materially decreased if the voltages impressed on the different phases are unequal. On a three-phase system, the three voltages between the legs 1–2, 2–3 and 1–3 should be approximately equal. Also on a two-phase the voltage 1–2 should equal 3–4. If these voltages, impressed on the induction motor, are not equal the maximum output of the motor as well as the current in the various legs is proportionately affected.

For example, with a two-phase motor, if the voltages in the two legs differ by 20 per cent., a condition sometimes met in normal practice, the output of the motor may be reduced 25 per cent. Then, instead of being able to give its maximum output of, say, 150 per cent. for a few moments, it will give but 112 per cent. The varying loads which the motor may have to carry may shut it down. In cases of low maximum output, the relative voltages on the various legs should always be investigated. If they vary, the trouble may be due to this variation.

In addition to the effect on the maximum output, the unequal distribution of current in a two-phase motor under such conditions may be quite serious. Consider a specific case of a 15-h.p., six-pole, 1,200-r.p.m., 220-volt motor, with the voltage on one leg 220 and the voltage on the other leg 180; current in leg No. 1 was 60 amp. and in leg No. 2 35 amp. at full-load. The normal current at full-load was 35 amp. Thus the fuse might blow in the phase carrying the high current, causing the motor to run single-phase. If an attempt is made to start the motor the blown fuse not being noticed, there would be no starting torque.

Consider the specific case of a six-pole, 10-h.p., 1,200-r.p.m., 160-volt, three-phase motor. The motor on normal voltage, at full-load, took 110 amp. in each leg. With unbalanced voltages of 161, 196 and 168, only full-load could be carried, although the average of these voltages is such that it might be assumed that 25 per cent. overload should be carried.

157. Induction Motor Starting Compensator Troubles.—Sometimes a mistake is made in the connections to the compensator, so that full voltage is used at starting and the lesser voltage after throwing over the switch. Then the motor at starting takes excessive current, and, since the maximum output is in proportion to the square of the voltage, the motor capacity is much reduced when it is apparently running on the operating position. Such action, therefore, can usually be accounted for by a wrong connection in the compensator. Sometimes a motor connected to a compensator takes more current at starting than it should, under which conditions a lower tap should be tried. Compensators are usually supplied with various taps and the one should be selected which produces the least disturbance on the line, giving at the same time the desired starting torque on the motor.

When a motor, having been connected to a compensator, will not start, the cause may be entirely in the compensator. The compensator may have become open-circuited, due to a flash within. The switch may have become deranged, so that it will not close, or a connection within the compensator may have become loosened. Possibly, when a motor will not start when connected to a compensator just installed, a secondary coil may be "bucked" against another secondary coil within the compensator so that no voltage is produced by the compensator at the motor. This results in no particular heating and in no apparent phenomenon which would account for the motor not starting. An ammeter in the motor leads will indicate the absence of current, or a voltmeter will indicate the absence of voltage.

158. **Induction Motor Collector Ring Troubles.**—It is essential that the contact of the brushes on the collector rings be good, else the contact resistance will be so great as to slow the motor down and to cause heating of the collector itself. This effect is particularly noticeable when carbon brushes are used. The contact resistance of a carbon brush under normal operation pressure and carrying its usual density of current (40 amp. per square inch) is 0.04 ohm per square inch. Thus, under normal conditions, the drop is 0.04×40, which equals 1.6 volts. If the contact is only one-quarter the surface, this drop would be 6.4 volts, and might materially affect the speed of the motor. Thus, if the speed is below synchronous speed more than it should be (normally it should not be over 4 per cent. below), an investigation of the fit of the brush upon the collector may show up the trouble.

If copper brushes are used, this trouble is much less liable to occur, since the drop of voltage, due to contact resistance when running at normal density (150 amp. per square inch), is only one-tenth that of carbon. The same trouble may occur due to the pigtail, which is usually used with carbon brushes, making poor contact with the carbon, which gives the same effect as a poor contact with the collector itself.

159. **Hunting of Induction Motors.**—In very rare cases an induction motor will hunt and cause much trouble. The phenomenon appears as a speed variation of 1 or 2 per cent. each side of the normal speed, with a period of vibration depending upon the conditions. It may be anywhere from 10 to 500 swings a minute.

This rare phenomenon of induction motors depends upon the drop in the line between the generator operating the induction motor and the motor itself, and upon the design and slot relations of field and armature. It will cease if the line resistance be cut out between the motor and the generator. If this is not possible, it can sometimes be stopped on a three-phase motor by changing from delta- to Y-connection, or possibly the grouping of the poles may be changed. In any case, the flux in the motor is altered.

The period of hunting has nothing whatever to do with the hunting of the generator. Hunting of a motor may occur even though the generator speed is exactly uniform. This action is entirely distinct from a variation of the uniformity of the speed of the generator due to the engine driving, which lack of uniformity is repeated by the motor itself. It is more vicious and usually results in a gradual increase of amplitude of swing until the motor finally gets swinging so badly that it finally breaks down and stops entirely. Ordinarily, the manufacturer is responsible, but a change of connections will often cure the trouble and keep the apparatus in operation until a permanent correction can be effected.

160. Improper End Play in Induction Motors.—Induction motors are so designed that the revolving parts will play endwise in the bearing; $\frac{1}{16}$ in. or so. If in setting up the machine the bearings so limit this end action that the rotor does not lie exactly in the middle of the stator, there is a strong magnetic pull tending to center the rotor. If the bearings will not permit this centering, the thrust collars must take the extra thrust which, in an induction motor, is considerable. If in addition to the magnetic thrust the belt pull is such as to also draw in the same direction, the trouble is increased. The end force may be such as to heat the bearing excessively and to cause cutting, soon rendering the motor inoperative.

In case of trouble with bearings, the end play should be tested by pushing against the shaft with a small piece of wood, placed on the shaft center. With the machine operating under normal conditions there should be no particular difficulty in pushing the shaft first one way from one side, and then the other way from the other side. If it is found that the revolving part is hugging closely against one side, the trouble can be corrected either by pressing the spider along the shaft in a direction toward which the hugging is occurring, or by driving the tops of the lamination teeth in the same direction. With a wooden wedge, the tops of the teeth can often be without any difficulty driven over $\frac{1}{8}$ to $\frac{3}{16}$ in. This movement will usually correct the trouble. Driving the teeth of the stator $\frac{1}{8}$ in. or so in the opposite direction to that of the end thrust will usually accomplish the same result. It is best to choose the teeth (stator or rotor) which are most easily driven over. The thin long ones move easier than do the short broad ones.

161. Oil Leakage of Induction Motors.—Sometimes a bearing will permit oil to be drawn out, perhaps a very little at a time. Ultimately enough will accumulate to show on the outside or on the windings of the machine. While a motor will run for a period with its windings wet with ordinary lubricating oil without being apparently injured, insulation soaked with oil will deteriorate and eventually fail.

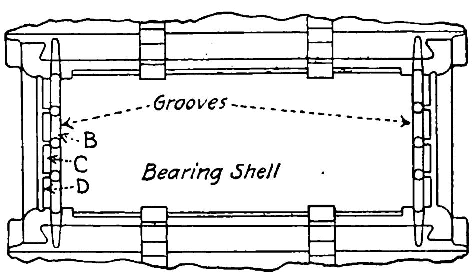


FIG. 72.—Grooves to prevent oil leakage.

One of the principal causes is a suction of the oil due to the drafts of air from the rotor, and one of the best methods of stopping the trouble, under ordinary conditions, is to cut grooves as shown in Fig. 72 at *B* and *D*. These grooves on a 50-h.p. motor may be $\frac{1}{8}$ in. deep and $\frac{3}{16}$ in. wide. Each groove has three holes drilled through the bearing shell to convey the oil collected by the grooves into the oil well. These grooves are just as effective with a split as with a solid bearing. It is impossible here to go into the various causes of oil leakage. The grooves as suggested are a general remedy and cover many cases.

162. General Summary of Synchronous-Motor Troubles.—Failure of a synchronous motor to start is often due to faulty connections in the auxiliary apparatus. These should be carefully inspected for open circuits or poor connections. An open circuit in one phase of the motor itself, or a short-circuit will prevent the motor from starting. Most synchronous motors are provided with an ammeter in each phase, so that the last two causes can be determined from their indications—no current in one phase in case of an open circuit, and excessive current in case of a short-circuit. Either condition will usually be accompanied by a decided buzzing noise, and in case of a short-circuited coil, it will often be quickly burned out. The effect of a short-circuit is sometimes caused by two grounds on the machine.

Starting troubles should never be assumed until a trial has been made to start the motor light, that is, with no load except its own friction. It may be that the starting load is too great for the motor.

If the motor starts but fails to develop sufficient torque to carry its load when the field circuit has been closed, the trouble will usually be found in the field circuit. First, determine whether or not the exciter is giving its normal voltage. Assuming the exciter voltage to be correct, the trouble will probably be due to one of the following causes. (1) Open circuit in the field winding or rheostat or (2) short-circuit or reversal of one or more of the field spools. Open circuit can often be located by inspection or by use of the magneto.

The majority of field troubles are caused by excessive induced voltage at start, or by the field circuit being broken. This excessive voltage may break down the insulation between field winding and frame or between turns on any one field spool, thus short-circuiting one or more turns, or it may even burn the field conductor off, causing an open circuit.

Causes of overheating in synchronous motors are about the same as those in alternating-current generators. Probably the most common cause of overheating is excessive armature current due to an attempt to make the motor carry its rated load, and at the same time compensate for a power factor lower than that for which it was designed. If the motor is not correcting low power factor, but doing mechanical work only, the field current should be adjusted so that the armature field is a minimum for the average load that the motor carries.

163. Difficulties in Starting Synchronous Motors.—A synchronous motor is weaker in starting than is an induction motor. In general, however, a synchronous motor will start itself and perhaps a very light load. Starting requires no field current as the flux which tends to start the motor is not the flux that operates it when it is up to speed. In starting, the field current is lagging, and a lagging current tends to pull down the voltage on the supply circuit, hence tends to lower the applied voltage. The starting torque, as in an induction motor, is proportional to the square of the applied voltage. For example, if the voltage is halved, the starting effort is quartered. When a synchronous motor will not start, it may be because the voltage on the line has been pulled down below the value necessary for starting.

In general, at least half voltage is required to start a synchronous motor. Difficulty in starting may also be caused by an open circuit in one of the lines to the motor. Assume the motor to be three-phase. If one of the lines is open the motor becomes single-phase, and no single-phase synchronous motor, as such, is self starting. The motor will, therefore, not start, and will soon get hot. The same condition is true of a two-phase motor, if one of the phases is open-circuited.

Difficulty in starting may be due to a rather slight increase in static friction. It may be that the bearings are too tight, perhaps from cutting during the previous run. Excessive belt tension, in case the synchronous motor is belted to its load, or any cause which increases starting friction will probably give trouble. Difficulty in starting may be due to field excitation being on the motor. After excitation exceeds one-quarter normal value, the starting torque is influenced. With full field on, most synchronous motors will not start at all. If the proper voltage is applied to a motor, and the circuits are all closed except the field circuit and the friction is a minimum, and still the motor will not start, the fault is probably with the manufacturer. Pole pieces often receive extra starting windings or conducting bridges are provided between the pole pieces to assist in starting. Possibly the manufacturer in shipping may have omitted these devices. In such cases one must refer to the factory.

Usually compensators are used for starting synchronous motors. If there is a reversed phase in a compensator, or, if the windings of the armature of the synchronous motor are connected incorrectly, there will be little starting torque. Incorrect connection can be located by noting the unbalanced entering currents. Readings to determine this unbalancing should be taken with the armature revolving slowly. The revolving can be effected by any mechanical means. While the motor is standing still, even with correct connections, the armature currents of the three phases usually differ somewhat. This is due to the position of the poles in relation to the armature, but when revolving slowly, the currents should average up. If the rotor cannot be revolved mechanically, similar points on each phase of the armature must be found. Then when the rotor is set successively at these points the currents at each setting should be the same. Each phase when located in a certain specific position as related to a pole, should, with right connections, take a certain specific current. With wrong connections, the currents will not be the same.

164. Open Circuit in the Field of a Synchronous Motor.—If in the operation of a synchronous motor the field current breaks for any reason, the armature current will largely increase, causing either a shut-down or excessive heat. It becomes important, therefore, in synchronous motors to have the field circuit permanently established.

165. Short-circuit in an Armature Coil of a Synchronous Motor.—A short-circuit in an armature coil of a synchronous motor burns it out completely, charring it down to the bare copper. When this occurs, the symptoms are so evident that there is no difficulty in identifying the trouble. Such a coil may under ordinary circumstances be cut out and operation continued. In an induction motor, the current in the short-circuited coil rises only to a certain value, but heats it many times more than normal. It is not necessarily burned out immediately, and perhaps it may not be burned out at all.

166. Hunting of Synchronous Motors.—Synchronous motors, served by certain primary sources of energy, tend to "hunt." The periodicity of the swinging is determined by properties of the armature and the circuit. It may reach a certain magnitude and there stick, or the swinging may increase until finally the motor breaks down altogether. This trouble usually occurs on long lines having considerable resistance between the source of energy and the synchronous motor. Sometimes it occurs under the most favorable conditions. Irregular rotation of a prime mover, such as a single-cylinder steam engine, is often responsible for the trouble. The usual remedy is to apply to the poles, bridges of copper or brass in which currents are induced by the wavering of the armature. These currents tend to stop the motion. Different companies use different forms of bridges. When hunting or pulsating occurs, and the motor is not already equipped with bridges, it is best to consult the manufacturer. In general, the weaker the field on a synchronous motor, the less the pulsation. Sometimes pulsation may be so reduced that no trouble results by simply running with a somewhat weaker field current.

167. Improper Armature Connections in Synchronous Motors.—This trouble usually manifests itself by unbalanced entering currents and by a negligible or very low starting torque. The circuits should be traced out and the connections remade until the three entering currents for three-phase, or the two entering currents for two-phase, are approximately equal. These currents will not be equal even with correct connection when the armature is standing still.

168. Polarity of Synchronous Motors.—Since the winding of a synchronous motor armature is in series all the way around the circumference and under all of the poles, except in exceedingly rare cases, the trouble from a reversed pole is much less serious than with an induction motor or direct-current machine. With a reversed pole everything operates fairly well. The only trouble is that the fields require more current than they should because of the pole that is opposing the field. If, therefore, excessive field current is required for minimum input to a motor, it is a good plan to test the polarity of all the spools with a compass.

169. Bearing troubles of synchronous motors are similar to those of induction motors. A difference is that, with a synchronous motor, the air-gap between the revolving element and the poles is relatively large, so that the wearing of the bearing, which throws the armature out of center, is not so serious as with an induction motor. End play should be treated the same as with an induction motor.

170. **Bearing Troubles of Motors and Generators.**—Modern generators and motors have self-oiling bearings. They should be filled to such a height that the rings will carry sufficient oil upon the shaft. If the bearings are too full, oil will be thrown out along the shaft. Watch the bearings carefully from the time the machine is first started until the bearings are warmed up, then note the oil level. The expansion of the oil due to heat and foaming raises the level considerably during that time. The oil should be renewed about once in six months, or oftener if it becomes dirty or causes the bearings to heat.

The bearings must be kept clean and free from dirt. They should be examined frequently to see that the oil supply is properly maintained and that the oil rings do not stick. Use only the best quality of oil. New oil should be run through a strainer if it appears to contain any foreign substances. If the oil is used a second time it should first be filtered and, if warm, allowed to cool. If a bearing becomes hot, first feed heavy lubricant copiously, loosen the nuts on the bearing cap, and then, if the machine is belt connected, slacken the belt. If no relief is afforded by these means, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze." Renew the oil supply before starting again. A new machine should always be run at a slow speed for an hour or so in order to see that it operates properly. The bearings should be inspected at regular intervals to insure that they always remain in good condition. The higher the speed, the more care should be taken in this regard.

A warm bearing or "hot box" is probably due to one of the following causes: (1) Excessive belt tension. (2) Failure of the oil rings to revolve with the shaft. (3) Rough bearing surface. (4) Improper lining up of bearings or fitting of the journal boxes.

STARTING AND CONTROLLING DEVICES FOR MOTORS

171. **The National Code rules require that each motor** and its starter be protected by fuses or a circuit-breaker and controlled by a switch which must plainly indicate whether on or off. The switch and cut-out (fuses or circuit-breaker) are preferably located near the motor and in plain sight of it. All wiring should be neat and workmanlike and the wires should be run in conduit wherever possible.

172. **Speed Control of Direct-current Electric Motors. Rheostats** (*The Electric Controller & Mfg. Company*).—A direct-current motor of any capacity, when its armature is at rest, offers a very low resistance to the flow of current and an excessive and perhaps destructive current would flow through it if it were connected directly across the supply mains while at rest. Consider a motor adapted to a normal full-load current of 100 amp. and having a resistance of 0.25 ohm; if this motor were connected across a 250-volt circuit a current of 1,000 amp. would flow through its armature—in other words, it would be overloaded 900 per cent. with consequent danger to its windings and also to the driven machine.

In the case of the same motor, with a rheostat having a resistance of 2.25 ohms inserted in the motor circuit, at the time of starting the total resistance to the flow of current would be the resistance of the motor (0.25 ohm) plus the resistance of the rheostat (2.25 ohms), or a total of 2.5 ohms. Under these conditions exactly full-load current, or 100 amp., would flow through the motor, and neither the motor nor the driven machine would be overstrained in starting. This indicates the necessity of a rheostat for limiting the flow of current in starting the motor from rest.

An electric motor is simply an inverted generator or dynamo, consequently when its armature begins to revolve a voltage is generated within its windings just as a voltage is generated in the windings of a generator when driven by a prime-mover. This voltage generated within the moving armature of a motor opposes the voltage of the circuit from which the motor is supplied, and hence is known as a "counter-electromotive force." The net voltage tending to force current through the armature of a motor when the motor is running is, therefore, the line voltage minus the counter-electromotive force.

In the case of the motor above cited, when the armature reaches such a speed that a voltage of 125 is generated within its windings, the effective voltage will be 250 minus 125, or 125 volts, and, therefore, the resistance of the rheostat may be reduced to 1 ohm without the full-load current of the motor being exceeded. As the armature further increases its speed, the resistance of the rheostat may be further reduced until, when the motor has almost reached full speed, all of the rheostat may be cut out, and the counter-electromotive force generated by the motor will almost equal the voltage supplied by the line so that an excessive current cannot flow through the armature.

In practice, a rheostat is provided for starting a direct-current electric motor. The conductor providing the resistance is divided into sections and is so arranged that the entire length or maximum resistance of the rheostat is in circuit with the motor at the instant of starting and that the effective length of the conductor, and hence its resistance, may be reduced as the motor comes up to speed.

In cutting out the resistance of a starting rheostat care must be used not to cut it out too rapidly. If the resistance is cut out more rapidly than the armature can speed up, a sufficient counter-electromotive force will not be generated to properly oppose the flow of current, and the motor will be overloaded.

173. **Rheostatic Controller.**—If all the resistance of the starting rheostat (see above paragraph) is not cut out, the motor will operate at reduced voltage, and hence at less than normal speed. A rheostat so arranged that all or a portion of its resistance may be left in a motor circuit to secure reduced speeds is called a "rheostatic controller." Such rheostatic controllers are used for controlling series and compound-wound motors driving cranes and similar machinery requiring variable speed under the control of an operator.

174. **In a series-wound motor the speed varies inversely as the load**—the lighter the load the higher the speed. A series-wound

motor of any size, when supplied with full voltage under no-load, or a very light load, will "run away" just as will a steam engine without a governor when given an open throttle.

For a given load, a series-wound motor with its rheostat in series draws the same current irrespective of the speed and for a given load the speed varies directly as the voltage. The speed at a given load may be varied by varying the resistance in the motor circuit; in the meantime if the load on the motor be constant the current drawn from the line will be constant regardless of the speed.

175. **Shunting the Field of a Series Motor.**—The above statements relate to the use of a rheostat in series with a series-wound motor. If a resistance or rheostat be placed in parallel with the field of a series-wound motor the speed will be increased instead of decreased at a given load. This is known as shunting the field of the motor. This shunt would never be applied till the motor has been brought up to normal full speed by cutting out the starting resistance. With a "shunted field" a motor drives a load at a speed higher than normal and therefore requires a correspondingly increased current.

176. **Shunted Armature Connection of a Series Motor.**—If a resistance is placed in parallel with the armature of a series motor, the motor will operate at less than normal speed when all the starting resistance has been cut out. This connection is known as a "shunted armature connection" and is useful where a low speed is desired at light loads and is particularly useful in some cases where the load becomes a negative one, that is, where the load tends to overhaul the motor, as in lowering a heavy weight.

177. **Speed Control of Shunt-wound Motors.**—A shunt-wound motor, unlike a series motor, when supplied with full voltage, maintains practically a constant speed regardless of variations in load within the limits of its capacity. It automatically acts like a steam engine having a very efficient governor. The speed of a shunt-wound motor may be decreased below normal by a rheostatic controller in series with its armature and may be increased above normal by means of a rheostat in series with its field winding. The latter rheostat is known as a "field rheostat," and, to be effective, must have a high resistance owing to the small current which flows through the shunt field winding.

178. **Speed Control of Compound-wound Motors.**—A compound-wound motor is a hybrid between a series and shunt-wound motor and its characteristics are likewise of a hybrid nature. A compound-wound motor will not "run away" under no-load as will a series motor, but its speed decreases as the load increases, though not so rapidly as is the case with a series-wound motor. The characteristics of the compound-wound motor render it particularly valuable in cases where the load is subject to wide variation. It will give a strong torque in starting and driving heavy loads and at the same time will not race dangerously when the load is suddenly relieved.

The speed of a compound-wound motor may be reduced below normal by means of a rheostat in the circuit of its armature. The speed may be increased above normal by shunting and even short-circuiting the series field winding, and may be still further increased by means of a field rheostat in series with the shunt field winding.

179. **In starting a direct-current motor** (see Fig. 73), close the line switch and move the operating arm of the rheostat step by step over the contacts, waiting a few seconds on each contact for the motor speed to accelerate. If this process is performed too quickly the motor may be injured by excessive current; if too slowly, the rheostat may be injured. If the motor fails to start on the first step, move promptly to the second step and if necessary to the third, but no farther. If no start is made when the third step is reached, open the line switch at once, allow the starter handle to return to the off position, and look for faulty connections, overload, etc. The time of starting a motor with full-load torque should not, as a general thing, exceed 15 sec. for rheostats for motors of 5 h.p. and lesser output, and 30 sec. for those of greater output.

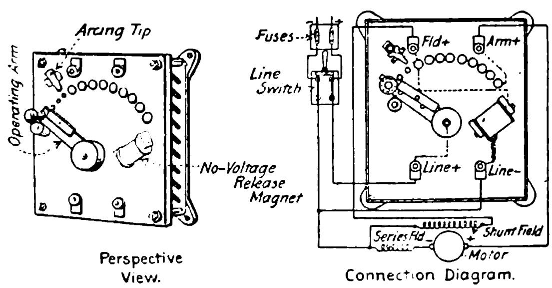


FIG. 73.—Direct-current motor starting rheostat.

180. **In stopping a direct-current motor,** open the line switch. The arm will return automatically to the off position. Never force the operating arm of any automatic-starting rheostat back to the off position.

181. **Starting rheostats for shunt-, compound- and series-wound direct-current motors** vary somewhat in detail, design, and method of connection with the ideas of the different manufacturers. The rheostat shown in Fig. 73 is fairly typical of those for starting motors of outputs up to 120 h.p.

182. **The low-voltage release device on a starting rheostat** consists of a spring, which tends to return the operating arm to the off position, and an electromagnet, which, under conditions of normal voltage, holds the operating arm in the running position. The coil of this magnet is regularly connected across the circuit with a protecting resistance in series, but can be connected in series with the shunt field of the motor if specially required. If the voltage drops below a predetermined value, the arm is released and returned by the spring to the off position.

183. **Arcing Devices on Starting Rheostats.**—Arcing tips consisting of pivoted fingers are sometimes mounted near the point where the circuit is opened. In passing to the off position, a lug on the end of the arm strikes and deflects the tip, which is in electrical connection with the first stationary contact; the current is diverted to the tip, which snaps back when released and opens the circuit very quickly, thus rupturing the arc. Blow-out coils can be mounted behind the first contact and will disrupt any arc formed in opening the circuit.

184. Overload Release Device on Starting Rheostats.—This device, which is not illustrated, includes an electromagnet, which, in case of overload, attracts its armature and forces an insulating wedge between two contacts, separating them and thereby opening the circuit of the low-voltage release magnet. The operating arm returns immediately to the off position. With some devices, the attraction of the armature forces two contacts closed which places a short-circuit around the low-voltage release magnet thereby de-energizing it and permitting the operating arm to return to the off position. It should be noted that the National Code rules require the use of fuses or circuit-breakers with each rheostat even though it be equipped with an overload release of this nature.

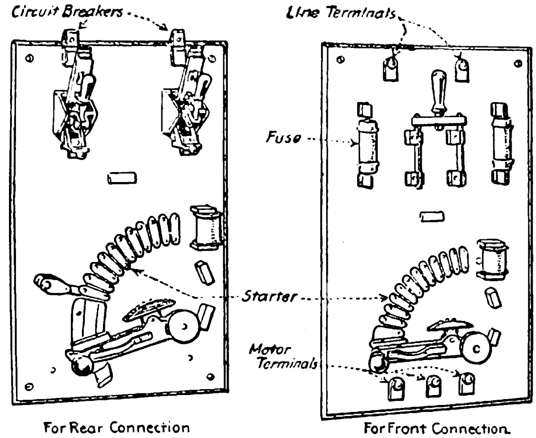


FIG. 74.—Direct-current motor starting panels.

185. Starting panels for direct-current motors are shown in Figs. 74 and 75. Panels, of which the illustrations are typical, are very desirable in that they concentrate all of the apparatus for the motor's control at one point and greatly simplify the wiring. Where such a panel is used it is merely necessary to run the two line wires to the line terminals of the panel and the three leads between the motor and the panel and the installation is ready for operation. The designs of different manufacturers vary in details. The panels can be obtained for either front or rear connection and with circuit-breakers or fuses for overload protection. Which is preferable is determined by the characteristics of the installation in question.

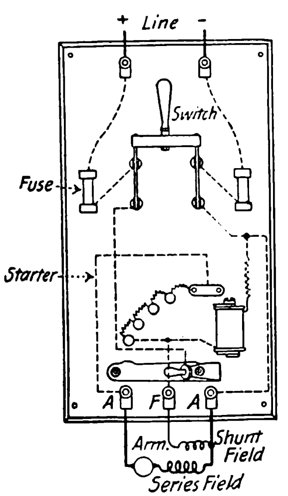


FIG. 75.—Wiring diagram of typical starting panel.

The advantages and disadvantages of protection of each type may be summed thus: (1) Fuses have a time element that circuit-breakers do not have; that is, fuses will not open an overloaded circuit as quickly as circuit-breakers. For this reason fuses may be preferable for motors that are liable to very brief overloads, especially where expert supervision of electrical apparatus is maintained, as in large mills and factories. A supply of extra fuses must be kept available. Where there are many fuse replacements the cost of fuse renewals is considerable. (2) Circuit-breakers can be reset in less time and with less trouble than is required to replace blown fuses, and no extra parts are required. Circuit-breakers may therefore be preferable where time saving is an important consideration. The first

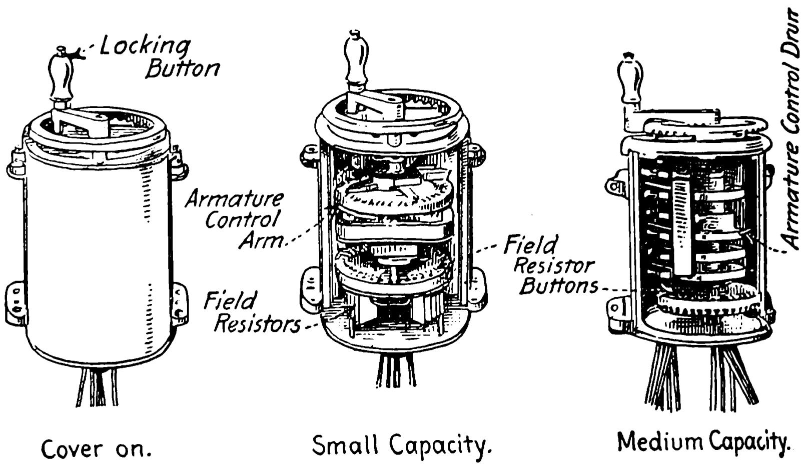


FIG. 76.—Machine tool controller.

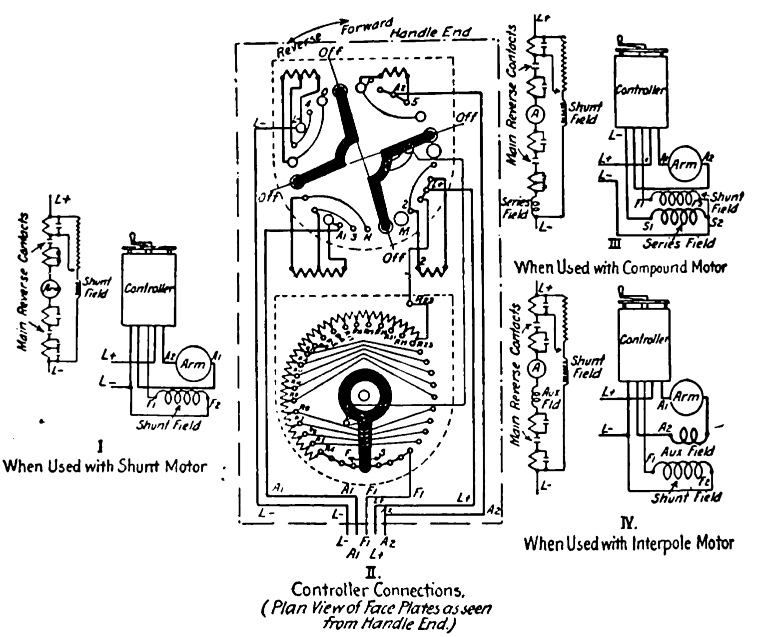


FIG. 77.—Connection diagram for machine tool controller of small capacity using revolving arms for both armature and field control.

cost of the circuit-breaker equipment is more than that for fuses, but for severe service the circuit-breakers are much the cheaper in the long run.

186. Rotary or Machine-tool Type Controllers for Direct-current Motors.—Although controllers of this type (Figs. 76, 77 and 78) find their most frequent applications on machine tools, they are very desirable for any service where the work is severe and where the expense of an enclosed controller is justified. Machine-tool work usually requires a combination starting and speed-regulating controller, that is, one whereby the motor is started by cutting out armature resistance. After the motor is started, its speed is regulated by varying the amount of resistance in series with the shunt field. These controllers can be purchased for this service and for control or starting service of practically any type. The methods of construction and connection are so numerous that only one type of drum controller, one which is used for machine-tool service, will be described here.

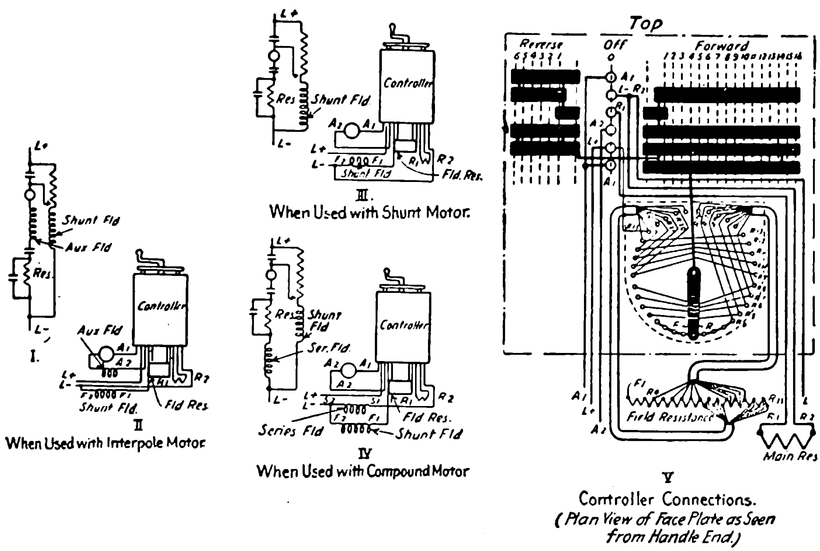


FIG. 78.—Connection diagram for machine tool controller of medium capacity using drum for armature control and revolving arm for field control.

Advantages of controllers of this type are that the contacts and arm are entirely enclosed and that the movement of a single handle in one direction or the other starts the motor in a corresponding direction and brings it to the running speed desired. The operating arm remains securely locked at the proper notch until released by the operator by pressing a button in the handle.

There are two switching devices in the controller shown in Figs. 77 and 78. One connects to the armature or starting resistor and the other connects to the field control resistor. Both switching devices are operated by the same handle. In drum controllers of small capacity the armature switching device consists of an arm passing over contact buttons and all of the resistors are mounted within the drum; that is, the controller is self contained. In controllers of large capacity, the armature resistance is cut in and out by a rotating drum similar to that used in street-railway service and all of the resistors are mounted external to the controller.

The field resistance is cut in and out by a rotating arm passing over contact buttons in all but the largest controllers for which a drum is used. Arc shields between drum segments and blow-out coils are provided where necessary. The controllers can be arranged to provide dynamic braking. Speed ranges of from 1 to 2 to, possibly, 1 to 6 are usually provided.

187. **Operation of Rotary or Machine-tool Type Controllers.**—(See Figs. 69, 77 and 78.) Continuous movement of the operating handle in either direction first starts the motor in the corresponding direction of rotation, then cuts out the starting resistance, and finally cuts in the field resistance until the desired running speed is reached. The handle should be moved over the starting notches in not over 15 sec. for motors of possibly 10 h.p. capacity and in not over 30 sec. for larger motors. The starting resistance should not be used for speed control.

For a quick stop when operating with weakened field, move the handle quickly to the first running notch, hold it there momentarily and then move it to the off position; the application of full field strength when the speed is high causes dynamic braking, thus checking the speed quickly and without shock. For a very quick emergency stop, the handle can be moved to the first reversing notch after checking the speed by dynamic braking, but this operation causes severe mechanical and electrical stresses; this reversing should never be carried beyond the first notch. When the motor is to be at rest for any length of time, open the line switch.

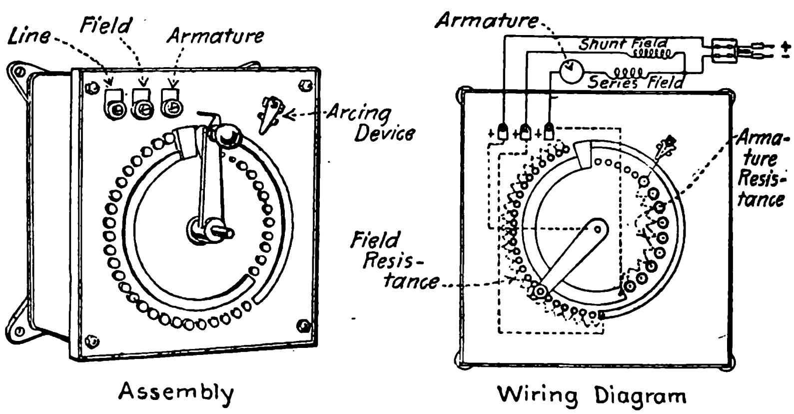


FIG. 79.—Non-automatic starting and speed-adjusting rheostat.

188. **A non-automatic starting and speed-adjusting rheostat for direct-current motors** is shown in Fig. 79. This device has no low-voltage or overload protection hence is suitable only for applications where skilled attendance is available. The operating arm makes contact as it is revolved between the circular bars and the resistance contact buttons. There are a number of field-control steps, hence close speed adjustment over a considerable range can be obtained. The contact buttons of the inner circular segment are connected to the starting resistor and the contacts of

the outer circle are connected with the running resistor. A reading of the following paragraph describing the operation of the device will render clear the principles involved.

189. Operation of a Non-automatic Starting and Speed-adjusting Rheostat.—(Fig. 79.) To start the motor, close the line switch or circuit-breaker and move the operating arm of the rheostat over the starting buttons to the first running position (the point where the two bar contacts overlap). A motor starting with full-load torque should be brought to this point in approximately 15 sec. Further movement of the operating arm increases the motor speed by field control. The motor can be operated continuously with the arm on any field contact button, but with rheostats of this design must not be allowed to run on any starting button. To stop the motor, open the line switch or circuit-breaker and move the rheostat arm to the off position. The latter movement must not be forgotten, since this rheostat has no automatic features. To protect the motor in case of failure of the power supply and its subsequent return after the motor has stopped, a low-voltage release circuit-breaker should be installed in series with each rheostat. *The rheostat handle must be in the off position* before the circuit-breaker is closed. (*Westinghouse Electric & Manufacturing Company.*)

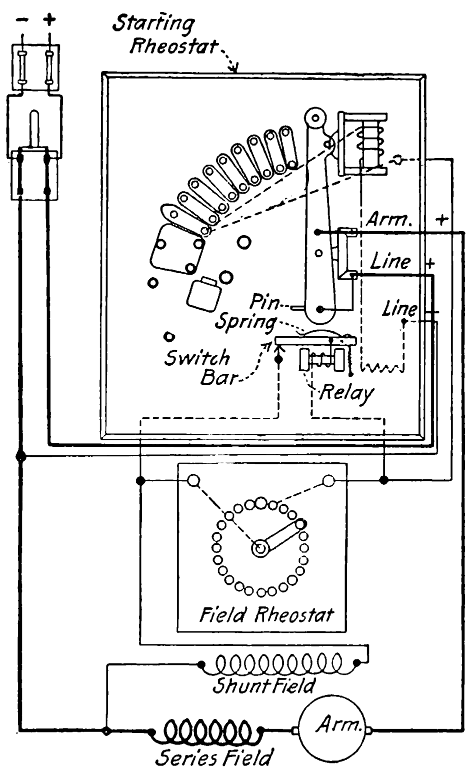


FIG. 80.—Field rheostat relay switch.

190. Field relay switches are required where separate rheostats are used for starting and controlling the speeds of motors. This is required by a National Code rule to prevent the possibility of starting a motor with weakened field. The switch, shown in Fig. 80, mounted under the starter handle accomplishes this function by short-circuiting the field rheostat during acceleration so that the motor must always start with full field regardless of the position of the field rheostat arm. The switch shown, or a similar one, can be applied to ordinary starting and speed-regulating rheostats and generally should be mounted on the rheostat at the factory of the firm that furnishes it.

The field relay switch shown consists of a small electro-magnet, a pivoted switch bar, and a stationary contact. The switch bar is normally held away from the contact by a helical spring. The magnet coil, switch bar, and contact are in series with a circuit that parallels the field rheostat.

When the operating arm of the starting rheostat is moved to the first step, a pin on its hub presses the relay switch bar against its stationary contact, thus short-circuiting the field rheostat. As the arm is turned the pin on the starter hub soon releases the relay switch bar; but the relay electro-magnet, energized when the contacts close, holds this bar temporarily in place. The winding of the relay electro-magnet is so proportioned that if there is little or no resistance in series with the motor shunt field, the relay magnet will release the switch bar before the motor is brought to full speed, leaving the field rheostat available for speed adjustment. But if the field rheostat arm is turned so that there is more resistance in series with the shunt field than would be safe to insert in one step, the electro-magnet will keep the relay switch closed until the arm of the field rheostat is brought back toward the off position.

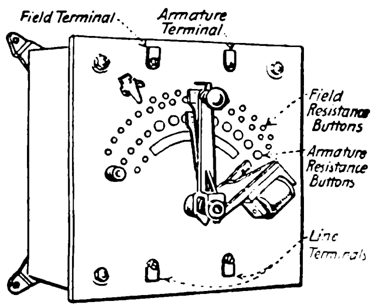


FIG. 81.—Starting and speed-adjusting rheostat.

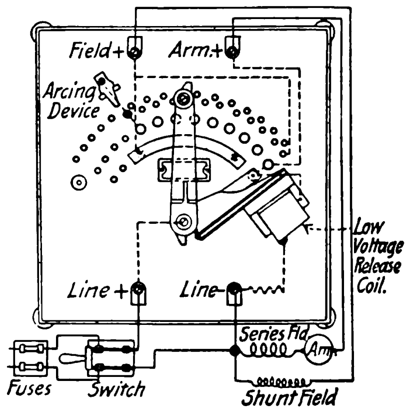


FIG. 82.—Wiring diagram for starting and speed-adjusting rheostat.

191. Starting and Speed-adjusting (Field Control) Rheostats for Direct-current Shunt- and Compound-wound Motors.—There are as many and more designs as there are manufacturers, but the equipment shown in Figs. 81 and 82 is typical and can be used for starting and regulating speed in non-reversing services where speed adjustment by field control is desirable. The apparatus is so arranged that the motor is always started with full field strength. In case of failure of the voltage, the field control resistance is automatically short-circuited and the motor is disconnected from the line.

The rheostat consists of a face plate carrying the contacts, operating arms, and safety devices, mounted in connection with two resistors. One is for starting and one is for adjusting the field strength. The face plate carries three rows of stationary contacts. The upper row is connected with the field adjusting resistor, the second row with the starting resistor; and the lower row contains a long curved segment for short-circuiting the field resistance in starting. A contact for short-circuiting the armature resistance when the arm is in the running position is sometimes provided.

The face plate supports two arms, an operating arm and a short-circuiting arm, pivoted to the same hub and arranged so that they cannot pass each other. The operating arm carries the handle and two contact fingers, one for the starting contacts and the other for the field contacts. The short-circuiting arm has a contact finger which slides over the contact bar, short-circuiting the field resistance in starting, and the armature resistance while running. In some designs this arm also carries laminated copper brushes which short-circuit the starting resistance when the arm reaches the running position. A spring tends to return the short-circuiting arm to the off position.

Under conditions of normal operation the short-circuiting arm is held in the running position against the force of the spring by an electro-magnet connected across the line in series with a protecting resistance. If the voltage falls below a predetermined point, the arm is released and returns to the off position, carrying the operating arm with it.

Rheostats for this service are frequently arranged so that the circuit is opened between a lug on the operating arm and a small pivoted finger with a centering spring mounted near the first starting contact and connected to it electrically. The current is always broken abruptly no matter how slowly the arm may be moved. Blow-out coils are sometimes mounted on the rear of the face plate to disrupt any arc that may form.

An overload release device can be mounted on all but the largest rheostats of this type. It consists of an electro-magnet which, in event of an overload, opens the low-voltage magnet circuit, thus releasing the short-circuiting arm. The tripping point is adjustable. The National Code rules require the use of a circuit breaker or fuses with a rheostat equipped with an overload release of this character. (*Westinghouse Electric & Manufacturing Company.*)

192. Operation of a Starting and Speed-adjusting Rheostat.—(Figs. 81 and 82.) The motor is started by moving the operating arm to the running position, stopping a few seconds on each starting contact to permit the speed to accelerate. The retaining magnet holds the short-circuiting arm in the running position where it short-circuits the starting resistor. The operating arm is then moved back over the field-resistance contacts until the desired speed is reached. For motors starting with full-load torque, the time of acceleration should be from 15 sec. to 30 sec., depending upon the capacity of the motor. To stop the motor, open the line switch. Both arms then return to the off position automatically.

193. Armature control speed regulators (Fig. 83) are used for speed reduction with shunt, compound or series motors in non-reversing service where the torque required decreases with the speed but remains constant at any given speed as with fans, blowers and centrifugal pumps. They can also be used for applications where the torque is independent of the speed, as with job printing presses. However, this method of speed control is not suitable for such applications where there is operation for long periods at reduced speed, since such operation is not economical. It is not possible, where the torque varies, to obtain constant speed with these controllers.

In the regulator shown the low-voltage release consists of an electro-magnet enclosed in an iron shell, a sector on the pivot end of the operating arm, and a strong spring which tends to return the arm to the off position. The magnet is mounted directly below the pivot of the arm and its coil is connected in shunt across the line in series with a protecting resistance. When the magnet is energized its plunger rises and forces a steel ball into one of a series of depressions in the sector on the arm with sufficient force to hold the arm

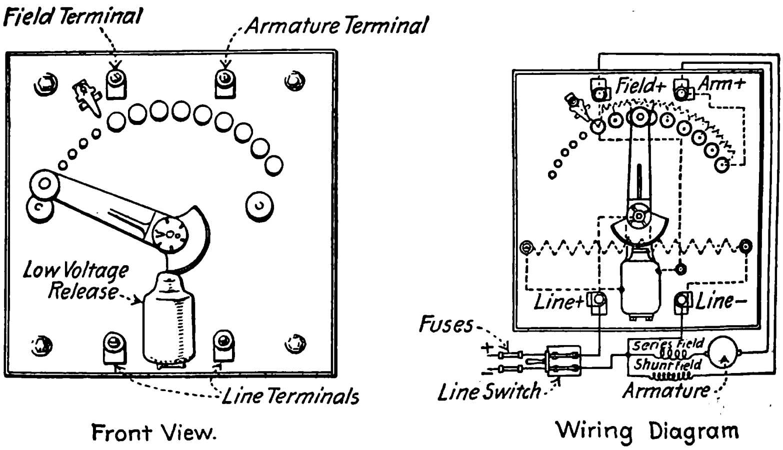


FIG. 83.—Armature control speed regulator.

against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned. When the voltage fails, the magnet plunger falls and the spring throws the operating arm to the off position. An overload release, similar to that described in another paragraph, which operates by opening the low-voltage coil circuit, is sometimes furnished on regulators of this type. Standard commercial rheostats of this type are designed to give about 50 per cent. speed reduction on the first notch. See the following paragraph on operation for further information.

194. Operation of Armature Control Speed Regulators.—(Fig. 83.) Continuous motion of the operating arm starts the motor and brings it gradually to maximum speed. Moving the arm over the first few contact buttons increases the shunt field strength if the motor is shunt or compound. The movement over the succeeding buttons cuts out armature resistance and permits the motor to speed up.

195. Objections to Armature Control (*Crocker and Arendts, Electric Motors*). (a) *Bulk of Rheostat.*—This may not be very objectionable if only a few motors are so controlled, but for a number the extra space becomes a factor, and in many cases it is difficult to find sufficient room near the motor.

(b) *Inefficiency of the System.*—The same amount of power is supplied at all speeds, but at low speeds only a small part of it is converted into useful work, the balance being wasted in the rheostat as heat.

(c) *Poor Speed Regulation with Varying Loads.*—Since the impressed voltage at the armature terminals is equal to the line voltage minus the resistance drop in the rheostat ($V_t = V - I_aR_x$), any change in the current drawn by the motor produces a change in the terminal voltage, the counter e.m.f., and therefore the speed.

196. Crane controllers for direct-current series and compound-wound motors are usually arranged somewhat as indicated in Fig. 84. The switching device consists of a disc of soapstone or other fire-proof insulating material carrying stationary contact pieces and a pivoted switch arm carrying four contactors. Blow-out coils are usually provided to effectively rupture the arcs that form when the contactors pass from one contact piece to the next. The resistors may be contained in the controller base, as in small controllers, or may be arranged for separate mounting as in large ones. In Fig. 84 the fine lines within the circle are shading lines which merely indicate that the circle is a soap stone disc. Only the heavy lines within the circle represent electrical connections. Fig. 85 shows two typical controllers.

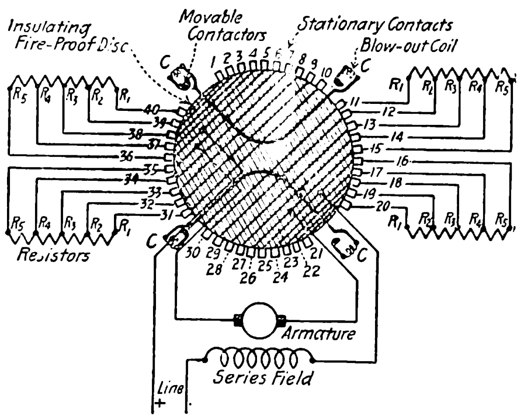


FIG. 84.—Connections of a 16-point crane controller connected to a series motor.

Movement of the controller handle in either direction past the off position starts the motor in the corresponding direction of rotation. At each step a section of resistance is short-circuited. At the full-speed positions all the resistance is short-circuited. Stops prevent over-running past the full-speed positions. Direct-current crane controllers increase or decrease the amount of resistance in series with the motor and thereby control its speed.

197. Dynamic braking of direct-current motors is effected by allowing a motor to be temporarily driven as a generator by its load. The mechanical energy of the moving machinery or descending load is thus converted into electrical energy and then into heat which is dissipated in resistance. The result is that the speed of the motor is promptly retarded. The amount of braking action can be adjusted by varying the current flowing in the motor armature.

A load exercising an active torque on the motor armature, such as an elevator car, cannot be brought to a full stop by this method, since with the decreasing armature speed the braking action also decreases. For final stopping, some form of mechanical brake, which acts automatically, is therefore necessary.

Dynamic braking is used in connection with motors for elevators, hoists, cranes, coal and ore handling machinery, railway cars, etc. It is employed for reducing the motor speed just before a stop, as in elevator service; or for controlling the speed of moving objects, as in lowering crane loads, retarding the speed of the cars descending grades, etc.

