" at full-load is usually about 5 to 7 per cent. At other loads it is approximately proportional to the load, therefore, at twice full-load the drop in speed will be approximately 10 to 15 per cent.

129. **The slip of an induction motor** is the ratio of the difference between the rotating magnetic-field speed (revolutions per minute or angular velocity) and the rotor speed to the rotating magnetic-field speed. The speed of the rotating magnetic field is equivalent to the synchronous speed of the machine (see table of synchronous speeds elsewhere in this section) which is determined by the frequency of the current and the number of poles of the machine. Then:

$$\text{Slip} = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}}$$

When there is no load on a motor the slip is very small, that is, the rotor speed is practically equal to the synchronous speed. Slip varies with the design of the motor and may vary from 4.0 to 8.5 per cent. at full-load in motors of from 1 to 75 h.p. of ordinary design.

Example.—What is the slip at full-load of a 4-pole, 60-cycle induction motor which has a full-load speed of 1,700 r.p.m.

Solution.—From Table 97 or Formula 94 the speed of the rotating field or the synchronous speed of a 4-pole, 60-cycle motor is 1,800 r.p.m. Then substituting in the above formula:

$$\text{Slip} = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}} = \frac{1{,}800 - 1{,}700}{1{,}800} = \frac{100}{1{,}800} = 5.5\%$$

Therefore the slip is 5.5 per cent. The voltage of the motor or whether it is single-phase, two-phase, or three-phase are not factors in the problem.

130. **The Induction Motor Inherently a Constant-speed Motor. The Regenerative Feature.**—A characteristic of the induction motor is that it tends to rotate at a definite synchronous speed irrespective of whether the motor is driving or being driven, providing there is no starting resistance in the rotor circuit. For instance, when a load is being lowered and the motor is connected to a source of energy, it acts as an alternating-current generator, the descending load furnishing the driving power. The motor delivers energy to the line. When load is being raised the motor absorbs energy from the line. This returning of energy to the line by a motor is termed regeneration. Consider an installation where cars loaded with ore are lowered down a slope on a railroad and the empty cars are hoisted back. The motor delivers about as much

power to the line when lowering as it consumes when hoisting, with the result that practically no energy is consumed in operating the system. The proof of this is that the watt-hour meter for such an installation runs backward about as much as it runs forward.

Another interesting example is a balanced passenger hoist wherein the passenger cars run over varying grades and sometimes one is loaded, at other times the other is loaded. The cars, when equipped with induction motors connected to a source of energy, run at a practically uniform speed without the use of brakes, whether the load overhauls the motor or not. This characteristic will not obtain if starting resistance is left in the rotor circuit, for then the motor will slow down in case it is delivering power to the cars and will operate at an over-speed if the cars are delivering power to the motor. (*Practical Engineer.*)

131. **To Reverse the Direction of Rotation of a Polyphase Induction Motor.**—For a two-phase, four-wire motor, interchange the connections of the two leads of either phase. For a two-phase, three-wire motor, interchange the two outside leads. For a three-phase motor, interchange the connections of any two motor leads.

132. **A single-phase induction motor,** when its rotor is not revolving, has no starting torque. After the rotor commences revolving there is a certain interaction of magnetic fields whereby there is exerted a continuous turning effort. While such a motor

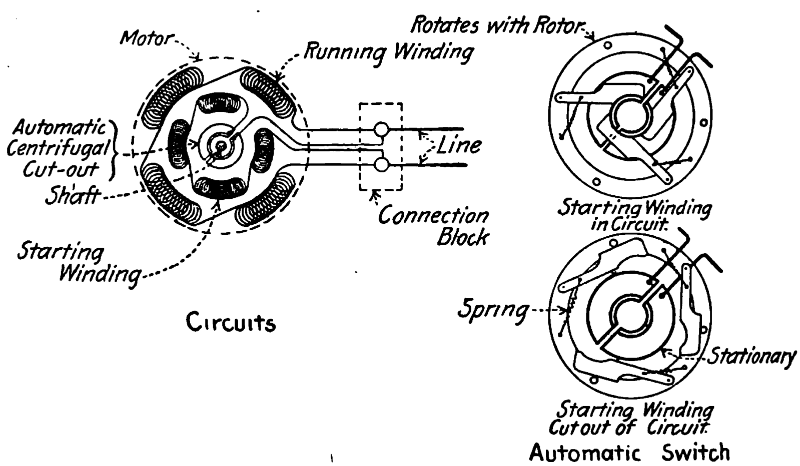

FIG. 67.—Single-phase motor diagram.

can be started by hand by giving the rotor a twist, the most common method of starting is by the so-called split-phase method. With this method the circuit supplying the motor is divided into two circuits and one is arranged in some way so as to have considerably more inductance than the other. Each circuit supplies a winding.