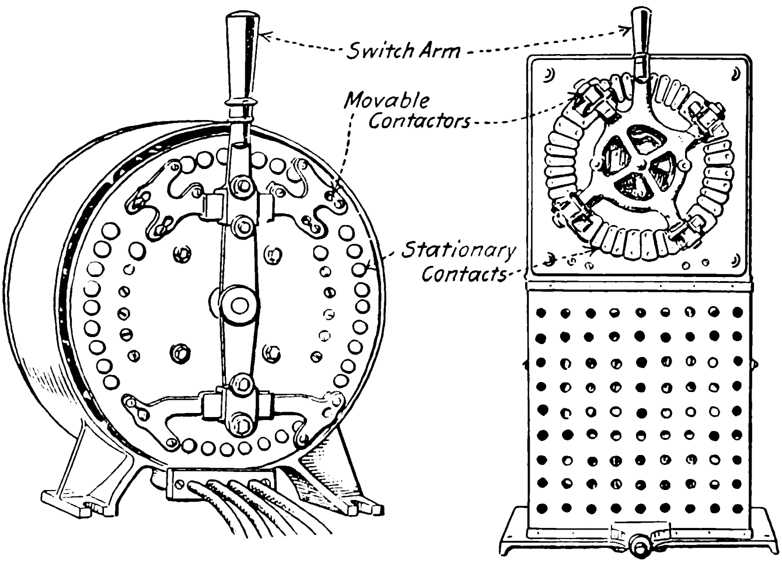


FIG. 85.—Crane controllers.

198. The principal advantages of dynamic braking are the practical absence of all wear and tear on the apparatus, convenience of application, and ease, accuracy, and certainty of control. In dynamic braking with a properly selected motor, active deterioration is limited to the controller contacts, which can be arranged for quick, easy, and inexpensive renewal. No special or additional apparatus is required for braking except the resistance which can be placed wherever convenient within a reasonable distance from the motor. The braking effect can be adjusted with great accuracy over a wide range by varying the armature current or the field strength by means of suitable resistance.

In some instances, notably with railroads, dynamic braking actually returns energy to the circuit; but in industrial service the energy generated is usually dissipated by resistance. In electric cars, during the winter months this dynamic braking current is in many cases run through heaters for warming the cars.

199. Heating with Dynamic Braking.—The most important limitation to the use of dynamic braking is the heating of the motor by the generated currents. For simple stopping duty this action is insignificant as it lasts only a few seconds; but with speed control in lowering a load by dynamic braking, the generated current may flow for an extended length of time and the heating may be considerable, especially as it is added to the heating of the machine when operated as a motor. This additional heating effect due to the braking current must be considered in selecting the motor.

200. **Dynamic-braking Connections.**—Fig. 86 shows by simple diagrams some of the possible connections. Diagram *I* shows the armature of a shunt motor short-circuited through a brake resistance, the field remaining across the line. Diagram *II* shows the

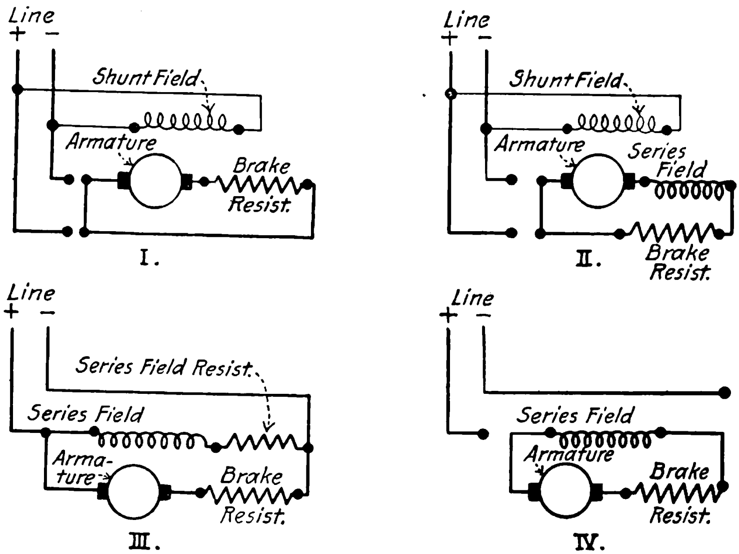


FIG. 86.—Dynamic braking connections.

armature of a compound motor short-circuited through the series field and a brake resistance, the shunt field remaining across the line. Diagram *III* shows the armature of a series motor short-circuited through the series field, a protecting resistance for the field, and a brake resistance—the field and its resistance being in series across the line. Diagram *IV* shows the armature and series field of a series motor short-circuited through a brake resistance, all of which are entirely disconnected from the line.

By cutting out the series field in diagram *II* the braking effect can be diminished, the connections then being as in *I*. The connections shown in diagram *III* are generally preferable for series motors during the first part of the braking operation, in order to insure building up as a generator. As soon as the generator action has begun, the connections can be changed to those shown in diagram *IV*. In each of the cases shown by the four diagrams the braking effect can be increased by short-circuiting sections of the brake resistance and thus increasing the armature current.

201. **The methods of starting induction motors** may be listed as follows:

(1) *By Connecting Directly to the Line.*—This method is ordi-

narily used only for small motors—those of less than 10 h.p. output—because on starting the motor takes an excessive current and the voltage regulation will be disturbed unless there is ample generating capacity and the conductors are of a generous cross-section.

(2) *By Inserting Internal Resistance in the Rotor Circuit.*—This method is used only with wound rotor machines. The resistance is cut in or out of the circuit by the operation of a switch on the motor shaft so arranged that the handle of the switch is stationary when the rotor is turning.

(3) *By Introducing External Resistance in the Rotor Circuit.*—This method can be used only with a wound-rotor machine having collector rings upon which brushes bear that connect with the resistance. The resistance is cut in or out of the rotor circuit by a controller somewhat similar to the ordinary direct-current motor controller.

(4) *By Using a Transformer having Low-voltage Taps.*—A low voltage can be impressed on the motor at starting by connecting it with a suitable switch to the low-voltage taps.

(5) *With a Starting Compensator or Auto-transformer.*—This is the usual method for motors of ordinary capacity and is similar to the transformer method in that low voltage from the compensator taps are impressed on the motor at starting.

(6) *By Connecting the Armature Coils in Star for Starting and in Delta for Running.*—This method is described in detail in a following paragraph.

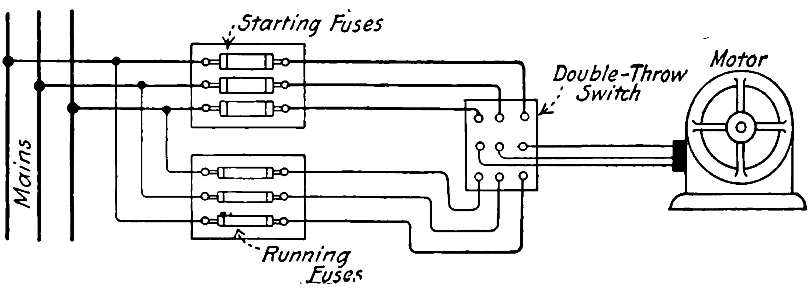


FIG. 87.—Starting small motor by throwing directly on the line.

202. A small induction motor can be started by throwing it directly on the line. (Fig. 87.) This method is, as a general thing, not used for motors of capacities exceeding 5 h.p. Two sets of fuses should be provided, one for starting and one for running, with a double-throw switch to connect the motor to either set. A switch having a spring so arranged that the blades will not remain in the starting position unless manually held there should be used. The starting current of an induction motor thrown directly on the line will be something between three and eight times the full-load running current. If only one set of fuses is used for a polyphase motor and they are of sufficient capacity to carry the starting current, one fuse may open but the motor will continue to operate on one phase, drawing a current considerably above normal. The probable result is a burnt-out motor.

203. **Self-contained starters for wound-rotor induction motors of relatively small capacity** (Figs. 88 and 89) can be purchased. The resistors for these are mounted within the enclosing case that carries the switching mechanism that increases or decreases the amount of effective resistance in the rotor circuit. As a rule, the resistors in these starters are designed only for starting service,

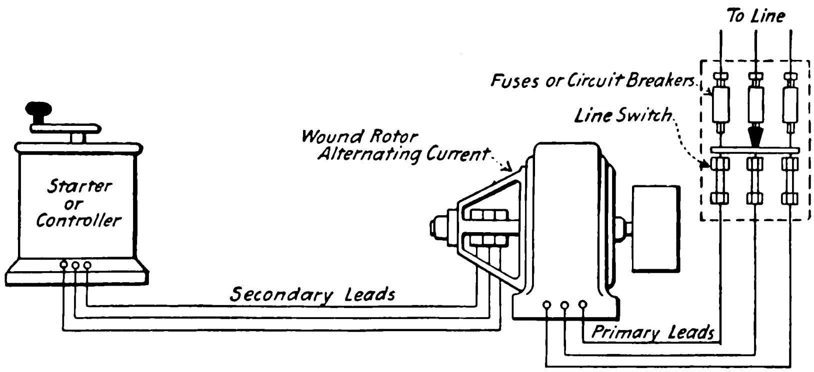


FIG. 88.—Connections of starter to wound rotor motor.

hence they can be used only where starts are infrequent and starting conditions are not severe. They are not usually designed for speed control for which service drum-type controllers with externally mounted resistances are used.

In the usual designs a set of resistors is connected with each phase of the motor (Fig. 90) secondary and all three are interconnected in star by the frame of the starter which is grounded, protecting the operator against shocks.

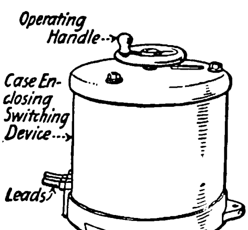


FIG. 89.—Enclosed starter for a phase-wound motor.

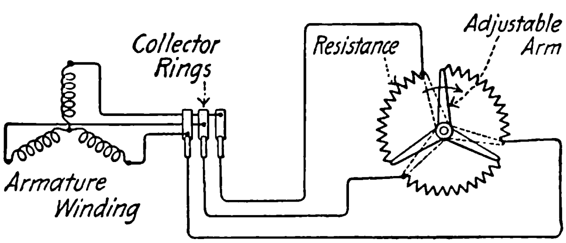


FIG. 90.—Method of varying rotor resistance of a wound rotor induction motor.

204. **In operating a self-contained starter for a wound-rotor motor** (Figs. 88 and 89) before closing the primary line switch or breaker, the handle of the starter must be in the starting position, where all the starting resistance is in circuit. If the connections are correct, and the load is not too great, the motor should start as soon as the line switch is closed; on failure to start, open the primary circuit, and examine the load conditions and the connections. With some starters the handle may have to be advanced

slightly beyond the starting position before the motor starts. As the motor speed accelerates the starter handle should be moved gradually to the running position, bringing the motor to full speed within the time which is usually specified by the manufacturer of the starter. In the running position all starting resistance is, in starters of most designs, short-circuited.

205. Starting a Coil-wound Rotor Motor (*Southern Electrician*) —With the coil-wound rotor, high and variable starting torque can be obtained by inserting a variable ohmic resistance directly in the rotor circuit. The rotor circuit is connected to a non-inductive resistance, which can be varied and gradually cut out as the motor attains speed. Figs. 90 and 91 illustrate the connections. When the rheostat handle is in the extreme left-hand position, the resistance is all out of circuit.

To start the motor, current is first switched on to the stator circuit by closing a triple-pole switch. The three-pole contact blades of the starting rheostat are now moved over from the off position on to the resistance studs, the first contacts of which place the whole of the resistance in circuit with the respective three-phase windings of the rotor. This prevents the current induced in the rotor windings by the stator circuit from reaching an excessive amount. The switch handle on being further rotated in a right-handed direction gradually cuts out the resistance until all the resistance is out of circuit. In this position the rotor windings are short-circuited.

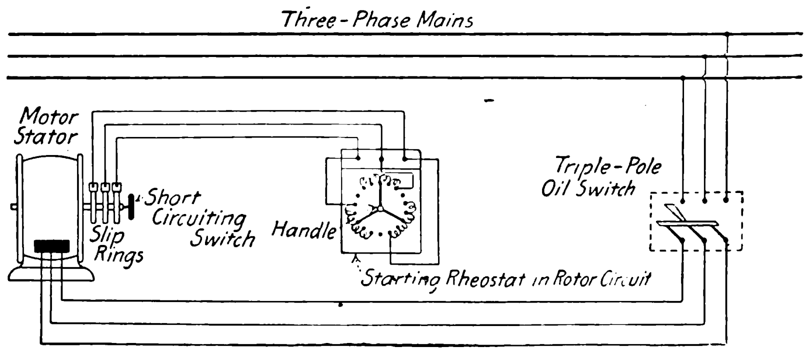


FIG. 91.—Starting arrangement for three-phase coil-wound rotor motor.

206. Commercial starting compensators for squirrel cage induction motors usually have three positions at which the starting lever will come to rest—an "off" position, a "starting" position, and a "running" position. The lever is so arranged that the switch that it controls cannot come to rest in any other positions unless forcibly restrained. The connections of a two-phase and of a three-phase compensator are shown in connection with the material on auto-transformers in Sect. V, *Transformers*. Connection arrangements for compensators of other types are shown on pages adjacent hereto.

In starting compensators, as usually arranged, when in the "off" position the switch is open and the motor and auto-transformer are entirely disconnected from the source of energy. When in the "starting" position, the source of energy is directly connected by the switch to the auto-transformer terminals and the low voltage taps of the auto-transformer are connected to the motor. Usually there are no fuses inserted in the starting leads at the compensator.

When thrown to the "running" position the switch connects the motor through fuses to the source of energy and the auto-transformer is entirely disconnected from the source of energy. The fuses provided in the running leads are for the protection of the motor against overload while it is in normal operation. The fuses protecting the tap circuit to the compensator where the tap circuit branches from the main are usually depended upon to protect the motor while it is starting.

207. Starting With and Without Compensators.—The starting current taken by a squirrel cage induction motor at the instant of starting is equal to the applied electro-motive force divided by the impedance of the motor. Only the duration of this current, and not its value, is affected by the torque against which the motor is required to start. The effect of starting without and with a compensator is illustrated by diagrams *I* and *II* in Fig. 92. In this diagram, motor *I* is thrown directly on a 100-volt line. The impedance of the motor is 5.77 ohms per phase, the starting torque 10 lb. at 1 ft. radius and the current taken 10 amp. In diagram *II* a compensator is inserted, stepping down the line pressure from 100 to 50 volts. This reduces the starting current of motor one-half and the starting torque becomes one-quarter

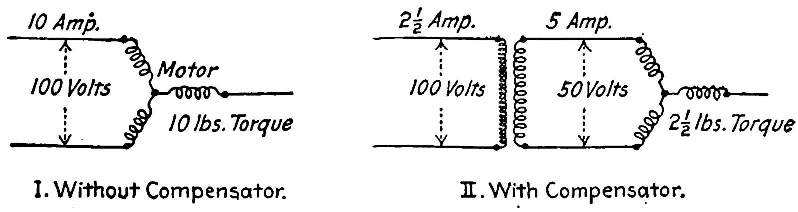


FIG. 92.—Starting with and without compensator.

its previous value or 2½ lb. at 1 ft. radius. The current in the line is reduced inversely as the ratio of transformation in the compensator and becomes 2½ amp.

Thus when a compensator is used the starting torque of the motor can be reduced to approximately the value required by the load and the current taken from the line correspondingly decreased. Where a compensator is not used an increase of rotor resistance results in a proportional increase in the starting torque of the motor with a very slight decrease in the starting current drawn from the line. Where a compensator is used with a motor having a high-resistance rotor the voltage can be reduced to a lower value than would be required with a low-resistance rotor for the same starting torque. Standard compensators are provided with several taps from which various combinations can be obtained.

208. Comparison of Auto-transformer and Resistance for Decreasing Voltage for Starting Squirrel Cage Motors.—The motor in Fig. 93 is supposed to require 100 amp. to start it; that is, to provide the energy necessary to produce the necessary starting torque. At *I*, where an auto-transformer is used to lower the

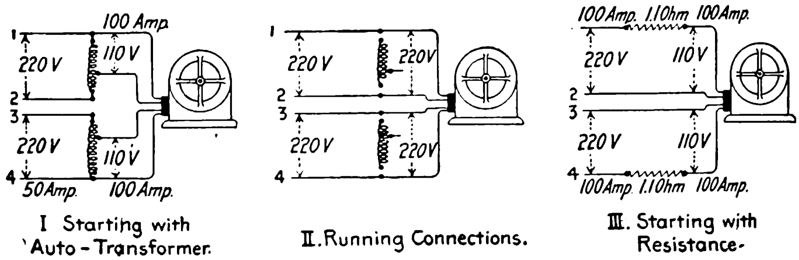


FIG. 93.—Starting with resistance and with compensator.

voltage to 110, a current of 100 amp. is produced in the motor primary with a current in the line of 50 amp. This condition is due to the transformer action of the auto-transformer. At *II* the running connections are shown wherein the auto-transformer is entirely disconnected from the circuit. At *III* are illustrated the conditions that would obtain were the voltage lowered for starting by inserting resistance in series with the line. Obviously 100 amp. must flow in all portions of the line even though the resistance of 1.1 ohm reduces the line voltage of 220 to a voltage of 110 which is impressed on the motor. There is a loss of energy in the resistance. Evidently the auto-starter method is preferable because with it the line current is reduced and there is practically no loss of energy. Although the example illustrated is for a two-phase motor the principle is the same for a three-phase motor.

209. Approximate Starting Currents and Starting Torques of Squirrel Cage Induction Motors with Different Impressed Voltages Obtained by Using a Compensator Starter.—Starting current and starting torque are expressed in terms of normal full-load current and full-load torque, and impressed voltage is expressed in terms of normal voltage:

Voltage impressed on motor, per cent.	Starting current taken from line, per cent.	Starting torque, per cent.
40	112	32
60	250	72
80	450	128
100	700	200

210. Taps of a Starting Compensator (*Southern Electrician*).—Compensators are usually shipped by their manufacturers connected to the auto-transformer tap giving the lowest torque. If the motor will not start its load with this tap connected the next higher voltage tap should be tried, and so on, until the tap is found that provides the required torque.

Compensators for use with motors of 15 h.p. and under sometimes have three taps giving voltages of 40 per cent., 60 per cent. and 80 per cent. of full-line impressed voltage. For motors above 15 h.p., four taps are frequently provided giving 40, 58, 70 and 85 per cent. of full-line voltage. The proper tap for giving the maximum starting torque without causing an inconvenient voltage disturbance in the supply circuit, can best be ascertained by experiment.

One make of compensator has for motors of from 5 to 18 h.p., taps starting the motor at 50, 65 and 80 per cent. of the full impressed line voltage, with respective line currents equal to 25, 42 and 65 per cent. of the current that would be taken by the motor if no compensator were used. For motors larger than 18 h.p., compensator-voltage taps are provided giving voltages equal to 40, 58, 70 and 85 per cent. of the full impressed line voltage, and respective currents approximately equal to 16, 34, 50 and 72 per cent. of the current that would be taken by the motor if it were started directly from the supply line.

211. **Starting compensators for motors of high-voltage or large current capacity** are arranged with the switches separate from the auto-transformer (Fig. 94). The equipment usually consists of one double-throw or two interlocked single-throw oil switches

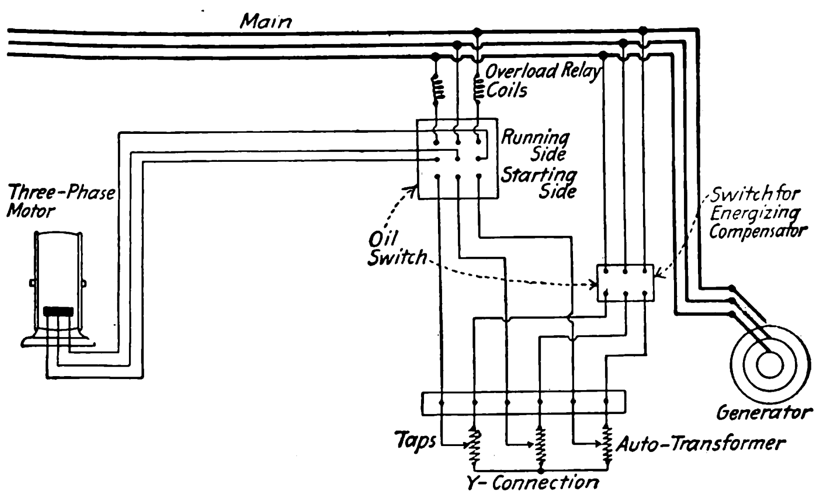


FIG. 94.—Starting compensator with separate switches, and auto-transformer for high-voltage or large capacity motor.

for the motor and a single-throw oil switch for energizing the auto-transformer. In the running leads to the motor may be inserted overload relays which will open the oil switches in case of overdraught of current. The oil switches are usually mounted on a switchboard panel while the auto-transformer may or may not be mounted on the panel. The construction indicated in the other compensator diagrams is used by certain manufacturers for motors of capacities up to and including 550 volts when the normal current does not exceed 300 amp. per phase and for motors of from printing presses. However, this method of speed control is not suitable for such applications where there is operation for long periods at reduced speed, since such operation is not economical. It is not possible, where the torque varies, to obtain constant speed with these controllers.

In the regulator shown the low-voltage release consists of an electro-magnet enclosed in an iron shell, a sector on the pivot end of the operating arm, and a strong spring which tends to return the arm to the off position. The magnet is mounted directly below the pivot of the arm and its coil is connected in shunt across the line in series with a protecting resistance. When the magnet is energized its plunger rises and forces a steel ball into one of a series of depressions in the sector on the arm with sufficient force to hold the arm

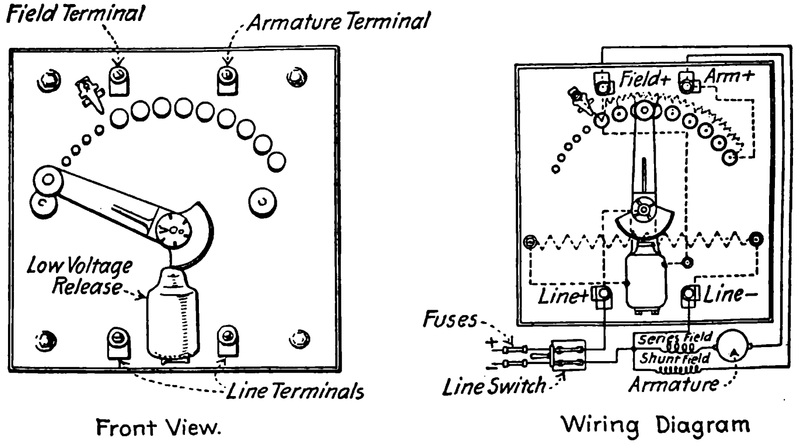


FIG. 83.—Armature control speed regulator.

against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned. When the voltage fails, the magnet plunger falls and the spring throws the operating arm to the off position. An overload release, similar to that described in another paragraph, which operates by opening the low-voltage coil circuit, is sometimes furnished on regulators of this type. Standard commercial rheostats of this type are designed to give about 50 per cent. speed reduction on the first notch. See the following paragraph on operation for further information.

194. **Operation of Armature Control Speed Regulators.**—(Fig. 83.) Continuous motion of the operating arm starts the motor and brings it gradually to maximum speed. Moving the arm over the first few contact buttons increases the shunt field strength if the motor is shunt or compound. The movement over the succeeding buttons cuts out armature resistance and permits the motor to speed up.

195. **Objections to Armature Control** (*Crocker and Arendts, Electric Motors*). (a) *Bulk of Rheostat.*—This may not be very

objectionable if only a few motors are so controlled, but for a number the extra space becomes a factor, and in many cases it is difficult to find sufficient room near the motor.

(b) *Inefficiency of the System.*—The same amount of power is supplied at all speeds, but at low speeds only a small part of it is converted into useful work, the balance being wasted in the rheostat as heat.

(c) *Poor Speed Regulation with Varying Loads.*—Since the impressed voltage at the armature terminals is equal to the line voltage minus the resistance drop in the rheostat ($V_t = V - I_aR_x$), any change in the current drawn by the motor produces a change in the terminal voltage, the counter e.m.f., and therefore the speed.

196. Crane controllers for direct-current series and compound-wound motors are usually arranged somewhat as indicated in Fig. 84. The switching device consists of a disc of soapstone or other fire-proof insulating material carrying stationary contact pieces and a pivoted switch arm carrying four contactors. Blow-out coils are usually provided to effectively rupture the arcs that form when the contactors pass from one contact piece to the next. The resistors may be contained in the controller base, as in small controllers, or may be arranged for separate mounting as in large ones. In Fig. 84 the fine lines within the circle are shading lines which merely indicate that the circle is a soap stone disc. Only the heavy lines within the circle represent electrical connections. Fig. 85 shows two typical controllers.

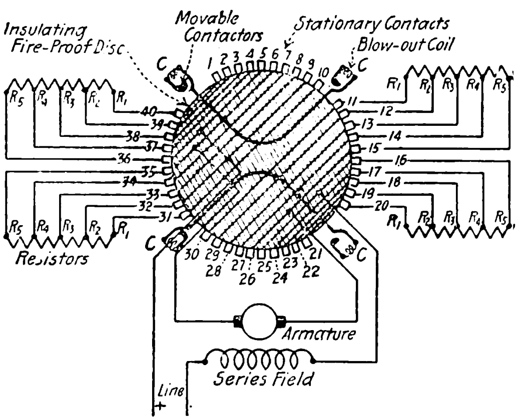


FIG. 84.—Connections of a 16-point crane controller connected to a series motor.

Movement of the controller handle in either direction past the off position starts the motor in the corresponding direction of rotation. At each step a section of resistance is short-circuited. At the full-speed positions all the resistance is short-circuited. Stops prevent over-running past the full-speed positions. Direct-current crane controllers increase or decrease the amount of resistance in series with the motor and thereby control its speed.

197. Dynamic braking of direct-current motors is effected by allowing a motor to be temporarily driven as a generator by its load. The mechanical energy of the moving machinery or descending load is thus converted into electrical energy and then into heat which is dissipated in resistance. The result is that the speed of the motor is promptly retarded. The amount of braking action can be adjusted by varying the current flowing in the motor armature.

A load exercising an active torque on the motor armature, such as an elevator car, cannot be brought to a full stop by this method, since with the decreasing armature speed the braking action also decreases. For final stopping, some form of mechanical brake, which acts automatically, is therefore necessary.

Dynamic braking is used in connection with motors for elevators, hoists, cranes, coal and ore handling machinery, railway cars, etc. It is employed for reducing the motor speed just before a stop, as in elevator service; or for controlling the speed of moving objects, as in lowering crane loads, retarding the speed of the cars descending grades, etc.

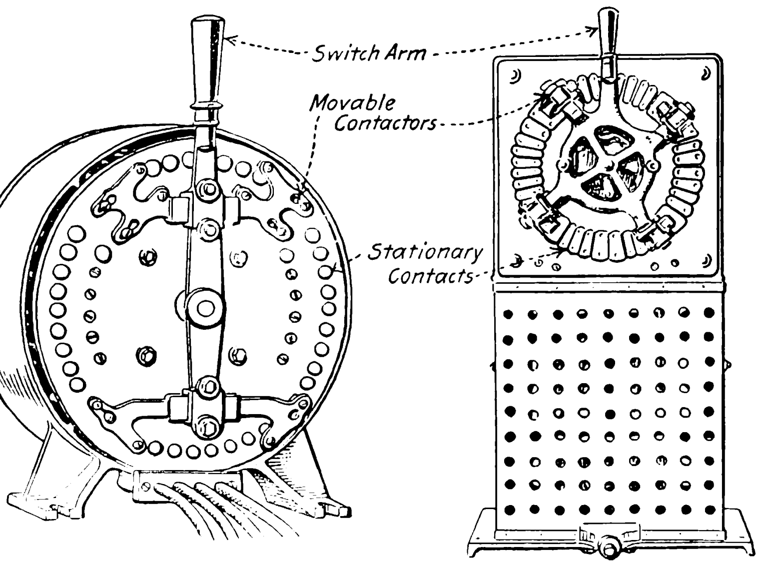


FIG. 85.—Crane controllers.

198. The principal advantages of dynamic braking are the practical absence of all wear and tear on the apparatus, convenience of application, and ease, accuracy, and certainty of control. In dynamic braking with a properly selected motor, active deterioration is limited to the controller contacts, which can be arranged for quick, easy, and inexpensive renewal. No special or additional apparatus is required for braking except the resistance which can be placed wherever convenient within a reasonable distance from the motor. The braking effect can be adjusted with great accuracy over a wide range by varying the armature current or the field strength by means of suitable resistance.

In some instances, notably with railroads, dynamic braking actually returns energy to the circuit; but in industrial service the energy generated is usually dissipated by resistance. In electric cars, during the winter months this dynamic braking current is in many cases run through heaters for warming the cars.

199. Heating with Dynamic Braking.—The most important limitation to the use of dynamic braking is the heating of the motor by the generated currents. For simple stopping duty this action is insignificant as it lasts only a few seconds; but with speed control in lowering a load by dynamic braking, the generated current may flow for an extended length of time and the heating may be considerable, especially as it is added to the heating of the machine when operated as a motor. This additional heating effect due to the braking current must be considered in selecting the motor.

200. Dynamic-braking Connections.—Fig. 86 shows by simple diagrams some of the possible connections. Diagram *I* shows the armature of a shunt motor short-circuited through a brake resistance, the field remaining across the line. Diagram *II* shows the

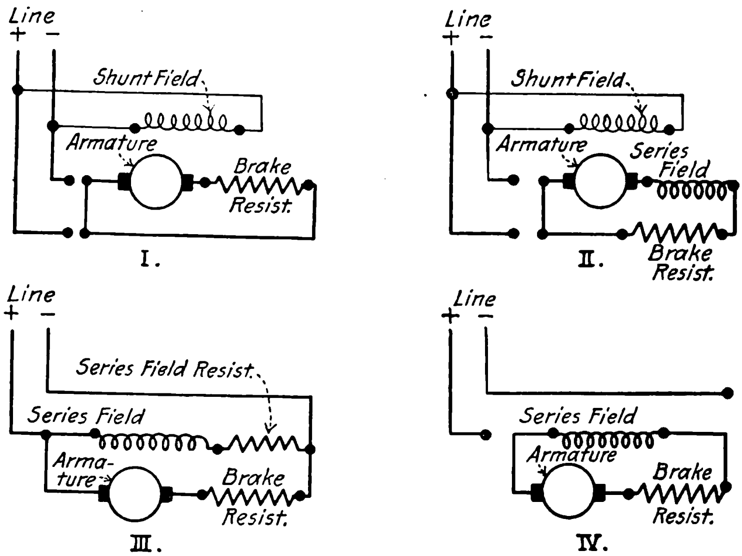


FIG. 86.—Dynamic braking connections.

armature of a compound motor short-circuited through the series field and a brake resistance, the shunt field remaining across the line. Diagram *III* shows the armature of a series motor short-circuited through the series field, a protecting resistance for the field, and a brake resistance—the field and its resistance being in series across the line. Diagram *IV* shows the armature and series field of a series motor short-circuited through a brake resistance, all of which are entirely disconnected from the line.

By cutting out the series field in diagram *II* the braking effect can be diminished, the connections then being as in *I*. The connections shown in diagram *III* are generally preferable for series motors during the first part of the braking operation, in order to insure building up as a generator. As soon as the generator action has begun, the connections can be changed to those shown in diagram *IV*. In each of the cases shown by the four diagrams the braking effect can be increased by short-circuiting sections of the brake resistance and thus increasing the armature current.

201. The methods of starting induction motors may be listed as follows:

(1) *By Connecting Directly to the Line.*—This method is ordi-

narily used only for small motors—those of less than 10 h.p. output—because on starting the motor takes an excessive current and the voltage regulation will be disturbed unless there is ample generating capacity and the conductors are of a generous cross-section.

(2) *By Inserting Internal Resistance in the Rotor Circuit.*—This method is used only with wound rotor machines. The resistance is cut in or out of the circuit by the operation of a switch on the motor shaft so arranged that the handle of the switch is stationary when the rotor is turning.

(3) *By Introducing External Resistance in the Rotor Circuit.*—This method can be used only with a wound-rotor machine having collector rings upon which brushes bear that connect with the resistance. The resistance is cut in or out of the rotor circuit by a controller somewhat similar to the ordinary direct-current motor controller.

(4) *By Using a Transformer having Low-voltage Taps.*—A low voltage can be impressed on the motor at starting by connecting it with a suitable switch to the low-voltage taps.

(5) *With a Starting Compensator or Auto-transformer.*—This is the usual method for motors of ordinary capacity and is similar to the transformer method in that low voltage from the compensator taps are impressed on the motor at starting.

(6) *By Connecting the Armature Coils in Star for Starting and in Delta for Running.*—This method is described in detail in a following paragraph.

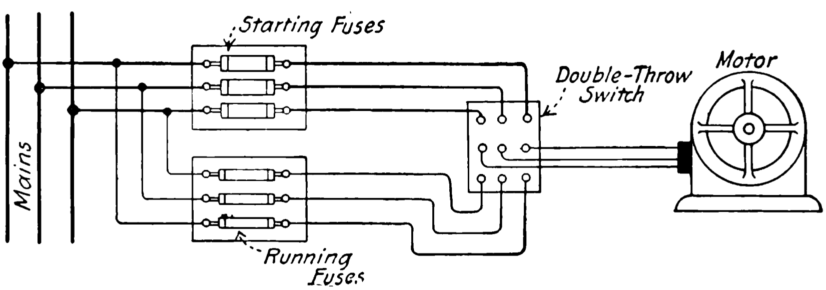


FIG. 87.—Starting small motor by throwing directly on the line.

202. A small induction motor can be started by throwing it directly on the line. (Fig. 87.) This method is, as a general thing, not used for motors of capacities exceeding 5 h.p. Two sets of fuses should be provided, one for starting and one for running, with a double-throw switch to connect the motor to either set. A switch having a spring so arranged that the blades will not remain in the starting position unless manually held there should be used. The starting current of an induction motor thrown directly on the line will be something between three and eight times the full-load running current. If only one set of fuses is used for a polyphase motor and they are of sufficient capacity to carry the starting current, one fuse may open but the motor will continue to operate on one phase, drawing a current considerably above normal. The probable result is a burnt-out motor.

203. **Self-contained starters for wound-rotor induction motors of relatively small capacity** (Figs. 88 and 89) can be purchased. The resistors for these are mounted within the enclosing case that carries the switching mechanism that increases or decreases the amount of effective resistance in the rotor circuit. As a rule, the resistors in these starters are designed only for starting service,

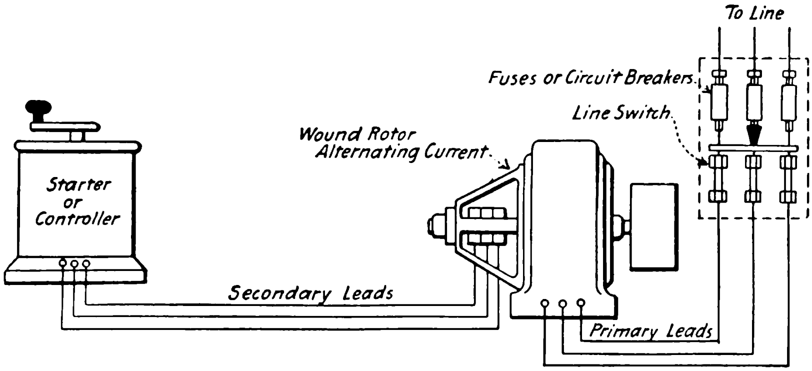


FIG. 88.—Connections of starter to wound rotor motor.

hence they can be used only where starts are infrequent and starting conditions are not severe. They are not usually designed for speed control for which service drum-type controllers with externally mounted resistances are used.

In the usual designs a set of resistors is connected with each phase of the motor (Fig. 90) secondary and all three are interconnected in star by the frame of the starter which is grounded, protecting the operator against shocks.

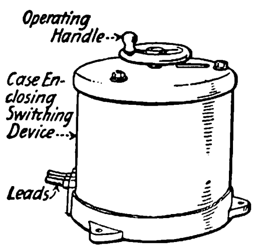


FIG. 89.—Enclosed starter for a phase-wound motor.

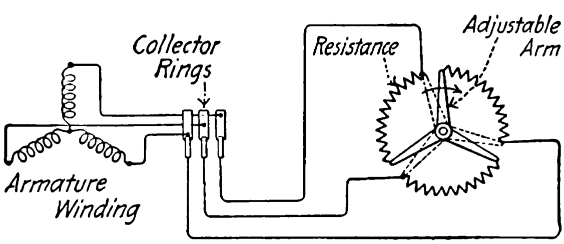


FIG. 90.—Method of varying rotor resistance of a wound rotor induction motor.

204. **In operating a self-contained starter for a wound-rotor motor** (Figs. 88 and 89) before closing the primary line switch or breaker, the handle of the starter must be in the starting position, where all the starting resistance is in circuit. If the connections are correct, and the load is not too great, the motor should start as soon as the line switch is closed; on failure to start, open the primary circuit, and examine the load conditions and the connections. With some starters the handle may have to be advanced

slightly beyond the starting position before the motor starts. As the motor speed accelerates the starter handle should be moved gradually to the running position, bringing the motor to full speed within the time which is usually specified by the manufacturer of the starter. In the running position all starting resistance is, in starters of most designs, short-circuited.

205. Starting a Coil-wound Rotor Motor (*Southern Electrician*) —With the coil-wound rotor, high and variable starting torque can be obtained by inserting a variable ohmic resistance directly in the rotor circuit. The rotor circuit is connected to a non-inductive resistance, which can be varied and gradually cut out as the motor attains speed. Figs. 90 and 91 illustrate the connections. When the rheostat handle is in the extreme left-hand position, the resistance is all out of circuit.

To start the motor, current is first switched on to the stator circuit by closing a triple-pole switch. The three-pole contact blades of the starting rheostat are now moved over from the off position on to the resistance studs, the first contacts of which place the whole of the resistance in circuit with the respective three-phase windings of the rotor. This prevents the current induced in the rotor windings by the stator circuit from reaching an excessive amount. The switch handle on being further rotated in a right-handed direction gradually cuts out the resistance until all the resistance is out of circuit. In this position the rotor windings are short-circuited.

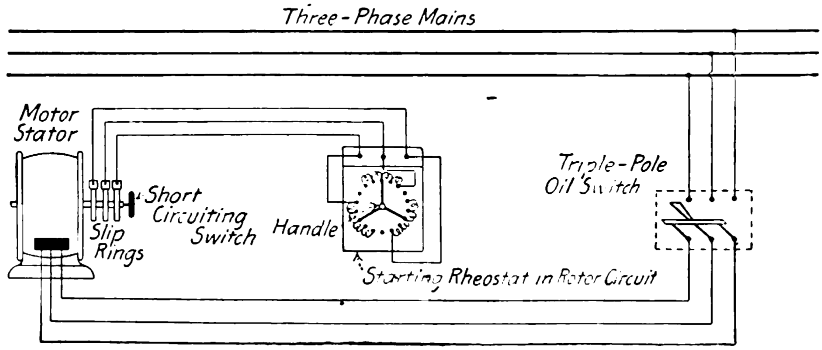


FIG. 91.—Starting arrangement for three-phase coil-wound rotor motor.

206. Commercial starting compensators for squirrel cage induction motors usually have three positions at which the starting lever will come to rest—an "off" position, a "starting" position, and a "running" position. The lever is so arranged that the switch that it controls cannot come to rest in any other positions unless forcibly restrained. The connections of a two-phase and of a three-phase compensator are shown in connection with the material on auto-transformers in Sect. V, *Transformers*. Connection arrangements for compensators of other types are shown on pages adjacent hereto.

In starting compensators, as usually arranged, when in the "off" position the switch is open and the motor and auto-transformer are entirely disconnected from the source of energy. When in the "starting" position, the source of energy is directly connected by the switch to the auto-transformer terminals and the low voltage taps of the auto-transformer are connected to the motor. Usually there are no fuses inserted in the starting leads at the compensator.

When thrown to the "running" position the switch connects the motor through fuses to the source of energy and the auto-transformer is entirely disconnected from the source of energy. The fuses provided in the running leads are for the protection of the motor against overload while it is in normal operation. The fuses protecting the tap circuit to the compensator where the tap circuit branches from the main are usually depended upon to protect the motor while it is starting.

207. Starting With and Without Compensators.—The starting current taken by a squirrel cage induction motor at the instant of starting is equal to the applied electro-motive force divided by the impedance of the motor. Only the duration of this current, and not its value, is affected by the torque against which the motor is required to start. The effect of starting without and with a compensator is illustrated by diagrams *I* and *II* in Fig. 92. In this diagram, motor *I* is thrown directly on a 100-volt line. The impedance of the motor is 5.77 ohms per phase, the starting torque 10 lb. at 1 ft. radius and the current taken 10 amp. In diagram *II* a compensator is inserted, stepping down the line pressure from 100 to 50 volts. This reduces the starting current of motor one-half and the starting torque becomes one-quarter

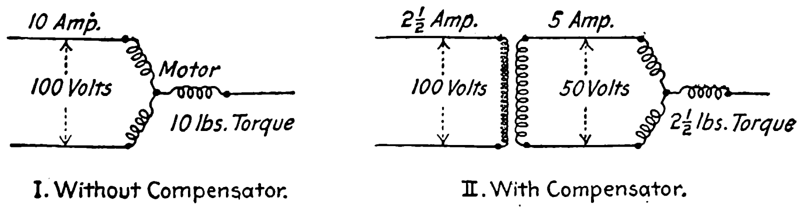


FIG. 92.—Starting with and without compensator.

its previous value or 2½ lb. at 1 ft. radius. The current in the line is reduced inversely as the ratio of transformation in the compensator and becomes 2½ amp.

Thus when a compensator is used the starting torque of the motor can be reduced to approximately the value required by the load and the current taken from the line correspondingly decreased. Where a compensator is not used an increase of rotor resistance results in a proportional increase in the starting torque of the motor with a very slight decrease in the starting current drawn from the line. Where a compensator is used with a motor having a high-resistance rotor the voltage can be reduced to a lower value than would be required with a low-resistance rotor for the same starting torque. Standard compensators are provided with several taps from which various combinations can be obtained.

208. Comparison of Auto-transformer and Resistance for Decreasing Voltage for Starting Squirrel Cage Motors.—The motor in Fig. 93 is supposed to require 100 amp. to start it; that is, to provide the energy necessary to produce the necessary starting torque. At *I*, where an auto-transformer is used to lower the

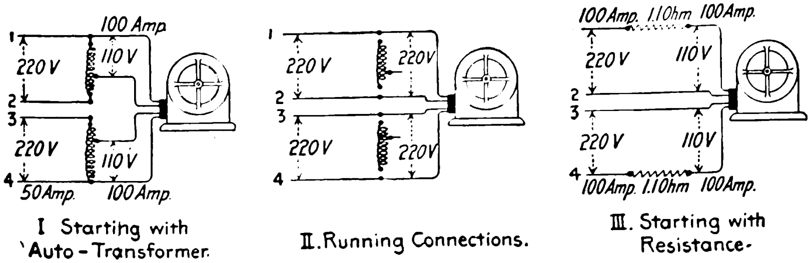


FIG. 93.—Starting with resistance and with compensator.

voltage to 110, a current of 100 amp. is produced in the motor primary with a current in the line of 50 amp. This condition is due to the transformer action of the auto-transformer. At *II* the running connections are shown wherein the auto-transformer is entirely disconnected from the circuit. At *III* are illustrated the conditions that would obtain were the voltage lowered for starting by inserting resistance in series with the line. Obviously 100 amp. must flow in all portions of the line even though the resistance of 1.1 ohm reduces the line voltage of 220 to a voltage of 110 which is impressed on the motor. There is a loss of energy in the resistance. Evidently the auto-starter method is preferable because with it the line current is reduced and there is practically no loss of energy. Although the example illustrated is for a two-phase motor the principle is the same for a three-phase motor.

209. Approximate Starting Currents and Starting Torques of Squirrel Cage Induction Motors with Different Impressed Voltages Obtained by Using a Compensator Starter.—Starting current and starting torque are expressed in terms of normal full-load current and full-load torque, and impressed voltage is expressed in terms of normal voltage:

Voltage impressed on motor, per cent.	Starting current taken from line, per cent.	Starting torque, per cent.
40	112	32
60	250	72
80	450	128
100	700	200

210. Taps of a Starting Compensator (*Southern Electrician*).—Compensators are usually shipped by their manufacturers connected to the auto-transformer tap giving the lowest torque. If the motor will not start its load with this tap connected the next higher voltage tap should be tried, and so on, until the tap is found that provides the required torque.

Compensators for use with motors of 15 h.p. and under sometimes have three taps giving voltages of 40 per cent., 60 per cent. and 80 per cent. of full-line impressed voltage. For motors above 15 h.p., four taps are frequently provided giving 40, 58, 70 and 85 per cent. of full-line voltage. The proper tap for giving the maximum starting torque without causing an inconvenient voltage disturbance in the supply circuit, can best be ascertained by experiment.

One make of compensator has for motors of from 5 to 18 h.p., taps starting the motor at 50, 65 and 80 per cent. of the full impressed line voltage, with respective line currents equal to 25, 42 and 65 per cent. of the current that would be taken by the motor if no compensator were used. For motors larger than 18 h.p., compensator-voltage taps are provided giving voltages equal to 40, 58, 70 and 85 per cent. of the full impressed line voltage, and respective currents approximately equal to 16, 34, 50 and 72 per cent. of the current that would be taken by the motor if it were started directly from the supply line.

211. **Starting compensators for motors of high-voltage or large current capacity** are arranged with the switches separate from the auto-transformer (Fig. 94). The equipment usually consists of one double-throw or two interlocked single-throw oil switches

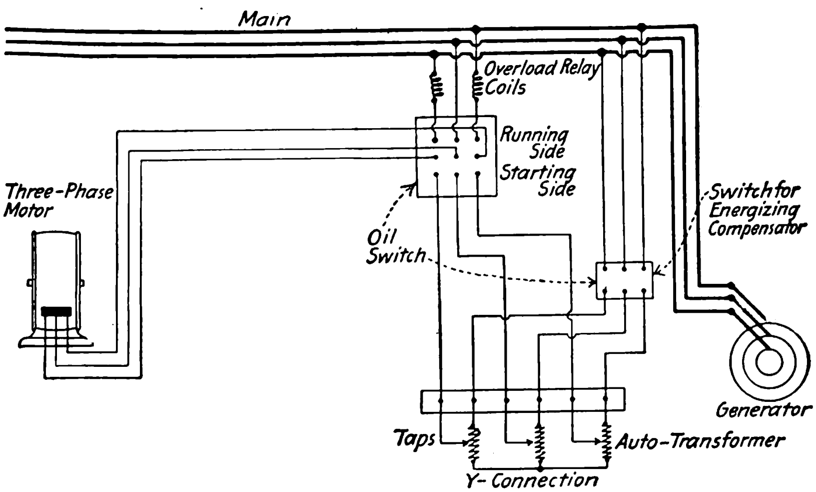


FIG. 94.—Starting compensator with separate switches, and auto-transformer for high-voltage or large capacity motor.

for the motor and a single-throw oil switch for energizing the auto-transformer. In the running leads to the motor may be inserted overload relays which will open the oil switches in case of overdraught of current. The oil switches are usually mounted on a switchboard panel while the auto-transformer may or may not be mounted on the panel. The construction indicated in the other compensator diagrams is used by certain manufacturers for motors of capacities up to and including 550 volts when the normal current does not exceed 300 amp. per phase and for motors of from

1,040 to 2,500 volts with currents not greater than 125 amp. per phase. Where motors take greater normal currents or are of higher voltage the arrangement of Fig. 94 is applied.

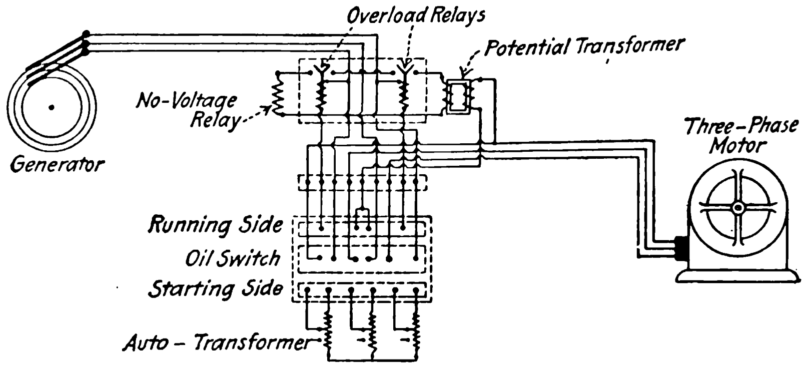


FIG. 95.—Potential transformer for no-voltage relay of high-voltage motor.

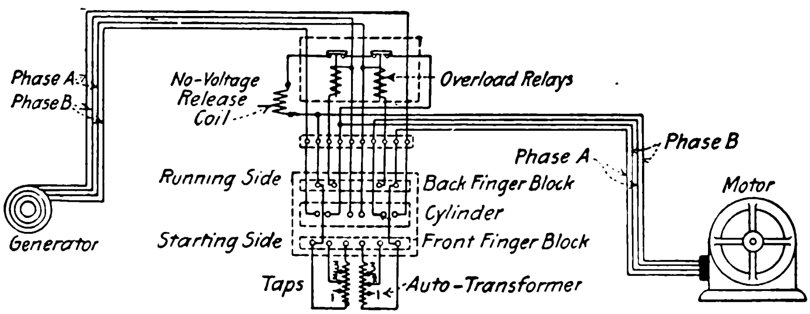


FIG. 96.—Overload relays on a two-phase starting compensator.

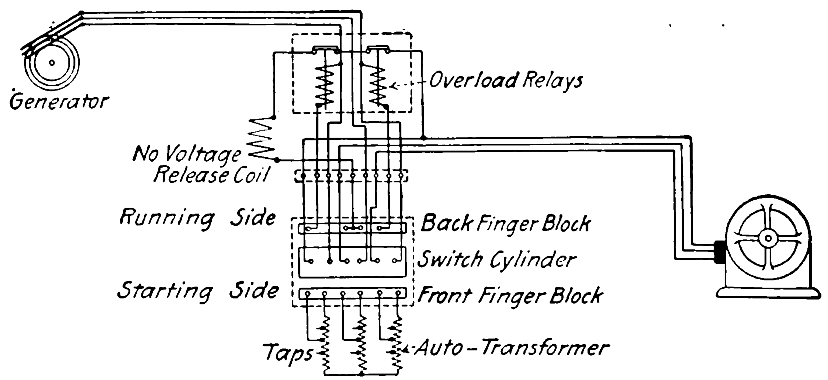


FIG. 97.—Overload release coils on a three-phase starting compensator.

212. **When no-voltage release compensator starters are used for high-voltage motors** a small voltage transformer is usually arranged as in Fig. 95 to energize the no-voltage coil. This ar-

rangement is used by certain manufacturers for compensators, with the no-voltage release attachment, for voltages of from 1,040 to 2,500. The secondary of the transformer furnishes 110 volts for which the no-voltage relay is wound.

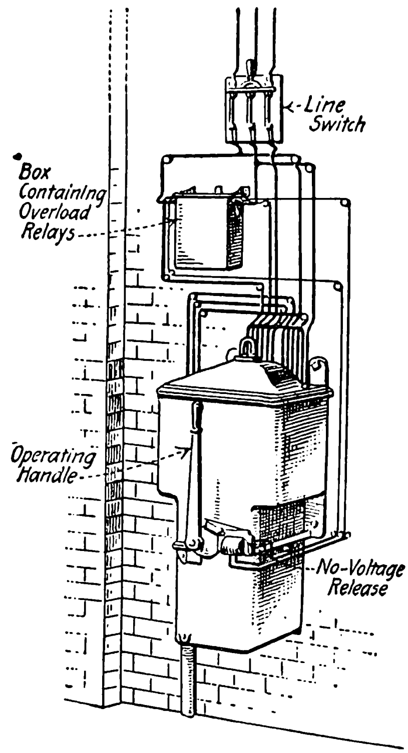


FIG. 98.—Installation of an auto-starter equipped with no-voltage and overload release attachments.

213. Overload release coils on compensators are arranged essentially as shown in Figs. 96 and 97. When there is an overload on either phase the iron plunger of the overload relay is drawn up which opens the no-voltage release coil circuit. This de-energizes the no-voltage release coil and the compensator circuit is automatically opened as described in the paragraph on the no-voltage release. The overload relays are usually arranged so that they can be adjusted to operate at different currents just as a circuit breaker can be adjusted. An inverse-time-element feature is usually incorporated whereby the relay will operate almost instantly on very heavy overloads but will not operate until a certain interval of time has elapsed (the length of the interval being approximately inversely proportional to the amount of overload) on lesser overloads. It will be noted from the diagrams that fuses are not necessary where the overload relays are used. A decided advantage of the overload relays is that they can be adjusted to protect a motor against

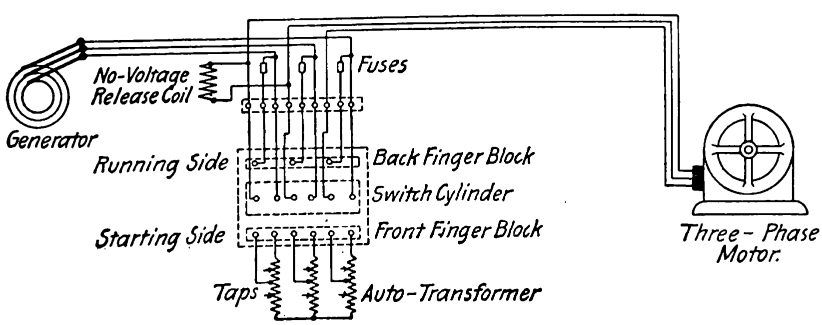


FIG. 99.—Starting compensator with no-voltage release.

running single-phase. If one phase opens, sufficient additional current will be drawn through the others to operate a relay which will open the circuit to the compensator. An installation of a Westinghouse compensator having no-voltage and overload relays is shown in Fig. 98.

214. **A no-voltage release can be provided on starting compensators.** The connection diagram is shown in Fig. 99 for a three-phase compensator and that for a two-phase compensator is similar. When a condition of no-voltage exists on the line, the *no-voltage release coil* is de-energized which permits the iron armature or core of the no-voltage coil to drop, which automatically releases the compensator handle which is returned to the off position by its spring. This opens the circuit through the compensator.

215. **A method of starting several polyphase induction motors from one compensator** is shown in Fig. 100. This can frequently be employed to advantage where there are a number of motors situated close together or where a number of motors must be

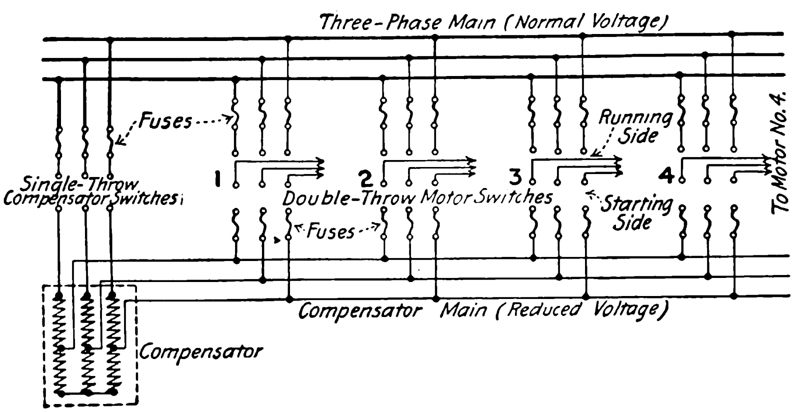


FIG. 100.—Starting several motors from one compensator.

started from one location. A double-throw switch is necessary for each motor to be started and there should be a switch for the compensator. If all of the starting switches are located close together, so that one operator can open or close them consecutively, the compensator need have a capacity only sufficient for serving the largest motor in the group. If the starting switches are so located that several can be operated at once by different men, the compensator must have a sufficient margin of capacity to provide for this. After all of the motors are started the compensator switch is opened, eliminating compensator losses. Where motors exceed possibly 7 h.p. in capacity, oil switches should be used for the starting switches.

216. **Fuses for Use in Connection with Compensator Starters.**— National Code standard fuses carried in holders mounted on slate bases are usually used for compensators for voltages up to 600 volts. For voltages of from 1,040 to 2,500, if fuses are used, the expulsion type is preferable. A table of fuse sizes for induction

motors is given elsewhere in this book, but where not otherwise specified fuses of a capacity corresponding to $1\frac{1}{4}$ times the full-load current of the motor are supplied.

217. **The delta-star method of starting three-phase, squirrel cage induction motors** is sometimes used (Fig. 101). The stator-coil terminals are brought out from the frame and connected to a double-throw switch as shown. In starting, the coils are connected in star and the current is $\frac{1}{1.73}$ or 0.58 of what it would be with the coils connected in delta. After the rotor has attained full speed the switch is thrown to the running position, which connects the coils in delta and normal voltage is thereby impressed on them. Motors must be specially constructed for this method of starting as it is not extensively used by the principal manufacturers.

218. **Speed Control of Polyphase Motors** (*B. G. Lamme*).—The speed of polyphase motors can be controlled by a number of different methods, of which the following are the most important. I. Adjusting the resistance of the secondary circuit. II. Adjusting the primary voltage. III. Using two motor primaries, one of which is capable of being rotated. IV. Changing the number of motor poles. V. Operating two or more motors connected in cascade. VI. Adjusting the frequency of the primary current. VII. Changing the number of phases of the secondary windings.

The results obtained by the use of these various methods differ widely, so that in selecting a variable speed alternating-current motor careful consideration must be given to the characteristics of the method of control in order to determine its suitability for the service. In many cases a combination of methods is required in order to produce the desired speed changes.

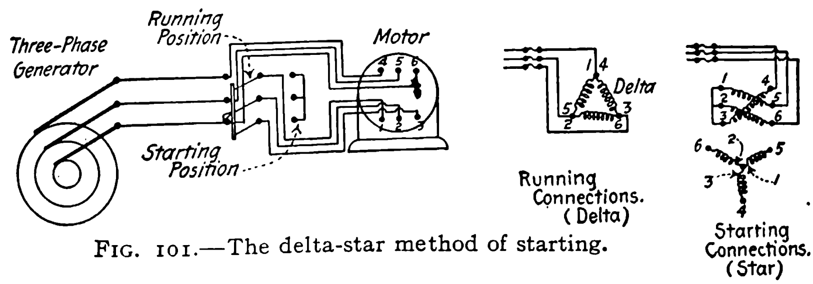


FIG. 101.—The delta-star method of starting.

219. **Speed Control of a Polyphase Motor by Adjusting the Resistance of the Secondary Circuit.**—With constant torque, the speed of the motor increases regularly as each step of the resistor is short-circuited and remains constant on any given notch. But with varying torque the motor speed varies also; that is, an alternating-current motor when operating with auxiliary resistance in the rotor circuit is properly classified as a *varying speed motor*. This method of speed control is, therefore, not suitable for service requiring several constant speeds with varying torque, such as machine-tool work, etc.

Speed control by means of adjustable secondary resistance is, however, very useful where constant speeds are not essential, for example, in operating cranes, hoists, elevators, and dredges, and also for service in which the torque remains constant at each speed, as in driving fans, blowers, and centrifugal pumps. In service where reduced speeds are required only occasionally and where small speed variation is not objectionable, this method of control can also be used to good advantage. On account of energy loss in the resistors, the efficiency is reduced when operating at reduced speeds, this reduction being greatest at the slowest speeds. The circuits are essentially the same as for starting by varying resistance in the rotor circuit, as shown in Figs. 90 and 91.

220. With secondary speed control the rotor usually has a Y-connected winding to which is connected, in series in each phase, an external resistance, Figs. 90 and 91. By moving the adjustable arm the amount of resistance in series in each phase can be varied from a maximum to zero and the speed varied from the highest speed to the lowest speed. This form of control is in general preferable to the primary control method and is used where a large number of speeds is required and it is not necessary for the motor to run at any considerable period at reduced speed.

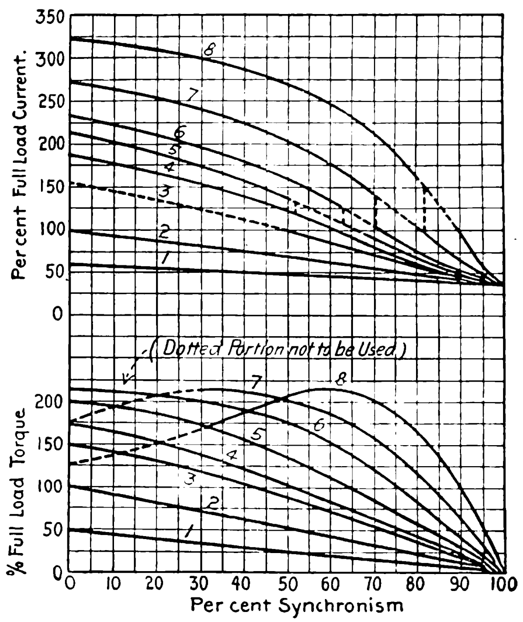


FIG. 102.—Typical current, torque, and speed curves for an induction motor with secondary speed control.

221. Speed-torque Curves of a Secondary Speed-control Induction Motor.—(See Fig. 102.) To determine the speed of such a motor on any point of the controller when operating against a given torque and to find the current taken at that speed and torque, refer to curves which show the speed, torque and current for phase-wound variable speed motors. Those of Fig. 102 are typical of ordinary capacities. For any given torque, follow along the abscissa corresponding to this value to its point of intersection with the torque curve for that particular notch of controller. Then follow up the ordinate until it intersects the current curve corresponding to the same controller notch and the value so obtained is the current taken by the motor.

Example.—Suppose it is desired to determine the current taken on the various points of the controller when starting a 25-h.p. 220-volt motor and bringing it from rest to full speed against full-load torque—the first point (Fig. 102) at which more than full-load torque can be obtained is the third notch and following the line upward to the current curve we see that the current taken is 150 per cent. full-load current. This value drops until about 45 per cent. synchronous speed is reached, when in order to hold up the torque it is necessary to throw to the fourth notch.

The current rises correspondingly to 130 per cent. full-load, then drops until 53 per cent. synchronous speed is reached. Then the controller must be moved to the fifth notch, thence it drops until 65 per cent. synchronous speed is reached, etc.

The dotted line indicates the variation in current.

222. Speed Control of a Polyphase Motor by Adjusting the Primary Voltage.—(Fig. 103.) Adjusting the primary voltage of a motor causes speed changes that are similar to those produced by adjusting the resistance of the motor secondary. The voltage variations can be obtained by means of adjustable resistors, auto-transformers, or choke coils in series with the primary.

This method has the disadvantages of poor speed regulation, low efficiency, and unsatisfactory control, especially when the primary voltage is high; it is not in general commercial use. Squirrel cage induction motors are, however, almost invariably started with reduced primary voltage obtained by means of auto-transformers. Fig. 104 indicates the external appearance of a variable-resistance starter for such service.

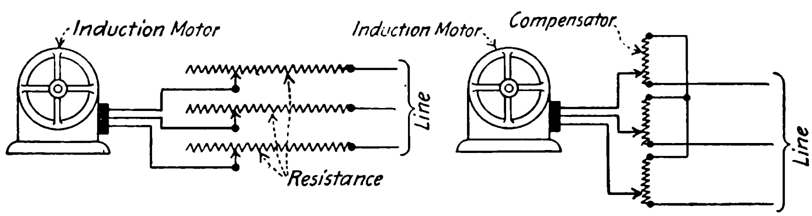


Fig. 103.—Methods of varying the voltage impressed on an induction-motor.

223. Primary Speed Control.—(Fig. 103.) Where a compensator is used, contactors, connected by conductors to the stator, are arranged to slide over the compensator taps, in a manner similar to that in which the lever arm slides over the segments of a rheostat, and thereby vary the voltage impressed on the rotor. The speed regulation of a motor controlled by this method is very poor and the power factor and efficiency decrease with the speed. Where a resistance is used for varying the voltage impressed on the stator, the regulation and efficiency of the machine are not as good as when a compensator is used.

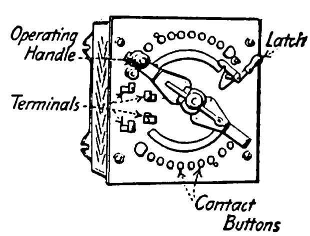


Fig. 104.—Primary resistance starter for a squirrel cage motor.

224. Speed Control of a Polyphase Motor with a Double Primary Arrangement.—The double primary motor resembles an ordinary squirrel cage induction motor in construction except that the primary is divided vertically into halves, each with separate core and windings. One-half can be rotated around the rotor by means of a worm-screw and rack device. Fig. 105 shows this construction. When the two halves of the primary are placed so that like poles are in line, the rotor windings are subjected to maximum magnetic flux from the primary, and the motor will run with minimum slip and therefore at its maximum speed. By turning the movable half of the primary, the flux acting on each rotor bar is gradually reduced, causing increased slip and a corresponding reduction of the motor speed for a given torque.

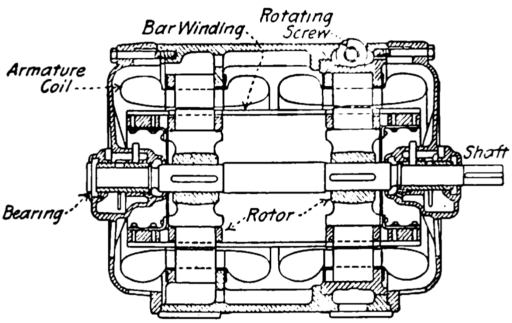


FIG. 105.—Longitudinal section of a double primary motor.

This operation is equivalent to varying the primary voltage and therefore cannot be used with advantage where constant speed with varying torque is desired. The mechanism is, however, self contained; the speed changes are effected without opening circuits; and the motor, having no brushes, operates without sparking.

225. Speed Control of a Polyphase Motor by Changing the Number of Motor Poles.—The synchronous speed of a polyphase motor is inversely proportional to the number of its poles. Thus on a 60-cycle circuit a two-pole induction motor has a synchronous speed of approximately 3,600 r.p.m., a four-pole motor 1,800 r.p.m., an eight-pole motor 900 r.p.m., etc. It is therefore possible to alter the speed of a motor by changing the number of its poles.

This can be accomplished by using two or more separate primary windings, each having a different number of poles, or by using a single winding which can be connected so as to form different numbers of poles. In general only two speeds are possible without great complication, the preferable ratio being 1 : 2. The rotor should be of the squirrel cage type as this is adapted to any number of poles, whereas the windings of a wound rotor must be reconnected for the different speeds.

With very few exceptions these motors are squirrel cage machines with special stator windings. They are designed to operate at full and half speed, the different speeds being obtained by changing the connection of the coils so as to halve or double the number of poles. Usually motors with the lower speed other than half speed require more complicated connections and necessitate bringing out a large number of leads from the motor. The motors can be designed for three or four speeds, but such will require two distinct stator windings. Obviously these motors are very special and their use is not advocated except when absolutely necessary.

The efficiency is approximately the same at each speed and the power factor which is lower at full speed than that of the normal motor is reduced very greatly at the lower speed. Also the output is proportional to the speed, while the percentage slip remains approximately the same for each speed, and the starting torque per ampere varies approximately inversely as the speed.

226. **Speed control of polyphase motors by operating two or more motors connected in cascade** offers, under some conditions of service, the most convenient and economical method of speed variation. In this arrangement all the rotors are mounted on one shaft or the several shafts are rigidly connected. The primary of the first motor is connected to the line, its secondary, which must be of the phase-wound slip-ring type, to the primary of the second motor and so on. The secondary of the last motor can be either of the squirrel cage or of the phase-wound type. In practice more than two motors are rarely used. The arrangement is shown in Fig. 106.

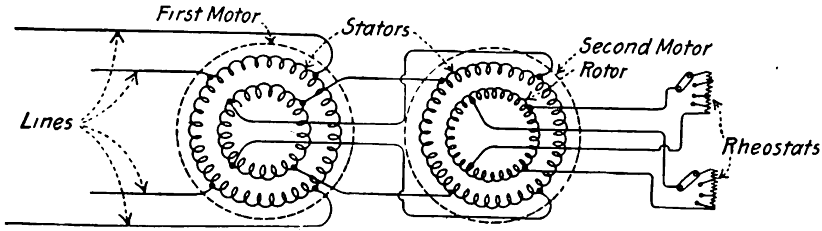


FIG. 106.—Two polyphase motors connected in cascade.

Speed changes are obtained by varying the connections of the motors, the following combinations being possible with two motors: Each motor can be operated separately at its normal speed with its primary connected to the line, the other motor running idle; the motors can be connected in cascade so that the rotors tend to start in the same direction (direct concatenation); or the motors can be connected so that the rotors tend to start in opposite directions (differential concatenation). If the first motor has 12 poles and the second 4, the following synchronous speeds can be obtained on a 25-cycle circuit.

(1) Motor *II* (4 poles) running single, 750 r.p.m.; (2) motors in differential concatenation (equivalent of 8 poles), 375 r.p.m.; (3) motor *I* (12 poles) running single, 250 r.p.m.; (4) motors in direct concatenation (equivalent of 16 poles), 187.5 r.p.m. By the use of adjustable resistance in the secondary circuits, changes from one speed to the next can be made with uniform gradations.

A great number of speed combinations are possible by the use of this method; the control is simple and safe, as few leads are required and main circuits are not opened for most of the speeds. The rotors can be made with smaller diameters than is possible with other multispeed motors, hence the flywheel effect is reduced to a minimum. In general, a cascade set is applicable where speed changes must be frequently made with high horse-power output and primary voltage, and where the speed ratios are other than 1:2.

227. **Speed Control of a Polyphase Motor by Adjusting the Frequency of the Primary Current.**—Since the synchronous speed

of an induction motor is equal to the alternations of the supply circuit divided by the number of poles in each circuit, a change in speed can be effected by changing the frequency of the circuit.

Fig. 107 shows the speed-torque and other curves of a motor when operated at 7,200, 3,600, 1,800, and 720 alternations per minute, or at 100, 50, 25, and 10 per cent. of the normal alternations. The speed-torque curves corresponding to the above alternations are *a*, *b*, *c*, and *d*. The current curves are *A*, *B*, *C*, and *D*. This figure shows that for the rated torque *T*, the current is practically constant for all speeds, but the electro-motive force varies with the alternations. Consequently, the apparent power supplied, represented by the product of the current by electro-motive force, varies with the speed of the motor, and is practically proportionate to the power developed.

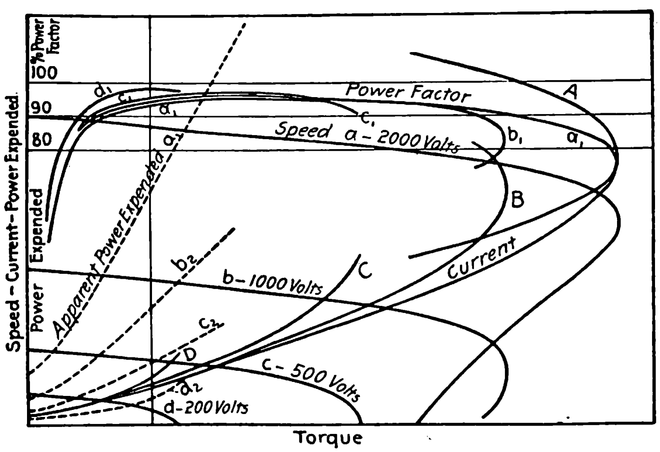


FIG. 107.—Performance curves of a polyphase induction motor with different applied frequencies and different applied electromotive forces.

In a few cases, where only one motor is operated, the generator speed can be varied. If the generator is driven by a water-wheel, its speed can be varied over a wide range, and the motor speed will also vary. If the generator field is held at practically constant strength, then the motor speed can be varied from zero to a maximum at constant torque with a practically constant current.

Another method of accomplishing this result is by the use of a frequency changer. Fig. 108 shows the arrangement. *B* and *C* are induction motors of the ordinary type; *A* is a direct-current motor directly connected to the rotor of *B*. *C* is the driving motor and *B* the frequency changer. The primary of *B* is connected to the line, its secondary to the primary of *C*. The frequency of the current delivered to *C* depends on the relation of the speed of the rotor *B* to the synchronous speed of *B*; the slower the rotation of the rotor the higher the frequency delivered to *C* and the higher the speed of *C*. The speed of the rotor *B* is controlled by adjusting the field of motor *A*. Motor *B* must be practically the same size as C; but motor A can generally be relatively smaller, the exact size depending on the maximum and minimum frequency and the power required for motor C.

This method can be applied with special advantage where direct-current motor drive is not desirable.

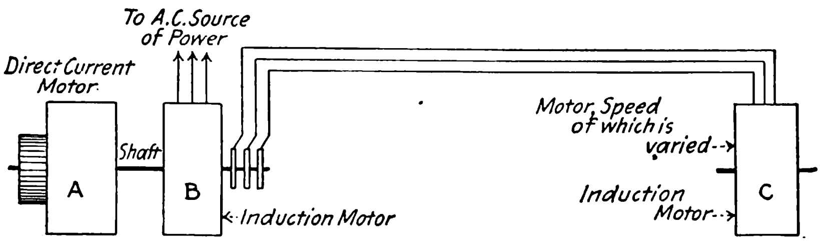


FIG. 108.—Speed adjustment by changing frequency.

228. Speed Control of a Polyphase Motor by Changing the Number of Phases of the Secondary Winding.—Phase-wound motors have in almost all cases secondaries with three-phase windings. If only one of the secondary circuits is closed the motor will run at about half speed, with very low power factor and poor efficiency. This method of speed adjustment (Fig. 109) is frequently used in experimental work, but has no extensive commercial applications.

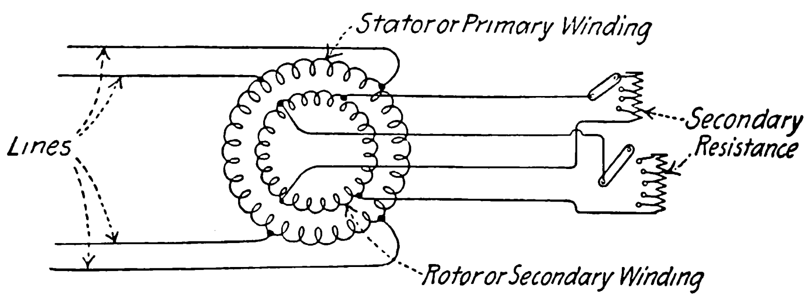


FIG. 109.—One secondary circuit closed (changing the number of phases of the secondary winding).

THE APPLICATION OF ELECTRIC MOTORS

229. Comparative Cost of Line-shaft and Individual Motor Drive for Machine Tools (*Amer. Mach.*, Sept. 26, 1912).—The most economical motor will compare favorably in first cost with line-shaft drive. Its first cost does not exceed by much that of installing line shafting, countershafting and belts. The difference is paid for in two or three years when so small an item as the power saved in friction of overhead mechanical transmission equipment alone is considered. The saving in production will pay for the difference in a very short time.

230. Direct-current Versus Alternating-current Motors.—Whether alternating-current or direct-current motors shall be used is usually determined by the kind of energy available. If a new power plant is to be installed, however, the operating conditions may sometimes affect the choice of current. Even in this case the characteristics of the new plant should agree with those of the nearest central station in order to obtain break-down service and to operate economically with central-station energy on reduced loads. For certain applications, direct-current motors are preferable; for example, in adjustable-speed service, as in machine-tool operation, in service where frequent starts must be made with very high torque, or in reversing service, as in the operation of cranes, hoists, etc.

The voltage of alternating-current circuits can be so readily transformed up or down that such energy is more economical for distribution over considerable areas. For plants extending over a considerable area or distributing energy to distances, say, of one-fourth mile or more, alternating current is nearly always more economical. In order to utilize alternating-current for distribution when direct-current motors are preferable, the installation of rotary converters or motor generators for changing from the one kind of current to the other is sometimes warranted.

The question of protecting motors from dust and refuse sometimes determines the system that must be employed. Where there is any possibility of injury from the accumulation of dirt or dust in motors, semi-enclosing or totally enclosing covers are essential on all motors having sliding contacts. Totally enclosing covers stop the ventilation of the motor and therefore increase the temperature for a given load, or decrease the capacity for a given temperature. Gritty dust, as in cement mills, causes rapid wear on the commutators, and totally enclosing covers are recommended when direct-current motors are used in such locations. Squirrel cage induction motors, having no sliding contacts, are preferable for all service of this nature.

The torque, or turning moment, sometimes determines which class of motors to use. According to its design, an alternating-current induction motor will start with a torque ranging from one to three or more times the torque required to develop full-load at rated speed, and will stop, or pull out, with a torque ranging from two to four times its full-load torque. Higher relative starting torque can be obtained by the use of larger alternating-current motors, but in some cases the more practical way is to employ direct-current motors.

231. Speed Classifications of Electric Motors.—The electric motor may assume practically an infinite number of different forms and can be applied to an almost unlimited number of uses. Each motor, however, possesses certain inherent speed characteristics by means of which it can be classified in one of several groups. The following classification is that which was adopted by the American Association of Electric Motor Manufacturers, January, 1909:

(a) *Constant-speed Motors.*—In which the speed is either constant or does not materially vary, such as synchronous motors, induction motors with small slip, ordinary direct-current shunt-wound motors and direct-current compound-wound motors, the no-load speed of which is not more than 20 per cent. higher than the full-load speed.

(b) *Multispeed Motors.*—Two-speed, three-speed, etc., motors which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as direct-current motors with two armature windings and induction motors with primary windings capable of being grouped so as to form different numbers of poles.

(c) *Adjustable-speed Motors.*—(1) Shunt-wound motors in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load; such as motors designed for a considerable range of speed by field variation.

(2) Compound-wound motors in which the speed can be varied gradually over a considerable range as in (1), and when once adjusted varies with the load similar to compound-wound constant-speed motors or varying-speed motors, depending upon the percentage of compounding.

(d) *Varying-speed Motors.*—Motors in which the speed varies with the load, decreasing when the load increases, such as series motors and heavily compounded motors. Examples of heavily compounded motors are those designed for bending roll and mill service, in which a shunt winding is provided only to limit the light-load operating speed.

232. **Determining the Speed Required of a Motor for a Given Application** (*Earl D. Jackson*, *Engineering Magazine*, September, 1911).—Ascertain accurately the desired speed or speeds of the machine to be driven, and the maximum horse-power as well as the average horse-power required. The speed or speeds of the driven machine may be ascertained by tests with an experimental motor, or from data furnished by the builder of the machine. Often individual motor drive is to replace steam or group drive, in which cases speeds are easily determined.

233. **The horse-power required of the motor** (*Earl D. Jackson*) should be determined accurately. The purchaser may rent an experimental motor and ascertain the power required. This is probably the most satisfactory way. Group drive generally requires that this be done, as the amount of power required for a group of machines is problematical. Note that from the input to the test motor, as measured with a wattmeter, or with a voltmeter and ammeter, should be subtracted the test-motor losses, as the motor to be purchased is rated on horse-power output or brake-horse-power. Money spent in the accurate determination of the power required is wisely expended.

Machine-tool builders, and motor manufacturers, are often requested to supply the information as to how large a motor should be. The machine-tool builder often overestimates the horse-power required to be on the safe side. The result is that the motors run at one-quarter to one-half load at greatly reduced efficiency. The electrical losses, and interest and depreciation on the unnecessary extra investment may amount to considerable in a large installation.

234. **Open Versus Enclosed Motors.**—The metal covers of closed motors reduce the efficiency and capacity of the motor by preventing free circulation of air around the active elements of the motor. Working conditions usually determine whether it is possible to use the open motor, which is, of course, the desirable practice, or whether the presence of excessive dust renders it necessary to enclose the moving parts of the motor partially or completely. The partially or semi-enclosed motor should not be placed in a concealed position because it will then be neglected. Perforated covers and wire screens clog up by dust and dirt, and a semi-enclosed motor becomes, virtually, a totally enclosed motor with a semi-enclosed rating and consequent trouble.

235. **Application of Vertical Motors.**—Vertical motors are recommended only when the nature of the drive renders it apparent that they possess great advantages over motors of the standard or horizontal type. Vertical motors are, in general, inclined to be troublesome and require greater attention. They are not generally kept in stock. The motor and repair parts must be replaced from factory stock and a delay in shipment usually results.

236. **The rating of motors** is determined by the continuity of operation, which must accordingly be considered in making a selection. The heating of the machine due to the passage of electric current through it largely determines the rating. If too great a load is imposed the motor will become excessively hot and the insulation will probably be injured. Obviously, a motor can be rated higher for intermittent service than for continuous service; conversely, a motor rated for intermittent service must not be used at the same rating for continuous service. In any service a motor can nearly always deliver more than its standard continuous rated output for short periods only, with intervening periods of rest. This fact is often overlooked, and motors larger than necessary are accordingly selected.

237. **Factors Affecting the Selection of Small Motors** (*Westinghouse Publication*). *Alternating-current, Single-phase Motors.*—Single-phase motors should be selected with starting torque that will bring the machine promptly up to speed. Allowance must be made for reduced voltage of circuits, since the starting torque varies as the square of the voltage. On account of too small wiring or insufficient transformer capacity, the voltage of many such circuits drops considerably at times. While the motor is starting, the voltage may drop to possibly 80 per cent. of its rated value at which the starting torque of the motor is only approximately 64 per cent. of the torque at full voltage. For these reasons, motors to drive machines from the ordinary lighting circuits should be selected for the worst probable starting conditions. Under especially severe starting conditions, centrifugal clutches are advisable on single-phase motors. The clutch operates automatically after the motor has attained nearly full speed, thus minimizing both the amount and the duration of the starting current.

The maximum turning effort, or torque, while the motor is running must also be ample for the worst load conditions to which the machine will probably be subjected, and with voltage at least 10 per cent. below rated voltage.

Direct-current Motors.—The operating characteristics of direct-current motors depend very largely on the field windings. The following comparison applies to shunt- compound- and series-wound motors of the same rating and efficiency, hence the same rated full-load current input. *Shunt-wound motors* take starting current in direct proportion to the starting effort or torque required, and the speed while operating remains practically constant at all loads. Such motors are most generally applicable unless the starting conditions are too severe.

Compound-wound motors will develop higher starting and maximum torques with the same current input than shunt-wound motors, but the speed while operating varies more widely with the load. They should be applied where high starting effort with low current is desired, and where some change of speed with load is not objectionable. Also on circuits with fluctuating voltage the series field winding of such motors helps to steady the current and speed.

Series-wound motors develop higher starting and maximum torques with a given current input than either shunt or compound motors; but while operating, the speed varies widely with the load, increasing to a dangerously high speed at no-load. Series motors are applicable where very heavy torque must be developed, either while starting or operating, and where varying speed with varying load is not objectionable. Series motors must not be belted or applied where the load may become very light, since if the belt should come off, or the load be removed in any other way, the speed would become excessive.

238. **The standard direct-current motor voltage** practically standardized for factory use is 220 volts. This voltage is both economically and operatively superior for direct-current motor systems to that of 110 volts sometimes employed.

239. Types of Direct-current Motors for Different Speed Requirements (*Engineering Magazine*, September, 1911)

Requirement	Type of motor
Approximately constant speed, no-load to full-load.	Shunt motor. Shunt-commutating pole motor.
Semi-constant speed, no-load to full-load.	Compound motor.
Adjustable speed, remaining approximately constant for one adjustment, no-load to full-load.	Shunt motor, with adjustable field resistance. Shunt-commutating pole motor with adjustable field resistance.
Adjustable speed, semi-constant for one adjustment, no-load to full-load.	Compound motor, with adjustable shunt field resistance.
Varying speed, varying with the load.	Series motor. Series-commutating pole motor.

240. Characteristics of Direct-current Motors and Their Fitness for Different Applications.—This subject is treated, in addition to the matter in the following paragraphs, in several paragraphs in this section starting with 249.

241. Induction-motor Applications (*A. M Dudley, Electric Journal*, July, 1908)

Squirrel cage		Phase-wound	
Constant speed	Variable speed	Constant speed	Variable speed
1. Motor-generator sets.	1. Starting motors.	1. Flour mills.	1. Hoists and winches.
2. Pumps.........	2. Crane motors.	2. Paper, machinery, pulp grinders, beaters.	2. Cranes.
3. Blowers........	3. Fly-wheel service, punches, shears, etc.	3. Belt conveyors.	3. Elevators.
4. Line-shaft drive.	4. Sugar centrifugals.	4. Wood planers.	4. Fly-wheel motor-generator sets.
5. Cement machinery.	5. Laundry extractors.	5. Air compressors.	5. Steel-mill machinery charging machines, hoists.
6. Wood-working machinery (except planers).	6. Brake motors.	6. Line shafting..	6. Coal and ore unloaders.
7. Cotton-mill machinery.	7. Cross-head motors.	7. Driving wheel lathes.	7. Dredging machinery.
8. Paper machinery, calendars, Jordan engines.	8. Valve motors.	....	8. Shovels.
9. Concrete mixers.	....	....	9. Mine haulage.

242. Squirrel Cage Induction-motor Applications for Constant-speed Service (*A. M. Dudley, Elec. Jour.*, July, 1908). *Motor-generator Sets.*—Small starting torque is required and good speed regulation, which characteristics are preeminently met by a squirrel cage motor with very low resistance in the secondary rings. A fair specification on a large set is that it shall start on 30 to 40 per cent. of full voltage, and draw current not in excess of $1\frac{1}{4}$ times full-load current.

Pumps.—With a centrifugal pump, decreasing the head pumped against increases the load on the motor. This type of pump will raise considerably more than four-thirds the amount of water 30 ft. that it will 40 ft., with the result that the motor is overloaded if it is designed for 40 ft. head. In this the centrifugal pump is exactly opposite to the plunger or reciprocating pump, which, being positive in its action, increases its load with increase of head and vice versa. (In some modern types of centrifugal pump the load decreases with decrease of head after reaching the maximum load corresponding to the head for which the pump is designed.

Blowers.—*Rotary blowers*, except positive blowers, have a characteristic similar to centrifugal pumps, in that the load varies with the amount of air delivered and becomes less as the pressure against which the blower is working increases. That is to say, the maximum load which could be put on a motor driving a blower of this nature would be to take away all delivery pipes and let the blower exhaust into the open air.

Line Shafting.—Squirrel cage motors are used very successfully for driving line shafting where the idle belts are run on loose pulleys, in this way keeping down the starting torque.

Cement Mills.—The possibility of entirely covering the bearings and the absence of all moving contacts make the squirrel cage motor successful where the more complicated construction and moving contact surfaces of the wound secondary motor or the direct-current machine are damaged by accumulation of dust. In starting up a tube mill it must be rotated through nearly 90 per cent. before the charge of pebbles and cement begins to roll. This makes the starting condition severe and a motor should have a starting torque of not less than twice full-load torque to do the work.

Wood-working Machinery.—On account of high friction and great inertia, the starting torque is sometimes so high and of so long duration (30 sec. to 1 min.) that it is sometimes better to apply a wound secondary motor.

Paper Machinery.—If calendars are driven with a constant-speed motor, it is necessary to make some provision either by mechanical speed-changing devices or a small auxiliary motor for securing a slow threading speed.

243. **Squirrel Cage Variable Speed Motor Applications.**—These motors in general have high-resistance end rings, high slip and high starting torque. The torque increases automatically as the speed decreases. In these general respects they resemble a direct-current series motor and are in fact fitted for the same class of work, with the added advantage that they have a limiting speed and cannot run away under light load.

Flywheel Service.—In driving tools which are used with flywheels, such as punches, shears, straightening rolls and the like, the usefulness of high slip comes in, as if the fly-wheel is to give up its energy, it is obliged to slow down in speed when the load comes on. A motor with good regulation and low slip would try to run at constant speed, carrying the flywheel and load as well, but the motor in question "lies down" and allows the flywheel to carry the peak load, speeding up again when the peak has passed.

In sugar centrifugals is an application where the sole purpose of the motor is to accelerate the load to full speed, in say 30 sec., where it is allowed to run 1 min. and then shut down to repeat the cycle a minute later. The centrifugal consists of a cylindrical basket with perforated walls and mounted around a vertical shaft as an axis. The same principle is used in laundry extractors where the wet linen is placed in a similarly perforated basket and the water whirled out by centrifugal force.

244. **Applications of Constant-speed Motors with Phase-wound Secondaries.**—There are classes of service which require

a heavy starting torque combined with close speed regulation after the motor is up to speed. These requirements are exactly satisfied by a motor with a phase-wound secondary. The secondary winding itself has a very low resistance, which results in a small "slip," high running efficiency, power factor and good regulation when the secondary is short-circuited. The insertion of external resistance enables the motor to develop maximum torque at the start with a moderate starting current.

Flour Mills.—The number of line shafts, belts and gears in flour mills makes a very heavy starting condition and the nature of the product and its quality demand absolute speed within a few revolutions per minute. The best solution is the phase-wound rotor.

Other Examples.—There is another class of machinery which is not so exacting about regulation but which has the same feature of heavy starting and runs continuously after once up to speed. Under this head come most of the applications of this type of motor. They are, paper-pulp grinders, which, on account of the inertia of the grindstones, are hard to start; pulp beaters, belt conveyors, which may be required to start when full of coal; rock or cement crushers; air compressors, which have a high starting friction because of the construction and the number of parts; line shafting where the belts run for the most part on the working pulleys and are therefore heavy to start. Under the best possible conditions, if line shafting is employed, the loss of power from this source alone, due to friction, is 25 per cent. to 30 per cent. and may run up to 40 or 50 per cent. This is a strong argument for individual drive of machines wherever practicable.

245. Application of Motors with Phase-wound Secondaries for Variable-speed Service.—The application, which is typical of this class, is found in hoist and crane service. Motors for this work are designed for intermittent operation and given a nominal rating based upon the horse-power which they will develop for ½ hr. with a temperature rise of 40 deg. cent. They never operate for as long a period as 30 min. continuously and they are called upon at times to develop a torque greatly in excess of their nominal rating. For these reasons motors of this class should never be applied on a horse-power basis, but always on a torque basis. Since torque is the main consideration and the service is intermittent these motors are usually wound for the maximum torque which they will develop and given a nominal rating based upon one-third to one-half of this torque. Double-drum hoists, hoisting in balance, and large mine haulage propositions in general require a motor rated on a different basis. For this service the motor should have the necessary maximum torque, and be able to develop for about two or three hours, with a safe rise in temperature, a horse-power equivalent to the square root of the mean square requirement of the hoisting cycle. These are only general rules and the most careful consideration should be given in each individual case to secure a motor which will perform the work satisfactorily.

Coal and Ore Unloading Machinery. Dredges. Power-shovels.—Owing to the complication of the cycle of operation there is more difficulty in providing a motor for this apparatus than in the case of a plain hoist. Usually the number of cycles per hour given is the maximum which the apparatus can develop and in practice it will not be possible to operate at so high a speed. This in itself is somewhat of a factor of safety, though it is not one that can be relied upon, as the test for acceptance is ordinarily made at the contract number of operations per hour.

The most impressive application of motors of this class, and perhaps in the operation of any electrical apparatus, is the fly-wheel motor-generator set for hoisting or heavy reversing roll service in steel mills. Service of this nature is extremely fluctuating in its requirements, having very great peaks one instant and almost nothing the next.

246. Operating Speeds of Various Machine Tools

Saws, circular (wood)	9,000 ft. per min. at rim
Saws, band (wood)	4,000 ft. per min. at rim
Saws, band (hot iron and steel)	200–300 ft. per min. at rim
Grindstones	800 ft. per min. at rim
Emery wheels	5,000 ft. per min. at rim
Drills (for wrought iron)	12 ft. per min. outer edge
Drills (for cast-iron)	8 ft. per min. outer edge
Milling cutters (for brass)	120 ft. per min. outer edge
Milling cutters (for cast-iron)	60 ft. per min. outer edge
Milling cutters (for wrought iron)	50 ft. per min. outer edge
Milling cutters (wrought steel)	35 ft. per min. outer edge
Screw cutting (gun metal, etc.)	30 ft. per min. at circum.
Screw cutting (steel)	8 ft. per min. at circum.
Boring (cast-iron)	10 ft. per min. at circum.
Sawing (wood)	1,500 ft. per min. at circum.
Sawing (brass)	70 ft. per min. at circum.
Sawing (gun-metal)	30 ft. per min. at circum.
Sawing (steel)	25 ft. per min. at circum.
Sawing (wrought iron)	30 ft. per min. at circum.
Sawing (cast-iron)	20 ft. per min. at circum.

247. Size of Motors to Drive Machine Tools

Machine	Size	H.p. of motor
Engine lathes, 14 to 48 in. swing	Light duty	2 to 7½
	Heavy duty	5 to 20
Vertical boring rolls	20 in.	5
	100 in.	15
	16 ft.	30
Radial drills	4 to 10 ft.	3 to 7½
Upright drills	15 to 50 ft.	½ to 3
Milling machines	Small	3
	Large	15
Planers	24×24 in.	5 to 7½
	56×56 in.	15 to 25
	14×12 ft.	75 main motor 12 rail motor
Shapers	14 to 36 in.	3 to 7½
Slotters	10 to 30 in.	3 to 15
Cold saws	1 to 3 ft.	2 to 10
Grinders	....	5 to 15

248. Motor-driven Wood-working Machinery.—Alternating-current, squirrel cage, constant-speed induction motors form the most suitable drive for the majority of wood-working machines.

In some few machines, as in "hogs" for reducing slabs to kindling, high flywheel effect makes starting difficult, and motors with phase-wound rotors and external resistance are preferable. For machines requiring adjustable speed, such as certain types of wood lathes, direct-current shunt-wound motors give the best results because of the greater range of speeds possible.

249. **Individual Motor Drive and Group Drive for Wood-working Machinery.**—Individual motor drive should be used for single machines that are operated more or less irregularly but at their full capacity. This applies to most wood-working machines. Group drive is satisfactory for machines used frequently but not simultaneously. Thus an emery wheel, knife grinder, carving machine, cabinet saw and disc sander can all be run by one motor, which can have a capacity of considerably less than the aggregate rating of the machines it is used to drive.

250. Size Motors Required to Drive Wood-working Tools

Machine	Size	Motor h.p.
Jointers	Small	2
	Large	5 to $7\frac{1}{2}$
Inside molders	8×4	15
	15×6	20 to 30
Outside molders	4×4	5
	8×4	10
	14×5	20
Mortising machines	....	3 to 5
Planers, matchers, and molders	9×6	30
	30×12	40
Surfacers	Small, slow feed	5
	Large, rapid feed	30
Belt sanders	....	3 to 5
Column sanders	....	3
Disc sanders	....	3
Drum sanders	16-in. drum	3
	42-in. drum	10
	60-in. drum	20
	80-in. drum	30
	102-in. drum	40
Spindle sanders	....	3
Band saws	Small	3
	Large	20
Band re-saws	8×24	15
	28×36	40
Circular saws, single cut off	14 in.	3
	36 in.	5
	60 in.	60
Circular rip saw	14 in.	10
	36 in.	15
Timber sizers	....	30 to 50
Tenonizing machines	Small	3 to 5
	Large	10 to 15

251. **Motor-driven Pumps** (*Westinghouse Diary*).—Either direct-current or alternating-current motors are satisfactory. (See 254.) For most cases shunt-wound direct-current and squirrel cage alternating-current motors are suitable; but when the starting conditions are severe, as when the pump must be started against a full discharge pipe, compound-wound direct-current and phase-wound alternating-current motors are preferable.

252. Power Required for Printing Machinery
(W. O. Webber, "Power")

		h. p.
	30 in. by 52 in., 2 rev., No. 8 Cottrell press, 19 impressions per min.	1.19
	27 in. by 41 in., No. 20 Adams press, 16 impressions per min.	0.68
	32 in. by 54 in., Huber perfecting press	2.44
	43 in. by 64 in., Huber perfecting press, automatic feed	5.55
	27 in. by 41 in., No. 4 Adams job press	0.43
	26 in. by 40 in., No. 2 Adams job press	0.34
	32 in. by 54 in., No. 1 Potter cylinder roller press	0.50
	26 in., No. 1 Hoe perfecting press	5.41
	Web paper-wetting machine	0.52
News-paper presses	One 10-page web perfecting press, 12,000 per hr.	15.39
	One 10-page web perfecting press, 24,000 per hr.	31.00
	One 12-page web perfecting press, 12,000 per hr.	20.45
	One 12-page web perfecting press, 24,000 per hr.	29.56
	One 32-page web perfecting press, 12,000 per hr.	28.73
Calico printing machin'y, 100 yard goods per min.	One 19-cylinder, soaper and dryer, full, 110 r.p.m.	3.97
	One cutting machine, full, 65 r.p.m.	2.77
	One set drying cans to cutting machine, full, 110 r.p.m.	2.33
	One back starcher, 3 wide machines, full, 115 r.p.m.	4.24
	One indigo skying machine, 5 vats all working full, 64 r.p.m.	4.78
	One 40-in., 5-roll calender, working full, 234 r.p.m.	9.80
	One single-color printing machine	10.60

253. Power Required to Drive Printing Presses
(Walter Scott and Co. specifications[1])

	Mach. No.	Size of bed in.	Imp. per hour	Rev. of shaft per imp.	h.p. motor
Class C, newspaper drum cylinder.	5	29 × 42	2,000	5	2
	6	33 × 47	1,800	5	2.5
	7	37 × 51	1,600	5	3
Class D, job news drum cylinder.	1	17 × 22	2,800	4	1.5
	3	24 × 29	2,400	5.09	2
	4	26 × 34	2,200	5.07	2.5
	5	29 × 42	2,000	5	2.5
	6	32 × 47	1,800	4.96	3
Class E, high-speed drum	2	20 × 25	3,600	6	2
	3	23 × 31	3,200	6.52	2.5
	4	26 × 36	2,850	7.56	3
	5	29 × 42	2,600	8.08	3.5
2-roller two rev. high-speed.	4	26 × 36	2,800	6.8	2.5
	5	29 × 42	2,600	7	3
4-roller two rev. high-speed.	4	27.5 × 36	2,600	7.4	3
	5	30.5 × 42	2,400	7.8	3.5
	6	35 × 46	2,200	8.06	4
	7	38 × 48	2,100	8.43	4.5
	8	41.5 × 52	2,000	8.81	5
	9	45 × 56	1,900	9.37	5.5
	10	48.5 × 62	1,800	9.75	6
	11	50 × 66	1,700	9.75	6

[1] Walter Scott and Co. recommend 1 h.p. more than is called for in each case, as this gives a liberal margin for coolness in running and reserve power for special work.