These windings are called the starting and running windings. The current in the starting winding differs in phase by practically 90 deg. from that in the running winding because of the excess inductance in the starting circuit. The starting winding is arranged at practically 90 electrical degrees from the running winding. This latter winding in the motor shown in Fig. 67 consists of a greater number of turns of larger wire, well distributed over the stator, while the starting winding consists of fewer turns and of considerably smaller wire. In this motor the starting winding itself is designed so that it has more inductance than the running winding. In some motors, an inductance coil, carried in the base of the motor, is connected in series with the starting winding to provide the necessary inductance.

The running winding remains in the circuit at all times of motor operation, while the starting one only remains in circuit until the motor has reached synchronous speed or nearly so. When the speed is reached at which the starting winding should be cut out, an automatic centrifugal switch (see illustration) operates and opens the "starting" circuit and the motor continues to operate solely by virtue of the "running" winding and circuit.

133. **Phase Splitting and Repulsion Starting of Single-phase Induction Motors.**—In the former method two windings are used in the stator of the motor; one of these is the working winding, the other the starting winding (see 132). In some cases an external starting box is employed to secure the necessary phase difference in the current, in others the reactance is part of the secondary winding itself.

Where a single-phase induction motor is started by the "repulsion" method (see 135) the rotor is similar to the armature of a direct-current motor, being provided with form wound coils and a commutator. There are two sets of brushes, bearing on the commutator, these sets being short-circuited upon each other. The stator is supplied with single-phase current, and there is no electrical connection between the stator and the rotor. The currents in the stator set up a flux which reacts on the rotor, repelling the successive coils and thereby causing rotary motion. When the motor approaches synchronous speed a centrifugal device of some description short-circuits the commutator bars and lifts the brushes, transforming the motor into the induction type with practically a squirrel cage rotor.

134. **The Starting Torque, Starting Current and Speed Regulation of Single-phase Induction Motors.**—The single-phase induction motor, with phase-splitting starting device, is suitable for machines in which the starting torque is not over 150 per cent. of full-load torque. Almost invariably some type of clutch is used which allows the motor to attain nearly synchronous speed before picking up the load. The starting current with 150 per cent. of full-load torque is approximately 250 per cent. of full-load current, and the maximum torque is from 150 to 200 per cent. of the full-load torque. The speed regulation from no-load to full-load is good, being better than in the multiphase motor. In general, however, the efficiency, power factor and maximum torque are not as good as in corresponding multiphase motors. They are suited only for driving machinery where the starting torque required is light. The single-phase induction motor, with the

repulsion method of starting, has a starting torque of from 2 to $2\frac{1}{2}$ times full-load torque, with 2 to $2\frac{1}{2}$ times full-load current. (*A. B. Morrison*, *Power*, March 4, 1913.)

135. **The condenser-compensator method of starting single-phase induction motors** is shown in Fig. 68. Two terminals of the stator winding, which is practically of the standard three-phase construction, are connected to the supply mains. The third terminal of the stator winding is connected to the line through an auto-transformer. The main to which it is connected is determined by the direction of rotation desired. A condenser is also connected across the transformer to provide capacity. Then when the motor has reached synchronous speed the starting winding can be cut out by opening the switch and the motor then operates upon running winding only.

136. **The compensated repulsion single-phase motor** is one in which the line current passes through the stator and also through the rotor by means of two sets of brushes bearing on the commutator. There is also a second set of brushes set at an angle to the first which are short-circuited on themselves. This motor differs from the straight repulsion type in that it contains two additional sets of brushes and the stator and rotor are in electrical contact.

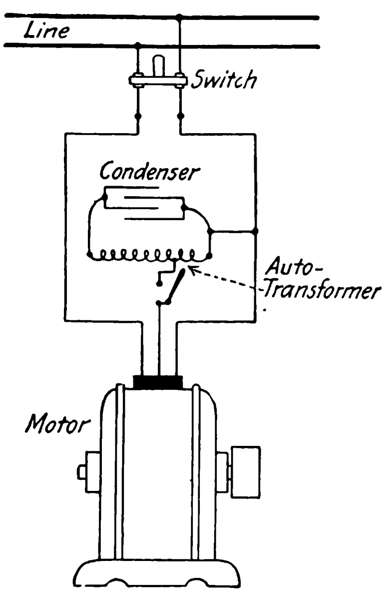

FIG. 68.—A single-phase, self-starting induction motor with a condenser starting arrangement.

137. **The compensated repulsion motor has a starting torque** of $2\frac{1}{2}$ to 3 times full-load torque with approximately twice full-load current, and the maximum torque is from 3 to $3\frac{1}{2}$ times full-load torque. The power factor is very high at all loads, but the efficiency is lower than in the induction motor. This type of motor is well adapted for loads where heavy starting torque is required with sudden overloads. It has the disadvantages of having a commutator and is somewhat more noisy than the induction motor after the latter is up to speed. (*A. B. Morrison, Jr.*, *Power*, March 4, 1913.)

138. **If a variable-speed single-phase motor is required,** some form of compensated repulsion motor is generally used. The behavior of the motor is very similar to that of the variable-speed wound-rotor multiphase-induction motor with resistance in series with the rotor. It is consequently, owing to its unstable speed characteristics, suited only to such applications as require a steady horse-power at given speeds. Its characteristics as regards starting torque, etc., are unchanged when used for variable speeds. The resistance is inserted in series with the brushes which are

normally short-circuited and the insertion of additional resistance decreases the speed. By the insertion of resistance in series with the brushes carrying the line current it is also possible to raise the speed of the motor slightly above synchronism.

139. Approximate Data on Single-phase Induction Motors, 110 to 440 Volts (*Electric Motors, Crocker and Arendt*).—The synchronous or no-load speed of any induction motor is determined by the number of its poles and the frequency. See **94.** Very small single-phase motors, such as fan motors, may not show performances as good as those tabulated below. Pull-out or "break-down" torque as tabulated is in terms of rated full-load torque.

Horse-power	No. of poles	Per cent. slip	Pull-out torque	Per cent. power factor at given loads				Per cent. efficiency at given loads				Synchronous speed at 60 cycles
				1/2	3/4	Full	1 1/4	1/2	3/4	Full	1 1/4	
1/2	4	6.0	1.5	46	58	66	68	53	60	63	60	1,800
1	4	4.0	1.6	55	59	73	75	60	63	68	62	1,800
2	4	2.5	1.8	56	65	77	76	71	75	78	77	1,800
5	4	2.5	1.8	78	83	86	86	71	76	77	76	1,800
10	4	2.5	1.8	75	81	84	83	75	79	80	79	1,800
20	6	2.0	1.9	78	80	86	87	85	88	86	85	1,200
30	8	2.0	1.9	68	80	85	84	77	81	83	82	900
50	4	2.3	2.0	91	94	93	91	82	84	86	86	1,800

140. Synchronous motors (*Carl D. Knight, Practical Engineer*, June 1, 1912).—Generally speaking, any modern alternating-current generator will operate with more or less satisfaction as a synchronous motor, and unless special operating features must be provided for, the two are often identical in construction.

There are two advantages of the synchronous motor, namely: it operates at a constant speed at all loads, provided the driving alternator runs at a constant speed, and its power factor is at all times under the control of the attendant; it can be used to correct low power factor of the system that feeds it in addition to driving a mechanical load, provided it has sufficient capacity.

The latter characteristic is often of considerable importance. It is well known that the power factor of the induction motor, even under full-load conditions, is seldom greater than 95 per cent., and it often falls as low as 50 or 60 per cent. at light load. The result is that an alternating-current generator driving a considerable number of induction motors ordinarily operates at a comparatively low power factor. If this alternator is loaded to its full kilowatt capacity at such a low power factor, overheating will result.

If the alternator is not loaded beyond its normal current capacity it operates at a low energy load but with the same heating losses as at full-load, on account of the reduced power factor. The advantage of the synchronous motor on such a system is, that by proper adjustment of its field current it may be made to draw from the line a current which is leading with respect to the voltage, and which will neutralize the lagging current taken by the induction motors. The current in the alternating-current generator can thereby be brought into phase with the voltage and the generator will operate under its normal conditions. When used in this manner as a compensator for lagging current, the synchronous motor must be of larger size than required by its power output, on account of the excess current which it draws from the line.