254. Power Required for Pumping.—The size of motor required for operating a pump can be roughly determined by the following formula:

$$\text{h.p.} = \frac{g.p.m. \times H}{2{,}000}$$

where *g.p.m.* is the gallons pumped per minute, and *H* is the total vertical lift in feet. This formula neglects friction head and assumes an efficiency of about 50 per cent. for the pumping unit. The following formula is exact for fresh water:

$$\text{h.p.} = \frac{g.p.m. \times (H+F)}{3{,}960 \times E}$$

where *F* is the friction head and *E* the efficiency of the pump expressed in hundredths. For sea water, the result should be multiplied by 1.026.

INSTALLATION OF MOTORS AND GENERATORS

255. Brief of Underwriters' Rules Covering the Installation of Generators (*Factory Mutual Fire Insurance Co's. Handbook*).—Generators should be located in clean, dry places, away from combustible materials; and a light location rather than a dark one is always preferable. It is not desirable to place them in the work-rooms of a plant where combustible material abounds, as in the ordinary textile mill, though they may sometimes be so located if properly cut off from the main room by a dust-tight plank partition. A location suitable for a first-class steam engine is none too good for a generator.

A solid foundation is necessary for smooth running. Where a generator or motor must be mounted on timbers, two parallel timbers, as shown in Fig. 110, are preferable to a four-sided framework, which encloses a place under the machine that is difficult to keep clean.

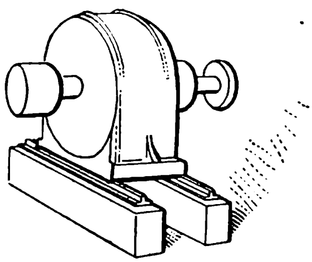


FIG. 110.—Machine mounted on two timbers.

256. Brief of Underwriters' Rules Covering Dynamo Wiring (*Wiring Rules of the Factory Mutual Fire Insurance Companies*).—Since there is generally a considerable number of wires brought close together in this room, particularly in the vicinity of the switchboard, the use of a "slow-burning" insulation is of great importance. As automatic sprinkler protection is not always advisable in dynamo rooms, the necessity for reducing as far as possible the chances of a fire at this point is at once evident. The desirability of fireproof construction throughout the dynamo room is especially emphasized.

Special care should be exercised in rigidly supporting and thoroughly insulating the wires from generator to switchboard, as the main cutouts are usually on the switchboard and a short-circuit between these wires would, therefore, be likely to burn out the armature.

257. Brief of Underwriters' Rules Covering the Installation of Motors (*Factory Mutual Fire Insurance Co's. Handbook*).—The use of voltages above 550 in rooms where manufacturing processes are being carried on will be approved only when every practicable safeguard has been provided. Plans for such installations should be submitted to the Inspection Department before work on them is begun.

Direct-current motors and alternating-current motors with brushes should be so located or enclosed, especially in dusty or linty places, that inflammable material or flyings cannot accumulate around them and become ignited by serious sparking at the brushes. Similar protection should also be provided in wet places, as most electrical machinery is injured by continued exposure to moisture.

Alternating-current induction motors of the type without brushes can be safely located in almost any part of a textile plant without being enclosed, being generally no more dangerous than any other piece of machinery running at the same speed.

For light work, direct-current motors which have all of the working parts enclosed in an iron case are on the market, and these "enclosed" motors may be treated in the same way as induction motors without brushes.

Where an enclosure around the whole motor is provided, it should include the starting rheostat or auto-starter, as well as the main switch and fuses or circuit-breaker, and should, if possible, be of such a size as will permit the attendant to enter it and easily get at any part of the apparatus. It should preferably be made largely of glass, so as to keep the motor in full view of the attendants, thus promoting cleanliness and making it possible to quickly discover any derangement. It should also be thoroughly ventilated, in order to prevent undue heating of the electrical machinery.

Where the use of a motor is permitted in a dusty or linty place without being enclosed, or if the enclosure provided for it is too small to include anything else, the rheostat or auto-starter and the main switch and fuses or circuit-breaker should be placed in a dust-tight cabinet of approved construction. Similarly, in wet places, these accessories should be protected from moisture in a cabinet which is thoroughly water-tight.

258. Commonwealth Edison Company Rules for Motor Wiring (*Commonwealth Edison Co. Handbook*).—Wiring for motors should be so arranged that the current used for power purposes may be metered separately from that used for lighting. Wiring for elevators should also be arranged so that current used on elevators may be metered separately from that used for other power. All motors larger than 1 h.p. must be wound for 220 volts, and it is preferred that motors of $\frac{3}{4}$ h.p. and larger be so wound.

No motors larger than 5 h.p. will be supplied on single-phase system, except by special permission, given by the Inspection Department of the Company in each case. Motors of 5 h.p. and larger will be supplied on the three-phase system at 60 cycles, 220 volts, where three-phase current is available. No motor will be connected which requires more than three times full-load current in starting without load.

259. Foundations are necessary (*Practical Electricity*) to support and maintain in alignment generators and other electrical machines of any considerable size. Foundations are made of masonry. Brick or stone set in mortar (preferably cement mortar) will do, but concrete is almost universally used because it is usually the cheaper. A 1 : 3 : 6 (1 part cement, 3 parts crushed stone or gravel and 6 parts sand by bulk) or even a 1 : 3 : 7 mixture of concrete will give excellent results. Brick or stone for foundations can be set in a 1 part cement and 3 parts sand mortar.

260. **The size of a foundation** is determined by the size of the machine supported and by the stresses imposed by the machine. The area of base of any foundation must be great enough that its weight and the weight of the machine supported will not cause it to sink into the soil. The bearing power of soils is given in Table **260A.** Where a machine is not subjected to any external forces, that is, where it is self-contained, the only requirement of the foundation (provided the machine is not one that vibrates excessively) is to keep it from sinking into the ground and the lightest possible foundation that will do this will be satisfactory. Therefore motor-generators and rotary converters do not require heavy foundations. Machines that are driven by or drive external apparatus require foundations heavy enough to resist the tendency of the external apparatus to tip or to displace the foundation. No rule can be given for determining the proper weight for a foundation, in such a case. However, with a solid foundation, it is usually true that if the foundation is large enough to include all of the foundation bolts of the machine and to extend to good bottom, it will be sufficiently heavy. Experience is required to enable one to design the lightest possible foundation that will do, so it is well for the beginner to be sure that his foundation is heavy enough.

260A. Bearing Power of Soils (*Standard Handbook*)

Soil	Tons per sq. ft.	Remarks
Good solid natural earth	4	New York building laws.
Pure clay, 15 ft. thick, no admixture of foreign substances except gravel	1.75	Chicago building ordinances.
Dry sand, 15 ft. thick, no admixture of foreign substances	2	Chicago building ordinances.
Clay and sand mixed	1.5	Chicago building ordinances.
Hard rock on native bed	250	Richey.
Ledge rock	36	Richey.
Hard-pan	8	Richey.
Gravel	5	Richey.
Clean sand	4	Richey.
Dry clay	3	Richey.
Wet clay	2	Richey.
Loam	1	Richey.

260B. Foundations for machinery should be entirely separate from those of the building (*Standard Handbook*). Not only must the foundations be stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair-felt, mineral wool and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from 2 to 3 ft. deeper and 2 or 3 ft. wider on all sides than the foundation, and the sand, or whatever material is used, occupies this extra space.

260C. A templet (Fig. 111) giving the location of all bolts to be used in holding the machine in place should be furnished, and the bolts may be run inside of iron pipes having an internal diameter a little greater than the diameter of the bolt. This allows some play to the bolt and is found very convenient for the final alignment of the machine. (See Fig. 112.) The bolts are sometimes cast in solid. Templets for foundation bolts can be made from $\frac{7}{8}$-in. boards. The bolts are supported in the templet while the concrete is being formed. See Fig. 111 for an example of a simple templet.

261. Foundation bolts are usually mild steel rods, threaded for nuts on both ends, of such diameter that they will readily pass through the holes in the machine bed-plates. For small machines, ordinary machine bolts will do. Bolts should always extend nearly to the bottom of the foundation. (See Fig. 112.)

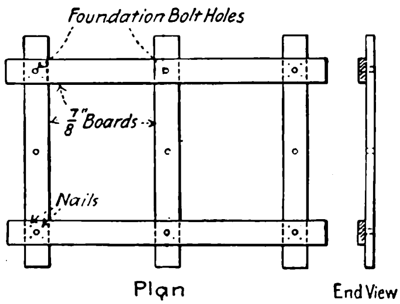


FIG. 111.—Simple foundation templet.

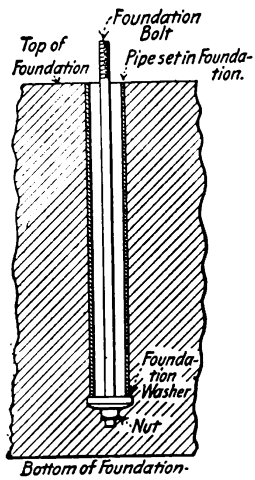
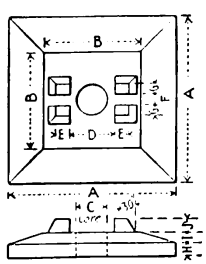


FIG. 112.—Bolt set in foundation.

262. Foundation washers are used on the lower ends of the bolts to retain them in the foundation. (See Fig. 112.) Ordinary round building washers, pieces of steel plate with holes punched in their centers, pieces of angle iron or old rails are sometimes used for foundation washers. But the form of cast-iron washer shown in Fig. 113 is better.



Diam Bolt	Weight	A	B	C	D	E	F	G	H	I	J
7/8"	8 lbs.	6	3 1/2	1 1/8	1 5/8	1/2	3/8	3/8	1/2	3/8	1/2
1"	15	8	4 1/4	1 3/8	1 3/4	1/2	1/2	3/8	5/8	3/8	1/2
1 1/4"	30	10	4 1/2	1 5/8	2 1/8	5/8	3/4	1/2	3/4	3/4	1/2
1 1/2"	45	12	5 1/2	1 7/8	2 1/2	3/4	7/8	1/2	7/8	5/8	1/2
1 3/4"	60	14	5 1/2	2 1/8	2 7/8	1	1	5/8	1	1/2	1/2
2"	100	16	6	2 3/8	3 1/4	1 1/8	1	5/8	1 1/8	7/8	1/2
2 1/4"	135	18	7	2 5/8	3 5/8	1 1/4	1 1/8	3/4	1 1/4	3/4	1/2
2 1/2"	154	20	9	2 7/8	4	1 1/4	1 1/8	1	1	1	1/2

FIG. 113.—Dimensions of foundation washers.

263. Foundation pockets are provided in foundations where it is thought desirable to have the bolts removable. A pocket is a hole in the side of a foundation arranged so that the nut on the lower end of a foundation bolt can be reached. (See Fig. 114.) Ordinarily foundations are not pocketed. The bolts are cast in solid. If bolts are removable it is not necessary to raise the bed-plate of a machine up over them to mount it. The bed-plate is shifted into position and then the bolts are dropped in. Washers similar to that of Fig. 115, which have a pocket for the nut, are preferable for pocketed foundations.

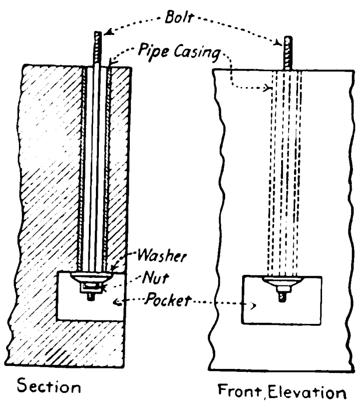


FIG. 114.—Foundation pocket.

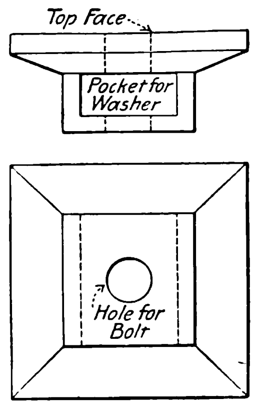


FIG. 115.—Foundation washer with pocket for nut.

264. **Foundation Design.**—Where feasible, the design of Fig. 116 should be used, which is as simple as can be laid out. The form for such a foundation consists of a substantial box having no bottom. Where the earth is self-sustaining such a foundation can be made by throwing the concrete into a hole of proper proportions (Fig. 117). The sides of the hole constitute the form. Founda-

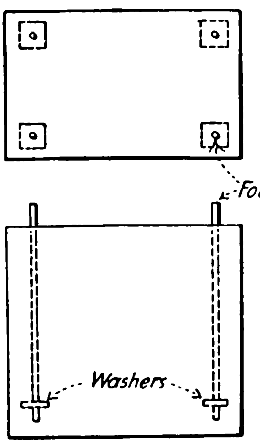


FIG. 116.—Simple foundation.

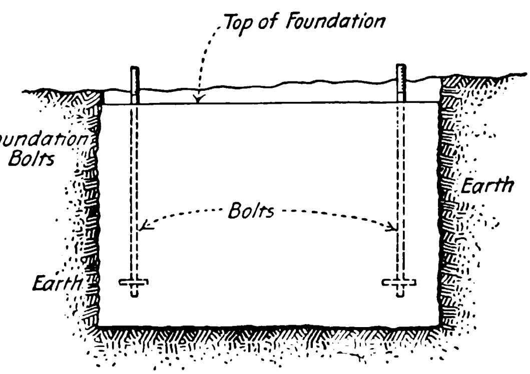


FIG. 117.—Foundation cast without forms.

tions of this type can be used for machines that have solid bed-plates, that is, for bed-plates through which air for ventilating the machine is not expected to rise. Where such a foundation, if cast solid, would be unnecessarily heavy, it can be hollowed out as suggested in Fig. 118.

Where considerable area of base is required, a solid foundation can be made, as suggested in Fig. 119, with an extended footing. The footing may consist of one or more steps. No step should be less than 8 in. thick. The "rise" and "width" of each step should be about equal. It is necessary sometimes to thus extend the base to maintain the pressure on the soil within a safe value.

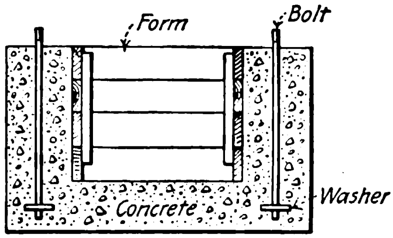


FIG. 118.—Hollowed out foundation.

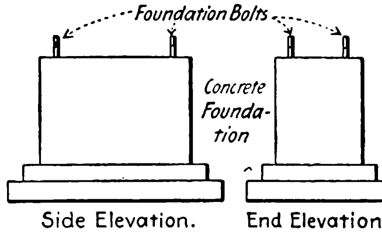


FIG. 119.—Foundation with extended footing.

Where machines have open bed-plates similar to that of Fig. 120 provision should be made for "ventilation" of the machine. It should be arranged so that air can rise all about it and keep it cool. Fig. 121 shows one type of "ventilated" foundation which is designed for the bed-plate of Fig. 120. A foundation for a large engine-driven generator can be made as suggested in Fig. 122. This design affords ample ventilation. A machine with an open

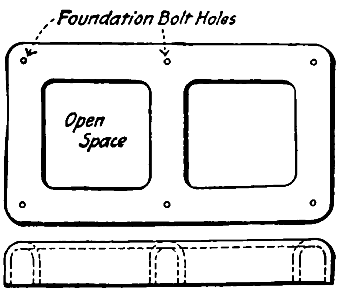


FIG. 120.—Open bed-plate.

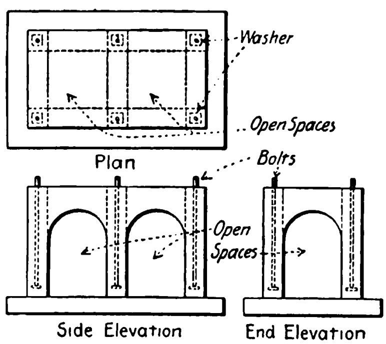


FIG. 121.—Ventilated foundation.

bed-plate can be supported on foundation columns as indicated in Fig. 123, a design used for water-wheel generators, but probably a design similar to that of Fig. 121 is better, in that it provides a support under the entire bed-plate. Undrained pits under machines should be avoided because they collect dirt and oil. A machine not exceeding 50 kw-amp. in capacity may be supported by a framework of timber. Other types of machines require heavier foundations and should be secured by foundation bolts set with a templet as above indicated. A drawing or blue-print of the generator base or bed-plate, will be furnished by the manufacturer of the machine on application.

265. Underwriters' Rules Specifying Sizes of Wires for Motor Leads.—A conductor carrying the current of only one motor must be designed to carry a current at least 25 per cent. greater than that for which the motor is rated. Where the wires under this rule would be over-fused in order to provide for the starting current, as in the case of many of the alternating-current motors, the wires must be of such size as to be properly protected by these larger fuses. (*See modification of this rule for a special case in* **267.**)

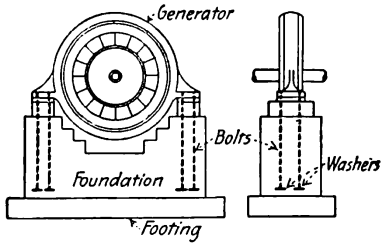


FIG. 122.—Foundation for an engine-driven generator.

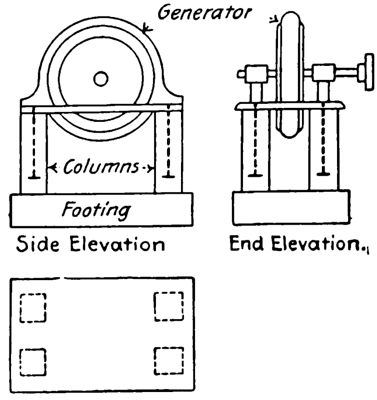


FIG. 123.—Machine supported on columns.

The current used in determining the size of a conductor carrying the current of only one varying-speed alternating-current motor must be the percentage of the 30-minute current rating of the motor as given in the following table:

Classification of Services.	Percentage of current rating of motor
Operating valves, raising or lowering rolls............	200
Rolling tables.....................................	180
Hoists, rolls, ore and coal handling machines	150
Freight and passenger elevators, shop cranes, tool heads, pumps, etc.	120

Varying-speed motors are motors in which the speed varies automatically with the load, decreasing when the load increases, and vice versa. It does not mean motors in which the speed is varied by the use of different windings or grouping of winding, or motors in which the speed is varied by external means, and in which, after adjusting to a certain speed, the speed remains practically constant.

266. Wiring Table for Direct-current Motors.—The values that are here tabulated represent experience of an employee of an Underwriting Department. Table based on average efficiencies quoted by several motor manufacturers. Table is compiled on the basis of installing conductors of 25 per cent. greater carrying capacity than required for the normal full-load running current of the motors. Commercial sizes of fuses, switches, etc., have been used even though they are of slightly greater capacity than that indicated necessary by the calculations.

Where two or more motors are supplied from one service or from the same feeder, the size of service or feeder may be determined by adding together the approximate full-load currents for the different motors as given in table, and basing the conductor size on this total current.

266. Wiring Table for Direct-current Motors (*continued*)

Horse-power	Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
¼	110	2.4	4	5	14
	220	1.2	3	5	14
	500	0.5	1	5	14
½	110	4.8	6	10	14
	220	2.4	4	5	14
	500	1.0	2	5	14
1	110	8.4	12	15	14
	220	4.3	6	10	14
	500	1.8	3	5	14
2	110	17.0	25	25	10
	220	8.5	12	15	14
	500	3.7	5	5	14
2½	110	20.0	25	25	10
	220	10.0	15	15	12
	500	4.4	6	10	14
3	110	24.0	30	30	8
	220	12.0	15	25	12
	500	5.3	8	10	14
3½	110	28.0	35	35	8
	220	14.0	20	25	12
	500	6.0	8	10	14
5	110	40.0	50	50	6
	220	20.0	25	25	10
	500	8.8	12	15	14
7½	110	60.0	75	75	3
	220	30.0	40	50	6
	500	13.5	18	25	12
10	110	80.0	100	100	1
	220	40.0	50	50	6
	500	17.5	25	25	10
15	110	120.0	150	150	00
	220	60.0	75	75	3
	500	26.3	35	35	8
20	110	154.0	200	200	0000
	220	77.0	100	100	1
	500	34.0	45	50	6
25	110	192.5	250	250	300,000
	220	96.3	125	150	0
	500	42.4	60	75	3
30	110	232.0	300	300	350,000
	220	116.0	150	150	00
	500	50.8	70	75	3
35	110	270.0	350	400	500,000
	220	135.0	175	200	000
	500	59.2	75	75	3

[1] 110-volt data applies to voltages of from 100 to 125 volts, 220-volt data to 200 to 250 volts and 500-volt data to 500 to 600 volts.

266. Wiring Table for Direct-current Motors (*continued*)

Horse-power	Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
	110	310.0	400	400	500,000
40	220	155.0	200	200	200,000
	500	67.8	90	100	1
	110	377.0	500	500	700,000
50	220	188.5	250	250	300,000
	500	83.0	110	150	0
	110	452.0	600	600	900,000
60	220	226.0	300	300	350,000
	500	99.5	125	150	0
	110	528.0	660	700	1,100,000
70	220	264.0	350	300	500,000
	500	116.0	150	150	00
	110	568.0	710	800	1,200,000
75	220	284.0	375	400	500,000
	500	124.0	150	150	00
	110	604.0	755	800	1,300,000
80	220	302.0	375	400	500,000
	500	133.0	175	200	000
	110	680.0	850	1,000	1,500,000
90	220	340.0	450	500	600,000
	500	149.0	200	200	200,000
100	110	746.0	950	1,000	1,800,000
	220	373.0	500	500	700,000
	500	164.0	225	250	0000
	110	934.0	1,170	1,200	2,105,500
125	220	467.0	600	600	900,000
	500	205.0	275	300	300,000
	110	1,106.0	1,390	1,500	2,400,000
150	220	553.0	700	800	1,200,000
	500	245.0	325	400	400,000

[1] See note at bottom of preceding page.

267. Determining Sizes of Wire and of Fuses for Induction Motors.—*The* 1915 *National Electrical Code* rules applying to this class of wiring are substantially as follows: Rule 23*e*—"*Where rubber-covered conductor carries the current of only one A. C. motor of a type requiring large starting current, it may be protected in accordance with Table B (other insulations than rubber) of No.* 18." Rule 68*h*—"*Fuses must be so constructed that with the surrounding atmosphere at a temperature of* 75 *deg. fahr.* (24 *deg. cent.) they will carry indefinitely a current* 10 *per cent. greater than that at which they are rated, and at a current* 25 *per cent. greater than the rating at which they will open the circuit without reaching a temperature which will injure the fuse tube or terminals of the fuse block. With a current* 50 *per cent. greater than the rating and at room temperature of* 75 *deg. fahr.* (24 *deg. cent.) the fuses starting cold must blow within the time specified as follows:*

0-30 *amp.*, 1 *min.;* 31-60 *amp.*, 2 *min.;* 61-100 *amp.*, 4 *min.;* 101-200 *amp.*, 6 *min.;* 201-400 *amp.*, 12 *min.;* 401-600 *amp.*, 15 *min.*

An induction motor designed to meet the best condition of normal operation should have as low an impedance as practicable, but a motor thus designed necessarily takes a very large current in starting, this current being inversely proportional to the impedance. This starting current, therefore, varies with the load the motor must start. The average condition found in practice is 100 per cent. load. With 100 per cent. load the starting current will be about four times normal current when a starting compensator is used and very close to five times normal current when the motor is thrown directly on the line. (See Fig. 124.) These curves show that this starting current does not last over 10 sec.

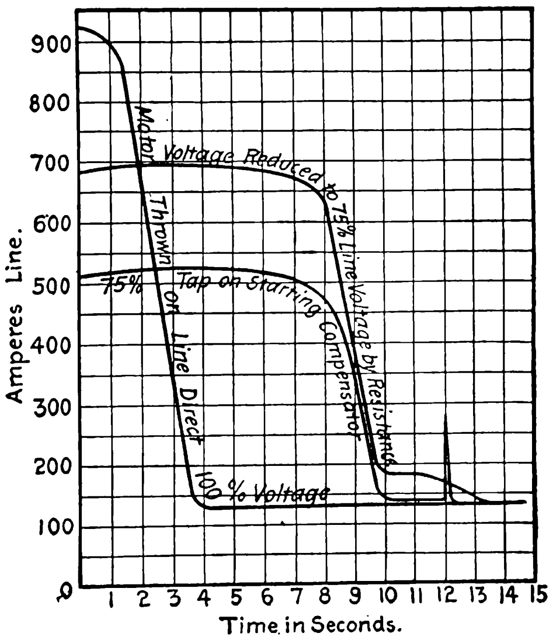


FIG. 124.—Starting currents taken by a 100-h.p., 440-volt induction motor loaded to its normal rating.

It will be found by computing the size of wire for any run of ordinary length, that the starting fuses necessitate that a larger wire be used than would be required to carry the full running current of the motor. This is still the case even when advantage is taken of Rule 23*e*, which allows rubber-covered wire to be fused to the carrying capacities given in *Table B* for wires with insulations other than rubber. However, further advantage may be taken of Rule 68*h*.

It will be found, by reference to the starting curves (Fig. 124), that the fuses will carry 50 per cent. over their normal rated capacity for a greater length of time than the duration of the starting current. From the foregoing it will therefore be evident that the size of wire for any induction motor may be computed by selecting a line fuse of a capacity equal to two-thirds of the starting current and selecting a size of wire having the carrying capacity nearest to the rating of the fuse, using the carrying capacity given in *Table B* of the *National Electrical Code.*

There seems to be no rule regarding the fusing of weatherproof wire which makes any concession for this class of insulation, but, owing to the fact that weatherproof wire is never installed in conduit and therefore radiates effectively, it would seem to be permissible to make the same reduction from *Table B* as is made between *Tables A* and *B*.

268. **The tables on alternating-current motor wiring** (270 to 273) are for installations where motors do not start under full-load. The wire sizes shown are those that should be used for the branch circuit, from the main or distribution center, to the motor. Sizes of wires, switches, etc., for slow-speed motors should be larger in proportion, as the full-load currents of slow-speed motors are larger than the values given in the table, for motors of standard speed. Add 12 per cent. for speeds of 900 to 600 r.p.m. In some cases and under some circumstances this percentage will not be sufficient.

Values given in the tables for sizes of wire, switches and fuses are not large enough for motors which start under practically full-load or greater, such as motors operating pumps or compressors starting under full pressure, rock crushers, or machinery having heavy flywheels. See Sect. II, Par. 127, for data regarding starting currents of motors.

Where several motors are supplied from one service or from the same feeders, size of service or feeder wire may be determined by adding together the values in columns marked "approximate full-load current" for all of the motors. If the starting current of one motor exceeds the value of the "Weatherproof rating" of the rubber-covered wire specified in the table for use with a given horsepower, the size in the table must be increased to a size corresponding with the starting-current value.

Note that the tables are compiled on the assumption that the starting current will be about twice the running current. Code rule No. 23*e* which permits the carrying-capacity value normally allowable for wires with insulations other than rubber to be used for rubber-insulated alternating-current motor leads, determines the conductor sizes tabulated. Voltage drop is not considered in the tables.

269. **The factors to be considered when designing a motor-drive for a machine** are: (*Abstracted from article by A. G. Popcke, American Machinist*, Oct. 3, 1912.) The space available; the surrounding conditions; the nature of the load; the speed of the shaft where power is to be applied; the speed of the motor used; the method of connecting the motor mechanically: (*a*) Direct connected; (*b*) belted; (*c*) geared; (*d*) connected by chain drive.

270. Three-phase Induction Motor Branch Circuits, 110, 220 and 440 Volts—Fuse, Switch and Wire Sizes

(All frequencies and standard speeds. See Par. 268 for limitations)

Horse-power	110 volts					220 volts					440 volts				
	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.
1	7	14	15	15	9	4	14	10	8	5	2	14	15	4	3
2	13	10	35	30	20	7	14	15	15	9	3	14	15	6	4
3	19	8	50	40	25	9	14	25	20	12	5	14	15	10	7
5	30	6	75	60	40	15	10	35	30	20	8	14	25	20	10
7½	44	4	100	90	55	22	8	50	45	30	11	12	25	25	15
10	51	2	150	110	64	26	6	75	55	35	13	10	35	30	20
15	76	0	200	175	95	38	5	100	75	50	19	8	50	40	25
20	102	00	250	225	150	51	2	150	110	65	26	6	75	55	35
25	129	000	300	275	175	64	0	200	175	80	32	6	75	65	40
30	154	0000	400	325	200	77	0	200	175	100	39	5	100	80	50
35	175	250,000	400	350	225	88	0	200	200	110	44	4	100	90	55
40	210	350,000	500	450	275	107	00	250	225	150	54	2	150	110	70
50	246	500,000	600	600	325	123	000	250	250	175	62	2	150	125	78
75	356	700,000	800	750	450	186	300,000	400	375	250	93	0	200	200	120
100	472	1,000,000	1,000	950	600	243	400,000	500	500	325	122	000	250	250	175
150	710	1,700,000	1,500	1,450	900	362	700,000	800	750	450	181	300,000	375	375	225
200	940	....	2,000	2,000	1,200	480	1,000,000	1,000	1,000	600	240	400,000	500	500	300

[1] Starting fuses so selected as to pass 200 per cent. full-load current. [2] Running fuses so selected as to pass 125 per cent. full-load current. [3] Switches and wire so selected as to safely carry current passed by starting fuses. See Par. 268.

271. Protection, Switches and Wire for Induction Motors—Three-phase, Three-wire, 2,200 Volts, 60 Cycles

(Underwriter's Equitable Rating Bureau, Portland, Oregon. *Electrical Review*, June 15, 1912)

Horse-power	Speed	Approximate full-load current	Size of wire, B. & S. gage	Size of oil switch in amp.	Size of starting protection, amp.	Size of running protection, amp.
15	1,800	3.7	14	60	10	5
	1,200	3.9	14	60	10	5
20	1,200	5.4	14	60	15	10
	900	5.8	14	60	15	10
25	1,200	6.5	14	60	20	10
	720	7.2	14	60	20	10
35	1,200	8.9	12	60	25	15
	720	9.8	12	60	30	15
50	900	13.7	10	60	40	20
	514	14.3	10	60	40	20
75	900	19.0	8	60	60	25
	514	20.7	8	60	60	30
100	720	24.4	6	100	75	35
	450	27.2	6	100	80	40
150	720	36.8	4	100	110	50
	450	40.9	2	200	125	60
200	600	50.0	2	200	150	75
	400	54.5	2	200	150	75

272. Single-phase Induction Motor Branch Circuits, 110 and 220 Volts—Fuse, Switch and Wire Sizes

(All frequencies, standard speeds. See Par. 268 for limitations)

	110 volts					220 volts				
Horse-power	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.
1	16	8	35	35	20	8	14	25	20	10
2	24	8	50	50	30	12	12	25	25	15
3	34	6	75	70	45	17	8	35	35	25
4	44	4	100	90	55	22	8	50	45	30
5	54	2	150	110	70	27	6	75	60	35
7½	80	0	200	175	100	40	5	100	80	50
10	106	00	250	225	125	53	2	150	110	70

[1] Switches and wire so selected as to safely carry current passed by starting fuses. [2] Starting fuses so selected as to pass 200 per cent. full-load current. [3] Running fuses so selected as to pass 125 per cent. full-load current. See Par. 268.

273. Two-phase, Four-wire Induction Motor Branch Circuits, 110 and 220 Volts—Fuse, Switch and Wire Sizes

(Standard speeds and frequencies. See Par. 268 for limitations)

Horse-power	110 volts					220 volts				
	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuse, amp.	[3] Size of running fuse, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuse, amp.	[3] Size of running fuse, amp.
1	6	14	15	12	8	4	14	10	8	5
2	11	12	25	25	15	6	14	15	12	8
3	16	8	35	35	20	8	14	25	20	10
4	18	8	50	40	25	9	14	25	20	12
5	26	6	75	55	35	13	10	35	30	20
7½	38	5	100	80	50	19	8	50	40	25
10	44	4	100	90	55	22	8	50	50	30
15	66	1	150	150	85	33	6	75	70	45
20	88	0	200	200	110	44	4	100	90	55
25	111	00	250	225	150	55	2	150	110	70
30	134	000	300	275	175	67	1	150	150	84
35	147	200,000	300	300	200	79	0	200	175	100
40	178	300,000	400	375	225	89	0	200	200	120
50	204	350,000	500	450	275	102	00	250	225	150
75	308	600,000	800	650	375	154	0000	400	325	200
100	408	900,000	1,000	850	550	204	300,000	400	400	275
150	616	....	.....	.....	800	308	600,000	800	650	400

[1] Switches and wire so selected as to safely carry current passed by starting fuses. [2] Starting fuses so selected as to pass 200 per cent. full-load current. [3] Running fuses so selected as to pass 125 per cent. full-load current. See Par. 268.

274. The space available is the first consideration that determines the location of a motor. In many cases it is impossible to conveniently connect a motor to accommodate the requirements of a machine. In these cases, the motor must be connected to a countershaft in a way similar to that shown in Fig. 125, or the motor can be mounted on the ceiling, on a post or girder near the machine. Belt or chain drive must be used in such cases.

A convenient location is sometimes found for a motor, but the presence of water, oil and grease or small chips renders it undesirable. Inclosed motors can be used to overcome the difficulty. The use of a semi-inclosed motor will often insure protection. If an open motor is used in such cases, it is usually placed on the ceiling, a pedestal or a near-by column or girder, a belt or chain connection being used. (A. G. Popcke, *American Machinist*, Oct. 3, 1912.)

Mechanical difficulties in finding a location for a motor can often be overcome, oil and water avoided, and compact units obtained by the addition of a countershaft at the base of a machine to which the motor is geared. Figs. 126 and 127 show the back view and side views of such an installation. Note the convenient location of the starting switch.

The nature of the work of metal-working machinery is usually such that gears can be used wherever the motor can be placed on a machine. Machines such as punches, shears and headers, where heavy loads of short duration occur, are equipped with flywheels, which help to take up the shock; for this reason motors can be geared to this type of machine. When applying a motor to a header or any machine where a large flywheel is used, and the machine is not adapted to gearing, an easy way to apply a motor is to belt it to the flywheel.

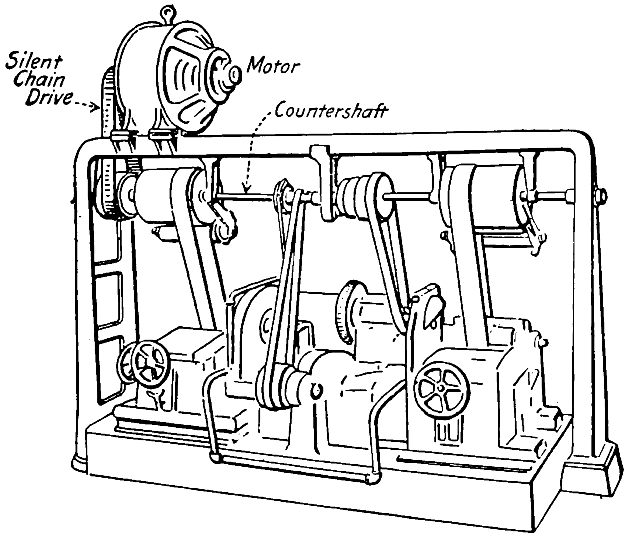


FIG. 125.—Motor driving countershaft with a silent chain.

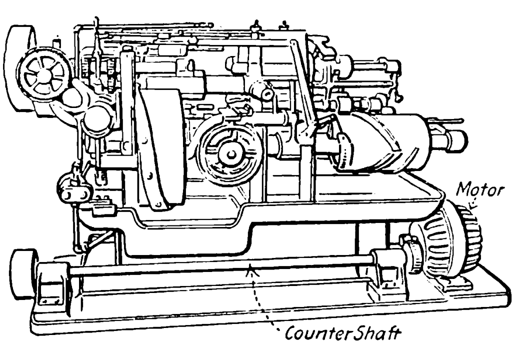


FIG. 126.—Back view showing countershaft at base.

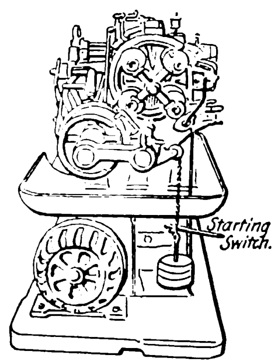


FIG. 127.—Countershaft geared to motor.

275. The speeds of the shaft on the machine to which power is applied is the principal factor which determines the speed of the motor to be connected. These speeds vary with the type of machine. On forging machines using large flywheels they are as low as 50 to 60 r.p.m.; on machine tools, such as lathes, drills, millers, etc., they average between 200 and 300 r.p.m. Speeds as high as 1,000 to 2,000 r.p.m. occur on grinders and wood-working machines. The method of taking care of these will be explained later.

276. Modern practice is to standardize the speeds of motors. This practice has been promoted by the extensive use of alternating current. Since 60 cycles is used in the majority of alternating-current systems, the standard speeds of direct-current motors are approximately the same as the speeds of 60-cycle, alternating-current motors.

The speeds obtainable with the 60-cycle motors mostly used are 1,700 to 1,800; 1,100 to 1,200; 850 to 900; 650 to 720, and 550 to 600 r.p.m. The higher speed given in each case is the synchronous speed at which the motor runs when not loaded. The speed decreases from 5 to 7 per cent. as the motor is loaded.

On 25-cycle circuits the speeds of motors most frequently used are 700 to 750; 550 to 600, and 350 to 375 r.p.m. The speeds of direct-current motors are given in the second column of Table **280**. A reference thereto will show the relation to the speeds of the alternating-current motors just given.

277. Mechanical Connections.—Motors can be either direct connected, belted, geared or connected to machines by chain drive. Direct connection with a flexible or rigid coupling can be used only where the speed of the shaft to which power is applied is the same as the motor speed. Belts, gears or chains must be used in all other cases.

278. Belt Drive of Motored Machines.—This is the most convenient method in the majority of cases and is the least expensive. It is, therefore, used more than the other two methods. The factors to be considered when applying a belt drive are: Speed reduction; pulley sizes; belt speeds; motor speed; distance between pulley centers; arc of contact; size of belt; use of idle pulleys; mounting of the motor.

279. Considerations in Obtaining Speed Reduction With a Belt Drive.—The speed reduction is the ratio of the speed of the motor to the speed of the shaft where power is applied. Obtaining the required speed reduction involves the size of the motor pulley, machine pulley and belt speed. The sizes of the pulleys used on motors have been standardized according to ratings, *i.e.*, horse-power and speed of motor. These are given in Table **280**, column 3. This fixes standard practice for belt speeds (see Table **280**, column 7).

As the diameter of a motor pulley is reduced, the strains on the motor bearings and shaft are increased. A minimum pulley is, therefore, specified by motor manufacturers for each motor rating (see Table **280**, column 5). The maximum diameter of the pulley on a motor is required only where speeds higher than the motor speed are required (grinders and wood-working machines). The maximum diameter is, in nearly all cases, limited by the belt speed, which should not exceed 5,000 ft. per minute. In some cases, with small motors especially, the size and location of the motor are such that the diameter of the motor limits the diameter of the largest pulley.

280. Standard Motor Ratings Showing the Standard and Minimum Pulleys Used in Each Case, Also Belt Speed with Standard Pulley

1	2	3	4	5	6	7	8
H.p.	R.p.m. D. C. motors	Standard pulley		Minimum pulley		Belt speed standard pulley, ft. per min.	Leather belt
		Dia.	Face	Dia.	Face		
1	1,700	3½	2½	3	1¾	1,560	Single
2	1,700	3½	3	3	3	1,560	Single
	1,200	4	3	3	3	1,250	Single
	850	4	4	3½	4	890	Single
3	1,800	4	3	3	3	1,890	Single
	1,150	4	3	3½	4	1,200	Single
	850	5	4½	4	4½	1,110	Single
5	1,800	4	4	3½	4	1,890	Single
	1,200	5	4½	4	4½	1,570	Single
	850	6	5	4½	5	1,340	Single
7½	1,700	5	4½	4	4½	2,220	Single
	1,150	6	5	4½	5	1,800	Single
	975	7	6	5	6	1,790	Single
	850	7	6	5	6	1,560	Single
	650	8	7	6	7	1,360	Single
10	1,700	6	5	4½	5	2,670	Single
	1,300	7	6	5	6	2,380	Single
	1,150	7	6	5	6	2,100	Single
	850	8	7	6	7	1,780	Single
	730	8	7	6	7½	1,530	Single
	600	9	8	6½	9	1,410	Single
15	1,700	7	6	5	6	3,100	Single
	1,250	8	7	6	7	2,620	Single
	1,100	8	7	6	7½	2,300	Single
	825	9	8	6½	9	1,940	Single
	675	10	9	7	8	1,770	Single
	600	11	10	7½	9½	1,730	Single
20	1,700	8	7	6	7	3,560	Single
	1,100	9	8	6½	9	2,600	Single
	900	10	9	7	8	2,360	Single
	750	11	10	7½	9½	2,160	Single
	650	11	10	8	9½	1,870	Single
25	1,400	9	8	6½	9	3,330	Single
	1,100	10	9	7	8	2,800	Single
	950	11	10	7½	9½	2,730	Single
	825	11	10	8	9½	2,370	Single
	600	12	12	9	10½	1,880	Double
30	1,700	9	8	6½	9	4,000	Single
	1,150	11	10	7½	9½	3,330	Single
	975	11	10	8	9½	2,800	Single
	725	12	12	9	10½	2,280	Double
	600	13	12	10	11	2,040	Double
35	1,700	10	9	7	8	4,450	Single
	1,150	11	10	8	9½	3,330	Single
	850	12	12	9	10½	2,670	Double
	675	13	12	10	11	2,300	Double
40	1,700	11	10	7½	9½	4,900	Double
	950	12	12	9	10½	3,000	Single
	775	13	12	10	11	2,640	Double
	600	14	12	12	13	2,200	Double
50	1,700	11	10	8	9½	4,900	Double
	975	13	12	10	11	3,320	Double
	750	14	12	12	13	2,750	Double
	565	16	13	12½	15	2,360	Double

281. Belt speed is figured as follows:

$$\text{Belt speed (feet per minute)} = \frac{\left(\begin{array}{c}3.14 \times \text{diam. of motor pulley} \\ \text{(inches)} \times \text{r.p.m. of motor}\end{array}\right)}{12}$$

282. The success of a belted motor application depends largely upon the arc of contact. The distance between centers of motor pulley and machine pulley, as well as the speed reduction, determine the arc of contact on the smallest pulley, usually the motor pulley. Motors can be furnished with idler-pulley attachments, Fig. 128, and these are applied to advantage where it is necessary to overcome a small arc of contact.

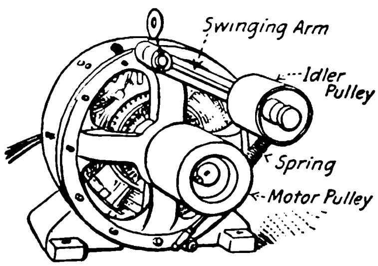


FIG. 128.—Idler pulley attachment to increase arc of contact.

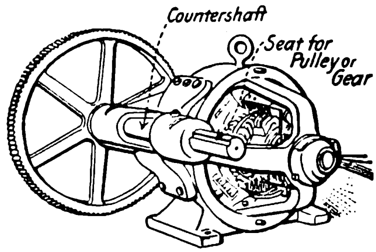


FIG. 129.—Back-geared motor suitable for extremely low speeds.

283. When necessary to obtain extremely low speeds back-geared motors should be used. (Fig. 129.) A good standard for a back-geared motor gives a speed reduction of 6 to 1 between armature and countershaft speed. Usually, if the required reduction in speed exceeds 6 to 1, a back-geared motor should be used.

Example.—If the reduction is 12 to 1 between the motor speed and the machine speed, a back-geared motor with a 6 to 1 speed reduction should be used, and the further reduction 2 to 1 obtained by means of a pulley on the countershaft of the back-geared motor.

It is poor practice in the majority of cases to use back-geared motors having an initial speed of 1,700-1,800 r.p.m. In applications requiring from 10 to 20 h.p., 1,200-r.p.m. back-geared motors should be used; above this 900-r.p.m. or 720-r.p.m. back-geared motors should be used.

284. The pulleys furnished with motors make provision for the proper width of the belt. Table 280 shows whether a single or double belt should be used. The width of the belt should be one inch narrower than the pulley face on pulleys up to 12-in. face; above that it should be two inches narrower than the pulley face.

285. The cost of a motor of given horse-power increases as the rated speed decreases. For instance, the cost of a 10-h.p. motor at 1,200 r.p.m. is approximately the same as a 5-h.p. motor at 600 r.p.m. The cost increases in the same proportion as the square root of the torque figured at 1-ft. radius. This quantity is figured by means of the following formula:

$$\text{Torque at 1-ft. radius} = \frac{5{,}250 \times \text{h.p.}}{\text{r.p.m.}}$$

Example.—A $7\frac{1}{2}$-h.p. motor at 1,150 r.p.m., ready for belting, costs approximately \$180, and a $7\frac{1}{2}$-h.p. motor at 650 r.p.m. costs approximately \$235. The torques are

$$\frac{5,250 \times 7\frac{1}{2}}{1,150} = 34.2 \text{ and } \frac{5,250 \times 7\frac{1}{2}}{650} = 60.5$$

The square roots of these are 5.85 and 7.8, respectively.

The ratio of these square roots is

$$\frac{7.8}{5.85} = 1.33$$

The ratio of prices is

$$\frac{235}{180} = 1.31$$

These two ratios check closely.

From a cost point of view, therefore, as high a speed motor as possible should be used, but a pulley diameter smaller than the minimum specified should not be used.

286. Belting Motors.—There are two general cases to be considered when belting motors; these are: (1) Where the dimensions of the machine pulley is fixed, as when belting to a flywheel. In this case the motor pulley must satisfy the requirements of the machine. Care must be taken not to use a pulley of a diameter smaller than the minimum specified. The arc of contact of the motor pulley must also be carefully considered, for the speed reduction is usually large.

(2) Where the machine pulley can be chosen to suit the standard motor pulley. Tables 289 and 288 were devised to aid in selecting the proper speed of motor and size of pulleys. Table 289 gives the machine speed at the left column and the motor speeds at the top of the table. The figures in the body of the table are the speed reductions for any combination of machine and motor speed indicated.

287. Determining the Arc of Belt Contact.—Before deciding upon any belt drive the arc of contact of the belt with the smaller pulley should be carefully checked. In machine-tool work, on applications where belts are used, the distance between centers is usually between 3 and 5 ft. Motor pulleys range in diameter from 3 to 12 in. and the arc of contact is usually considered when the ratio of reduction is between 3 and 6.

Table 288 gives the arc of contact when the size of the motor pulley, ratio of reduction and the distance between pulley centers are known.

Example.—Refer to Table 288. The motor pulley is 6 in., the ratio of reduction is 4 and the distance between centers is 5 ft.

Solution.—The table shows the arc of contact as 162 deg.

Table 291 shows the effect of the arc of contact on the transmitting power of the belt. The decrease with decreased arc of contact is expressed by a percentage which the power transmitted at a given arc of contact is of the power transmitted at 180 deg. Thus if the arc of contact is 140 deg., only 78 per cent. of the power figured by the belt formula given in a following paragraph, based on a 180-deg. arc of contact, can be transmitted.

To transmit the required power the pulley and belt width must be increased or an idler pulley must be used to increase the arc of contact.

Example.—Illustrating the application of Tables 280, 289 and 288. The speed of the machine is 185 r.p.m.; the horse-power required is $7\frac{1}{2}$; the distance between centers is 5 ft. What motor speed and what pulleys should be used for the belt drive?

Solution.—Refer to Table 289. This shows that for 150 to 200 r.p.m. a 720-r.p.m. motor should be used.

Refer to Table 288. A $7\frac{1}{2}$-h.p., 650-r.p.m. motor has an 8×7-in. standard pulley and a 6×7-in. minimum pulley.

The speed reduction with this motor is

$$\frac{650}{185} = 3.5$$

Refer to Table 288. The arc of contact for a ratio of reduction of 3.5 (average of 3 to 4), distance between centers of 5 ft. and 8-in. motor pulley, is 160 deg. (average of 164 and 157), and with a 6-in. motor pulley is 165 deg. (average of 162 and 168). Either will give successful service. The machine pulley would be, with an 8-in. motor pulley, $3.5\times8=28$ in. and with a 6-in. motor pulley, $3.5\times6=21$ in.

The face in either case will be 7 in. and a single 6-in. leather belt should be used. The combination of 8-in. motor pulley and 28-in. machine pulley is preferred because the motor pulley is standard.

The above example covers a case where the machine pulley can be selected at will. In cases where a motor is to be belted to a flywheel or to a pulley which cannot be easily changed, the procedure is as explained in the following.

Example.—The size of the machine pulley (flywheel) is 72 in.; the speed of the pulley is 100 r.p.m.; the horse-power required is 15, and the distance between centers is 6 ft. What motor speed and motor pulley should be used?

Solution.—Consider a reduction of 6 : 1 belted directly. The motor speed must be 600. The size of the motor pulley

$$\frac{\text{machine pulley}}{\text{ratio of reduction}} = \frac{72}{6} = 12 \text{ in.}$$

Table 280 shows that a 12-in. pulley can be used with a 15-h.p., 600-r.p.m. motor. It is 1 in. greater than the standard pulley diameter. Table 288 shows that for a 12-in. motor pulley, a ratio of reduction of 6, and 6 ft. distance between centers, the arc of contact is outside the limits of the table and very small (less than 120 deg.).