141. **A synchronous condenser** is a synchronous motor that operates to correct power factor only and does not pull any mechanical load.

142. **Disadvantages of the Synchronous Motor.**—To offset its advantages, the synchronous motor has disadvantages which ordinarily limit its application to relatively large capacities, and to installations where it can be used as a compensator for lagging current. The chief disadvantage is that the motor has small starting torque even at full-load current. The motor also requires a supply of direct current for its field excitation.

143. **The Uses of Synchronous Motors** (*Standard Handbook*).—Due to the fact that synchronous motors require more care than induction motors, are not self-exciting and are started with some difficulty, synchronous motors are seldom employed where induction motors can be used. Where an induction motor would be objectionable on account of the large lagging wattless currents which affect the voltage regulation, a synchronous motor may be used to advantage. It is also used as a "synchronous condenser" in connection with induction motor loads for power factor correction as noted above.

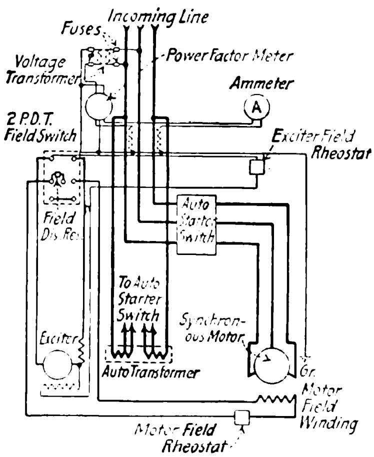

FIG. 69.—Connections for a self-starting synchronous motor.

144. **The steps in starting a synchronous motor** are about as follows:

(1) See that motor is clean, that bearings are well supplied with oil, and that oil rings are free to turn.

(2) See that all switches are open.

(3) Close the double-throw field switch, cutting in the field rheostat with its resistance all in.

(4) Close the main-line switch (if any) in the circuit and throw in the double-throw switch, throwing it in the starting position. The motor should start and speed up to synchronism in from 30 to 60 sec.

(5) When motor is up to speed, throw field switch over to the other (running) position with rheostat all in.

(6) Throw double-throw main switch over to running position, putting motor on full line voltage.

(7) Adjust field rheostat for minimum armature current.

Fig. 69 shows the method of connecting a three-phase, self-starting synchronous motor to its exciter. This diagram shows a double-throw switch in the field circuit. This switch, however, may (where the exciter is connected to the same shaft as the synchronous motor) be single-throw and the field connected direct through the exciter armature with the rheostat in the circuit. The field is thus short-circuited at standstill and is gradually charged as the motor speeds up.

145. Starting Synchronous Motors.—Practically any polyphase synchronous motor may be started by applying full-load voltage to the armature, leaving the field open until the motor has reached its normal speed. Such a procedure would require, however, 2 or more times the full-load current of the machine. Since the power taken by a synchronous motor starting in this manner is of very low power factor, the line disturbances might be considerable. Starting at full line voltage is also liable to induce in the field windings an excessively high voltage, often resulting in breaking down the insulation.

To limit the starting current to a reasonable value, auto starters or compensators are often used. These are similar and used in exactly the same manner as the starting compensators used with induction motors. When starting with a compensator the field-winding circuit is opened by a switch provided for the purpose or the field circuit may be closed through a resistance until the motor has attained its normal speed.

This arrangement does not provide a great starting torque, and in most modern synchronous motors the revolving field of the motor is provided with a special auxiliary winding similar to the winding on the rotor of a squirrel cage induction motor. It has been possible to construct motors having nearly 30 per cent. of full-load torque at approximately $1\frac{1}{2}$ times full-load current. Beside improving the starting torque this squirrel cage winding also has a tendency to reduce the hunting or pumping effect which is sometimes encountered in the operation of synchronous motors.

Where the motor to be started is comparable with the size of the generator which drives it, it is often necessary to connect a small induction motor to the synchronous motor to bring it up to speed. When approximately normal speed has been reached the synchronous motor is thrown on the line as before, and the field closed immediately.

When a large starting torque is required, as, for example, in driving a considerable amount of shafting, it is often impractical to start the load and the motor from rest simultaneously. In such instances it is customary to install a friction clutch or similar device between the motor and its load, so that the motor may attain its normal speed before any load is imposed upon it.

Occasional installations are encountered where the motor is the only load on the driving generator. In such cases it is possible to connect the synchronous motor to the line before starting the alternator. On starting the alternator, both will come up to speed together.

Cases have been known in which the motor was a small part of the load on the driving alternator, that is, the alternator was larger compared with the motor, when an auto starter was used to raise the voltage at start instead of to reduce it. This method gives a fairly good torque, but requires large current, and the operator must be certain that the motor windings will not be damaged before trying such a method.

In cases where it is desired to use an alternating-current generator as a motor and no compensator is available, water rheostats can be used to good advantage, one being placed in series with each phase. They are short-circuited when the motor has attained normal speed. (*Practical Engineer.*)

TROUBLES OF ALTERNATING-CURRENT MOTORS AND GENERATORS, THEIR LOCALIZATION AND CORRECTION

146. Troubles of Alternating-current Machinery.—Much of the material under this heading is based on that in the book *Motor Troubles*, by E. B. Raymond. For further data relating to alternating-current-machinery troubles and their correction see the author's ELECTRICAL MACHINERY, published by the McGraw-Hill Book Company.

147. Induction Motor Troubles (*H. M. Nichols, Power and the Engineer*).—The author asserts that the unsatisfactory operation of an induction motor may be due to either external or internal conditions. The voltage or the frequency may be wrong, or there may be an overload on the machine. Low voltage is the most frequent cause of trouble. The starting current sometimes amounts to twice the running current, with the result that the voltage is particularly low at starting. The best remedy for this disorder is larger transformers and larger motor leads, one or both. The troubles that occur most frequently within the motor itself are caused by faulty insulation, and by uneven air gap due to the springing of the motor shaft or to excessive wear in the bearings. If a wound-rotor machine refuses to start, the trouble may be due to an open circuit in the rotor winding. A short-circuited coil in the motor will make its existence known by local heating in the latter. Most motors designed to employ a starting resistance will not start at all if the resistance be left out of the secondary circuit.

148. Troubles of Alternating-current Generators (*Westinghouse Instruction Book*).—The following causes may prevent alternating-current generators from developing their normal e.m.f.:

The speed of the generator may be below normal.

The switchboard instruments may be incorrect and the voltage may be higher than that indicated, or the current may be greater than is shown by the readings.

The voltage of the exciter may be low because its speed is below normal, or its series field reversed, or part of its shunt field reversed or short-circuited.

The brushes of the exciter may be incorrectly set.

A part of the field rheostat or other unnecessary resistance may be in the field circuit.

The power factor of the load may be abnormally low.

149. Causes of Shutdowns of Induction Motors.—Sometimes there is trouble from blowing fuses. Or possibly, and more serious, the fuses do not blow and the motor, perhaps humming loudly, comes to a standstill. Under these conditions, the current may be 10 times normal, so that the heating effect, being increased as the square of the current or 100 fold, causes the machine to burn out its insulation.

Since the torque or turning power of an induction motor is proportional to the square of the applied voltage (one-half voltage produces only one-quarter torque), it is evident that lowering the voltage has a decided effect upon the ability of the motor to carry load, and may be the cause of its stopping. Another cause may be that the load on the motor is more than equal to its maximum output.

The bearings may have become worn, so that the air-gap (which ordinarily is not much over 0.040 in. and on small motors as small as 0.015 in.) has been gradually reduced at the lower side of the rotor to practically zero. The rotor commences to rub on the stator. The friction soon becomes so great that it is more than the motor can carry. The result is that it shuts down.

A shut-down may be due to bearings introducing excessive friction. Hot bearings, in turn, may be due to excess of belt tension, dirt in the oil, oil rings not turning, or to improper alignment of the motor to the machine that it drives. Hence, under such conditions, it should be ascertained whether the voltage has been normal, whether the air-gap is such that the armature is free from the field, and whether the load imposed upon the motor is more than that for which it was designed. In any installation a system should be arranged whereby an inspector will examine the gap, bearings, etc., periodically.

Rarely, shutting down may be due to the working out of the starting switch, which may be located within the armature. Such a switch is operated by a lever engaging a collar which bears on contacts which, as they move inward, cut out the resistance in series with the rotor winding and located within it.