288. Arcs of Belt Contact for Different Ratios of Reduction, Distances Between Centers and Pulley Diameters

Ratio of reduction	Distance between centers, feet	Diameter of motor pulley, inches									
		3	4	5	6	7	8	9	10	11	12
3	3	170	166	163	160	157	153	150	147	145	141
	4	173	170	167	165	163	161	158	156	155	151
	5	175	172	170	168	167	164	162	161	160	157
4	3	165	160	155	150	145	142	156	132	126	122
	4	168	165	162	158	154	152	148	144	140	137
	5	172	168	166	162	159	157	155	151	148	146
5	3	160	153	148	142	134	128	122	....	....	....
	4	165	161	157	152	146	142	138	....	....	....
	5	168	164	162	157	153	150	146	....	....	....
6	3	153	147	139	131	122	.....	.....	....	....	....
	4	161	156	150	144	138	.....	.....	....	....	....
	5	164	161	156	152	146	.....	.....	....	....	....

289. Relation of Machine and Motor Speeds and Recommendations for Belt Drive

B = Motor belted direct. **Bbg** = Back-geared motor belted. Bbg = 1.33, etc., the number indicates reduction from countershaft speed if a back-geared motor with a 6 to 1 reduction is used. The heavy-faced type indicates the motor speed recommended for most cases.

Speed of driven machine	Approximate motor speed 1,800		1,200		900		720		600	
1,500	1.2	**B**	....		....		....		....	
1,000	1.8	**B**	1.5	B	....		....		....	
800	2.2	**B**	1.5	B	1.12	B	....		....	
600	3.0	**B**	2.0	**B**	1.5	B	1.2	B	1.2	B
500	3.6	**B**	2.4	**B**	1.8	B	1.44	B	1.2	B
400	4.5	B	3.0	**B**	2.25	B	1.8	B	1.5	B
350	5.13	B	3.4	**B**	2.52	**B**	2.06	B	1.7	B
300	6.0	B	4.0	B	3.0	**B**	2.4	B	2.0	B
250	7.2		4.8	B	3.6	**B**	2.9	**B**	2.4	B
200	9.0		6.0	B	4.5	B	3.6	**B**	3.0	**B**
150	12.0		8.0	Bbg 1.33	6.0	B	4.8	**B**	4.0	**B**
100	18.0		12.0	**Bbg** 2.0	9.0	Bbg 1.5	7.2	Bbg 1.2	6.0	**B**
90	20.0		13.4	**Bbg** 2.23	10.0	Bbg 1.67	8.0	Bbg 1.33	6.7	Bbg 1.11
80	22.5		15.0	**Bbg** 2.5	11.3	Bbg 1.88	9.0	Bbg 1.5	7.5	Bbg 1.25
70	25.3		17.1	Bbg 2.85	12.9	**Bbg** 2.15	10.2	Bbg 1.7	8.6	Bbg 1.43
60	30.0		20.0	Bbg 3.33	15.0	**Bbg** 2.5	12.0	Bbg 2.0	10.0	Bbg 1.67
50	36.0		24.0	Bbg 4.0	18.0	**Bbg** 3.0	14.4	Bbg 2.4	12.0	Bbg 2.0

290. Obtaining a Successful Belt Drive.—A successful drive can be obtained for the application of 287 by using a 12×10-in. pulley on the motor and employing an idler pulley. It is not customary for motor manufacturers to supply idler attachments on motors so large. In such cases an idler pulley attachment is more successful if mounted on a foundation, floor or bracket on the machine driven.

The use of a back-geared motor in a case like this is awkward because the pulley on the motor countershaft must be of large diameter. If a back-geared 1,200-r.p.m. motor were used, the countershaft speed being 200 r.p.m., a 36-in. pulley would be required on the motor countershaft, making an awkward looking drive, as this pulley would be larger than the motor.

291. Relation of Arc of Contact to Power Transmitted by Belting

Arc of contact in Degrees	Per cent. of power transmitted[1]
180	100
170	94
160	89
150	83
140	78
130	72
120	67

[1] Based on power transmitted with 180 deg. arc of contact.

292. General Rules Covering the Installation of Belting.—If possible, the lower side of the belt should be the driving side. The distance between pulley centers should be great enough to allow some sag in the upper side of the belt, or an idler pulley should be used to increase the arc of contact. The following general rules are from *Kent's Mechanical Engineers' Pocket-book.*

"1. Narrow belts over small pulleys, 15 ft. between pulley centers, the loose side of the belt having a sag of $1\frac{1}{2}$ to 2 in.

2. Medium-width belts on larger pulleys, 20 to 25 ft. between pulley centers, with a sag of $2\frac{1}{2}$ to 4 in.

3. Main belts on very large pulleys, 25 to 30 ft. between centers, with a sag of 4 to 5 in."

If the distance is too long the belt will flap unsteadily, resulting in unnecessary wear of both the belt and the bearings; if too short, the severe tension required to prevent slipping will cause rapid wear of bearings and may cause them to overheat.

The foregoing distances represent good safe practice for long life of belt and bearings. Shorter distances are frequently used but necessitate tighter belts, or the use of wider pulleys and belts, or larger pulleys and higher belt speeds. Very short belts can be made to work satisfactorily by the aid of idler pulleys, which increase the arc of contact.

It is not desirable that the slope of the belt direction be over 45 deg. from horizontal; the belt should never run vertical, if possible to avoid it, since the advantage of sag to increase the arc of contact is then lost. The pulley should be a little wider than the belt.

Belts should be run with the least tension required to prevent slipping or flapping. The slack side should have a gently undulating motion. Lateral movement of the belt on the pulley indicates poor pulley alignment or unequal stretching of the edges of the belt. Belt joints should be as smooth as possible, and a lapped joint should always trail, never lead over the pulley. Belts should be kept clean and dry; if any belt dressing is applied let it be very sparingly.

293. Minimum Distance between Pulley Centers.—A rule that has given satisfaction in practice is this. The distance between the pulley centers should not be less than 3 times the sum of the diameters of the pulleys. A better drive will result if the distance is 4 or 5 times the sum of the diameters.

294. Horse-power of Belting.—The ability of a belt to transmit power depends upon (1) the safe working effective tension allowable for the belting, (2) the arc of contact of the belt with the smaller pulley, and (3) the speed of the belt. The rule and formulas given herein are based on the assumption that the arc of contact on the smaller pulley is 180 deg. or one-half the circumference. If it is less than this, one of the correction factors given in **291** should be applied.

The effective tension is not the tension in either the loose or the tight side of the belt, but is the difference between the tensions in these two sides. It is due to the effective tension that power is transmitted by the belt. "Effective tension" is sometimes called "working tension."

It is evident that the horse-power rating of a belt is a rather flexible thing and depends entirely on how great an effective tension is considered allowable. With a heavy tension a small belt will transmit a great amount of power for a short period but will soon stretch, cease to transmit its load, and become worthless. The values given for effective tension in the accompanying tables have been proven by experiment to be ones that will provide belts of reasonably long life without excessive first cost.

295. Safe Working Effective Tension Per Inch Width for Endless Leather Belts (*Page Belting Company*).—These values apply only to belts that can be cemented at the joints by skilled workmen and thereby be made endless. For rough and ready work, for belts having their ends held together with ordinary laces or fasteners, use the belting tables given elsewhere.

Kind of belt	Approx. thickness	Working tension
Single	$\frac{3}{16}$ in.	66 lb.
Single	$\frac{1}{4}$ in.	86 lb.
Light double	$\frac{17}{64}$ in.	90 lb.
Heavy double	$\frac{18}{64}$ in.	96 lb.
Heavy double	$\frac{20}{64}$ in.	100 lb.
Heavy double	$\frac{24}{64}$ in.	120 lb.
Heavy double	$\frac{28}{64}$ in.	130 lb.

296. To Find the Horse-power a Belt of Known Dimensions will Transmit.—Multiply the safe effective working tension of the belt per inch width (take this from Table **295**) by the width of the belt in inches, and multiply this product by the speed of the belt in feet per minute, and divide the result by 33,000. The quotient will be the number of horse-power the belt is capable of transmitting. (See the table of approximate values, **299**.)

Or, expressing this rule as a formula and combining all of the constants into one factor:

$$\text{h.p.} = \frac{W \times D \times T \times \text{r.p.m.}}{126{,}500}$$

Wherein: h.p. = horse-power belt will transmit, W = width of belt in inches, T = safe effective working tension in pounds per inch width of belt, from **295**, D is the diameter of either pulley in inches, r.p.m. = the revolutions per minute of the same pulley.

Example.—What horse-power will the light double leather belt in Fig. 130 transmit? Width = 6 in., and belt is driving a pulley 15 in. in diameter at 100 r.p.m.

Solution Using the Rule.—Safe effective working tension of light double belt is, from **295**, 90 lb. per inch width.

$$\text{Speed of belt in feet per minute} = \frac{100 \text{ r.p.m.} \times 15 \text{ in. diam.} \times 3.1416}{12 \text{ in.}} =$$

392.7 ft. per min.

$$\text{Then:} \quad \frac{90 \text{ lb.} \times 6 \text{ in.} \times 392.7 \text{ ft. per min.}}{33{,}000} = 6 \text{ h.p.}$$

Or solving with the formula:

$$\text{h.p.} = \frac{W \times D \times T \times \text{r.p.m.}}{126{,}500} = \frac{6 \times 15 \times 90 \times 100}{126{,}500} = \frac{810{,}000}{126{,}500} = 6 \text{ h.p.}$$

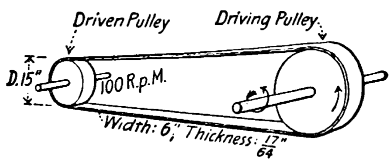


FIG. 130.—Example in finding horse-power of belting.

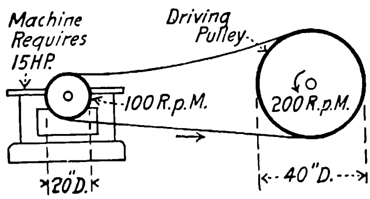


FIG. 131.—Example in finding size belt required.

297. To Find the Width of a Belt Required to Transmit a Given Horse-power.—Read the preceding paragraph. Multiply the safe effective working tension (Table **295**) per inch width by the speed of the belt in feet per minute, and divide the product by 33,000. The quotient is the horse-power a belt 1 in. wide will transmit, provided it is in contact with at least 180 deg. or one-half the pulley circumference.

Having found the amount of power for a belt 1 in. wide, divide the whole number of horse-power given by the horse-power transmitted by a belt 1 in. wide and the quotient will be the width of the belt required.

Or expressing this as a formula using the same notation as in **296**:

$$W = \frac{126{,}500 \times \text{h.p.}}{D \times T \times \text{r.p.m.}}$$

Example.—What width single thickness leather belt should be used to drive the machine of Fig. 131. Diameter of driven pulley is 20 in. Speed is 100 r.p.m.

Solution.—Safe effective working tension of single thickness belt per inch width is, from 295, 66 lb. First find the speed in feet per minute thus:

$$\frac{20 \text{ in. diam.} \times 100 \text{ r.p.m.} \times 3.14}{12 \text{ in.}} = 523 \text{ ft. per min.}$$

Then: $$\frac{66 \text{ lb.} \times 523 \text{ ft. per min.}}{33,000} = 1.05 \text{ h.p. per inch width of belt.}$$

Therefore $\frac{15 \text{ h.p.}}{1.05 \text{ h.p.}} = 14.3$ in. wide belt required. A 15-in. belt must be used.

In practice instead of using a 15-in. single thickness belt for this application a heavier or double belt would be used whereby the belt width could be decreased accordingly.

Solving the same problem using the formula:

$$W = \frac{126,500 \times \text{h.p.}}{D \times T \times \text{r.p.m.}} = \frac{126,500 \times 15}{20 \times 66 \times 100} = \frac{1,897,500}{132,000} = 14.3 \text{ in.}$$

A 15-in. wide belt must be used because standard belting increases in width by 1-in. increments.

298. Horse-power Transmitted by Canvas Belt (*Page Belting Company*).—Horse-power transmitted by 4-ply canvas belt = 1 h.p. for each inch wide for each 800 ft. of belt speed per minute.

6-ply belts transmit 50 per cent. more.
8-ply belts transmit 75 per cent. more than 4-ply.
10-ply belts transmit 100 per cent. more than 4-ply.
12-ply belts transmit 125 per cent. more than 4-ply.

Comparison

4-ply = single leather or 3-ply rubber.
6-ply = light double leather or 4- and 5-ply rubber.
8-ply = double leather or 6- or 7-ply rubber.
10-ply = heavy double leather or 8-ply rubber.

299. Tables of Safe Horse-power of Belting (*Page Belting Company*).—The following tables will be found useful for quickly and safely determining the amount of power that belting will transmit. It is always wise to leave a wide margin between what a belt must do and what it can do and such a margin is provided by the values in the table.

Horse-power for single leather

Width of belt	Belt speed, ft. per minute									
	600	1,200	1,800	2,400	3,000	3,600	4,200	4,800	5,400	6,000
1 in.	1	2	3	4	5	6	7	8	9	10
2 in.	2	4	6	8	10	12	14	16	18	20
3 in.	3	6	9	12	15	18	21	24	27	30
4 in.	4	8	12	16	20	24	28	32	36	40
5 in.	5	10	15	20	25	30	35	40	45	50
6 in.	6	12	18	24	30	36	42	48	54	60
8 in.	8	16	24	32	40	48	56	64	72	80
9 in.	9	18	27	36	45	54	63	72	81	90
10 in.	10	20	30	40	50	60	70	80	90	100
12 in.	12	24	36	48	60	72	84	96	108	120
14 in.	14	28	42	56	70	84	98	112	126	140
16 in.	16	32	48	64	80	96	112	128	144	160

Horse-power for double leather

Width of belt	Belt speed, ft. per minute										
	400	800	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,000	5,000
4 in.....	4	8	12	16	20	24	28	32	36	40	50
6 in.....	6	12	18	24	30	36	42	48	54	60	75
8 in.....	8	16	24	32	40	48	56	64	72	80	100
10 in.....	10	20	30	40	50	60	70	80	90	100	125
12 in.....	12	24	36	48	60	72	84	96	108	120	150
16 in.....	16	32	48	64	80	96	112	128	144	160	200
20 in.....	20	40	60	80	100	120	140	160	180	200	250
24 in.....	24	48	72	96	120	144	168	192	216	240	300
30 in.....	30	60	90	120	150	180	210	240	270	300	370
36 in.....	36	72	108	144	180	216	252	288	334	370	450
40 in.....	40	80	120	160	200	240	280	320	360	400	500

The previous rules given for figuring horse-power are more accurate than the tables, and will show that a belt can transmit more than the tables specify. The tables allow a margin of safety for the belts being laced or otherwise fastened but not "made endless," and also for a relatively small "arc of contact" on pulleys.

300. **To find the speed of a belt in feet per minute,** multiply the circumference of either pulley, in feet, by its number of revolutions per minute. To obtain the circumference, multiply the diameter by 3.14 or, roughly, by $3\frac{1}{7}$.

301. Minimum Diameter of Pulleys for Long Life of Heavy Belts (*Westinghouse Diary*)

For double belts.............................. 12 in.
For double belts extra flexible.................... 10 in.
For double 3-ply belts........................ 18 in.

302. **The ratio of diameter of two pulleys,** one a driver and the other driven, should not be greater than 6 to 1 for ordinary drives. That is, the diameter of the large pulley should not be more than 6 times greater than the diameter of the small one. A preferable ratio is 4 or 5 to 1.

303. **Maximum Speeds for Belts.**—Roughly, belt speeds should not exceed 1 mile (5,280 ft.) per minute. This speed is given when the diameter of either pulley in inches multiplied by its r.p.m. equals 20,000 ($D \times$ r.p.m. $= 20{,}000$).

304. **Rule for Finding Length of Belts.**—When it is not feasible to measure with the tapeline the length required, the following rule, which gives a very accurate result when the pulleys are of the same diameter and an approximately accurate result when the pulleys are of different diameters, can be used:

Add the diameters of the two pulleys (D and d, Fig. 132) together, divide the result by 2 and multiply the quotient by $3\frac{1}{7}$; add the product to twice the distance (L) between the centers of the shafts and the result is the length required. All values should be expressed either in feet or in inches. Expressed as a formula, using the notation of Fig. 132, the rule becomes:

$$\text{Length of belt} = [(D+d)1.57] + 2L$$

Example.—What is the length of the belt required for the two pulleys of Fig. 133. Diameters of pulleys are 16 in. and 18 in. Distance between centers is 10 ft. or 120 in.

Solution.—Substitute in the formula:
Length of belt $= [(18 + 16)1.57] + 2 \times 120 = (34 \times 1.57) + 240 = 293.4$ in. $= \frac{293.4}{12} = 24.4$ ft.

If one pulley is considerably larger than the other a little extra allowance should be made, because the distance between the points of tangency of the belt on the two pulleys is somewhat greater than the exact distance between the centers of the shafts.

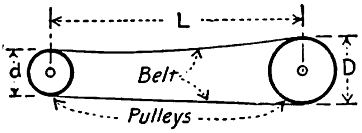


FIG. 132.—Notation for belt length formula.

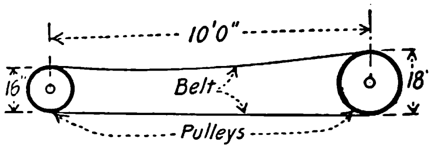


FIG. 133.—Example in finding belt length.

305. Rule for Measuring Belts in the Roll.—Add to the diameter of the roll in inches the diameter of the hole in the center of the roll. Multiply this sum by the number of coils in the roll and multiply this product by 1.32. The three figures on the left indicate the number of feet in the roll.

Example.—Roll of 5 in. single leather belt measures $37\frac{5}{8}$ in. outside diameter; hole is $4\frac{5}{8}$ in. in diameter; number of coils in roll is 84. How long is the belt?

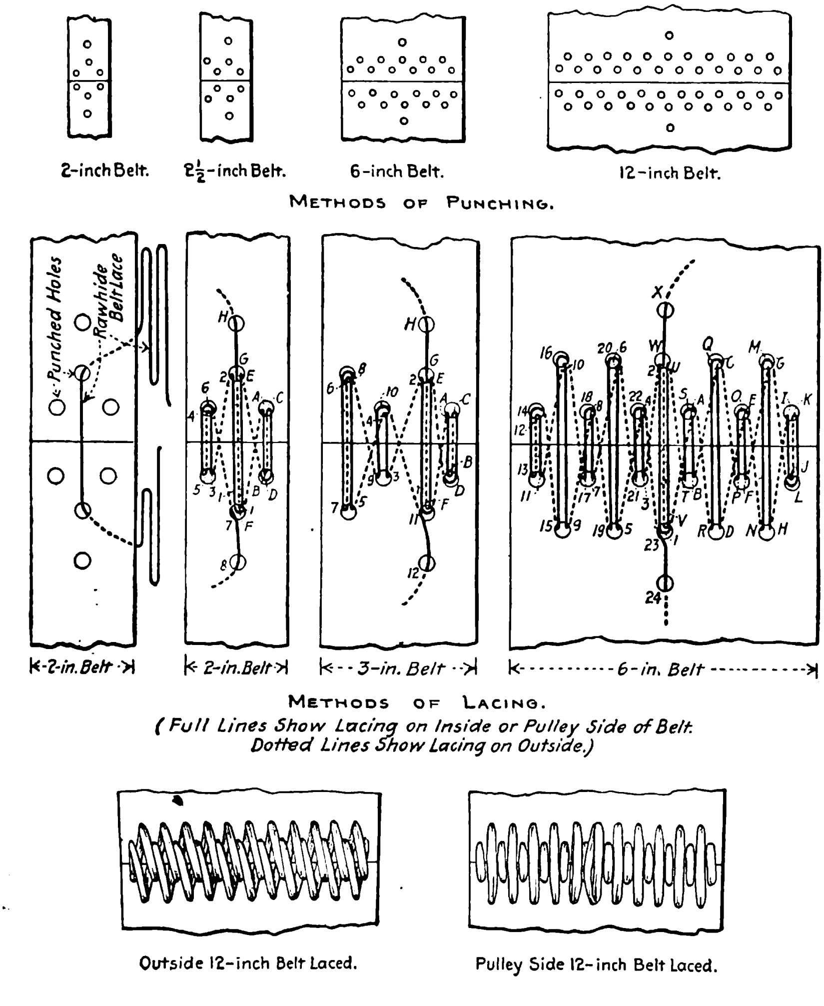
Solution.—Using the above rule:
$37\frac{5}{8} + 4\frac{5}{8} = 42\frac{1}{4} \times 84 = 3{,}549 \times 1.32 = 4{,}684{,}68.$
Taking the first three figures on the left: The roll contains $468\frac{1}{2}$ ft. By actual measurement the roll is found to contain 469 ft.—(*Page Belting Company.*)

306. Ox-leather belts give the best results under ordinary conditions. No other belts will stand the shifter or shipper; cotton belts are weakened when wet; rubber belts are rotted when oiled; but leather will stand wet and dryness, cold and heat, and last a long time even when oil saturated.—(*Scientific American.*)

307. Splicing Belts (*Page Belting Company*).—Where possible the ends of the belt should be fastened together by splicing and cementing. If belts are to be laced or fastened otherwise than with cement, cut off the ends perfectly true using a try-square. Punch the holes exactly opposite one another in the two ends as in Fig. 134. The grain side of the belt should be run next to the pulley and the belt should be run off of, not against, the laps. Undoubtedly, exclusive of cementing, lacing is the best method for fastening belt ends together, as the lacing is as flexible as the belt and runs noiselessly over the pulleys. The best lacing is the cheapest. Cheap lacing is very expensive in the long run.

Use a small lace so that the holes will be small. For belts 1 in. to $2\frac{1}{4}$ in. wide, use $\frac{1}{4}$-in. lacing; $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in. use $\frac{5}{16}$-in. lacing; 5 in. to 12 in. use $\frac{3}{8}$-in. lacing. For wider belts use wider lacing in proportion. Avoid thick lacing. Light, strong lacing is the best.

In punching a belt for lacing it is desirable to use an oval punch, the longer diameter of the punch lying parallel with the length of the belt, so that a minimum amount of leather across the belt will be cut out. There should be in each end of the belt two rows of holes, placed zigzag. Make the holes the smallest possible that will admit the lace. In a 2-in. belt there should be 3 holes in each end; in a $2\frac{1}{2}$-in. belt, 4 holes; in a 3-in. belt, 5 holes; in a 4-in.



Finished Joint.

Fig. 134.—Method of lacing belts.

belt, 7 holes; in a 5-in. belt, 9 holes; in a 6-in. belt, 11 holes; in an 8-in. belt, 15 holes; in a 10-in. belt, 19 holes; in a 12-in. belt, 23 holes.

The center of no hole should come nearer to the side of the belt than $\frac{5}{8}$ of an inch nor nearer the end than $\frac{7}{8}$ of an inch. The second row should be at least $1\frac{3}{4}$ in. from the end. On wide belts these distances should be even a little greater.

Begin to lace in the center of the belt, and take much care to keep the ends exactly in line, and to lace both sides with equal tightness. The lacing positively must not be crossed on the side of the belt that runs next to the pulley.

308. **In putting on new belts,** a common rule is to draw them up and stretch them $\frac{1}{8}$ in. for every foot in length of belt.

The strongest part of belt leather is near the flesh side, about one-third the way through from that side. It is, therefore, desirable to run the grain (hair) side on the pulley, in order that the strongest part of the belt may be subject to the least wear. The flesh side is not as liable to crack as is the grain side when the belt is old; hence it is better to crimp the grain than to stretch it. Leather belts run with the grain side to the pulley will drive 30 per cent. more than if run with the flesh side. The belt, as well as the pulley, adheres best when smooth, and the grain side adheres best because it is smoother.

309. **A belt adheres much better, and is less liable to slip, when run at a high speed than at a low speed.** Therefore, it is better to gear a mill with small pulleys, and run them at high velocity, than with large pulleys, and run slower. A mill thus geared costs less and has a much neater appearance than with large, heavy pulleys.

310. **Belt Troubles.**—The belt on any belt-connected machine should be tight enough to run without slipping, but the tension should not be too great or the bearings will heat. The crowns of driving and driven pulleys should be alike as "wobbling" of belts is sometimes caused by pulleys having unlike crowns. If this is caused by bad joints, they should be broken and cemented over again. A wave motion or flapping is usually caused by slippage between the belt and pulley, resulting from grease spots, etc. It may, however, be a warning of an excessive overload.

This fault may sometimes be corrected by increasing the tension but a better remedy is to clean the belt. A back and forth movement on the pulley is caused by unequal stretching of the edges of the belt. If this does not cure itself shortly, examine the joints. If they are evenly made and remain so, the belt is bad and should be discarded.

311. **Gear Drive.**—Gearing is the most positive form of power transmission and is usually employed when the motor can be mounted directly on a machine. The points to be considered on a gear drive are the following: (1) Speed reduction; (2) pitch of the gears; (3) number of teeth on the gears (pinion and gear); (4) face of the gear; (5) pitch line speed; (6) distance between centers; (7) use of idler gears; and (8) mounting of the motor.

The speed reduction is the same as for the belt drive. Each motor rating has a minimum pinion to limit stresses to safe values. The pitch, number of teeth and face for motor pinions have been standardized for back-gear motors and the best practice when gearing a motor directly to machines is to use these motor pinions if possible. Table 326 gives the standard motor ratings and other valuable gearing information. (The information on gear drives given herein is largely from an article in the *American Machinist*, Oct. 3, 1912, by A. G. Popcke.)

312. **The method of gearing** depends largely upon the distance between centers and the space available for the motors. In all cases the pinion must not be selected smaller than the minimum specified in **326**. The pitch-line speed must not exceed the limits given. There are two general cases covering the mounting of a motor to drive a machine through gears; these are:

(1) Where the dimension of the motor or machine limits the distance between centers of the motor shaft and the driven shaft.

(2) Where this limitation, (1), does not exist.

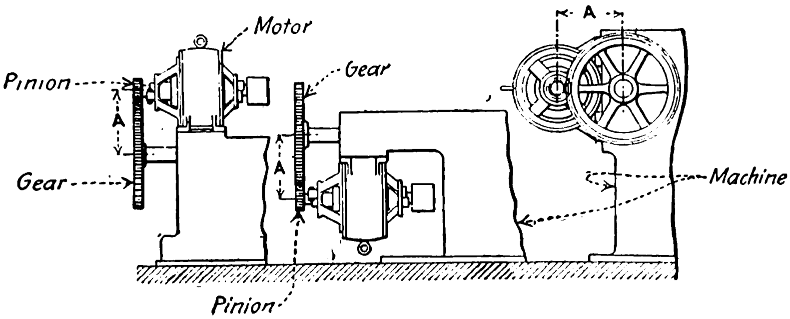


FIG. 135.—Motor mountings for gear drive (distances between gear centers limited).

The first case occurs when a motor is mounted on top, side or bottom of a machine, as shown in Fig. 135. The dimension causing limitations is indicated by *A* in these illustrations. The proper distance can be obtained by using large enough gears; the limit is pitch-line speed. An intermediate idler gear frequently overcomes the difficulties here experienced.

In the second case the relation of the motor and machine is shown in Fig. 136. In this case the motor can be mounted on a base and the motor pinion can mesh with the gear on the machine in any convenient position.

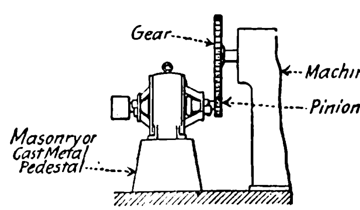


FIG. 136.—Motor mounting for gear drive (no limitation to center distance).

If reductions greater than 7 to 1 are required, it is usually necessary to obtain the reduction by the use of two sets of gears. The back-geared motors discussed under "Belt Drive" can be used to furnish one set of gears in these cases. Thus if a reduction of 10 to 1 is desired, a back-geared motor with a standard 6 to 1 reduction, with a further reduction from the countershaft of the motor to the machine of $\frac{10}{6}$ to 1 or 1.66 to 1 will fulfill the requirements.

Example.—The speed of the driven shaft of the machine is 210 r.p.m.; the h.p. is 10; the motor is mounted on the machine and the limiting distance between centers is 12 in. What are the sizes of gear and pinion to be used? The machine is a punch and shear.

Solution.—In this case a pitch-line speed of approximately 1,000 ft. per min. will be employed. Table 326 shows that a 10-h.p. at 850 r.p.m. is the highest speed motor that can be used for this pitch-line speed. The ratio of reduction is then

$$\frac{850}{210} = 4.05 \text{ (use 4 to 1)}$$

The distance between centers for any set of gears is determined by the formula:

$$a = \frac{b}{2P}$$

where a is the distance between centers in inches, b is the sum of the number of teeth in both gears and P is the diametral pitch. In this case

$$a \text{ or } 12 = \frac{b}{2 \times 5};\ b = 120$$

The number of teeth in the pinion is,

$$\frac{b}{\text{Ratio of reduction plus 1}} = \frac{120}{5} = 24 = \text{number of teeth}$$

The number of teeth in the gear is $4 \times 24 = 96$.

Table 326 shows that the pitch-line speed for this motor with 20 teeth is 890 ft. per minute. The pitch-line speed with 24 teeth is

$$\frac{24}{20} \times 890 = 1{,}068 \text{ ft. per min.}$$

If quiet operation is desired a cloth or rawhide pinion should be used with a $3\frac{3}{4}$-in. face. Thus the gears are specified as follows:

Motor pinion—rawhide—$P = 5$, face $3\frac{3}{4}$ in., 24 teeth. Machine gear—steel $P = 5$, face 3 in., 96 teeth.

The bore for each is determined by the diameter of the shaft to which it is connected. The pinion is wider than the gears, so that the rawhide only engages with the gear. If it were the same width, the brass end-plates of the rawhide pinion would engage with the gear, causing noise.

313. **In the selection or specification of pinions for motors** (*C. W. Drake, Electric Journal*) for geared applications, three dimensions must be determined, namely, the face, diameter and pitch. These dimensions vary symmetrically according to the strength required, or, in other words, according to the torque exerted in transmitting power. As the horse-power and speed of the motor in any case determine the torque, it is evident these are the factors determining the proper dimensions of a pinion for the motor. A line of pinions with dimensions increasing symmetrically with the torque will therefore answer the purpose for all combinations of horse-power and speed. Every geared application requires special consideration, since the nature of the service, the shaft diameter, etc., may affect the dimensions of the pinion.

In gear drive the pinion is subject to most rapid wear owing to its smaller diameter. It is as important to have a pinion of good wearing qualities as it is to have one of sufficient strength and for a pinion of a given material, the ability to withstand wear depends mainly, if not wholly, on the width of the face. With a steel pinion and a cast-iron gear the former is usually the limiting factor of life and the latter the limiting factor of strength.

314. **Cast-steel gears** are about twice as strong as cast-iron, and should be used when the face of a corresponding cast-iron gear would be 4.5 in. or more, although the cost is approximately double that of cast-iron. With continuous contact all along the length of the teeth, the strength of the gear is approximately proportional to the face and the square of the circular pitch, but gear teeth seldom make such contact until worn down in service. With

new gears the whole pressure is brought to bear on the high spots, and stripping may occur before they are worn down; hence the necessity of using the stronger material.

315. **Bronze and Rawhide Pinions.**—For equal strength the working face of rawhide pinions must be about 25 per cent. wider than corresponding steel pinions. For quiet operation, only the rawhide should be in contact with the gear, although for high torque motors and for other severe service the gears may be widened to cover the entire pinion, thus making use of the metal flanges. Where steel pinions would make objectionable noise, rawhide pinions should be used if the stresses permit, since the pitch-line speed with a rawhide pinion is limited more by the rapid wear of the pinion than by noise. A pitch-line speed of 2,000 ft. per min. is considered a fair average limit for rawhide, but 2,500 to 3,000 ft. per min. may be used under especially favorable conditions regarding attendance, lubrication, absence of moisture or high temperature, for intermittent service, or where the life of the pinion is not important.

The wear and noise of bronze pinions are intermediate between those of rawhide and steel. Bronze pinions are particularly adapted to conditions where heat and moisture prohibit the use of rawhide. Their cost is about the same as rawhide.

316. **Noise of Gears and Pitch-line Speed Limits.**—Spur gears ordinarily begin to make a noticeable noise at pitch-line speeds of about 600 ft. per min., but under average conditions may not become disagreeably noisy with pitch-line speeds under 1,200 ft. per min. The amount of noise allowable depends on the noise made by surrounding machinery, on the character of the workmen, and on the nature of the work in the vicinity. A noise that would be unnoticeable in a boiler shop might be exceedingly disagreeable in a shop that was otherwise comparatively quiet. Where noise is not a limiting feature there is no limit to allowable pitch-line speeds, except the increased wear and depreciation of the motor, gears and driven machine; but depreciation may become a very important factor with high pitch-line speeds, say 2,500 ft. per minute, or sometimes even less. Tests recently made to determine a design for gears that will give the least noise and yet have sufficient strength and wearing qualities, indicate the following facts, other conditions being the same:

1. Gears having large teeth give forth a relatively greater volume of noise at a low pitch that does not carry far, while gears having smaller teeth give forth a smaller volume of noise at a higher pitch that carries farther.

2. Most of the noise comes from the gear, and not from the pinion or the motor.

3. A gear designed so that it will give a dead sound when struck a blow with a hammer will be the least noisy in operation.

317. **Conditions for Noiseless Operation of Gears.**—Rigid and massive supports and close fitting bearings for both the motor and the driven machine are conducive to a noiseless gear drive, and the pinion should always be placed close to the motor bearing. A gear application with motor mounted upon the ceiling might be

twice as noisy as the same application with motor mounted on a concrete foundation.

318. **Pinions for High Torque Motors.**—For series motors and those heavily compounded, as bending roll motors, or for motors subject to very severe service of any kind, select a pinion suitable for a constant-speed motor of the same rated r.p.m., but of about 50 per cent. higher horse-power.

319. **Selection of Ratio for Back-geared Motors.**—A ratio of about 6 to 1 is usually standard for back-geared motors, and should be selected wherever possible, but smaller ratios down to 3 to 1 or maximum ratios up to 7 to 1 may be obtained in certain capacities of motors for service where the conditions of the application warrant the use of such ratios. (See preceding paragraphs on this subject.)

320. **Outboard Bearings for Geared Motors.**—Outboard bearings should be used for geared motors of about 40 h.p. and above in heavy geared service requiring continuous operation with frequent reversing and overloads; also for all motors of about 100 h.p. and above in any geared service. The proper use of outboard bearings cannot be emphasized too strongly, since on account of increased expense there is a tendency to omit them even where good engineering demands their use.

321. **How to Use the Chart for Determining Gear Dimensions** (*C. W. Drake, Electric Journal*).—The dimensions for pinions for average conditions of motor-drive service are given in Fig. 137. This chart is useful in making preliminary estimates or selections of pinions for geared motors. The chart applies without correction *to steel pinions only*. The diameters are considered about standard for the various ratings, although both smaller and larger pinions can generally be used, the limiting size for small pinions being the strength and number of teeth, and, for large pinions, the pitch-line speed.

For example, to determine the steel pinion for a 5-h.p. motor at 1,200 r.p.m., find the intersection of the oblique line marked 5 *h.p.* with the horizontal line through 1,200 *r.p.m.* On the vertical line through this intersection may be found 21.9 *lb. torque*, 2.3 *in. pinion face*, 3.2 *in. pitch diameter*, and a diametral pitch of 4.85. A 2.25-in. pinion face is good practice here, since pinion-face dimensions with fractions smaller than 0.25 in. are not commonly used. The diametral pitch is also usually a whole number, except for very large pinions, where half pitches are sometimes used, so that a pitch of 5 would probably be used in the above case. Since the number of teeth is the product of the pitch diameter and the diametral pitch, the assumed pitch diameter, 3.2 in., is satisfactory with the 5 pitch, because it gives a whole number of teeth; that is, 16.

322. **Gearing Definitions and Formulas.**—A circle whose circumference passes through the point of contact on each tooth of a gear or pinion when this point is on the line connecting the centers of the two wheels is called the *pitch circle*. The diameter of this circle is the *pitch diameter* and its circumference is the *pitch line*.

Diameter, when applied to gears, is always understood to mean the pitch diameter.

Diametral pitch is the number of teeth to each inch of the pitch diameter. To illustrate: If a pinion has 18 teeth and the pitch diameter is 3 in., there are 6 teeth to each inch of the pitch diameter and the diametral pitch is 6.

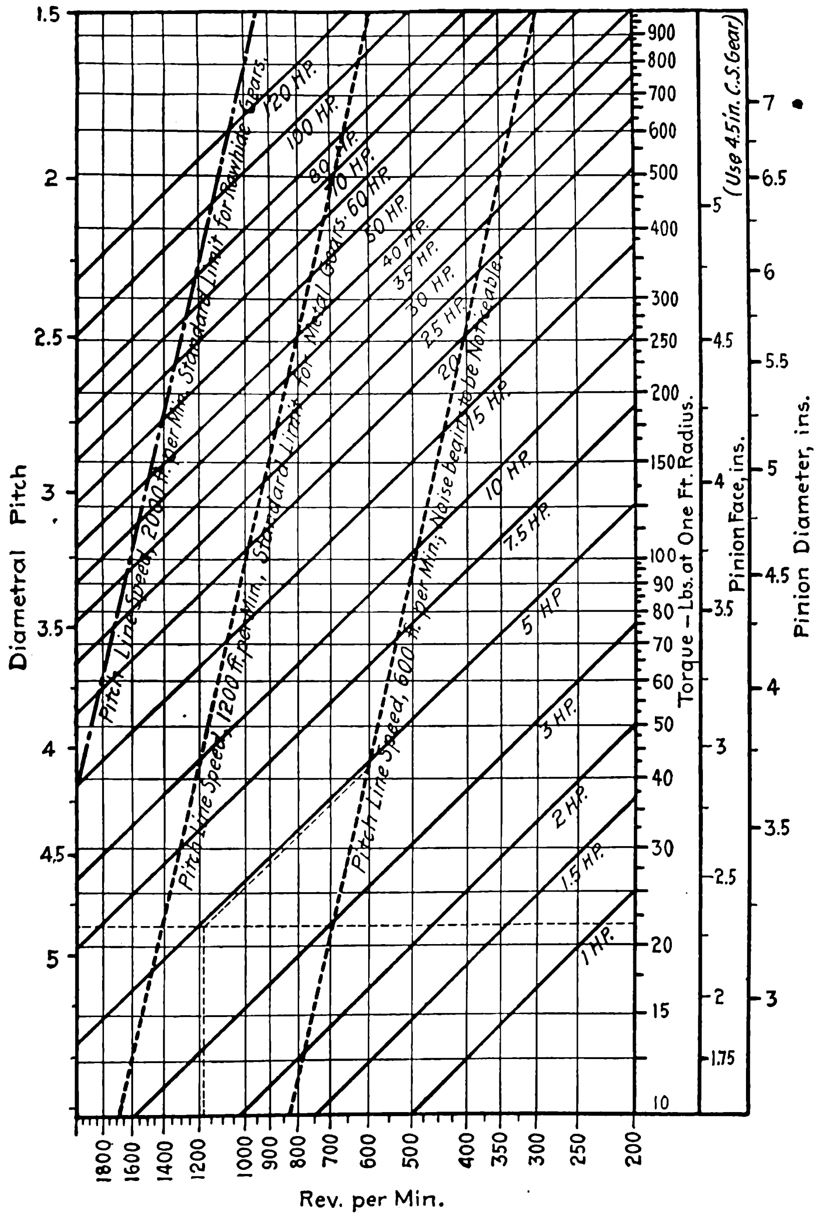


FIG. 137.—Chart for determining approximate commercial values of pinion diameter, pinion face, diametral pitch, pitch line speed, and torque, with revolutions per minute and horse-power of motor given. See accompanying paragraph for directions as to how to use.

Circular pitch is the distance from the center of one tooth to the center of the next, measured along the pitch line.

In the following formulas, for use in gear problems:

d^1 = Pitch diameter of pinion	D^1 = Pitch diameter of gear
d = Outside diameter of pinion	D = Outside diameter of gear
p = Circular pitch	n = Number of teeth on pinion
p^1 = Diametral pitch	N = Number of teeth on gear
S = Distance between centers $= \frac{1}{2}(D^1+d^1)$	r = Gear ratio $= \frac{N}{n} = \frac{D^1}{d^1} = \frac{D}{d}$

$$\pi = 3.1416$$

$$p = \frac{\pi}{p^1} = \frac{\pi d}{n+2} \quad \text{(1)} \qquad d^1 = \frac{2S}{r+1} \quad \text{(6)}$$

$$p^1 = \frac{\pi}{p} = \frac{n+2}{d} \quad \text{(2)} \qquad D^1 = \frac{2Sr}{r+1} \quad \text{(7)}$$

$$n = d^1p^1 = \frac{\pi d^1}{p} = dp^1 - 2 \quad \text{(3)} \qquad n = \frac{2Sp^1}{r+1} \quad \text{(8)}$$

$$p^1 = \frac{n}{d^1} \quad \text{(4)} \qquad N = \frac{2Sp^1 r}{r+1} \quad \text{(9)}$$

$$S = \frac{N+n}{2p^1} \quad \text{(5)} \qquad S = \frac{d^1(r+1)}{2} \quad \text{(10)}$$

323. Chain Drive.—To determine a chain drive the following information is necessary: (1) The speed of the driven shaft on the machine; (2) the speed of the motor; (3) the size of sprockets—pitch and number of teeth; (4) width of the chain; (5) the chain speed, and (6) the horse-power transmitted.

The design of chains is more complicated than that of belts and gears and it is, therefore, best to let the various chain manufacturers specify the chain, giving them the above information. The minimum sprocket to be used on a motor is the same as the minimum pinion given in Table **326**. Chain speeds should not exceed 1,200 to 1,600. ft. per min. The best practice does not exceed 1,000 ft. per min.

324. Gear and Belt Drives for Adjustable-speed Motors.—The hereinbefore mentioned tables dealt with constant-speed motors. Adjustable-speed motor problems are solved similarly. The belt speeds and pitch-line speeds must be carefully considered at the maximum speeds of the motors. The minimum pulleys and pinions are determined by the minimum speeds of the motors. Table **327** gives the ratings commonly used and pulley and gear information.

325. Vertical motors can be applied to advantage in some cases where driven shafts are vertical. Their ratings and speed characteristics are the same as those of horizontal motors.

326. Gear Data For Motor Applications.

(A. G. Popcke, *American Machinist*, Oct. 3 1912.)

Horse-power	R.p.m.	Diam. pitch	Number of teeth			Face		Standard pitch-line speed	Min. diam.	Max. no. of teeth for pitch-line speed of	
			Standard pinion	Min. raw-hide pinion	Min. pinion steel	Steel	Rawhide and cloth			1,000 ft. per min.	2,000 ft. per min.
1	1,700	8	17	15	13	1	1½	940	1.63	18	36
1	1,200	8	17	15	13	1½	2	665	1.63	25	50
2	1,700	8	17	15	13	1½	2	940	1.63	18	36
2	1,200	8	22	20	19	1¾	2¼	870	2.38	25	50
2	850	6	18	21	19	1¾	2¼	615	2.38	36	72
3	1,800	8	22	20	19	1¾	2¼	1,300	2.38	....	34
	1,150	8	22	21	19	1¾	2¼	830	2.38	26	52
	850	6	18	18	18	2¾	3⅜	670	3.0	27	54
5	1,800	8	22	21	19	1¾	2¼	1,300	2.38	....	34
	1,200	6	18	18	18	2¾	3⅜	940	3.0	19	38
	850	6	21	19	18	2¾	3⅜	990	3.0	27	54
7½	1,700	6	18	18	18	2¾	3⅜	1,400	3.0	....	26
	1,150	6	21	19	18	2¾	3⅜	1,050	3.0	20	40
	975	5	19	18	18	3	3¾	970	3.6	19	38
	850	5	19	18	18	3	3¾	850	3.6	22	44
	650	5	20	18	18	3	3¾	685	3.6	29	58
10	1,700	6	21	19	18	2¾	3⅜	1,420	3.0	....	27
	1,300	6	22	19	18	2¾	3⅜	1,250	3.0	....	35
	1,150	5	19	18	18	3	3¾	1,150	3.6	....	33
	850	5	20	18	18	3	3¾	890	3.6	22	44
	730	5	21	18	18	3½	4¼	805	3.6	26	52
	600	5	21	19	19	3½	4¼	665	3.8	31	62
15	1,700	5	19	18	18	3	3¾	1,700	3.6	....	22
	1,250	5	20	18	18	3	3¾	1,300	3.6	....	30
	1,150	5	21	18	18	3½	4¼	1,210	3.6	....	35
	825	5	21	19	19	3½	4¼	910	3.8	23	46
	675	4½	22	18	18	4	5	870	4.0	25	50
	600	4½	22	19	19	4	5	770	4.22	29	58
20	1,700	5	20	18	18	3	3¾	1,780	3.6	....	22
	1,100	5	21	19	19	3½	4¼	1,220	3.8	....	35
	900	4½	22	18	18	4	5	1 150	4.0	19	38
	750	4½	22	19	19	4	5	960	4.22	23	46
	650	4	21	18	18	4¼	5¼	890	4.5	23	46
25	· 1,400	5	21	19	19	3½	4¼	1,550	3.8	....	27
	1,100	4½	22	18	18	4	5	1,400	4.0	....	31
	950	4½	22	19	19	4	5	1,220	4.22	....	36
	825	4	21	18	18	4¼	5¼	1,130	4.5	18	36
	600	4	22	19	18	4¼	5¼	860	4.5	25	50
30	1,700	5	21	19	19	3½	4¼	1,880	3.8	....	22
	1,150	4½.	22	19	19	4	5	1,470	4.22	....	30
	975	4	21	18	18	4¼	5¼	1,330	4.5	....	31
	725	4	22	19	18	4¼	5¼	1,050	4.5	21	42
	600	3¼	20	....	18	4½	..	970	5.53	20	40
35	1,700	4½	22	18	18	4	5	2,180	4.0	....	20
	1,150	4	21	18	18	4¼	5¼	1,580	4.5	....	27
	850	4	22	19	18	4¼	5¼	1,220	4.5	18	36
	675	3¼	20	....	18	4½	..	1,080	5.53	18	36
40	1 700	4½	22	19	19	4	5	2,180	4.22	....	20
	950	4	22	19	18	4¼	5¼	1,370	4.5	....	32
	775	3¼	20	....	18	4½	..	1,250	5.53	....	32
	600	3	18	....	15	4½	..	940	5.0	19	38
50	1,700	4	21	18	18	4¼	5¼	2 340	4.5	....	18
	975	3¼	20	....	18	4½	..	1,580	5.53	....	25
	750	3	18	....	15	4½	..	1,170	5.0	15	30
	565	3	20	....	18	4½	..	990	6.0	20	40

327. Adjustable-speed Motor Ratings and Pulley and Gear Data For Use When Connecting Adjustable-speed Motors to Drive Machinery

(A. G. Popcke, *American Machinist*, Oct. 3, 1912.)