If the short-circuiting brushes work back, introducing resistance into the armature circuit while the machine is trying to carry load, it will at once slow down in speed and probably stop, usually burning out the starting resistance. Of course, this can occur only from faulty construction. The remedy is to fit the brushes properly, so that they will not work out. It is well to inspect them at the time of air-gap inspection.

150. Low Torque while Starting Induction Motors.—Although the circuit to the motor be closed, sometimes it does not start. The same general laws of voltage, etc., apply to the motor at starting as when running. Hence, the points mentioned under "Shut-downs" should be investigated and if necessary corrected. The resistance, which is frequently inserted in the armature, may be short-circuited, thus giving a low starting torque. Unless a starting compensator is used for starting, it is necessary, in order to obtain a proper starting torque with a reasonable current, that a resistance be inserted in the rotor circuit. The resistance not only limits the current, which would, with the motor standing still, be large, but it causes the current of the armature to assume a more effective phase relation, so that with the same current a far larger torque is obtained. A partial or complete short-circuit of the resistance partially or wholly ruins the starting torque.

151. **Low Maximum Output of Induction Motors.**—The maximum load which a motor can carry may be less than desired, or less than the name plate indicates. If the voltage, air-gap, load, etc., are right, it may be possible that a mistake has been made in connections. It is then easiest to return the motor to the factory, but if immediate operation is essential, the armature connections can easily be changed so as to give a large increase in output. To ascertain what to do, remove the bracket on the side of the motor which covers the connections between the coils. Each motor has a certain number of poles. Pick out one phase, and find out how many groups of coils are connected up. From this, the number of poles can be determined. A better way is to calculate this from the speed of the motor and the frequency of the circuit on which it is running. See 94.

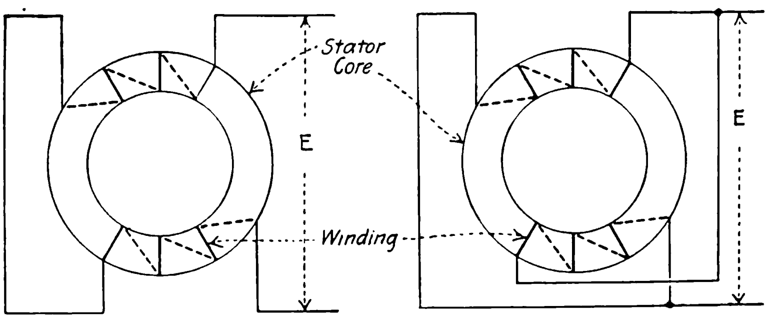

FIG. 70.—Connections of induction-motor coils.

From an examination of the connections it can be easily determined whether the poles in any place are connected in series or in multiple, or in series-multiple. Thus, in a motor, the connections may be as shown in Fig. 70, *I*, which shows the windings of one phase of a four-pole motor. If the connections be changed to those in Fig. 70, *II*, each coil will then receive double its former voltage and the motor will give four times the output. Before making a change in connections such as that indicated here one must ascertain to a certainty that the increased current that will result will not injure the windings.

It should be borne in mind, however, that this makes the motor less efficient, increasing the exciting current, and thus lowering the power factor. If conditions demand it, this method may be followed. The temperature under the new conditions should be carefully watched to see that there is not undue heating. The only change in connections that can be used for quarter-phase motors is of the type of the one just described.

With three-phase motors the poles can be grouped not only as previously suggested, but a variation of connections from delta to star, or the reverse, can be made. A delta-connected, two-pole motor is shown in Fig. 71, *I*, where the three phases are indicated by the letters, *A*, *B* and *C*. Any one of these phases may have poles connected in either series or multiple. In a delta connection with the coils spaced 120 deg. apart, as shown in Fig. 71, *I*, each phase has the line voltage *E*.

In the star connection the phases are joined as in Fig. 71, *II*. In this case, as in Fig. 71, *I*, each phase may have poles in series or in multiple. In the case of Fig. 71, *II*, each coil has a voltage of $0.58 \times E$.

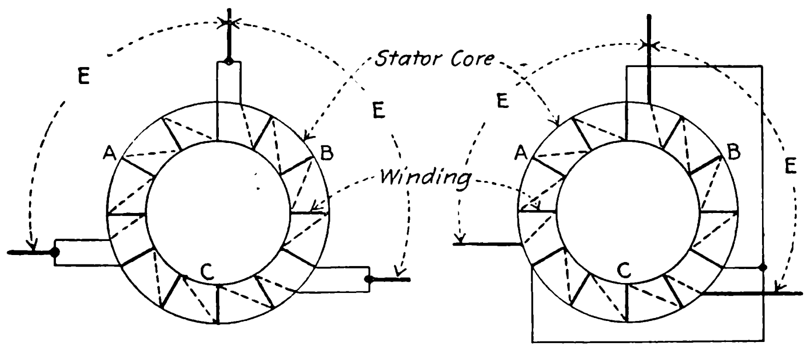

FIG. 71.—Three-phase motor coil connections.

152. Winding Faults of Induction Motors.—When a new induction motor is received, it sometimes happens that in attempting to operate the machine, although it will start, the currents are excessive and unbalanced, undue heating appears or a peculiar noise is emitted and accompanied possibly by dimming of the lights on the same circuit and the lowering of speed with perhaps actual shut-down of other induction motors thereon. If, after examination, there is found to be no difficulty with the air gap, belt tension, starting resistance or bearings, the probabilities are that the coils of the motor have been wrongly connected or that the winding has been damaged during transportation. Certain indications of these conditions are shown by instrument readings. The winding faults in a three-phase motor may be:

1. One coil of the rotor may be open-circuited. The armature or rotor may have a defective winding just as may the field. A coil-wound rotor construction is used only when a starting resistance is used. When a compensator is used no starting resistance is required, and the winding consists simply of bars connected at the ends by a ring.
2. Two coils or phases of the armature may be open-circuited.
3. Armature may be connected properly but field coil or phase may be reversed.
4. Part of field may be short-circuited.
5. One phase of field may be open-circuited.

The symptoms shown for certain of these trouble conditions are indicated in the following data from actual tests on a 5-h.p., six-pole, 1,200 r.p.m., 60-cycle induction motor.

153. **With an open circuit in field or stator** in a three-phase motor, current would flow only in two legs. There would be no current in the other leg and the motor would not start from rest with all switches closed. However, a three-phase motor or a two-phase motor will run and do work single-phase if it is assisted in starting. The starting torque is zero, but as the speed increased the torque increases.

With a small motor, giving a pull on the belt will introduce enough torque so that it will pick up its load. Therefore while an open circuit in the field winding should be found and repaired, if there is not time for repairs, the motor can be operated single-phase to about two-thirds of normal load. The power factor conditions and effects on the rest of the circuit are practically no worse than when the motor is running three-phase. The torque of a 1-h.p., three-phase induction motor from rest to synchronism, when running single-phase, is indicated in Fig. 64. The torque curve of a 20-h.p., three-phase motor is given in Fig. 65, and of a 1-h.p., three-phase motor in Fig. 66.

154. **Balking of Induction Motors.**—With induction motors having certain slot relations between armature and field, at one certain percentage of speed, the torque will go almost to zero. The motor will start its load properly, but will suddenly lose its torque at some slow speed, perhaps one-tenth normal. Such trouble may be caused by a magnetic locking effect of the teeth of the armature with the poles of the field. This phenomenon, with ordinary measuring instruments and facilities cannot easily be measured. But with special torque measuring instruments the peculiar synchronous locking can be measured and exactly located. If all other investigations show no cause of weak torque during the rise of the speed from rest to synchronism, the relation between the number of poles and slots in the rotor may account for the trouble. This is an unusual condition, but on squirrel cage motors it has existed. There is no remedy but a change in design, so that the manufacturer must take action for correction.

155. **Squirrel Cage Armature or Rotor Troubles.**—Unusual operation due to reversals of phase, phases open-circuited, and other causes, occur with squirrel-cage armatures as well as with wound armatures. Poor soldering of the armature bars may be the cause. Sometimes a solder flux may be used that will insure proper operation for a while, but time will develop poor electrical contacts due to chemical action at the joints. If the resistances of all of the squirrel cage joints are uniformly high, the effect is simply like that of an armature having a high resistance, which causes a lowering of the speed and local heating at the joints. If some of the joints are perfect, but some bad, the motor may not have the ability to come up to speed and there will be unbalanced currents.

156. **Effects of Unbalanced Voltages on Induction Motors.**—The maximum output of a polyphase induction motor may be