Horse-power	R.p.m.		Smallest pulley		Gear data					Pitch-line speed, at min. diam.		Max. teeth not to exceed 2,000 ft. per min. at max. speed
					Pitch	Face		Min. teeth	Min. diam			
	Min.	Max.	Dia.	Face		Steel	Rawhide			Min. speed	Max. speed	
1	740	2,200	3	3	8	1¾	2¼	19	2.38	460	1,380	27
	600	1,800	3	3	8	1¾	2¼	19	2.38	375	825	46
	450	1,800	3	4	8	1¾	2¼	19	2.38	280	1,120	34
2	1,100	2,200	3	3	8	1¾	2¼	19	2.38	690	1,380	27
	740	2,200	3	4	8	1¾	2¼	19	2.38	460	1,380	27
	450	1,800	4	4½	6	2¾	3⅜	18	3.0	355	1,420	25
3	1,000	2,000	3	4	8	1¾	2¼	19	2.38	625	1,250	30
	660	2,000	4	4½	6	2¾	3⅜	18	3.0	520	1,560	23
	450	1,800	4½	5	6	2¾	3⅜	18	3.0	355	1,422	25
	375	1,500	5	6	6	2¾	3⅜	18	3.0	294	1,176	30
5	1,000	2,000	4	4½	6	2¾	3⅜	18	3.0	790	1,580	23
	750	1,500	4½	5	6	2¾	3⅜	18	3.0	590	1,180	30
	600	1,800	5	6	6	2¾	3⅜	18	3.0	470	1,410	25
	450	1,800	6	7	5	3	3¾	18	3.6	425	1,700	21
	375	1,500	6	7½	5	3½	4¼	18	3.6	355	1 420	25
7½	900	1,800	5	6	6	2¾	3⅜	18	3.0	705	1,410	25
	800	1,600	5	6	5	3	3¾	18	3.6	755	1,510	24
	600	1,800	6	7	5	3	3¾	18	3.6	570	1,710	21
	500	1,500	6	7½	5	3½	4¼	18	3.6	475	1,425	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	350	1,400	6½	9	5	3½	4¼	19	3.8	350	1,400	27
10	850	1,700	6	7	5	3	3¾	18	3.6	800	1,600	22
	750	1,500	6	7	5	3	3¾	18	3.6	710	1,420	25
	600	1,8c0	6	7½	5	3½	4¼	18	3.6	570	1,710	21
	500	1,500	6½	9	5	3½	4¼	19	3.8	500	1,500	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	375	1,500	7	8	4½	4	5	18	4.0	390	1 560	23
15	780	1,560	6½	9	5	3½	4¼	19	3.8	780	1 560	24
	600	1,200	7	8	4½	4	5	18	4.0	630	1,260	28
	500	1,500	7½	9½	4½	4	5	19	4.22	555	1,665	23
	400	1,200	8	9½	4	4¼	5¼	18	4.5	470	1,410	25
	375	1,500	9	10½	4	4¼	5¼	18	4.5	440	1,760	20
20	650	1,300	7½	9½	4½	4	5	19	4.22	720	1 440	26
	550	1,100	8	9½	4	4¼	5¼	18	4.5	645	1,290	28
	500	1,500	9	10½	4	4¼	5¼	18	4.5	590	1,770	20
	400	1,200	10	11	3¼	4½	....	18	5.53	580	1,740	21
	300	1,200	12	13	3	4½	....	15	5.0	390	1,560	19
25	550	1,100	9	10½	4	4¼	5¼	18	4.5	645	1,290	28
	400	1,200	12	13	3	4½	....	15	5.0	525	1,575	19
	300	1,200	12½	15	3	4½	....	18	6.0	470	1,880	19
30	550	1,100	10	11	3¼	4½	....	18	5.53	800	1,600	23
	350	1,050	12½	15	3	4½	....	18	6.0	550	1,650	22
	250	1,000	14	18	3	4½	....	18	6.0	390	1,560	23
40	550	1,100	12	13	3	4½	....	15	5.0	720	1,440	21
	350	1,050	12½	15	3	4½	....	18	6.0	550	1,650	22
	250	1,000	16	21	3	4½	....	19	6.33	415	1,660	23
50	500	1,000	12½	15	3	4½	....	18	6.0	790	1,580	23
	325	975	16	21	3	4½	....	19	6.33	540	1,620	23

328. Speeds of Pulleys and Gears.—The fact that the circumference of a pulley or gear is always 3.1416 (or roughly $3\frac{1}{7}$) times its diameter renders it easy to compute speeds by considering only the diameters of both driver and driven pulleys. Belting from one 6-in. pulley to another gives the same speed to both; but if the driving pulley has a diameter of 16 in. and the driven pulley one of only 4 in., it is evident that the small pulley will make 4 complete revolutions for each revolution of the large pulley. If the positions of the pulleys are reversed and the small pulley is made the driver, the large pulley will make but one revolution for every four of the small pulley. The same rule applies to gears if the pitch diameter and not the outside diameter is taken. Or instead of the pitch diameter the number of teeth in the gears may be considered. See Table 329 for rules for determining pulley and gear speeds and diameters. (*American Machinist's Handbook.*)

329. Rules for Determining Pulley Speeds and Diameters.—These rules apply equally well to a number of pulleys belted together or to a train of gears if all the driving and all the driven pulley diameters and speeds are grouped together.

Having	To find	Rule
Diam. of driving pulley Diam. of driven pulley Speed of driving pulley	Speed of driven pulley	Multiply diam. of driving pulley by its speed and divide by diam. of driven pulley
Diam. of driving pulley Speed of driving pulley Speed of driven pulley	Diam. of driven pulley	Multiply diam. of driving pulley by its speed and divide by speed of driven pulley
Diam. of driving pulley Diam. of driven pulley Speed of driven pulley	Speed of driving pulley	Multiply diam. of driven pulley by its speed and divide by diam. of driving pulley
Diam. of driven pulley Speed of driven pulley Speed of driving pulley	Diam. of driving pulley	Multiply diam. of driven pulley by its speed and divide by speed of driving pulley

330. An Easy Way to Remember the Rules for Pulley Speeds and Diameters.—The speed and the diameter of one of the pulleys is always known and either the speed or the diameter of the other pulley is known. Always multiply together the two quantities (the speed and diameter) which relate to the same pulley and then divide this product by the other quantity (either the speed or the diameter as the case may be) which relates to the other pulley. The quotient will be value desired.

SECTION III

OUTSIDE DISTRIBUTION

POLE LINES

1. **The reports of the committee on overhead line construction of the National Electric Light Association** contain what are probably the best and most complete specifications for pole-line construction for lighting and power distribution that have ever been compiled. Much of the matter in this section regarding pole lines has been abstracted from those reports.

2. **Northwestern Cedarmen's Specifications for Poles.**—"Sizes 5 in., 25 ft. and upward.

"Above poles must be cut from live growing timber, peeled and reasonably well proportioned for their length. Tops must be reasonably sound and when seasoned must measure as follows:

"5-in. poles, 15 in. circumference at top end.
"6-in. poles, $18\frac{1}{2}$ in. circumference at top end.
"7-in. poles, 22 in. circumference at top end.

"If poles are green, fresh cut or water soaked, then 5-in. poles must be 5 in. plump in diameter at the top end, 6-in. poles must be $19\frac{1}{2}$ in. in circumference, and 7-in. poles $22\frac{3}{4}$ in. in circumference at top end.

"One way sweep allowable not exceeding 1 in. for every 5 ft.; for example, in a 25-ft. pole, sweep not to exceed 5 in. and in a 40-ft. pole 8 in.; in longer lengths 1 in. additional sweep permissible for each additional 5 ft. in length. Measurement for sweep shall be taken as follows: That part of the pole when in the ground (6 ft.) not being taken into account when arriving at sweep, tightly stretch a tape line on the side of the pole where the sweep is the greatest, from a point 6 ft. from butt to the upper surface at top, and having so done measure widest point from tape to surface of pole, and if, for illustration, upon a 25-ft. pole said widest point does not exceed 5 in. said pole comes within the meaning of these specifications.

"Butt rot in the center including small ring rot outside of the center, total rot must not exceed 10 per cent. of the area of the butt.

"Butt rot of a character which plainly seriously impairs the strength of the pole above ground is a defect.

"Wind twist is not a defect unless very unsightly and exaggerated.

"Rough large knots, if sound and trimmed smooth, are not a defect."

NOTE.—Large purchasers ordinarily adopt somewhat more rigid specifications than the above.

3. **The Best Wood for Poles.** (*The Standard Handbook.*)—Cedar is believed on the whole to be the best wood for poles, but on the Atlantic coast the supply of this timber is nearly exhausted. Chestnut stands next, but this tree is more slender and hence is

likely to be weaker for the same diameter of top. In the South, yellow pine would appear to be the natural pole, but notwithstanding the pitchy quality of this wood it rots with alarming rapidity after being cut and set in the ground, so that juniper or cypress is chiefly used. In the middle West so-called Norway pine, usually cut in the forests of Oregon or in the Canadas, can be secured. On the Pacific Coast red wood is used to a large extent.

4. Weights of Wood Poles

Length of pole	Cedar—weight in lb.				Chestnut—weight in lb.		
	5-in. top	6-in. top	7-in. top	8-in. top	6-in. top	7-in. top	8-in. top
20	125	180	240	....	.....	....	....
25	200	260	340	430	500	600	720
30	290	360	450	580	600	800	940
35	400	480	600	760	.....	1,030	1,200
40	.....	640	780	980	.....	1,310	1,520
45	.....	830	1,020	1,270	.....	1,660	1,940
50	.....	1,050	1,300	1,600	.....	2,080	2,480
55	.....	1,310	1,640	2,000	.....	2,600	....
60	.....	....	2,080	.....	.....	....	....

The above figures are the average of shipping weights used by a large number of dealers in poles. Although poles are usually designated by the diameter of the top, as "5-in," "6-in," etc., this may be misleading, because an acceptable pole may not be exactly circular. The circumference of the top should be measured with a tape line and for seasoned poles should be approximately as follows: 5-in. poles, 15 in. circumference at top; 6-in. poles, 18½ in. circumference at top; 7-in. poles, 22 in. circumference at top.

5. Dimensions of Poles for Lighting and Power Lines.—The table gives average dimensions for poles for light transmission lines or for ordinary distribution lines. Heavier poles are used for heavy lines and lighter ones for lighter lines.

Length, feet	Cedar		Juniper		White chestnut	
	Cir. at top, inches	Cir. 6 ft. from butt, inches	Cir. at top, inches	Cir. 6 ft. from butt, inches	Cir. at top, inches	Cir. 6 ft. from butt, inches
25	25	36	25	36	....	....
30	25	40	25	38	22	36
35	25	43	25	43	22	40
40	25	47	25	47	22	43
45	25	50	25	50	22	47
50	25	54	25	54	22	50
55	25	56	25	56	22	53
60	25	63	25	59	22	56
65	25	66	25	63	22	59
70	....	....	....	....	22	62
75	....	....	....	....	22	65
80	....	....	....	....	22	69

6. Preserving Poles. Creosoting. (*Standard Handbook*).—Owing to the increasing scarcity of timber there is a growing interest in preservative methods that endeavor to impregnate the pole with some chemical solution which shall successfully resist or retard decay, but with the exception of what is called creosoting few have found much favor. By this method the pole is placed in a large tank hermetically sealed. After the tank is closed superheated steam is applied and the pole cooked sufficiently to raise its temperature to about 250 deg. fahr. Then by means of an air pump the tank is exhausted and the sap in the pole tends to flow outward and may be removed from the tank. This is intended to thoroughly season the pole, after which the tank is filled with dead oil of tar (creosote) and hydrostatic pressure applied, until such a quantity of oil is forced into the timber as may be specified.

It is usual to specify that creosoting shall be done with a steam pressure of not less than 45 lb. applied for not less than 4 hr. and then a vacuum of not less than 20 in. until all sap ceases to flow. The dead oil of tar (creosote) should be liquid at 100 deg. fahr., should contain at least 25 per cent. of constituents that do not volatilize at a temperature of 600 deg. fahr., should not contain over 5 per cent. of tar acid and no admixture of any substance not derived from the distillation of coal tar. After the oil is pumped into the tank it is usual to require that from 12 lb. to 25 lb. per cubic foot of timber shall be forced into the wood. The amount of oil is determined by noting the quantity pumped into the tank and the quantity pumped out after treatment, the difference being that absorbed by the wood. This difference divided by the volume of the timber treated gives the quantity of oil absorbed. The creosoting process is growing in favor.

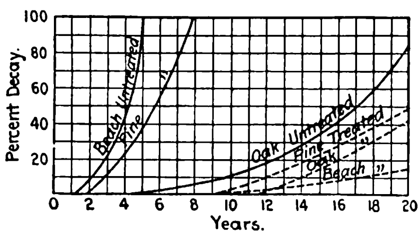


FIG. 1.—Life of treated and untreated poles.

Fig. 1 shows, as would be expected, that the softer and more porous woods that suffer most rapid decay are most benefited, and have the longest life after treatment. Such woods can absorb the most oil. The cost of treatment varies with the amount of oil injected and local conditions. Roughly, it usually about doubles the cost of the timber, while the life is increased from three to ten fold.

7. Steel poles are used because of their reliability and good appearance. Such poles are built up of structural steel, or made of special tubes. Poles made up of sections of wrought-iron pipe welded together are very common in railway work along city streets.

8. Reinforced-concrete poles (*Standard Handbook*) are the most permanent and usually the most expensive. The life of a properly designed concrete pole is practically unlimited. The facility with which special purposes may be served with reinforced concrete is also a great advantage. The exterior form may easily be modified to harmonize with any desired scheme of decoration.

When it is desired to lead wires from the pole top to ground, the poles may be made hollow, and thus at a slight additional cost the wires are completely hidden from view and protected from the weather. Concrete poles may fail, but they will not fall to the ground. The principal drawback to this form of construction has been the cost and the difficulty of manufacture. They are heavy and cumbersome to transport, so that, where possible, it is well to make them in the neighborhood where they are to be used. Both concrete and steel poles may be transported in small packages over mountains and erected on the spot, but in this respect steel is much superior to concrete.

9. Cost of Concrete Poles.—The cost of installation depends to such a great extent upon the accessibility of the point of erection that it is impossible to give any general rule for its determination. Certain reinforced-concrete poles 35 ft. high 6 × 6 in. at the top and 14 × 14 in. at the butt weighed 2,500 lb. and cost to build $15 each. Another type of reinforced-concrete pole 35 ft. long, 7 in. diameter at the top and 11 in. diameter at the butt cost $11 to build, cement being $1.50 a barrel, sand $2 per cu. yd. and labor $2 per day. A 60-ft. pole for a 500-ft. span, 14 in. diameter at the butt, designed to carry a direct pull of 16,000 lb. at the top and a torsional effect of an arm 4 ft. long carrying 8,000 lb., cost $160 each.

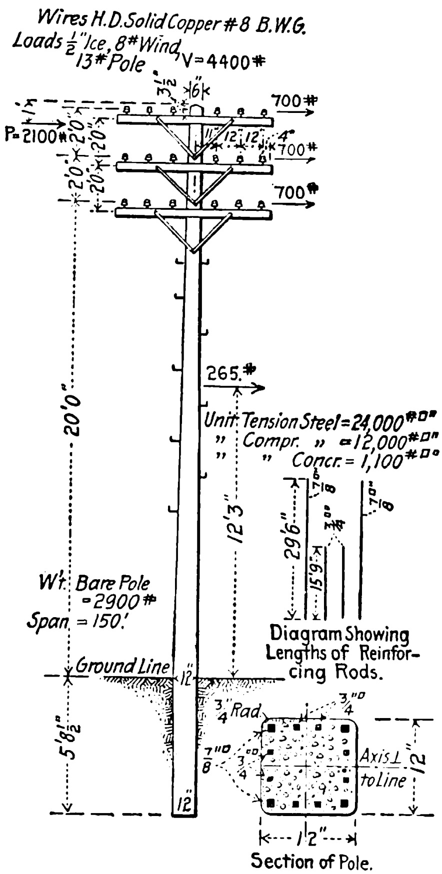


FIG. 1A.—A 30-ft. reinforced concrete pole (Universal Portland Cement Co.).

10. The design of reinforced concrete poles requires considerable skill. Where one who is unfamiliar with concrete pole design must build them, he had best accept the proportions of poles that have been built and that are giving good service. A very useful booklet—*Concrete Poles*—will be mailed free to any one interested by the Universal Portland Cement Co. of Pittsburg. This book gives the dimensions of many concrete poles. The design of Fig. 1A is from the booklet. The pole is proportioned, for a 150-ft. span, to successfully withstand a gale, with the wind at a velocity of 70 miles per hour, and ½-in. ice on the wires. The horizontal load thus imposed by the wind on all of the 18 wires, tending to overturn the pole, is 2,100 lb. The sides of the reinforcing bars are $1\frac{1}{4}$ in. in from the faces of the pole. The concrete is a 1:2:4 mixture. It should be mixed wet, using carefully selected materials with the fine aggregate next to the forms. Air-bubbles should be eliminated by careful tamping or churning. Corners of the pole should be chamfered off. The square reinforcing rods, which are of the mechanical bond type, are bound together by a web system not shown in the illustration. The web system consists of a spiral of No. 12 steel wire wound outside of the rods and securely bound to them. The rods are also secured together with horizontal ties 1 in. wide and $\frac{1}{4}$ in. thick, spaced 3 ft. to 5 ft. apart. The reinforcement thus forms an independent skeleton which can be assembled and lowered into the forms. It is stated that it is most economical to cast poles exceeding 35 ft. in height in their final vertical positions. Shorter poles are erected with a derrick. Gains for cross-arms and holes for bolts are cast in poles. Metal pole steps may be cast in solid also.

11. Depth to Set Poles in the Ground.

One rule is that they should, on straight lines, be set in the ground $\frac{1}{6}$ of their lengths. The following table indicates good practice for normal soils.

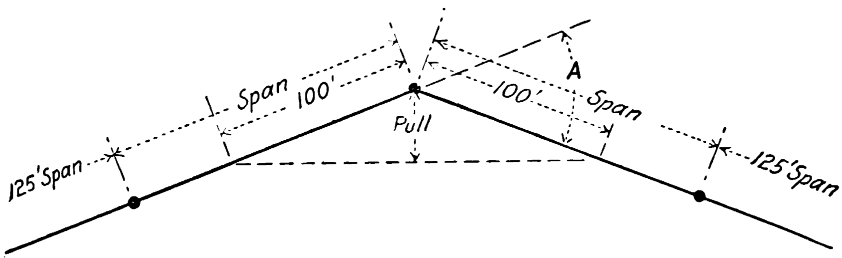
Pole length, over all, in feet	Depth to set in ground	
	Straight lines	Curves, corners, and points of extra strain
30	5.0 ft.	6.0 ft.
35	5.5 ft.	6.0 ft.
40	6.0 ft.	6.5 ft.
45	6.5 ft.	7.0 ft.
50	6.5 ft.	7.0 ft.
55	7.0 ft.	7.5 ft.
60	7.0 ft.	7.5 ft.
65	7.5 ft.	8.0 ft.
70	7.5 ft.	8.0 ft.
75	8.0 ft.	8.5 ft.
80	8.0 ft.	8.5 ft.

12. **The size of pole to use** cannot be definitely specified without knowing local conditions. Municipal ordinances sometimes regulate the heights of poles and wires. Where there are trees along the line, the wires should be carried entirely above them or through the lower branches, which interfere less than do the higher ones where the foliage is thicker. For lines on highways it is usually customary to place the lowest wire at least 18 ft. above the highway and 21 ft. is better. Railway companies frequently specify 22 ft. between the top of the rail and the lowest cross-arm. Wires should be at least 15 ft. above sidewalks. The height of the pole will depend upon the number of cross-arms to be carried. It is desirable to avoid abrupt changes in the level of wire, so where the line runs up hill and down dale shorter poles should be used on the hill tops and longer ones in the valleys.

Guy wires should be at least 18 ft. above a highway and 12 ft. above a sidewalk.

In cities it is good practice to use 35-ft. poles to carry either one or two cross-arms; 40-ft. poles to carry three or four cross-arms; and 45-ft. poles to carry over four cross-arms. For suburban lines 30-ft. poles are often used. For very light lines carrying only three or four wires, 6-in. poles 25 ft. long are sometimes used, though so light a pole is inexpedient if the number of wires is likely to increase. The height of a pole is always considered as the total length over all.

13. **Poles should be spaced,** in straight portions of a line, about 125 ft. apart. In curves and at corners the spans should be about as indicated in Fig. 2.



Note: If the "Pull" is less than 5', the Spans Adjacent to the Angle Pole shall be Standard Length (125'). If the "Pull" exceeds 5', the Spans Adjacent to the Angle Pole shall be Reduced to the Distance "Span" Given in Table.

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

FIG. 2.—Pole spacing and side guys on curves (National Electric Light Association).

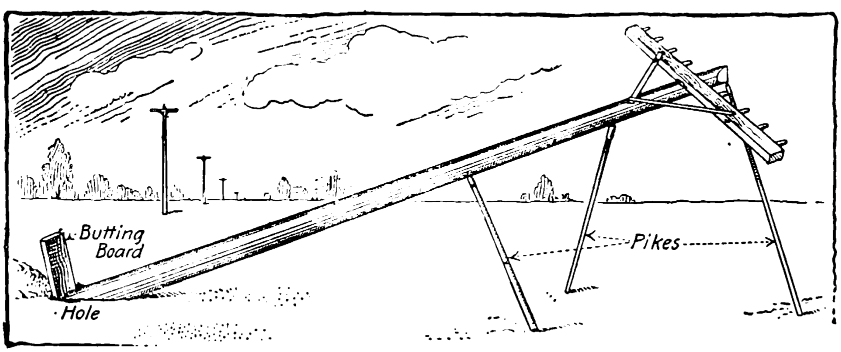


FIG. 2A.—Method of setting a pole with pikes.

14. **Holes for poles** should be large enough to admit the poles without any slicing or chopping and should be of the same diameter from top to bottom. The diameter of the hole should always be at least large enough so that a tamping bar can be worked on all sides between the pole and the sides of the hole.

15. **Setting Poles.**—On straight lines poles should be set perpendicularly. On curves poles should slant slightly so that the tension of the wires will tend to straighten them. In filling a hole after the pole is in it, only one shoveler should be employed and as many more men as can conveniently work around the pole should tamp in the earth as the shoveler throws it in. Some of the surplus earth should be piled around the butt of the pole so the water will drain away. Fig. 2A illustrates the method of setting a pole with pikes.

16. **Setting Poles in Loose and Weak Soils.**—Where the soil is fairly firm the sand-barrel, Fig. 3, is a valuable expedient. This consists of a strong barrel or barrels placed at the bottom of the hole into which the pole is set. The barrel is filled with a firm substantial soil. By this means the pole is given a larger bearing area. Sometimes a temporary sand-barrel is used consisting of a special iron cylinder that is placed around the pole filled with firm dirt and then hoisted away.

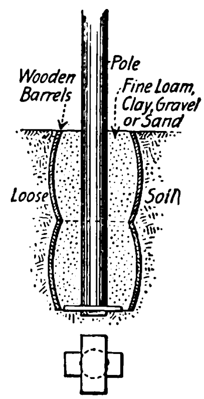


FIG. 3.—Sand barrel.

Where the soil is quite weak it is customary to use a base of concrete, Fig. 4A. A suitable mixture is one part cement, three parts of sand and three parts of broken stone or coarse gravel. Another expedient, Fig. 4B, consists in bolting transversely to the butt of the pole one or more logs some 6 or 7 ft. in length. This provides an additional bearing area that in many cases will be sufficient to support the pole. In marshy ground a more elaborate foundation (Fig. 4, C and D) is often necessary, and is made by building a wooden foundation to support the pole.

17. **When setting poles in rock** the hole may be blasted, or a hole $1\frac{1}{2}$ in. in diameter may be drilled in the rock (Fig. 5) into which an iron pin is placed that extends about 6 in. above the surface. A similar hole is drilled in the butt of the pole, and the pole mounted on the pin. It must then be braced by three or four wood struts spiked to the pole 6 ft. from the ground, running diagonally to the rock and formed thereto, or by guy wires made fast to metal pins set in the rock.

18. **Setting Poles with a Gin-pole.**—A few men can set a large pole with a "gin-pole" as suggested in Fig. 6. The gin-pole can be a short wooden pole or, where the poles to be raised are not too heavy, a length of wrought-iron pipe. The "gin" need be only $\frac{1}{2}$ as long as the pole to be raised. In setting a pole the "gin" is first raised to an almost vertical position with its top over the pole hole. It is held in that position by fastening the guy lines. Then the hook of the tackle blocks is engaged in a sling around the pole and the pole is raised, by men or by a team of horses, by pulling on the free end of the tackle block line. When high enough that its lower end can be slipped into it, the pole is dropped into the hole, adjusted to a vertical position with pikes and the earth is tamped in. Sometimes "gin-poles" are permanently mounted

on wagons for transportation and are then called **pole derricks.** They are great savers of time and money.

19. Resetting Poles.—When a pole becomes old and rotten at its butt it can be reset if the expense of a new pole is not justified. In resetting, the pole is temporarily sustained with 3 or 4 pole pikes

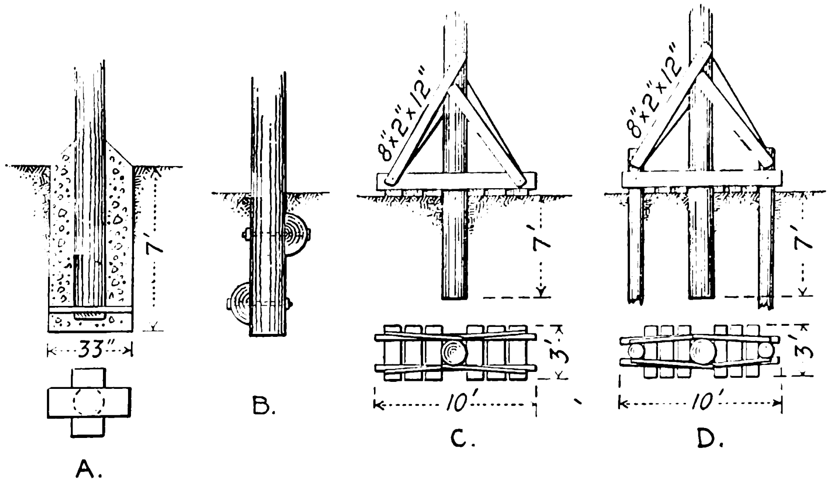
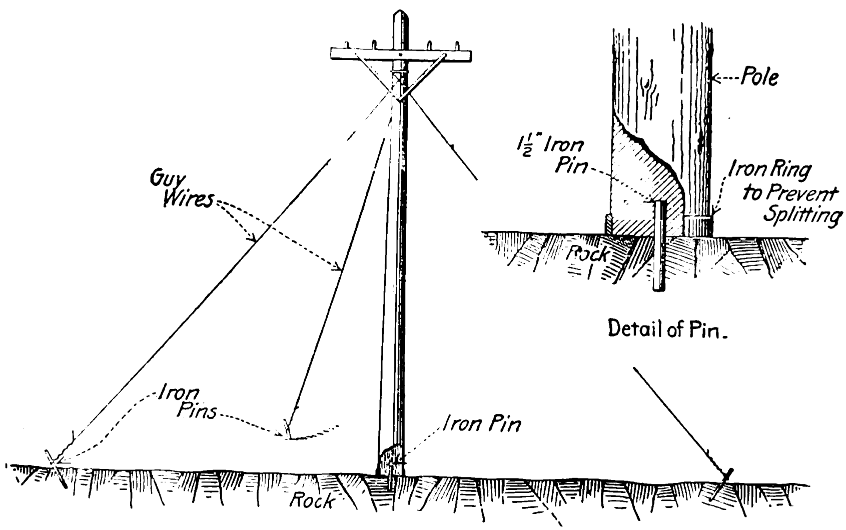


FIG. 4.—Methods of setting poles in poor soils.



Method of Guying Pole.

FIG. 5.—Method of setting pole on rock.

and chopped off just above the ground line. Then the lower end of the portion of the pole above ground line is set to one side and the butt in the ground dug out and thrown away. The lower end of the upper portion of the pole is then dropped into the hole. A reset pole is as many feet shorter than it formerly was as its butt was set feet in the ground. Sometimes the hole is dug around the butt before the pole is chopped off. The method of reinforcing with concrete and steel described in 20 is usually much superior to resetting.

20. Reinforcing Old Poles with Concrete and Steel. (*Electric Journal*, January, 1910).—Wooden poles usually become unsafe

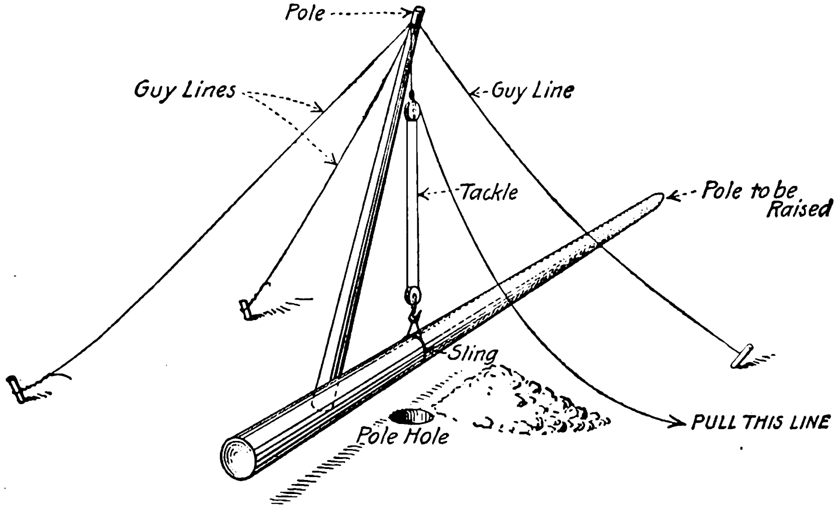


FIG. 6.—Gin-pole for raising poles.

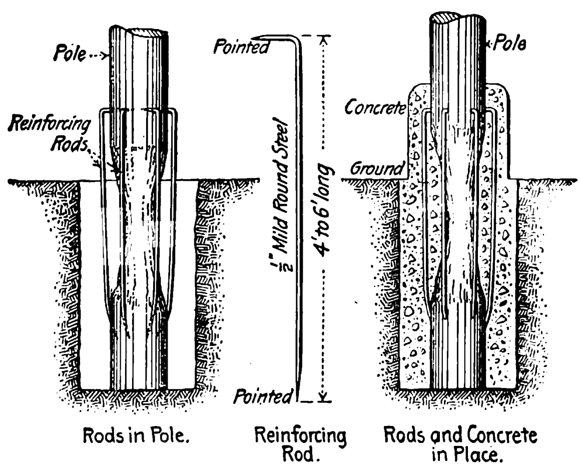


FIG. 7.—Reinforcing pole with concrete.

because of butt rot at the ground line. Such poles can be repaired without moving the wires they support by reinforcing them with steel and concrete as shown in Fig. 7. For ordinary poles and conditions, 10 mild steel rods ½ in. in diameter and 4 ft. to 6 ft. long are used for reinforcing. The lower end of each reinforcing rod is pointed and is driven into the portion of the butt that remains in the hole. The other end is bent at right angles, and pointed. It is driven into the pole above the ground line. A 1–2½–5 mixture of concrete is used for the main body and a richer mixture is used for the portion above ground line and is molded in a cylindrical sheet-iron form. The concrete extends to about 1½ ft. above the ground line. Poles 15 to 20 years old have been satisfactorily repaired by this method without moving the wires

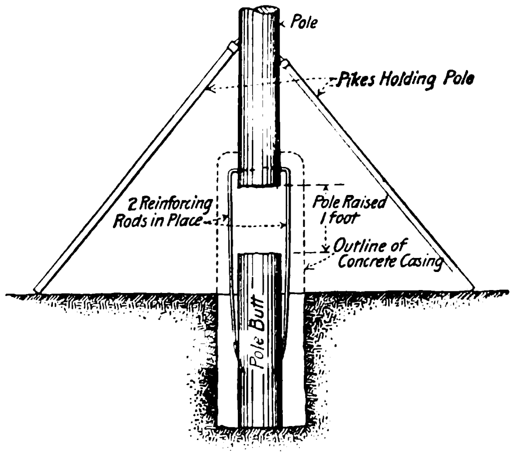


FIG. 8.—Raising and reinforcing a wooden pole.

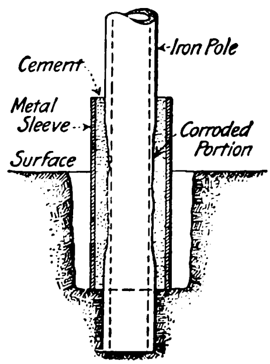


FIG. 9.—Repairing metal pole.

supported. Poles have been raised 12 in. and then reinforced as shown in Fig. 8, and this without moving a cross-arm or fixture on the pole.

21. The cost of concrete and steel reinforcing is said to average about $3.50 per pole and is always less than the cost of replacement. It is stated that ordinary poles reinforced by this method are capable of withstanding a horizontal strain of 1,000

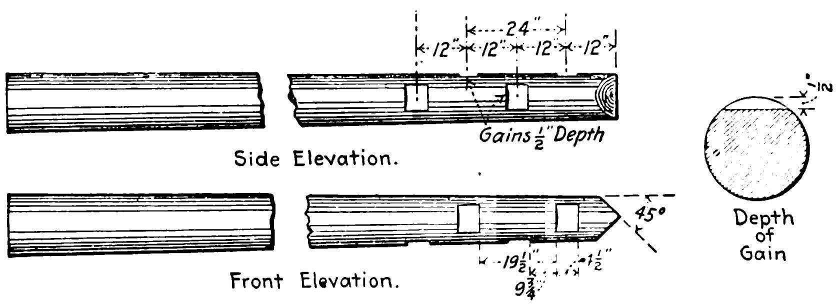


FIG. 10.—Gains in pole.

lbs. applied 27 ft. above the ground line. The reinforcement can be made almost as strong as one pleases by using more concrete and rods. The method is patented.

22. Repairing Steel Poles.—Metal poles sometimes corrode very rapidly at the ground and often when discovered the corrosion is too far advanced to make any preventive measures effective. A very satisfactory method (Fig. 9) of repairing steel poles is to place a loose-fitting metal sleeve around the butt of the pole and fill the space between the two with Portland cement.

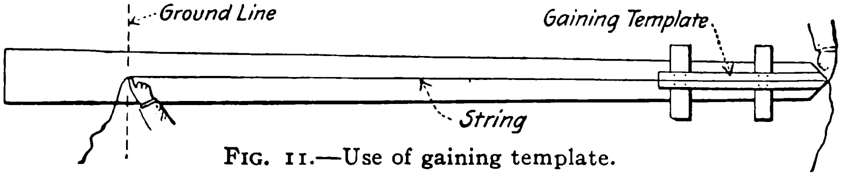


FIG. 11.—Use of gaining template.

23. Poles are gained or framed as shown in Figs. 10, 11 and 12. The gaining templet of Fig. 13 is convenient in laying out the gains. The gain should be exactly the width of the cross-arm

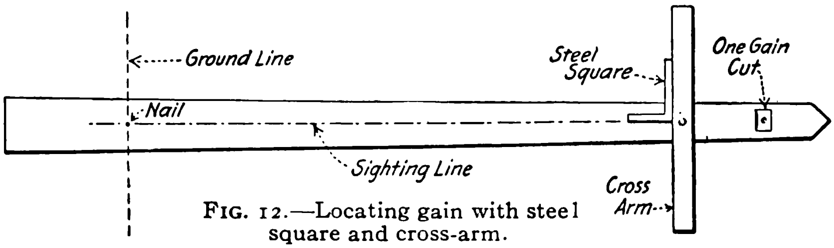
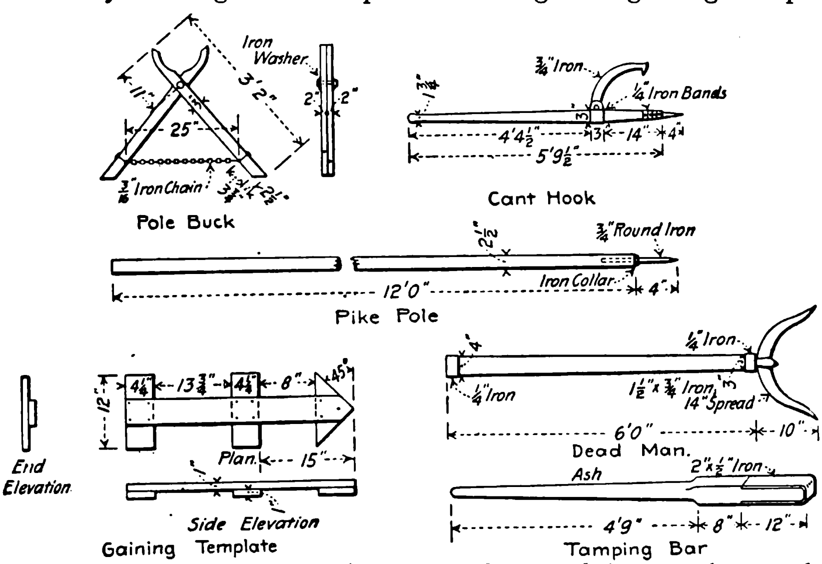


FIG. 12.—Locating gain with steel square and cross-arm.

insuring a snug fit. In good work gains should always be spaced on 24-in. centers and should be ½ in. deep. Nothing is accomplished by making them deeper. In using the gaining templet



Note.—The tool illustrated above as a *Cant-Hook* is properly termed a *Peavie*. A peavie has a splice in the end of its handle, while a cant-hook has no splice.

FIG. 13.—Some line-construction tools.

(Fig. 11) the point of the "roof" of the templet is placed exactly over the point of the roof of the pole and the templet is shifted until its center line (which should be marked thereon) lies exactly under a cord stretched from the roof point to the center of the pole, at the ground line. Then the positions of the cross-arm gains are indicated by knife scratches made along the sides of the cross pieces on the templet.

Where a gaining templet is not available a cross-arm (Fig. 12) can be laid on the pole with a steel square held against its lower face, the outer edge of the short limb of the square lying at the center of the pole and the center of the cross-arm. Rotate the cross-arm in a horizontal plane until, by sighting, it is evident that the edge of the square coincides with an imaginary center line to a nail in the center of the butt at the ground line. Indicate the gain location by knife scratches along the cross-arm sides.

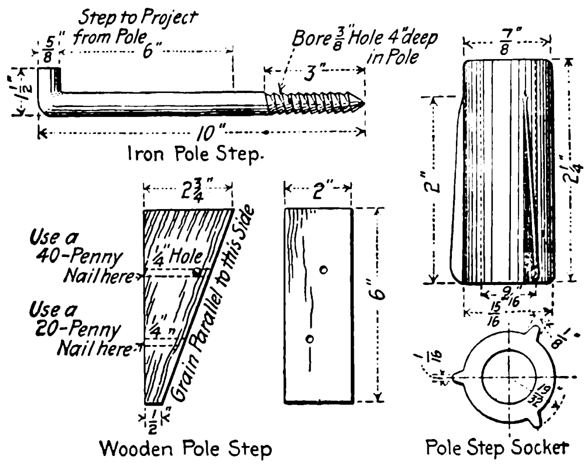


FIG. 14.—Pole steps and socket.

24. Pole steps (Fig. 14) can be located on the pole as shown in Fig. 15. A $\frac{3}{8}$-in. hole 4 in. deep is bored for the iron step. It is driven into the hole until it projects 6 in. from the pole and is then turned with a wrench until the hook end is vertical. The wooden step is held to the pole with one 40-penny and one 20-penny nail or with cut spikes. Often the wooden steps are omitted. The lowest iron step should be at least 7 ft. from the ground. Pole steps should extend from the pole in the same direction as that of the street on which the pole is set.

25. Pole step sockets, Fig. 14, are sometimes substituted for the wooden steps. The sockets drive into a $\frac{7}{8}$-in. hole. To climb the pole a lineman can temporarily insert bolts or similar pieces of metal into the sockets.

26. Pole braces are used where guying is not feasible and cost more than equivalent guys. Fig. 16 shows methods of bracing poles. The upper end of each brace fits in a notch cut in the pole and is bolted thereto.

27. Guying.—Probably there are not as many guys on pole lines as there should be to insure continuity of service and minimum maintenance expense. Lines should be guyed not for normal conditions but for the most severe conditions that are liable to obtain. The guys should be frequent and heavy enough to sustain the line after the heaviest snow storm or during the worst possible wind storm. A guy should be used on every pole where the tension of the wires tends to pull the pole from its normal position.

TERMINAL POLES SHOULD ALWAYS BE HEAD GUYED and on lines carrying three or more cross-arms, the two poles next to the terminal pole should also be head guyed to distribute the stress.

LINE GUYS are installed on straight pole lines to reinforce them against the excess stresses introduced by storms. It is good practice to install head line guys, as shown in Fig. 17, at about every twentieth pole. This applies only to lines carrying more than one cross-arm.

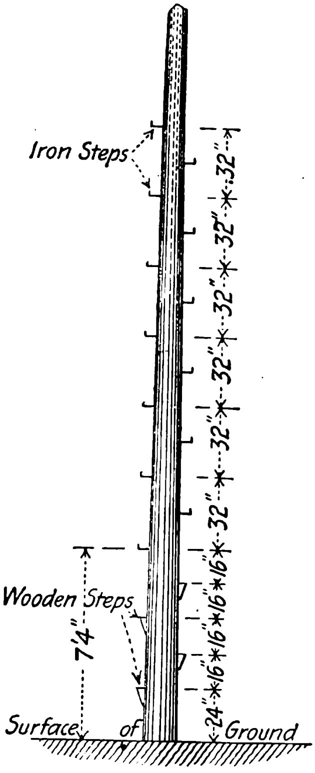


FIG. 15.—Location of pole steps on pole.

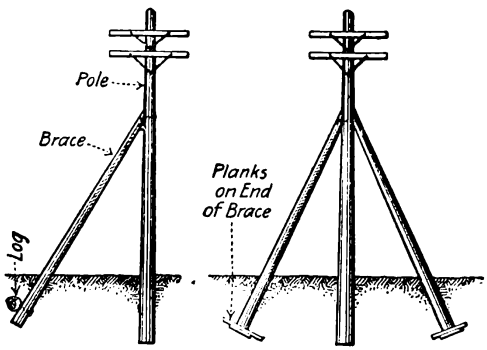


FIG. 16.—Bracing poles.

THE INSTALLATION OF ADDITIONAL SIDE GUYS, arranged at right angles to the line, to trees, stubs or anchors, is recommended. The side guys are attached to the same pole as the head guys.

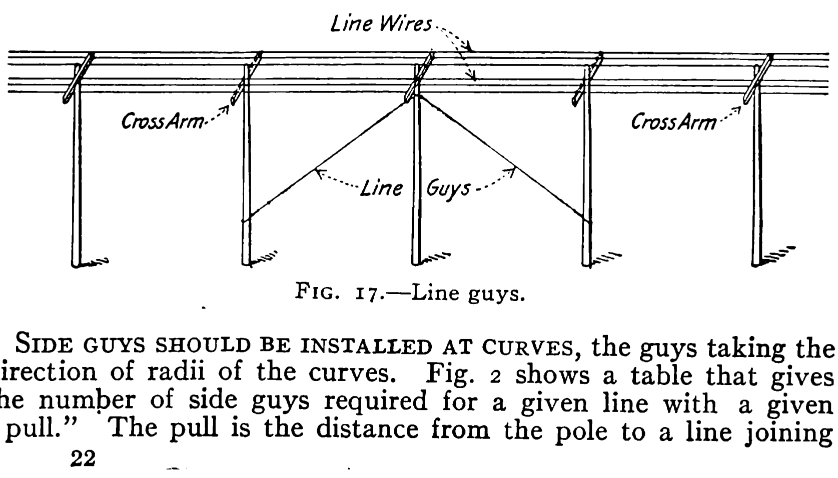


FIG. 17.—Line guys.

SIDE GUYS SHOULD BE INSTALLED AT CURVES, the guys taking the direction of radii of the curves. Fig. 2 shows a table that gives the number of side guys required for a given line with a given "pull." The pull is the distance from the pole to a line joining two points in the line 100 ft. on either side of the pole. See the illustration, Fig. 2.

POLES ON EITHER SIDE OF A LONG SPAN should be head guyed as shown in Fig. 18.

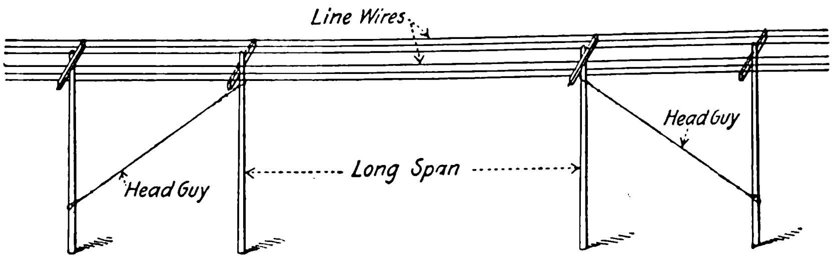


FIG. 18.—Head guys for a long span.

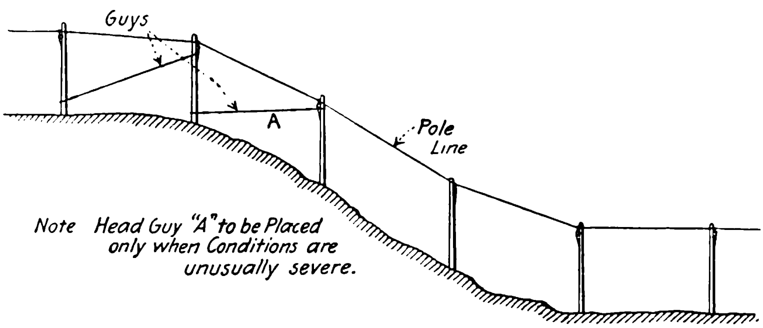


FIG. 19.—Head guys at a steep hill.

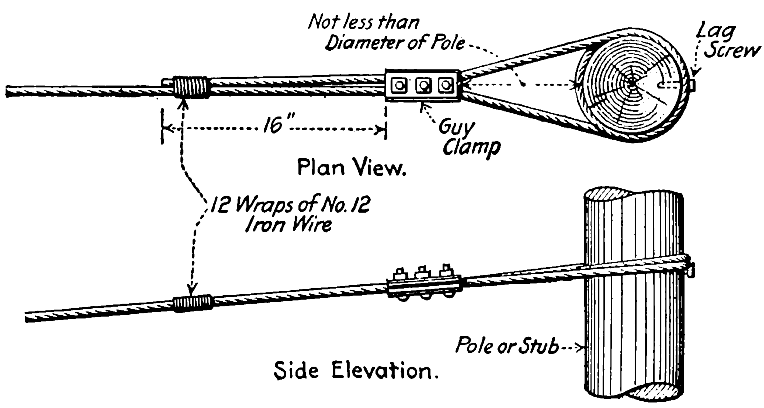


FIG. 20.—Guy attachment to pole or stub.

LINES ON STEEP HILLS SHOULD BE GUYED as shown in Fig. 19 with head guys.

GUY WIRES SHOULD BE KEPT MORE THAN 8 FT. FROM THE GROUND where possible to prevent persons from making accidental contact with them. A clearance of at least 3 ft. should be maintained between guys and electric wires, otherwise changes in temperature may cause the wires to come in contact.

28. The method of making up a guy on a pole or stub is shown in Fig. 20. Galvanized iron plates called pole plates are sometimes used on soft poles, on cedar poles particularly, under the guy wire to prevent it from cutting into the pole. These plates are about $\frac{1}{16}$ in. thick, 3 in. wide and 5 in. long. Where there is but one guy per pole, it is made up around the pole just under the top cross-arm as shown in Figs. 21 and 22. Where there are two guys to the pole, one is made up just under the top cross-arm and one just under the bottom cross-arm. Where more than two guys are used, the additional ones should be spaced as equally as possible between the top and the bottom guys that are made up under the top and bottom cross-arms respectively. Where there are two or more guys to a pole, each should be independent of the others. The different guy wires should not cross one another. Where two or more guys support a pole, a turn buckle should be inserted in all but one to equalize the stresses.

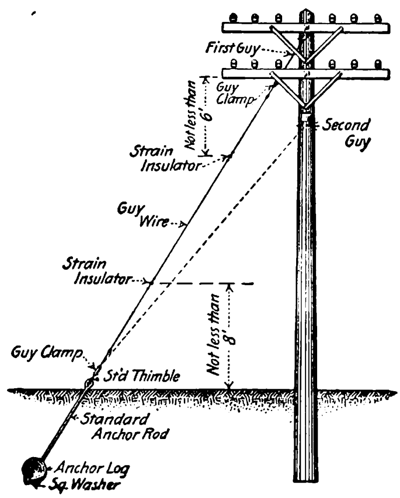


FIG. 21.—An anchor-guyed pole.

29. The method of installing an anchor guy is shown in Figs. 23 and 25. A guy rod and washer are shown in Fig. 24. The eye

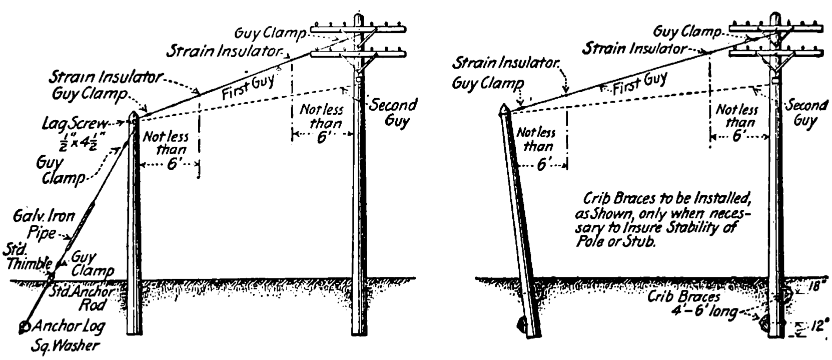


FIG. 22.—Poles guyed to stubs.

of the guy rod should extend about 1 ft. above the surface of the earth. Guy rods should not be installed where they will interfere with traffic. An "anchor shield" of $2\frac{1}{2}$-in. or 3-in. galvanized iron pipe extending to about 8 ft. above the ground should be placed over anchor guy wires near roadways as shown in Fig. 22. The foot of an anchor guy should be as far away from the foot of the

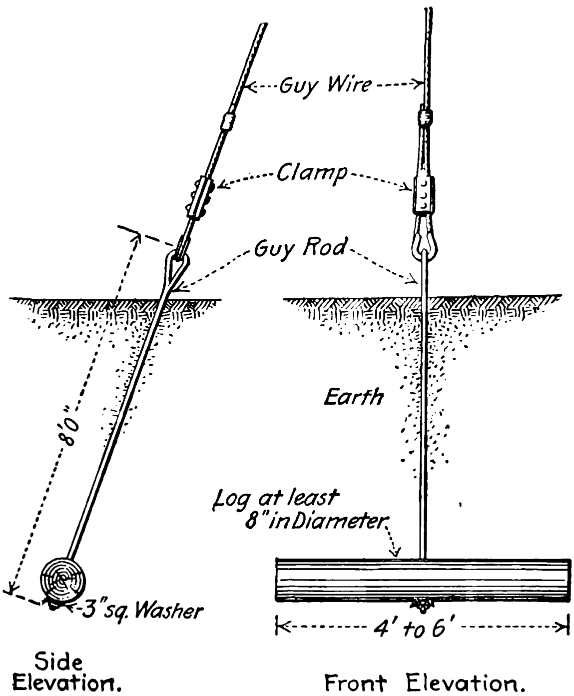


FIG. 23.—A guy rod and anchor.

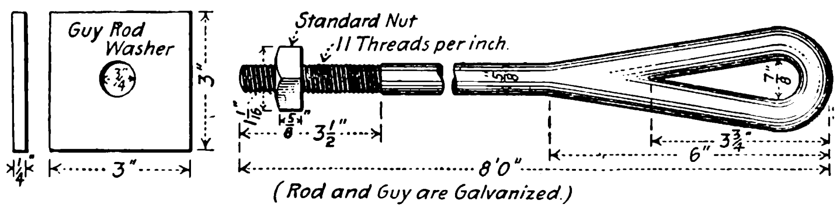


FIG. 24.—Guy rod and washer.

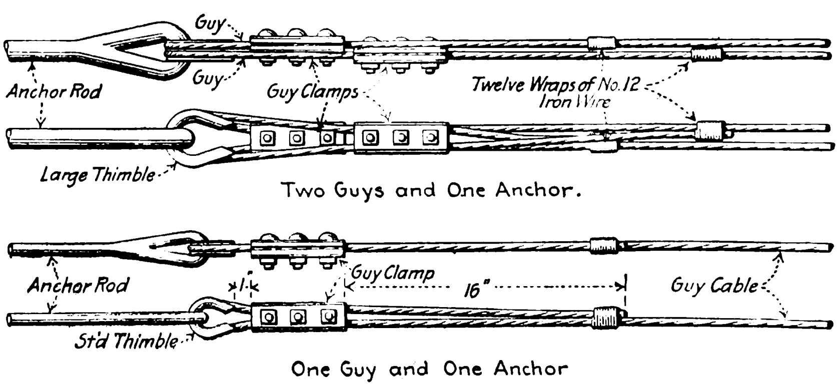


FIG. 25.—Methods of making up guys on guy rods.

pole as possible—at least a distance equal to ¼ the height of the pole.

30. **The methods of installing stub guys** are shown in Fig. 22. The stubs should be long enough that the guy wires will clear roadways by at least 18 ft., side walks by 12 ft. and electric wires by 3 ft. Stubs are used only when a line cannot be guyed properly

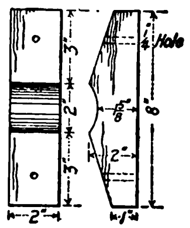


FIG. 26.—Details of tree-blocks.

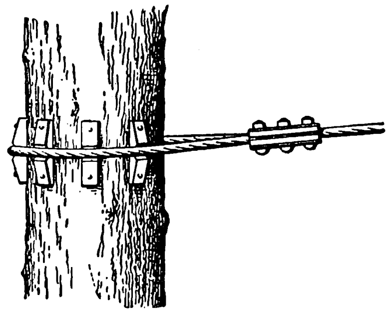


FIG. 27.—Guy wire fastened to tree.

to trees or poles. Stubs should satisfy the specifications of 2 for poles.

31. **In guying to a tree,** tree blocks (Figs. 26 and 27) should be used and the wire should pass but once around the tree. Tree guying is undesirable and should not be done unless absolutely necessary. Guys should preferably be attached to trunks or to limbs that are not less than 8 in. in diameter. Do not attach to a

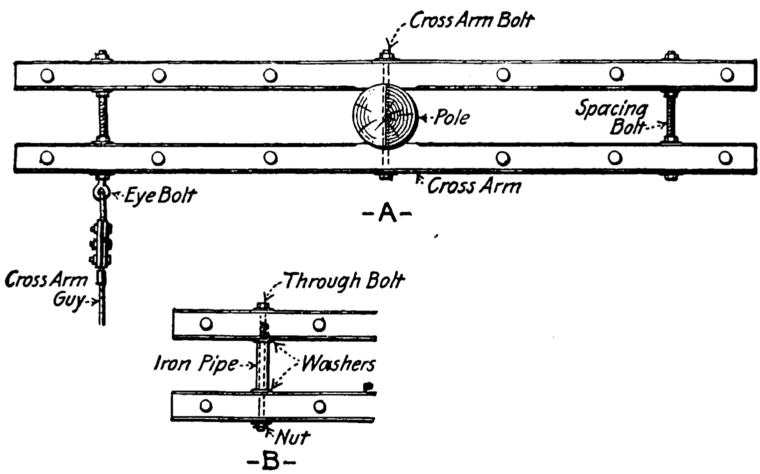


FIG. 28.—Method of arranging double arms.

limb that will swing with the wind and sway the pole. Enough tree blocks should be used so that the guy wire cannot touch the tree.

32. **Cross-arm guys** are used where the pull on a cross-arm is unbalanced. Figs. 28, 29 and 30 show examples. Cross-arm guys

usually extend from the arm to a pole or stub but sometimes for light strains the Y or "bridle" guy (Fig. 31) is used.

33. A line must be thoroughly guyed where it crosses a road. Figs. 32 and 33 show two methods of holding a line at such a point.

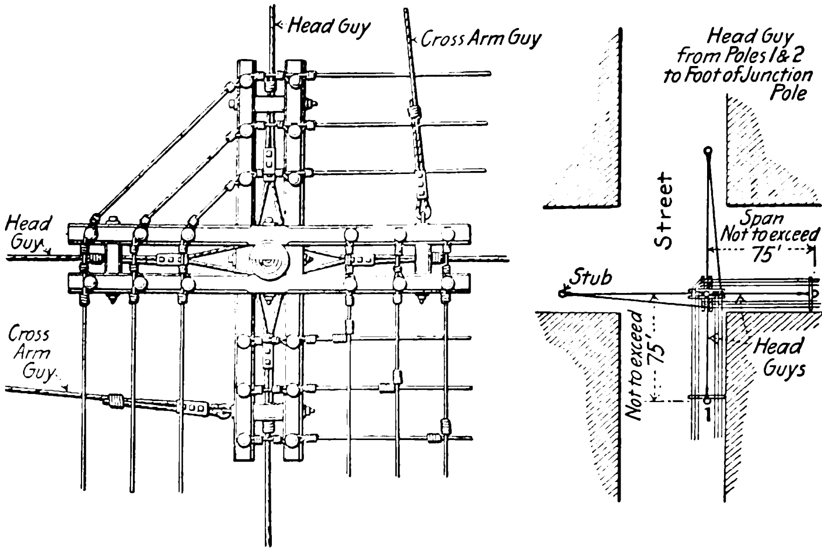


FIG. 29.—Method of turning corner with one pole.

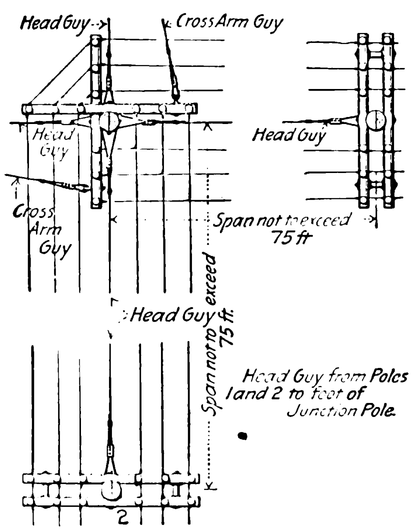


FIG. 30.—Corner pole without double arms.

The method involving the use of side guys is preferable, but the other one will give good service where side guys cannot be installed.

34. Guy-Wire Insulation.—Strain insulators should be inserted in all guy wires to poles carrying electric lighting or power wires.

Two insulators should be inserted in each guy. One is located at least 6 ft. from the pole itself or 6 ft. below the lowest line wire. The other is located at least 6 ft. from the lower end of the guy and at least 8 ft. from the ground. The two strain insulators are

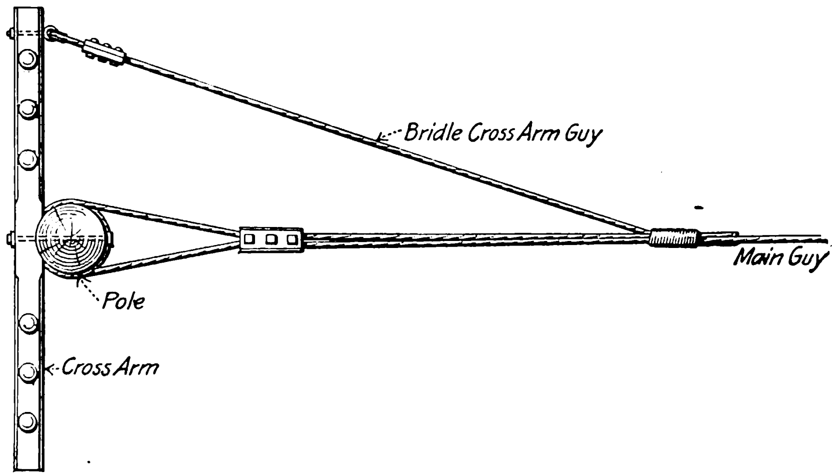


FIG. 31.—Bridle guy.

sometimes coupled in series in short guys. Wooden tree blocks (Fig. 26) are used for insulation under guys attached to iron poles.

35. Strain insulators are used in guys as shown in illustrations in this section and are also used in line wires at dead ending points.

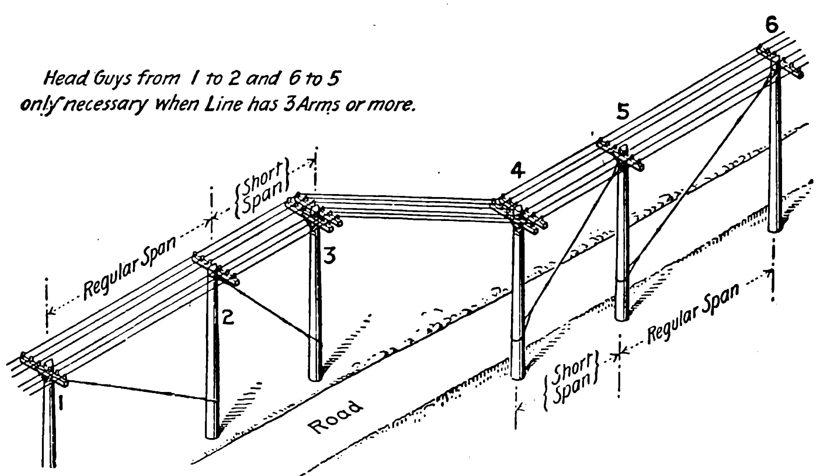


FIG. 32.—Guying at road crossing without side guys.

Composition, porcelain and wooden strain insulators are made. Wooden strain insulators (Fig. 34) are popular with some companies and afford excellent insulation but have the objection that if one burns, the wires that it supports fall. Composition and porcelain strain insulators can be made so that even if the insulating material fails, the supported wires will not fall. Figs. 35 and 36 show types meeting these requirements. The strain insulator of Fig. 35 is cheap and satisfactory and has lately become very popular in electric lighting line construction.

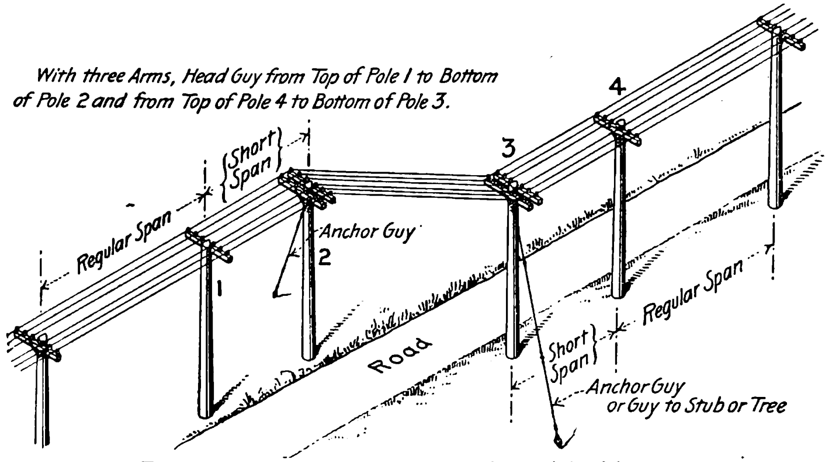


FIG. 33.—Guying at road crossing with side guys.

36. Emergency strain insulators can be made by knocking the ends out of common glass line wire insulators as illustrated in Fig. 37. To break out the end, hold the insulator in one hand

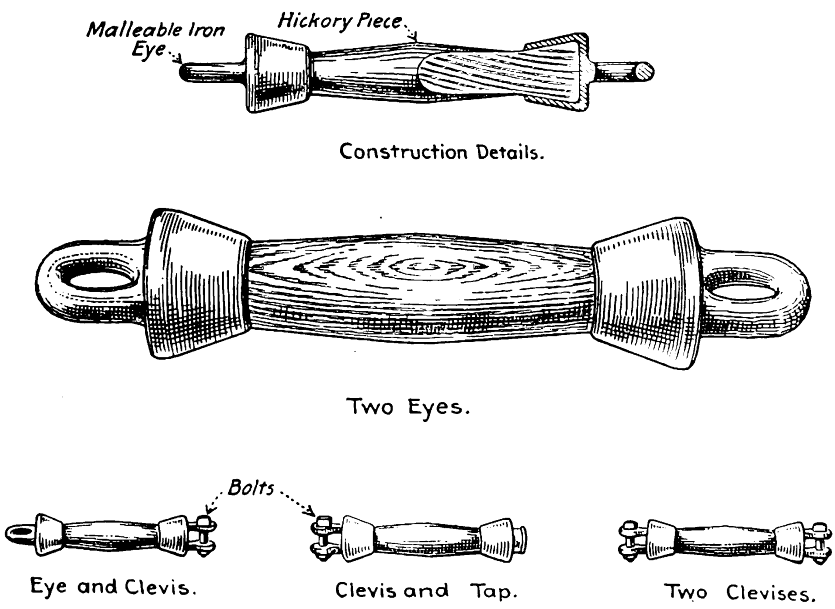


FIG. 34.—Wooden strain insulators.

and strike the inside of the top a sharp blow with the handle of a pair of plyers or of a pair of connectors or with a screw driver held in the other hand. Where one emergency insulator will not give

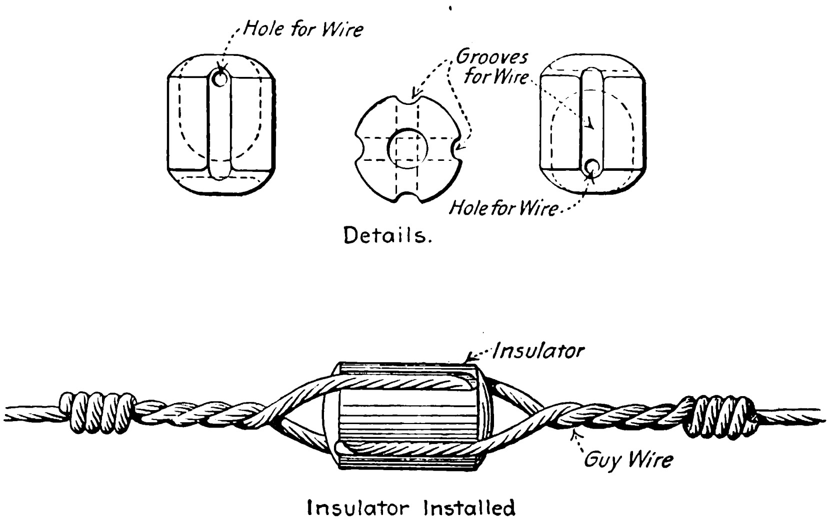


FIG. 35.—A strain porcelain insulator.

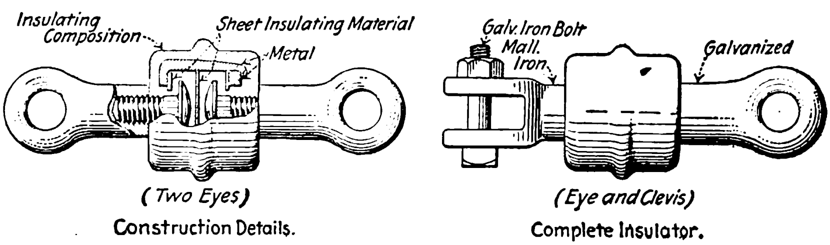


FIG. 36.—Composition strain insulators.

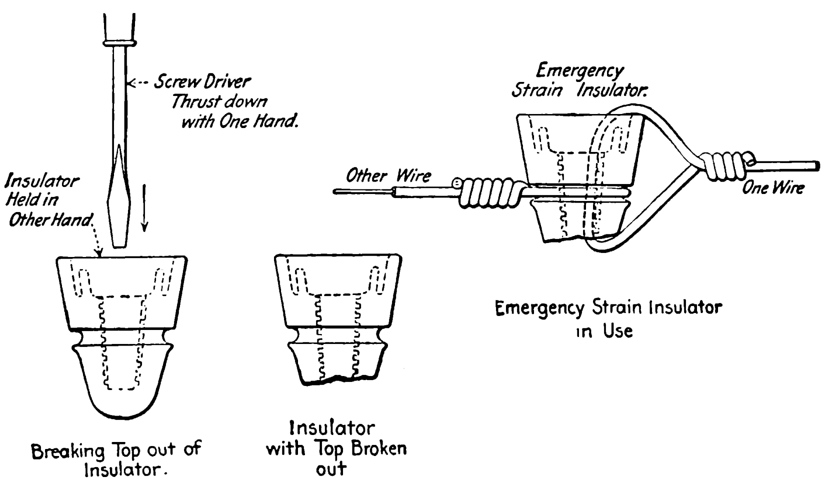


FIG. 37.—Emergency strain insulators.

sufficient insulation, two or more can be used in series. Emergency strain insulators thus made are not strong enough for heavy guy wires but are more suitable for insertion in line wires.

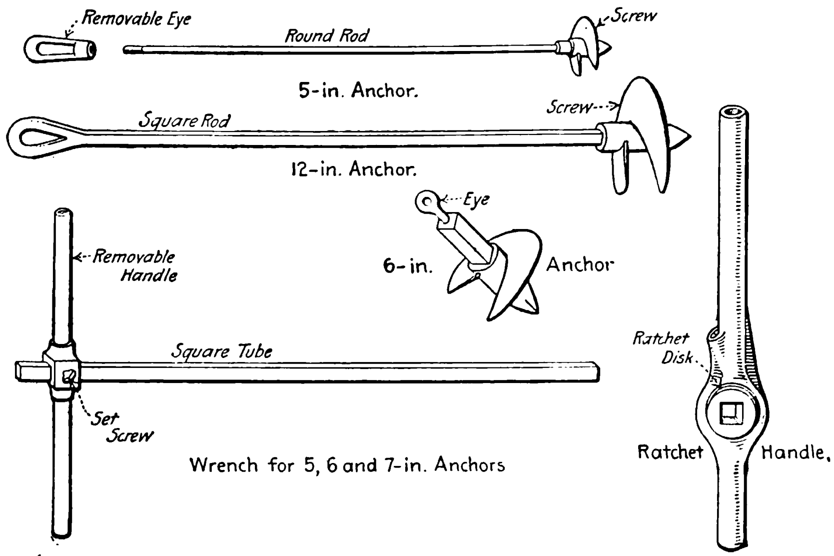


FIG. 38.—Matthew's anchors and wrenches.

37. Patented guy anchors can be used in certain kinds of soil very effectively. Fig. 38 shows one kind of anchor that is screwed into the earth with a wrench. The resistance of this sort of an anchor to withdrawal is not measured by the weight of a column

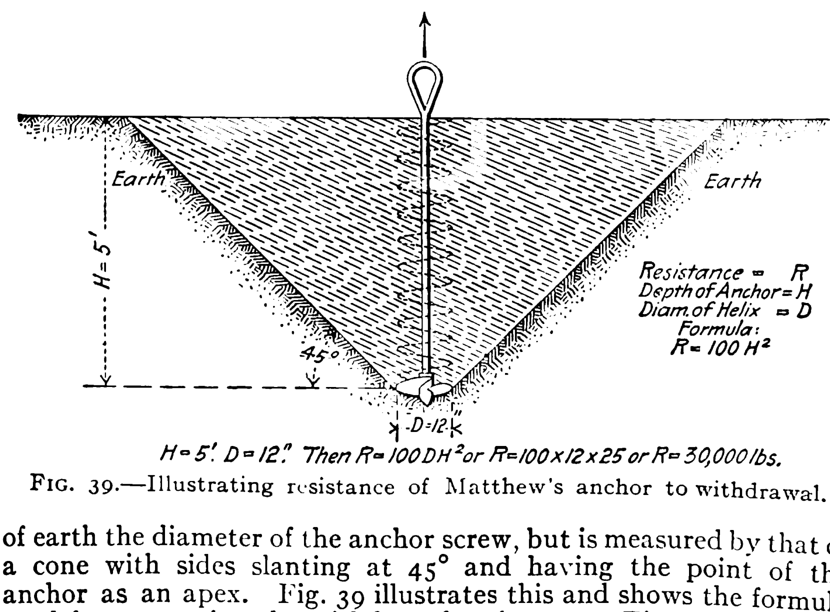


FIG. 39.—Illustrating resistance of Matthew's anchor to withdrawal.

of earth the diameter of the anchor screw, but is measured by that of a cone with sides slanting at 45° and having the point of the anchor as an apex. Fig. 39 illustrates this and shows the formula used for computing the withdrawal resistance. Fig. 39 shows the anchor inserted perpendicularly, but an anchor should always be inserted at the same angle that the guy wire assumes, so the rod of the anchor will be in a direct line with the guy wire. Table 38 gives the actual resistances to withdrawal of the anchors.

38. Pounds Tension Required to Pull Out Matthews Guy Anchors

At Various Depths According to Prof. Carpenter's Formula (see Formula on Diagram Fig. 39).

Depth in feet	Holding Strain in Pounds					
	5 in.*	6 in.*	7 in.*	8 in.†	10 in.†	12 inch†
	lb.	lb.	lb.	lb.	lb.	lb.
3½	6,125	7,350	8,575	....	....	....
4	8 000	9,600	11,200	12,800	16,000	19,200
4½	10,125	12,150	14,175	16,200	20,250	24,300
5	12,500	15,000	17,500	20,000	25,000	30,000
5½	15,125	18,150	21,175	24,200	30,250	36,000
6	....	....	....	28 800	36,000	43,200
7	....	....	....	39 200	49,000	58,800
8	....	....	....	51,200	64,000	76,800
9	....	....	....	64,800	81,000	97,200
10	....	....	....	80,000	100,000	120,000

39. Directions for Installing Matthews Guy Anchors. 5-, 6-, AND 7-IN. WITH RODS.—Remove the eye of the anchor; pass the rod through the wrench and replace the eye, which will serve to hold the wrench rigidly to the anchor, then screw the anchor in, at the same angle as the guy wire is to run, as far as ground conditions will permit. When in as far as possible, remove the eye and pull out the wrench. Then replace the eye, thus making anchor ready for guy wire. The handle bars of the wrench are adjustable and held in place with a set screw. They can be moved back as the anchor screws in.

8-, 10-, 12-IN. WITH RODS.—Place bar or other lever in eye of anchor and screw it in as far as ground conditions will permit, always at the angle that the guy wire is to run. Time will be saved and the anchor start easier if a few spades of earth are removed before starting anchor. When the anchor is set, attach the guy strand to the eye. Always pull anchor back as far as possible before finally tying the guy wire.

NOTE.—If conditions are such that many anchors must be installed close to buildings, fences, etc., a rachet wrench should be used.

IN DRY, HARD GROUND.—In setting all anchors in hard ground, the work will be much easier if a hole is made with a digging or crow bar or a wood auger with a long shank. This makes the path of the anchor easier. A little water poured down this hole before starting the anchor will help considerably where the ground

*It is impractical to install the 5- and 6-in. anchors at a greater depth than 5½ ft.

†The 8-, 10- and 12-in. anchors will not bear a great strain at a lesser depth than 4 ft.

is hard and dry. In installing 8-, 10-, and 12-in. anchors in very hard ground, clamp a lever to the rod by means of a chain, a foot or so above the ground. As the anchor is screwed down the lever can be moved up. The anchor will start easier if a few spades full of earth are removed at the angle desired to set the guy. If a man stands on the helix of the anchor when starting until the point bites the ground it will assist.

In localities where loose gravel or small flat rock occurs, drill a hole with a digging bar or crowbar, as suggested above. If a small rock is encountered it can be broken by the bar. If a large rock is "discovered," the bar can be removed and the hole drilled in another place. This will allow the use of anchors in many places where it would seem impossible to install them.

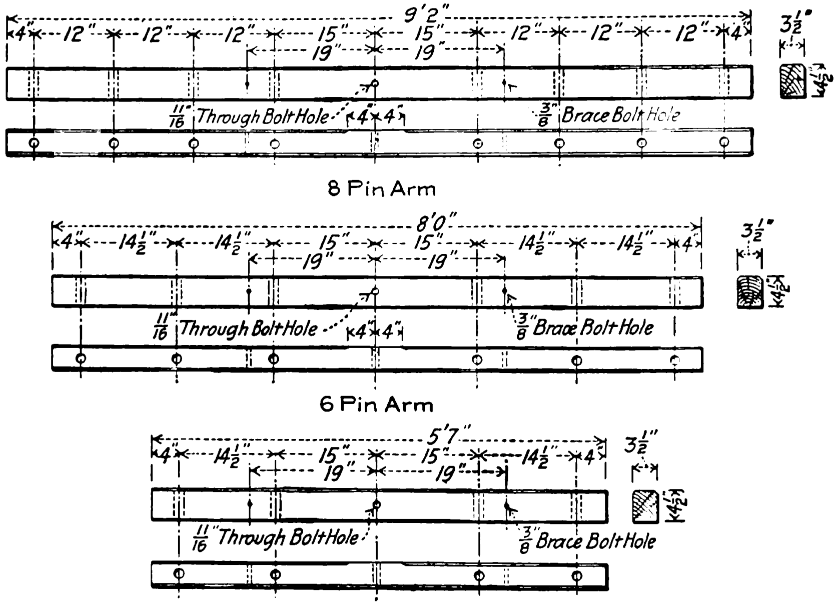


FIG. 40.—Cross-arm dimensions recommended by the N. E. L. A.

40. Guy Wire and Cable.—For unimportant work where strains are not heavy, a single strand of No. 4 or No. 6 galvanized steel wire is sometimes used (see index for table) but modern practice favors galvanized steel cable or "strand." (See index for table.) For cross-arms and other light guying, a ¼-in. steel cable (tensile strength 2,300 lb.) can be applied. The standard guy for regular pole guying is a $\frac{5}{16}$-in. special steel cable which should have a tensile strength of at least 6,000 lb. Many telephone lighting and power companies use this size and grade.

41. Cross-arms.—Table 43 shows the dimensions of the so-called standard arms. Fig. 40 shows the dimensions of cross-arms recommended by the National Electric Light Association. These arms have a spacing between center pins of 30 in., which is believed to provide a safe climbing space. Cross-arms are best made of long-leaf yellow pine, Norway pine, or Oregon fir. Cross-arm dimensions have not actually been standardized throughout the country. It is probable that arms of the N. E. L. A. dimensions (Fig. 40) will come into extensive use. It is modern practice not to paint cross-arms as soon as they are made. They are either treated with a wood preservative or are permitted to season naturally for at least three months and are then painted with two coats of green white-lead paint before erection. No cross-arm having a spacing of less than 20 in. between center pins or 10½ in. between side pins should be used. The six-pin arm (Fig. 40) is recommended for general use.

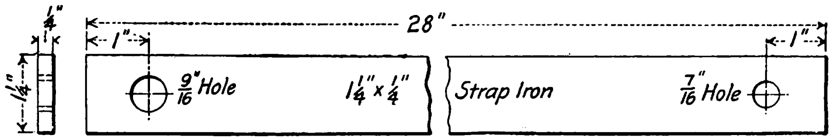


FIG. 41.—Cross-arm brace, N. E. L. A. recommendations.

42. **Cross-arm bolts** are standard ⅝-in. machine bolts preferably galvanized (Fig. 42). A square washer (Fig. 42) is used under both head and nut.

43. **Standard Cross-arms.** Finished size, 3¼ in. by 4¼ in. Bored for 1½-in. or 1¼-in. pins, two ⅜-in. carriage bolts and one ⅝-in. or two ½-in. bolts, as may be directed. Pin holes shall be a driving fit; carriage bolt holes 7/16 in. diameter; ½-in. machine bolt holes 9/16 in. diameter; ⅝-in. machine bolt holes 11/16 in. diameter.

Length ft.	No. pins	Pin spacing			Approximate weight, lb.
		Ends, in.	Sides, in	Centers, in.	
3	2	4	....	28	10
4	4	4	12	16	14
5	4	4	15	22	17
6	4	4	21	22	21
6	6	4	12	16	21
8	....	4	16½	22	28
8	....	4	12	16	28
8½	10	3	10	16	29½
10	8	4	15	22	35
10	10	4	12	16	35
10	12	4	9⅝	16	35

44. **Cross-arm braces** (Fig. 41) are of strap iron (mild steel) and are preferably galvanized. Braces are attached to the front of each cross-arm, each by a 4½-in. carriage bolt (Fig. 42), before the arm is fastened to the pole. The head of the bolt is at the back of the arm and has a round washer (Fig. 42) under it. The nut is on the brace side. There are braces of other sizes in use but the one of Fig. 41 appears to be best suited for general work. The braces are secured to the pole by a square-head coach or lag screw (Fig. 42) usually ½ in. by 3½ in. Table 46 shows proportions of lag screws of other dimensions. Dimensions of lag screws furnished by thirty-five different manufacturers vary.

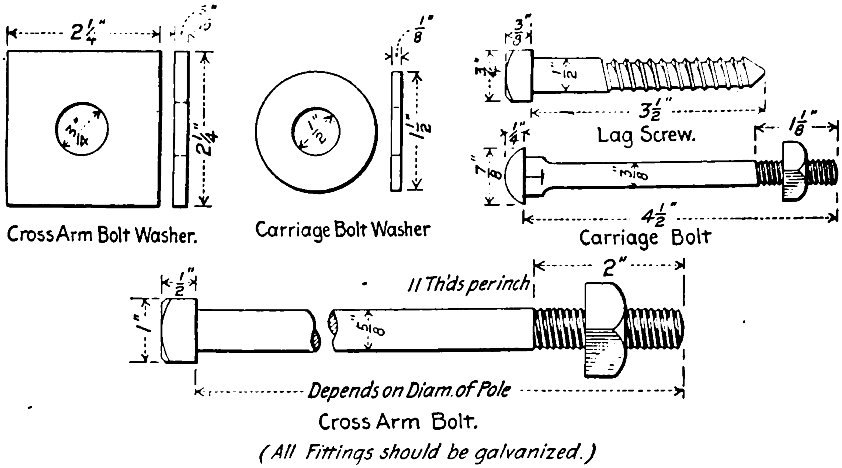


FIG. 42.—Cross-arm fittings, N. E. L. A. recommendations.

45. Dimensions of Machine Bolts and Nuts.

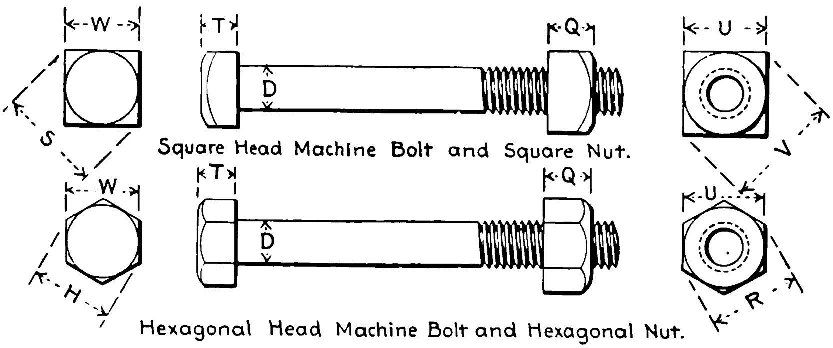


FIG. 42A.—Machine bolts and nuts.

D	T	W	S	H	Q	U	R	V
1/4	3/16	3/8	17/32	7/16	3/16	7/16	1/2	5/8
5/16	15/64	15/32	21/32	35/64	1/4	17/32	5/8	3/4
3/8	9/32	9/16	51/64	21/32	5/16	5/8	47/64	57/64
7/16	21/64	21/32	15/16	3/4	3/8	23/32	27/32	1 5/64
1/2	3/8	3/4	1 1/16	27/32	7/16	13/16	61/64	1 5/32
5/8	15/32	15/16	1 21/64	1 5/64	9/16	1	1 5/32	1 27/64
3/4	9/16	1 1/8	1 19/32	1 19/64	11/16	1 3/16	1 3/8	1 43/64
7/8	21/32	1 5/16	1 55/64	1 1/2	13/16	1 3/8	1 19/32	1 61/64
1	3/4	1 1/2	2 1/8	1 47/64	15/16	1 9/16	1 11/16	2 7/32
1 1/8	27/32	1 11/16	2 25/64	1 31/32	1 1/8	1 13/16	2 3/32	2 9/16
1 1/4	15/16	1 7/8	2 21/32	2 5/32	1 1/4	2	2 5/16	2 27/32
1 3/8	1 1/32	2 1/16	2 59/64	2 25/64	1 3/8	2 3/16	2 17/32	3 3/32
1 1/2	1 1/8	2 1/4	3 3/16	2 19/32	1 1/2	2 3/8	2 47/64	3 3/8
1 5/8	1 7/32	2 7/16	3 3/4	2 13/16	1 5/8	2 9/16	2 31/32	3 5/8
1 3/4	1 5/16	2 5/8	3 23/32	3 1/32	1 3/4	2 3/4	3 3/16	3 57/64
1 7/8	1 13/32	2 13/16	3 63/64	3 1/4	1 7/8	2 15/16	3 25/64	4 5/32
2	1 1/2	3	4 1/4	3 15/32	2	3 1/8	3 5/8	4 27/64

46. Gimlet Point Square Head Coach or Lag Screw.—Lag screws 1½ in. long and under are threaded the entire length. Lag screws longer than 1½ in. are threaded but three-fourths of their lengths

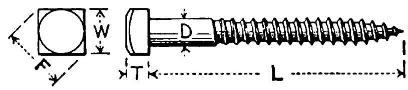


FIG. 43.—Square-head gimlet-point coach or lag screw.

D Diameter	T Thickness of head	W Width of side of head	F Distance across corners	Clearance bore for body of screw	L
1/4	3/16	3/8	17/32	5/16	Screws increase in length by ½-in. increments from 1½ in. to and including 8 in. Screws from 8 in. to 12 in. increase in length by 1-in. increments. Screws of diameters of ¼ in., 5/16 in., and ⅜ in. are made in lengths of 1½ in. to and including 6 in.; 7/16 in. dia. from 1½ in. to 9 in. long; ½ in. dia., 1½ in. to 12 in., 9/16 in. and ⅝ in. dia., 2 in. to 12 in.; ¾ in. dia., 2½ in. to 12 in.; ⅞ in. dia.; 3 in. to 12 in., 1 in. dia., 3½ in. to 12 in. long.
5/16	15/64	15/32	21/32	3/8	
3/8	9/32	9/16	51/64	7/16	
1/2	3/8	3/4	1 1/16	9/16	
5/8	15/32	15/16	1 21/64	11/16	
3/4	9/16	1 1/8	1 19/32	13/16	
7/8	21/32	1 15/16	1 55/64	15/16	
1	3/4	1 1/2	2 1/8	1 1/16	

47. Common or Button Head Carriage Bolts.

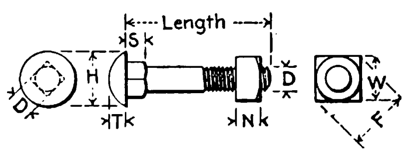


FIG. 44.—Common carriage bolt.

D Diameter, inches	Threads per inch	T Thickness of head	S Length of square part	H Diameter of head	W Width of nut	N Thickness of nut	F Across corners of nut
1/4	20	3/32	1/4	17/32	1/2	1/4	23/32
5/16	18	1/8	5/16	21/32	19/32	5/16	27/32
3/8	16	5/32	3/8	25/32	11/16	3/8	31/32
1/2	13	7/32	1/2	1 1/32	7/8	1/2	1 1/4
5/8	11	9/32	5/8	1 9/32	1 1/16	5/8	1 1/2
3/4	10	3/8	3/4	1 9/16	1 1/4	3/4	1 25/32
7/8	9	7/16	7/8	1 13/16	1 7/16	7/8	2 1/32
1	8	1/2	1	2 1/16	1 5/8	1	2 19/64

48. Punched Wrought-iron Washers.

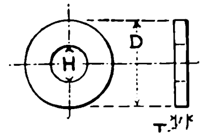


FIG. 45.—Punched wrought-iron washer.

Diam. bolt	D Outside diam.	T Approx. thick	H Diam. hole	Diam. bolt	D Outside diam.	T Approx. thick.	H Diam. hole
$\frac{3}{16}$	$\frac{9}{16}$	$\frac{3}{64}$	$\frac{1}{4}$	1	$2\frac{1}{2}$	$\frac{5}{32}$	$1\frac{1}{16}$
$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$2\frac{3}{4}$	$\frac{5}{32}$	$1\frac{1}{4}$
$\frac{5}{16}$	$\frac{7}{8}$	$\frac{1}{16}$	$\frac{3}{8}$	$1\frac{1}{4}$	3	$\frac{5}{32}$	$1\frac{3}{8}$
$\frac{3}{8}$	1	$\frac{5}{64}$	$\frac{7}{16}$	$1\frac{3}{8}$	$3\frac{1}{4}$	$\frac{11}{64}$	$1\frac{1}{2}$
$\frac{7}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$	$\frac{1}{2}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$\frac{11}{64}$	$1\frac{5}{8}$
$\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{32}$	$\frac{9}{16}$	$1\frac{5}{8}$	$3\frac{3}{4}$	$\frac{11}{64}$	$1\frac{3}{4}$
$\frac{9}{16}$	$1\frac{1}{2}$	$\frac{3}{32}$	$\frac{5}{8}$	$1\frac{3}{4}$	4	$\frac{11}{64}$	$1\frac{7}{8}$
$\frac{5}{8}$	$1\frac{3}{4}$	$\frac{1}{8}$	$\frac{11}{16}$	$1\frac{7}{8}$	$4\frac{1}{4}$	$\frac{11}{64}$	2
$\frac{3}{4}$	2	$\frac{1}{8}$	$\frac{13}{16}$	2	$4\frac{1}{2}$	$\frac{11}{64}$	$2\frac{1}{8}$
$\frac{7}{8}$	$2\frac{1}{4}$	$\frac{5}{32}$	$\frac{15}{16}$	....	....	....	....

49. Side arms are used (Fig. 46) in alleys and other locations where it is necessary to clear obstructions. These cross-arms are special, the dimensions are given in the illustration, and the fittings used on them are special. Side guys or crib braces (see illustration) are used where the line wires are heavy, to counteract the tendency of the pole to tip.

50. Double arms are used wherever the stress on the arms is unusually severe or where every precaution is necessary to insure safety. Double arms are often used on the poles at each side of a street, at each side of railroad crossings, at corners or other points where the direction of a line changes. Figs. 28, 29, 30, 32, 33, 47, 48, and 49 show examples of double-armed poles. The two cross-arms can be separated by wooden spacing blocks, Fig. 47, by spacing bolts, Fig. 28, *A*, or by spacing nipples, Fig. 28, *B*.

The spacing blocks can be sawed from a cross-arm. A $\frac{11}{16}$-in. hole bored through the

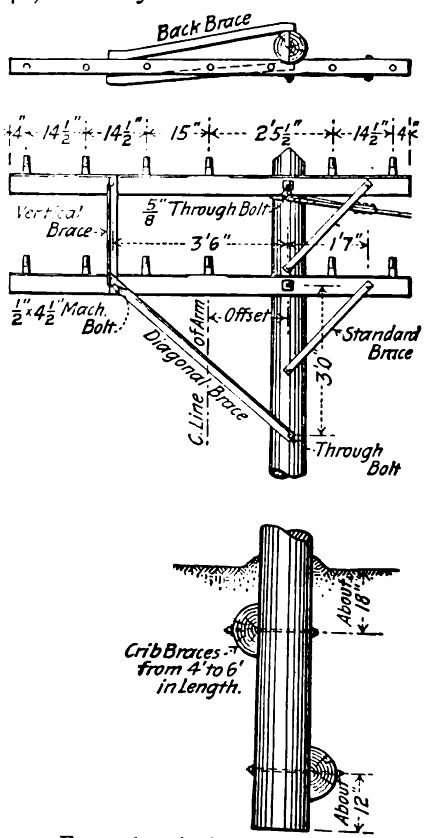


FIG. 46.—A side-arm pole.

block and cross-arm accommodates a $\frac{5}{8}$-in. bolt. A washer is used under bolt head and nut. Spreader bolts can be used instead of spacing blocks (Fig. 28, *A*); the bolts are threaded their entire lengths. A galvanized iron pipe nipple can also (Fig. 28, *B*) be used to separate the cross-arms. There is not a great deal of choice between the methods if the fittings for each are available. Probably the wooden spacing-block method is most used because the supplies required for it are always readily obtained "on the job." Where an arm guy is to be attached to the cross-arm, an eye-spreader bolt can be used as shown. Single-armed poles are now often used particularly on junction poles, as shown in the accompanying illustrations, in locations where double arms were

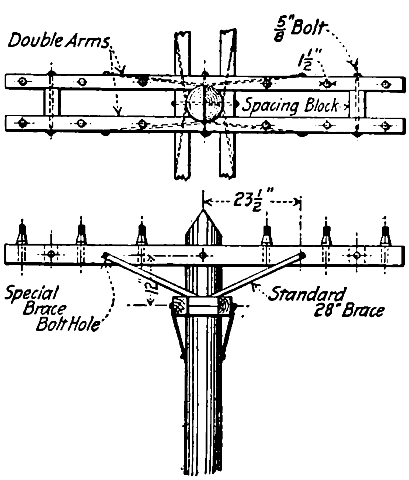


FIG. 47.—A buck-armed pole, doubled arms.

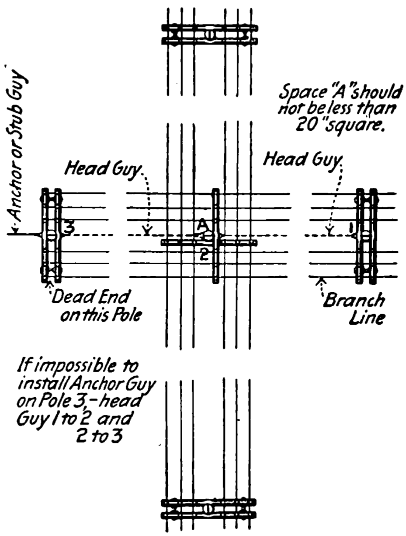


FIG. 48.—Junction pole without double arms.

formerly thought necessary. The single arms are preferable in that they allow greater climbing space for linemen.

51. Reverse or buck arms are used at corners. See Figs. 29, 30, 47 and 48. When placing 'buck arms, ample room must be provided through which a lineman can reach the top of the pole. A 20-in. square space is the minimum. Cross-arm braces on buck-arm poles should be attached to the arms at a point $23\frac{1}{2}$ in. from the center of arm instead of at 19 in., the standard distance for ordinary framing. The $\frac{3}{8}$-in. holes for the brace (carriage) bolts must be specially bored, at the above spacing, in buck arms. The 23-in. spacing is correct for 28-in. braces.

52. Cross-arm pins should be of locust. Oak pins are sometimes used but they are treacherous and may break when they should not and thereby cause accidents. Table **56A** and Fig. 53 show dimensions of some standard pins. The pin dimensions recommended by the National Electric Light Association for ordinary distribution use are shown in Fig. 51.

53. Pins are held in cross-arms with a six-penny nail as shown in Fig. 52. The nail should not be driven entirely in. Enough of its length should extend so that the cutting jaws of a pair of plyers can be forced under the head and the nail thereby withdrawn. If this suggestion is followed and it is necessary to remove a pin, it can be readily accomplished.

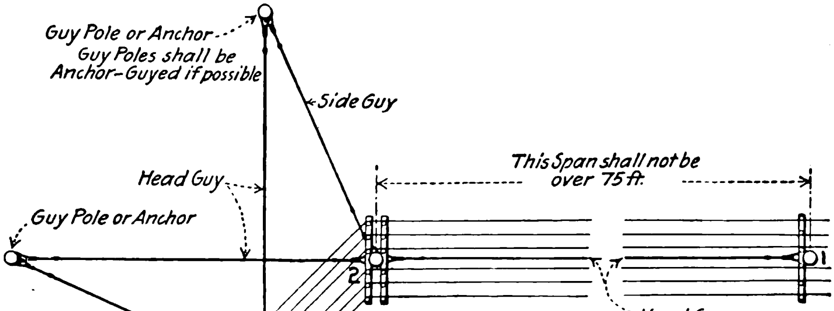


FIG. 49.—A right-angle turn.

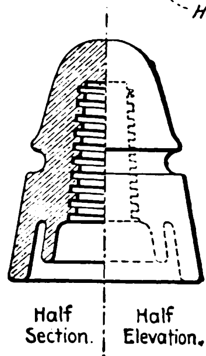


FIG. 50.—Double petticoat insulator.

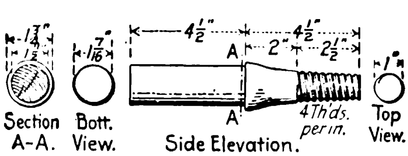


FIG. 51.—Pin recommended by the N. E. L. A.

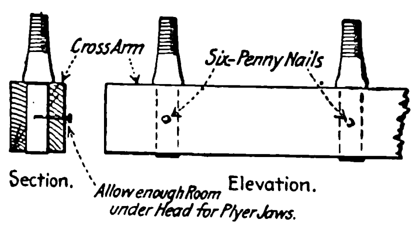


FIG. 52.—Fastening pin in cross-arm.

54. Insulators.—Glass insulators are ordinarily used for conductors at pressures of 2,200 volts and under. However, porcelain insulators are much cheaper than they once were and porcelain is now a formidable competitor of glass as an insulator material for even the lower voltages. Insulators should be of the deep-groove double-petticoat type. The insulator illustrated in Fig. 50 will give excellent service at pressures under 4,000 volts.

55. Glass insulators are cheaper than porcelain, and owing to its transparency, flaws can be detected by a simple inspection.

(*Standard Handbook.*) Glass has an exceedingly high dielectric strength and specific resistance. It condenses moisture on its surface and the action of the distilled water destroys the smoothness of the surface and allows dirt to collect and form a leakage path around the insulator.

56. **Porcelain insulators** give less trouble from leakage and are superior to glass in resisting constant and large changes in temperature. The surface resistance is increased by using a number of petticoats.

56A. **Wooden Insulator Pins.**—All standard insulator pins of 1-in. and $1\frac{3}{8}$-in. top diameter have four threads to the inch and a tapering diameter of $\frac{1}{16}$-in. increase for each inch in length.

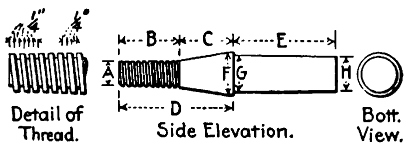


FIG. 53.—Wooden insulator pin.

Dimensions in inches								Shipping wt. per 1,000 lb.
A	B	C	D	E	F	G	H	
1	$2\frac{1}{2}$	$2\frac{1}{4}$	$4\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{7}{16}$	400
1	$2\frac{1}{2}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$4\frac{1}{4}$	2	$1\frac{1}{2}$	$1\frac{7}{16}$	510
1	$2\frac{1}{2}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{11}{16}$	700
1	$2\frac{1}{2}$	4	$6\frac{1}{2}$	5	$2\frac{1}{2}$	2	$1\frac{15}{16}$	930
$1\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$4\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{7}{16}$	400
$1\frac{3}{8}$	$2\frac{1}{4}$	5	$7\frac{1}{4}$	$4\frac{1}{4}$	2	$1\frac{1}{2}$	$1\frac{7}{16}$	510
$1\frac{3}{8}$	$2\frac{1}{4}$	5	$7\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{11}{16}$	700
$1\frac{3}{8}$	$2\frac{1}{4}$	$4\frac{1}{4}$	$6\frac{1}{2}$	5	$2\frac{1}{2}$	2	$1\frac{15}{16}$	930
$1\frac{3}{8}$	$2\frac{1}{4}$	$7\frac{1}{4}$	$9\frac{1}{2}$	5	3	2	$1\frac{15}{16}$	1,160
$1\frac{3}{8}$	$2\frac{1}{4}$	$8\frac{3}{4}$	11	5	$3\frac{1}{2}$	2	$1\frac{15}{16}$	1,280
$1\frac{3}{8}$	$2\frac{1}{4}$	$9\frac{3}{4}$	12	5	$3\frac{1}{2}$	2	$1\frac{15}{16}$	1,360

57. **In locating circuits on poles** the through wires or trunk lines should be carried on the upper cross-arms and the local wires, those which are tapped frequently should be carried on the lower cross-arms. The two or three wires of a circuit should always be carried on adjacent pins. This is of particular importance with alternating-current circuits as the inductance, consequently the inductive voltage drop, is increased as the distance between the wires of a circuit is increased. Wires of a circuit should always take the same pin positions on all poles to facilitate trouble hunting. Series circuits which do not operate during the day time may often be carried on the pole pins of a cross-arm. High-tension multiple circuits that are "hot" continuously are well placed at the ends of the arms out of the way of linemen. The neutral wire should always be in the center of a three-wire circuit. Fig. 54 shows one good arrangement on a two, four-pin-arm pole.

58. Wire and Wire Sizes for Electric Light and Power Lines.—No wire smaller than No. 6 is used in good construction for line wire. No. 8 is sometimes used for services, not more than 75 ft. long, that do not cross a street. Solid wires are often used for sizes up to and including No. 00 and cable (stranded wire) is used for larger conductors. Triple-braid weatherproof is the standard insulation of aerial line wires. Annealed or soft-drawn wire is preferable to hard-drawn because it is more readily handled and, in the sizes used, has ample tensile strength.

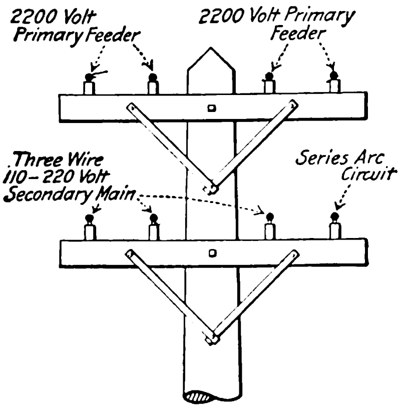


FIG. 54.—Location of circuits on a two-arm pole.

59. The perpendicular distance between all wires except where they are firmly attached to poles or other supports should be at least 24 in.

60. Clearances Required by the National Electrical Code.—The following indicates what is required for lines operating at pressures exceeding 5,000 volts. It represents, however, excellent practice for 2,000-volt lines. (The matter is taken from the Factory Mutual Insurance Company's handbook.)

When it is necessary to carry 5,000-volt lines near buildings, they must be at such height and distance from the building as not to interfere with firemen in event of fire; therefore, if within 25 ft. of a building, they must be carried at a height not less than that of the front cornice, and the height must be greater than that of the cornice as the wires come nearer to the building, in accordance with the following table:

Distance of wire from building, feet	Elevation of wire above cornice of building, feet
25	0
20	2
15	4
10	6
5	8
2½	9

It is evident that where the roof of the building continues nearly in line with the walls, as in Mansard roofs, the height and distance of the line must be reckoned from some part of the roof instead of from the cornice.

In order to make the intent of the above rule and its application as clear as possible, the following example is given. Fig. 55 shows in full lines a three-story building with flat roof and simple cornice overhanging about 2 ft. The poles carrying the high-pressure wires are set just inside the curbing, say 15 ft. from the building. The cross-arm is 6 ft. long, bringing the outside wires say 3 ft. each side of the pole. Therefore the wire nearest the building is 10 ft. from the cornice, in horizontal projection.

Reference to the above table will show that under these conditions the wires must be at least 6 ft. above the cornice. If, now, the building had had a very steep-pitched roof or especially one of the Mansard type, as shown in the dotted lines in this sketch, it will be readily seen that the above arrangement would not be satisfactory, for the wires would be very liable to interfere with fighting fire in the roof. Assuming that the upper corner of the dotted roof is 5 ft. back of the edge of the main cornice, this part of the roof is 15 ft. from the nearest wire and consequently the wires must be raised 6 ft. above their previous position in order that they may be 4 ft. above the roof, as required in the above table when within 15 ft. of the building, as in this case. The cut shows very clearly to what extent the dotted Mansard roof affects the height of the pole.

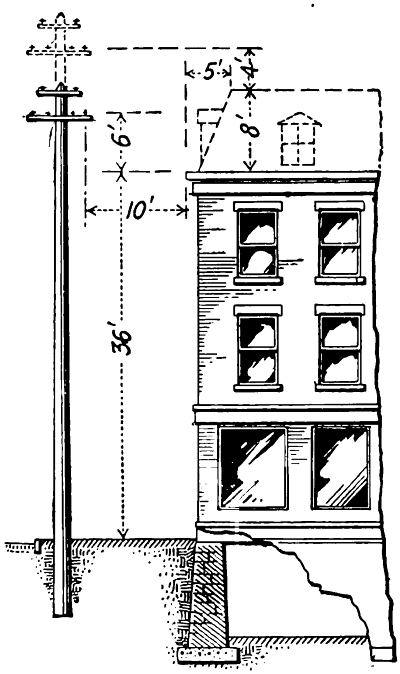


FIG. 55.—Wire location with reference to cornice.

61. Stringing Wire.—There are two methods, the choice depending on local conditions and the size and length of the circuit. By one method a reel of wire is set at one end of the line, and a rope carried 1,500 or 2,000 ft. over the cross-arms and attached to the wire that is then drawn over the arms. The other way is to place the reel on a cart, and after securing the end of the wire to the last pole the cart is started and the wire paid out till the second pole is reached, and then the wire is hoisted up and laid on the arm. Wire should always be paid out from the coil, the coil revolving, so that the wire will not be twisted. Where wire is not received on reels it should be placed on them before paying out.

62. Proper Sag in Annealed Copper Line Wires.—The wires should be pulled up until the sag equals that indicated in the following table. The permissible sag is the same for wires of all sizes and varies only with the length of span and the temperature of the air at the time of stringing the wire.

The table is based on soft-drawn copper wire, ultimate tensile strength 34,000 lb. per square inch. Triple-braided weatherproof insulation. Factor of safety, 4. Minimum temperature, −20 deg. fahr.

Span in feet	Deflection in inches						
	Temperature in degrees Fahrenheit						
	30°	40°	50°	60°	70°	80°	90°
50	8	9	9	10	11	11	12
60	10	11	11	12	13	14	14
70	11	12	13	14	15	16	17
80	13	14	15	16	17	18	19
90	14	16	17	18	19	20	21
100	16	17	19	20	21	23	24
110	18	19	21	22	24	25	26
120	19	21	23	24	26	27	28
140	22	24	26	28	30	32	33
160	26	28	30	32	34	36	38
180	29	32	34	36	39	41	43

63. Tying in Wires.—Normally the wires should rest in the insulator grooves as shown in Fig. 56, *A*, but where there is a side stress the wires should be so arranged that the pull comes against the insulators rather than away from them, Fig. 56, *B*. A single tie for the smaller wires is shown in Fig. 57, *A*, and a back tie for the

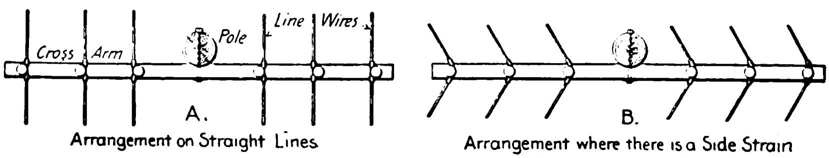


FIG. 56.—Positions of wires in insulator grooves.

larger wires is shown at *B*. The single tie wire is about 12 in. long and the back tie about 18 in. long. The back tie is made as follows: Bend the tie around the insulator under the line wire, with 4 in. on one side of the insulator and the balance on the other side. Wrap the short end three times around the line wire, leaving a space equal to the diameter of the tie wire between successive wraps.

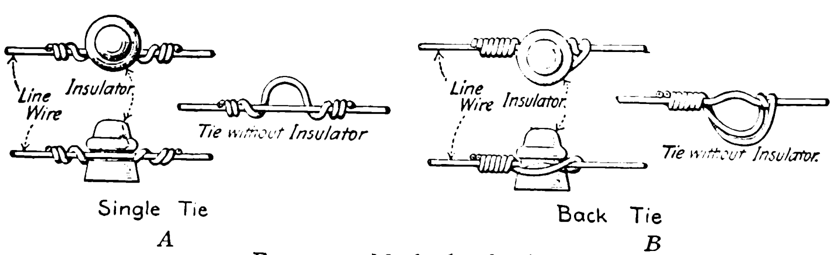


FIG. 57.—Methods of tying.

Now wrap the long end of the tie wire three times completely around the line wire, then back around the insulator and wrap it in the spaces left between the wraps of the other end of the tie wire. The ends of all tie wires should be cut off close to the line wire as shown in the illustration.

64. Tie Wires.—Tie wires should be insulated with the same material as the line wire. Do not use a tie wire twice as, after once being bent and strained, it will be brittle. The following table of sizes has been recommended for ordinary stresses. For very heavy stresses heavier tie wires should be used.

Size, line wire	Size, tie wire	Kind of tie
6	6	Single.
4	6	Single.
2	4	Single.
1	4	Back.
00 and larger	2	Back.

65. Tree Wiring.—Where wires are so carried through trees that they would rub against branches they should be supported by tree insulators of some sort or should be encased in abrasion molding. Wires should not be rigidly attached to branches or limbs because the swaying of the tree might break the wires. Fig. 58 shows some improvised tree insulators so arranged that the wires have enough play to insure against breakage. Several good patented tree insulators are on the market.

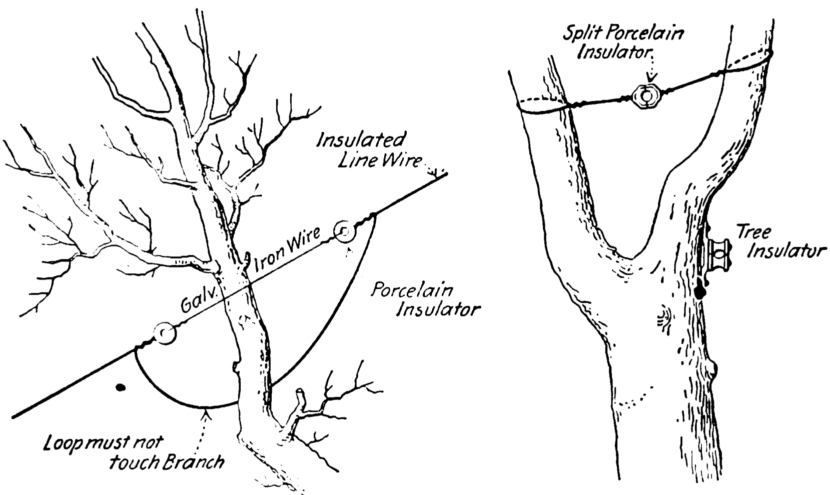
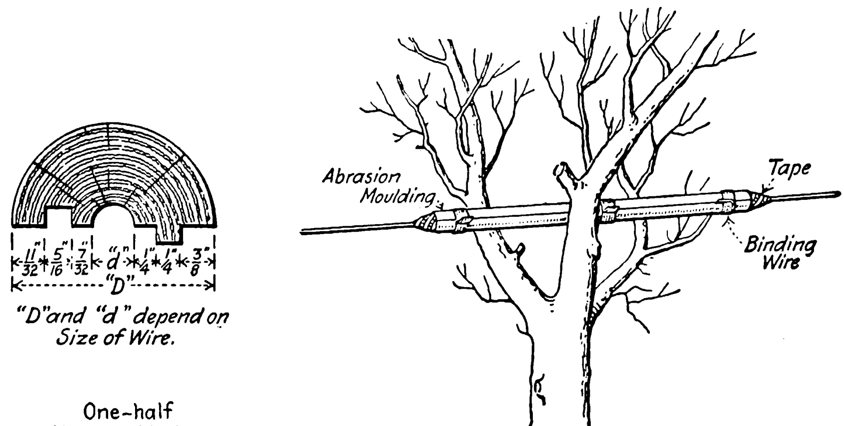


FIG. 58.—Improvised tree insulator.

66. Abrasion Molding.—Fig. 59 shows one type, made of wood, bound to the conductors with wire and taped at the ends to prevent slipping. Improvised tree moldings can be made from wooden strips nailed into the form of a box. The molding takes the brunt of the wear and prevents injury to the insulation. A length of abrasion molding should be sufficiently long that a branch cannot catch on its end.

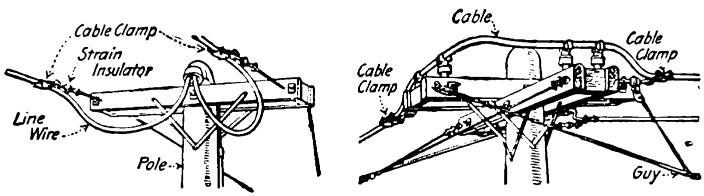
67. Cable clamps can often be used with economy at dead-ending points and corners. Fig. 60 shows some examples. Through the use of a cable clamp the "making up" of "dead ends," which is very expensive for heavy cables, is avoided; the line wire can be carried, without cutting, around a corner or in any new direction. The manufacturers claim, and it is probably true, that it is cheaper to purchase and install a cable clamp than to "make up a dead end" in any wire larger than No. 0000. The cable clamp grips the bare



One-half Abrasion Moulding.

Abrasion Moulding Installed.

FIG 59.—Abrasion moulding.

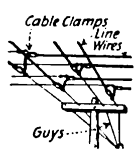


Dead-Ending two Cables at an Underground Junction. Pole with two Cable Clamps.

Outside Corner Turn, Using Clamps and Bridle Guy.

FIG. 60.—Application of cable clamp.

conductor, the pressure being furnished by four bolts. A strain insulator must be used to insulate the clamp from the bolt or turnbuckle that supports it. The dimensions of a Matthew's clamp for all wires of sizes from 000 to and including 2,000,000 cir. mils are given in Fig. 61.



Right-Angled Turn where it is not feasible to Locate Corner Pole.

FIG. 60A.—Application of cable clamp.

68. Specification and Test for Galvanized Iron and Steel for Line Construction.—The galvanizing shall consist of a coating of zinc, evenly and uniformly applied. The zinc shall be so applied that it will adhere to the surface of the iron or steel. The finished product shall be smooth.

Any specimen shall be capable of withstanding the following test: The sample shall be cleaned before testing, first with carbona, benzine or turpentine and cotton waste (not with a brush), and then thoroughly rinsed in clean water and wiped dry with clean cotton waste. The sample shall then be immersed in a standard solution of copper sulphate for 1 min. and then removed, immediately washed in water and thoroughly wiped dry. This process shall be repeated. If, after the fourth immersion there is a copper-colored deposit on the sample, or the zinc is removed, the lot from which the sample was taken shall be rejected. In the case of No. 14 galvanized-iron or steel wire, the time of the fourth immersion shall be reduced to ½ min.

69. Copper Sulphate Solution.—The standard solution of copper sulphate consists of commercial copper sulphate crystals in water. This solution has a specific gravity of 1.185 at 70 deg. fahr. While a sample is being tested the temperature of the standard solution should at no time be less than 60 deg. fahr., nor more than 70 deg. fahr.

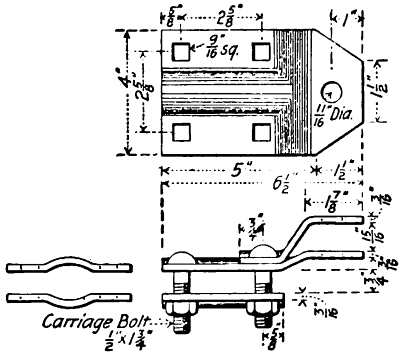


FIG. 61.—Dimensions of Matthew's cable clamp.

70. Cost per mile of pole-lines for 3-phase 2,300 to 6,600 volts. Data from six north-central and south-western states, 1909. From "Data," October, 1910. Figures are exclusive of painting, copper, engineering and general expense.

	Installation of minimum cost	Installation of maximum cost	Average
50 30-ft. poles	$171.00	$200.00	$218.90
50 sets pole hardware	8.30	16.00	10.25
50 2-pin cross-arms	17.00	11.50	14.00
150 insulators	6.75	11.20	9.00
Labor setting	55.00	200.00	109.00
Labor stringing wire	30.00	40.00	35.00
Incidentals	10.00	50.00	30.00
	$297.05	$528.70	$426.15

UNDERGROUND CONDUIT

71. Underground conduit construction is now an important and specialized branch of electrical engineering. In this book is given only enough information to enable one to lay out and install such minor underground structures as may be required in isolated plant or industrial plant work. Underground construction always costs more than overhead construction. In this country, "built-in" systems—those in which the cable is buried in the earth without protection—are seldom used because if trouble occurs on the conductors it is necessary to excavate to remove them.

72. Commercial duct materials are iron pipe, wood, cement-lined pipe, cement, vitrified clay and bituminized wood pulp. Only iron pipe, cement and virtified clay are recommended in this book as it is believed that, all things considered, these are the only materials that can be thoroughly depended on for power service.

73. **Creosoted wood ducts** are low in cost but will probably decay in time. Their life is said to be about twenty years if thoroughly creosoted. Wood ducts are inflammable and may burn in case of a short-circuit within them.

74. **Cement-lined pipe** was once used extensively but it was found that the arcs of short-circuits within such a duct cracked the cement lining. It chipped off and blocked the duct. There is little if any cement-lined pipe being installed at present.

74A. **Cement duct,** known as "Stone Duct," manufactured by a patented process that insures homogeneousness and strength is now being largely used in the Chicago district.

75. **Bituminized fiber duct** is easily laid and when new permits cables to be drawn into it readily because of its smooth oily interior surface. It is a comparatively recent product and its life is as yet undetermined. Furthermore, cases have been reported where duct lengths, in piles left to action of the heat of the sun, have been distorted by the weight of the duct lengths piled above them. Cases have also been reported where cables have stuck in fiber conduit and their withdrawal was thereby prevented. Probably this condition is most likely to occur where the duct is heated continuously either by overloaded conductors or by adjacent steam pipes. The upper portion of the duct sags down until it rests on the cable or possibly obstructs the duct if there is no cable in it.

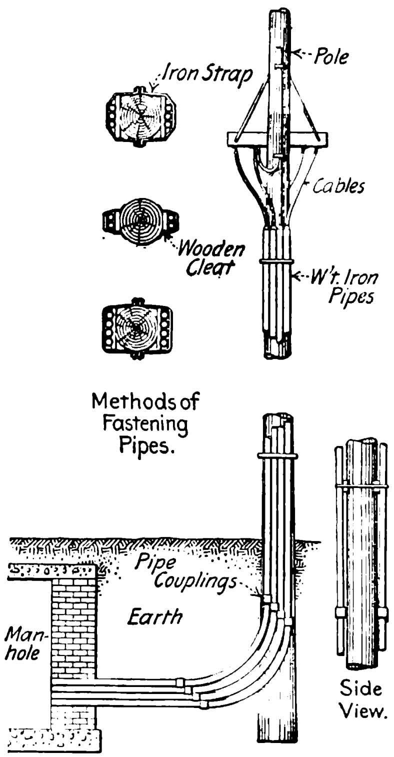


FIG. 61A.—Wrought-iron pipe laterals.

76. **Iron pipe** makes an admirable subway but its cost prevents its use except under certain conditions. Iron pipe appears to be the cheapest dependable duct material for laterals (Fig. 61, A) because it is not necessary to imbed it in concrete. It is also used where it is necessary to install many ducts in a limited space. It can be bent almost at will. Where it is necessary to thread a network of underground structures iron pipe is the only usable material. Where vitrified clay duct can be used it is to be preferred. Wrought-iron electrical conduit can be used for underground conduit but it is the practice of the larger companies to buy ordinary commercial wrought-iron pipe, usually 3 in. Wrought-iron pipe is preferable to steel pipe, which is often sold for wrought-iron, because the wrought-iron resists corrosion much more effect-

ively than does steel. See index for dimensions of wrought-iron conduit which are the same as those for wrought-iron pipe.

77. **Vitrified clay single duct** or hollow brick is the most popular for power cables. Fig. 62 shows a typical length. The dimensions of ducts furnished by the different manufacturers may vary from those of the illustration. The single duct is preferred because its walls are thick and in laying every joint is broken, eliminating the

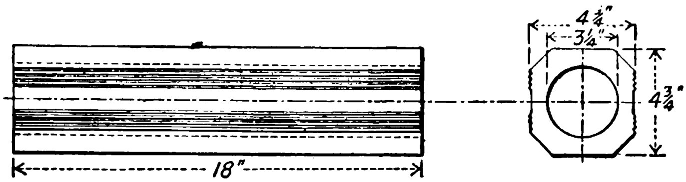


FIG. 62.—A piece of single duct.

possibility of the arc of a short-circuit on one cable affecting cables in other ducts in the same run. Single ducts can also be more readily laid around obstructions such as pipes and, furthermore, curves can be more readily formed with them than with multiple ducts.

78. **Vitrified clay multiple duct** is sometimes used for conduits for power cables but it is not as popular as single duct for the reasons given under "Single Duct." The four-way multiple duct is the

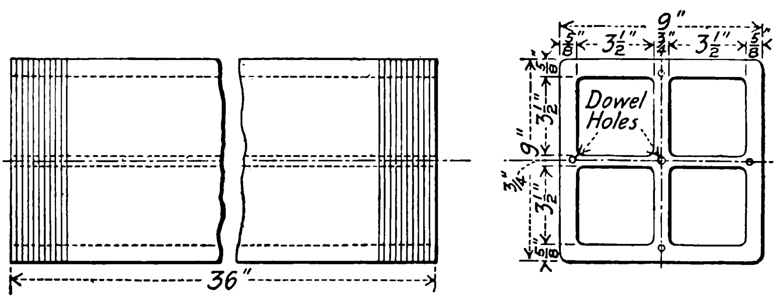


FIG. 63.—A piece of multiple duct.

most popular size (Fig. 63), although the six-way duct is frequently used. Nine,- twelve- and sixteen-way multiple ducts can be manufactured but they are seldom used because of their excessive weight and liability to breakage. The dimensions of the multiple ducts of a certain nominal size made by different manufacturers vary. Those shown in Fig. 63 for a four-way duct are typical.

79. **In laying any kind of a conduit,** after the trench is excavated its bottom should be rammed until solid and then leveled off and graded so as to pitch, from the center point between manholes toward each manhole, about 1 ft. in 100 ft. This is to insure effective drainage. The upper face of the conduit should be at least 2 ft. below the surface of the ground. The trench should

be 6 in. wider than the conduit to provide space for the 3-in. casing of concrete which is usually necessary around vitrified conduits. No wooden form is required for the concrete if the earth is compact and self-supporting. In yielding soils a rough wooden form, which can be removed after the concrete has set, can be used. The 3-in. bed of concrete should be placed parallel with the bottom of the graded trench. After the pieces of duct material are laid,

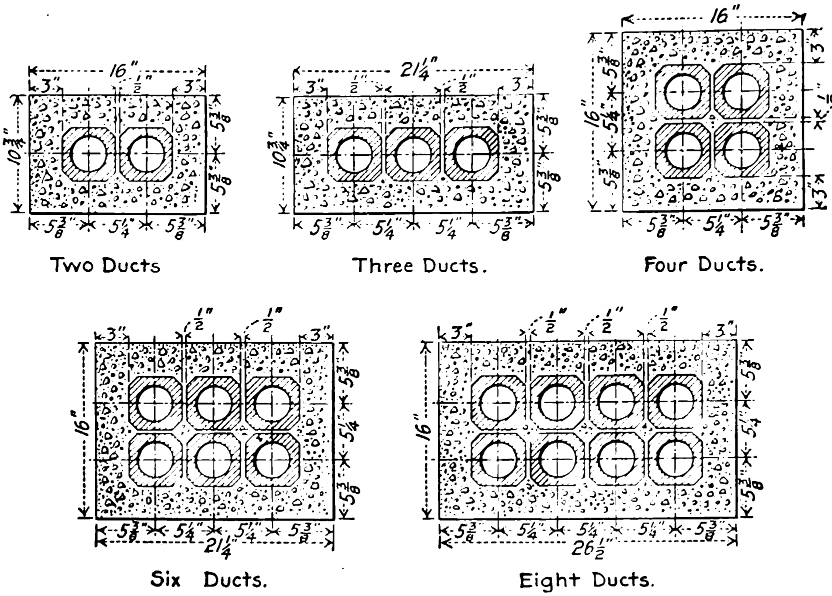


FIG. 64.—Arrangement of single-duct subway.

the 3-in. concrete sides should be carefully tamped in. Care must be taken not to disturb the duct alignment. Then the 3-in. concrete cover is spread over the ducts. Where the subway is composed of more than one tier, cement mortar should be placed between tiers as shown in the illustrations.

80. Laying Single-duct Conduit.—(See Fig. 64 for sections of single-duct runs.) A concrete bed, usually 3 in. thick, is placed on the bottom of the trench after the latter has been properly excavated, leveled and graded. After the bed is set the duct is laid in cement mortar. A mandrel (Figs. 65 and 66) is used to keep the successive pieces in line. It is customary to enclose the conduit in a continuous concrete encasement 3 in. to 4 in. thick.

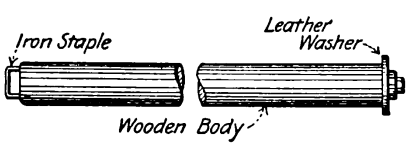


FIG. 65.—Mandrel for aligning conduit.

The mandrel is pulled through with a long hook as the conduit progresses, to align the ducts. The leather washer scrapes away any mortar that has oozed through between joints and leaves the duct quite clean. The end of a No. 12 galvanized-iron wire is frequently attached to the inner end of the mandrel and is pulled into the conduit as its construction progresses. The wire is used to pull in the drawing-in rope which is used to pull in the cable.

The single ducts furnished by some manufacturers are provided with male and female ends which assist in aligning the ducts.

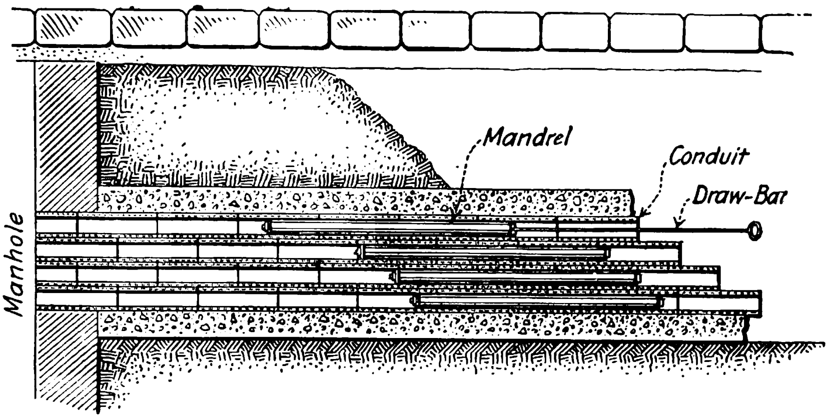


FIG. 66.—Showing use of mandrel.

81. **Laying Multiple Duct.**—Multiple duct is laid in about the same way as single duct. Fig. 67 shows sections of multiple-duct runs. The pieces are laid end-to-end and the joints, if there is more than one tier in the subway, are broken. The pieces are maintained in alignment by iron dowel pins or keys (Fig. 68)

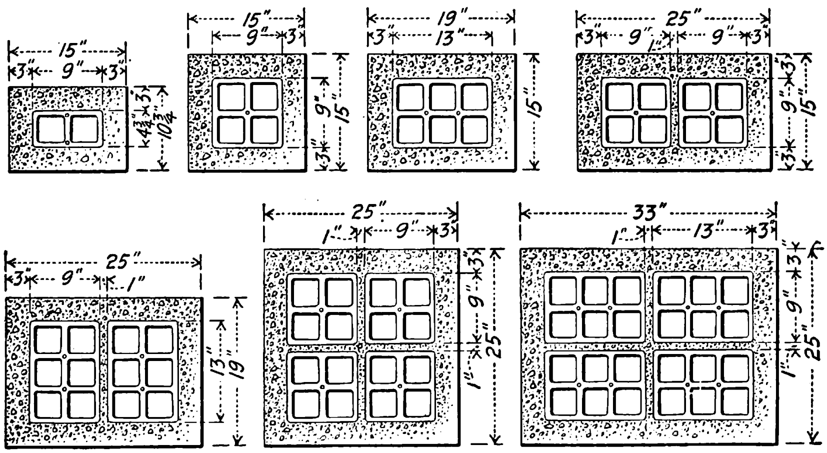


FIG. 67.—Sections of multiple duct.

which fit in holes in the pieces. All joints are wrapped with pieces of burlap or coarse muslin, 4 in. wide and 3 ft. long for 4-duct tile, which are moistened to make them stick. They are then coated with cement. The cloth prevents the entrance of cement or concrete into the ducts.

Sometimes a mandrel (Fig. 65) $\frac{1}{4}$ in. to $\frac{1}{2}$ in. smaller than the hole is drawn through as the construction progresses, as suggested in Fig. 66, to insure alignment of the pieces. The handle on the mandril should be long enough to reach back two joints so that one may be sure that the last three pieces set align, as they may have become displaced in setting.

After the pieces are set, be careful that they are not displaced prior to depositing the concrete jacket. The ducts should be cleaned out after the concrete jacket has been placed by drawing a wire brush or flue cleaner (Fig. 69) through them. The brush is somewhat bigger than the duct hole. Sometimes a metal scraper (Fig. 69) is also used.

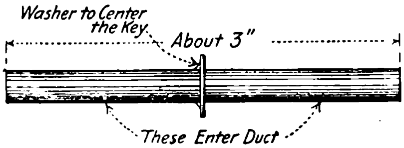


FIG. 68.—Steel key for multiple duct.

Multiple duct has been laid without any concrete casing, merely a concrete bed, as suggested in Fig. 70. This construction is economical in first cost but is apt to give trouble through settling

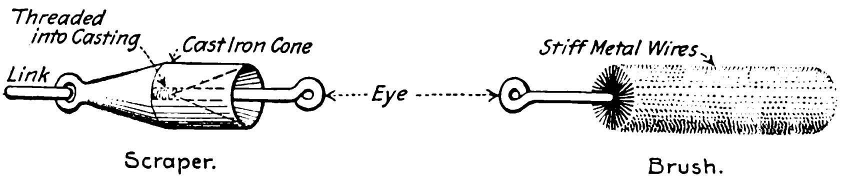


FIG. 69.—Scraper and brush for conduit.

of the earth or displacement due to future excavation. Creosoted boards are sometimes laid on top of a conduit run to protect against laborer's picks. Experience has shown that the average laborer will stop when his pick strikes a board but he will pick his way through concrete or duct material.

Multiple-duct conduit can be carried around obstructions, as shown in Fig. 71, by beveling the ends of the pieces. If the turn is too short it may be difficult or impossible to "rod" the duct and to pull the cable in.

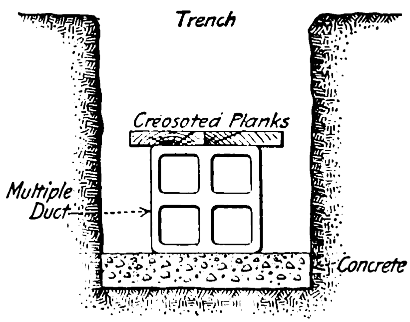


FIG. 70.—Protective planks over multiple duct.

82. To cut vitrified conduit a groove is chipped completely around the piece on the line at which it is desired to cut it. A hammer and cold-chisel are used for chipping the groove. Usually it will break off on the chipped line after continued chipping, but it may not. Some experience is required before one becomes skillful at this work. Short lengths can be furnished by the conduit manufacturers and their use is recommended.

83. In installing iron-pipe conduit no concrete casing is considered necessary if only one duct is involved. Where there are several ducts in the run, the ducts are sometimes laid on a 3-in. foundation of concrete and concrete is tamped between and around the ducts as shown in Fig. 64 for single vitrified duct. Where the ducts will not be exposed to the dangers of future excavation the cost of the concrete is probably not justified. Iron pipe is sold usually in 20-ft. lengths. Joints between adjacent lengths

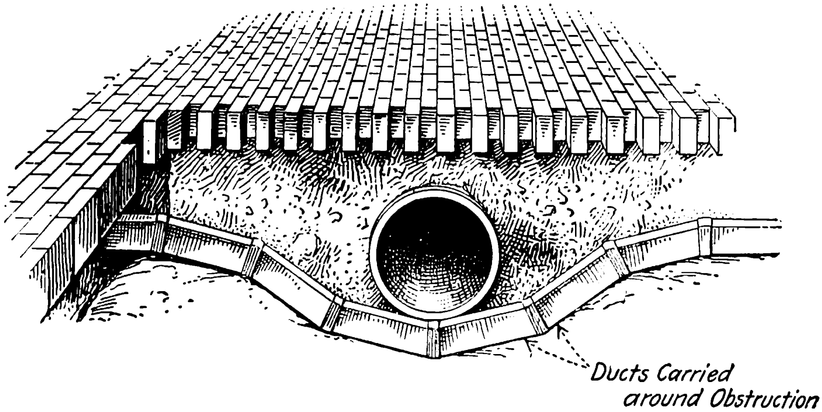


FIG. 71.—Breaking around an obstruction with vitrified duct.

are made with ordinary pipe couplings. (Fig. 61, *A*.) See Index for dimensions of conduit and fittings which are the same as those for pipe. The burrs at the ends of pipe lengths must be carefully removed to prevent damage to the cable. Where it is inconvenient to use a coupling, a pipe union can be used instead or the fitting can be omitted (Fig. 72) and the abutting ends encased in a block of concrete. The ends should be wrapped with a piece of sheet iron wired in position before the concrete is applied.

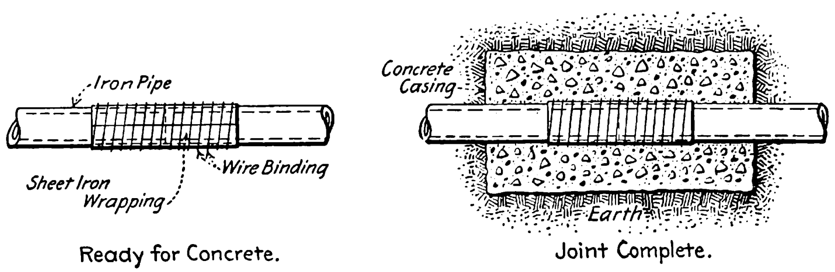


FIG. 72.—Cement joint on wrought-iron pipe.

Iron pipe for conduit is sometimes painted, inside and out, with asphaltum, but this is not considered necessary by all engineers.

84. Concrete for conduit work should be clean, that is, foreign substances should not be permitted to enter into its composition. If the surface on which it is to be mixed is not smooth and clean, mixing boards or pans should be used. Foreign material impairs the strength of concrete and it becomes porous and leaky. The concrete should be mixed from Portland cement, clean sand, and gravel or broken stone, in the proportions by volume, of one part of cement to three parts of sand and five parts of gravel or stone. Just sufficient water should be used to thoroughly wet the mixture and to permit a small amount of water to come to the surface when the concrete is tamped into final position. The cement, sand and stone should be "turned" on the mixing board at least three times dry, and at least twice after wetting. The concrete should be placed immediately after mixing. When the concrete has been placed in the trench, several hours should be allowed for it to take its initial set before the trench is filled in. This is necessary to prevent throwing the ducts out of alignment, or fracturing the "green" concrete.

85. Cost of Laying Vitrified Conduit Per Lineal Foot (*H. C. Spellman, The World,* April 7, 1910).—Cost includes conduit, excavation, refilling, removal and replacement of pavement and a 3-in. jacket of concrete on all four sides of the conduit line. In fact, the figures shown are total costs for a complete subway run.

No. of conduits	Brick, granite, stone (grouted)	Asphalt tarred brick	Cedar (on concrete)	Cedar or cobble on sand	In grass plat	Dirt
1	$1.15	$1.10	$1.00	$0.70	$0.60	$0.50
2	1.25	1.20	1.10	0.80	0.70	0.60
3	1.35	1.30	1.20	0.90	0.80	0.70
4	1.45	1.40	1.30	1.00	0.90	0.80
5	1.55	1.50	1.40	1.10	1.00	0.90
6	1.65	1.60	1.50	1.20	1.10	1.00
7	1.75	1.70	1.60	1.30	1.20	1.10
8	1.85	1.80	1.70	1.40	1.30	1.20
9	1.95	1.90	1.80	1.50	1.40	1.30
10	2.05	2.00	1.90	1.60	1.50	1.40
11	2.15	2.10	2.00	1.70	1.60	1.50
12	2.25	2.20	2.10	1.80	1.70	1.60
13	2.35	2.30	2.20	1.90	1.80	1.70
14	2.45	2.40	2.30	2.00	1.90	1.80
15	2.55	2.50	2.40	2.10	2.00	.190
16	2.65	2.60	2.50	2.20	2.10	2.00
17	2.75	2.70	2.60	2.30	2.20	2.10
18	2.85	2.80	2.70	2.40	2.30	2.20
19	2.95	2.90	2.80	2.50	2.40	2.30
20	3.05	3.00	2.90	2.60	2.50	2.40
21	3.15	3.10	3.00	2.70	2.60	2.50
22	3.25	3.20	3.10	2.80	2.70	2.60
23	3.35	3.30	3.20	2.90	2.80	2.70
24	3.45	3.40	3.30	3.00	2.90	2.80

86. Manholes are necessary in a subway system to permit of the installation, removal, splicing and rearrangement of the cables. A manhole is merely a subterranean vault or masonry chamber of sufficient size to permit of proper manipulation of the cables. The conduits enter the vault and on its sides devices are arranged whereby the cables within the manhole can be supported.

87. The location of manholes is determined largely by the layout of the district that is to be supplied with power. Wherever a branch or lateral extends from the main subway there must be a manhole, and there must be manholes at intersections of subways. In general, cables are not made in lengths exceeding from 400 ft. to 600 ft. and, as it is necessary to locate splices in manholes, the distance between manholes cannot exceed these values. Furthermore it is not advisable to pull in very long lengths of cable because the mechanical strain on the conductors and sheath may then become too great during the pulling-in process. It is recommended that manholes be located not more than 500 ft. apart.

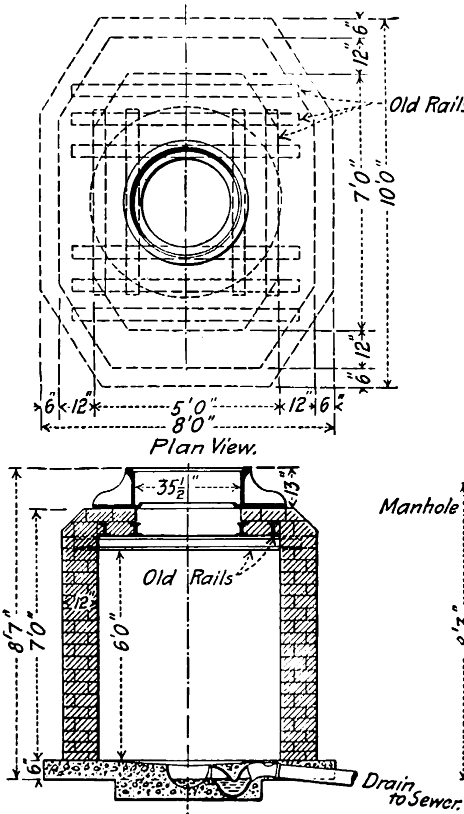


FIG. 73.—A 5 ft.×7 ft. brick manhole.

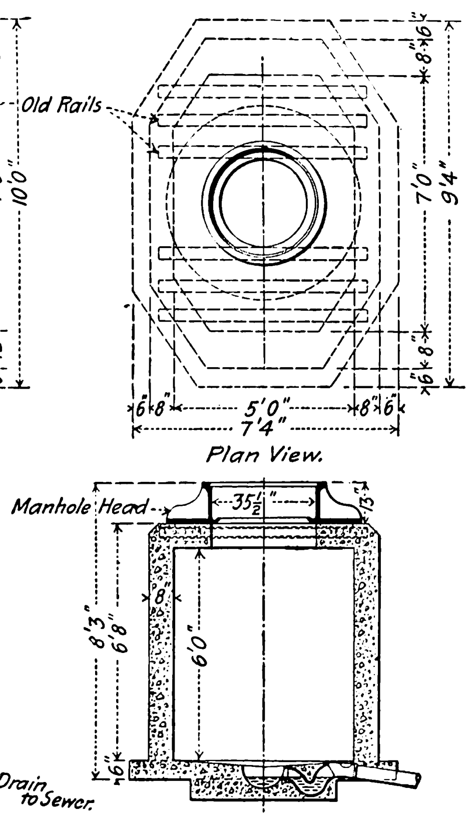


FIG. 74.—A 5 ft.×7 ft. concrete manhole.

88. Manholes are made of many shapes and sizes to meet the ideas of the designer and to satisfy local conditions. It is established, however, that the form shown in Fig 73 is best for the average condition. Where there are obstacles about the point where a manhole is to be located, the form of the manhole must be modified so as to avoid them. The form approximating an ellipse is used so the cables will not be abruptly bent in training them around the manhole.

89. Manholes are built of either brick or concrete, or of both of these materials. Where many manholes are to be built of one size and there are no subterranean obstructions, concrete is usually the cheapest and best material. But where only a few are to be constructed or where there are many obstructions a manhole with a concrete bottom, brick sides, and a concrete top is probably the best. Such a manhole can be constructed without having to wait for concrete to set before forms can be removed and, furthermore, no forms, except some planks to support the top, are necessary

90. **The size of manholes** will vary with the number of cables to be accommodated, but in any case there must be sufficient

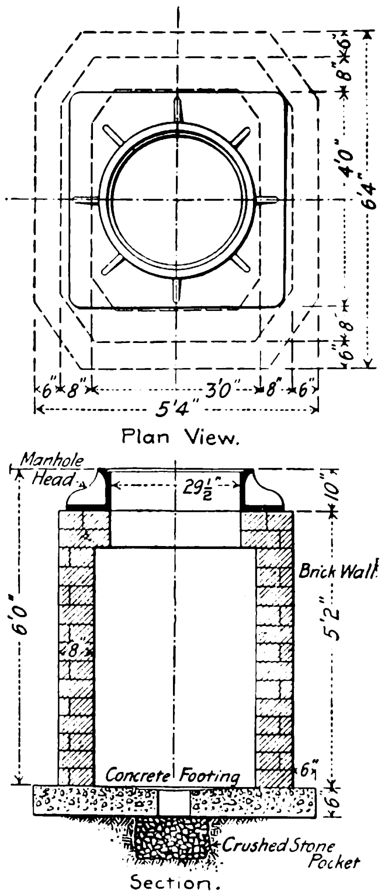


FIG. 75.—A 3 ft.×4 ft. manhole.

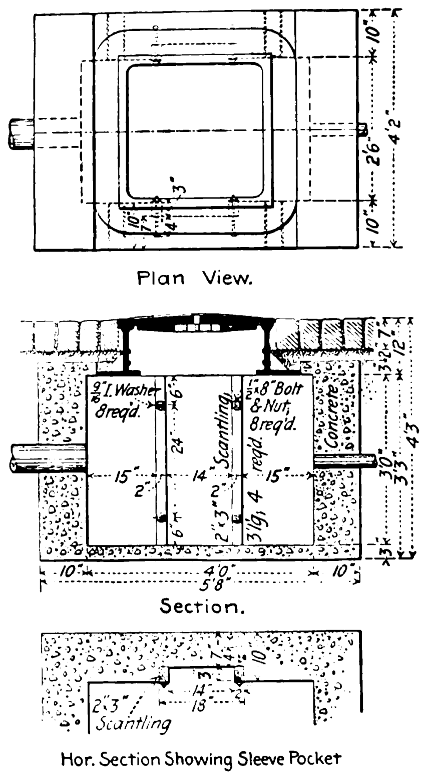


FIG. 76.—A concrete service box.

room to work in the manhole. A 5 ft. by 7 ft. manhole (Fig. 73) is probably as large as will be required in isolated plant work, while a 3 ft. by 4 ft. manhole (Fig. 75) is about as small as should be used.

91. **A concrete manhole is built** by first depositing the concrete floor (Fig. 74) and then erecting the form for the sides on this floor. In a self-supporting soil the sides of the hole constitute the form for the outside of the manhole. If the soil is not self-sup-

porting, an outer form of rough planks must be made which is usually left in the ground. Steel reinforcing—old rails are good—must be placed in the concrete top of a large manhole. In a small manhole the manhole head or cover will extend over the side walls and no reinforcing, or manhole roof for that matter, are required. All reinforcing steel should be completely encased in concrete to prevent corrosion.

92. **A manhole with brick walls is built** (Fig. 73) by first depositing the concrete floor and then building up the brick walls thereon. Where the manhole is large the roof can be of either

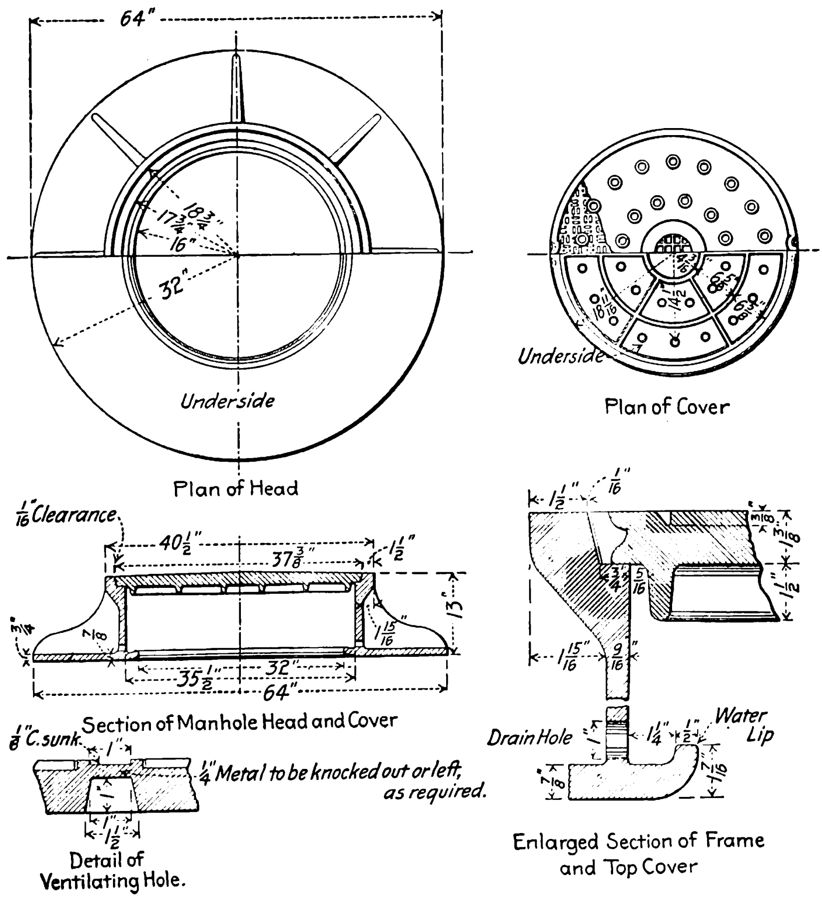


FIG. 77.—Head for large manholes.

steel-reinforced concrete or brick set between rails. Probably for installations where only a few manholes are to be built the brick-between-rails method is the best. For a small manhole no masonry roof is necessary as the cast-iron manhole head forms the roof.

93. **Distribution or service boxes,** so called, which are really small manholes, often serve the purpose of, and can be used instead of larger vaults in industrial and isolated plant installations. A

design for a concrete service box is shown in Fig. 76. A brick one would be of approximately the same dimensions. The depressions in the side walls are sleeve pockets. The splicing sleeves on the cables lie partially in these, after installation, and therefore less of the valuable working space of the box is occupied by them. In spite of the fact that a square manhole cover can fall into the hole, heads with square covers are often used for distribution boxes so as to provide an orifice giving maximum working room.

94. Manhole heads are frequently made of cast-iron, but cast steel is better. Fig. 77 shows a design for cast-iron, for a large

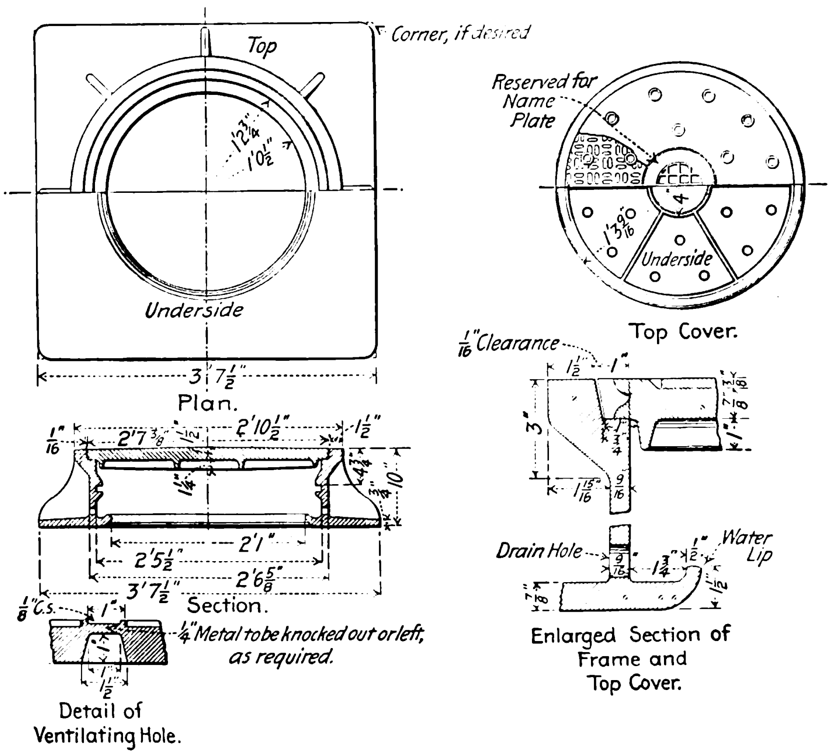


FIG. 78.—Head for small manholes.

manhole, and Fig. 78 one for a smaller manhole. Covers should be round so that they cannot drop into the hole. So-called water-tight covers are now seldom used as it is not feasible to make a satisfactory water-tight cover at reasonable expense and water gets into the manholes in any event. Covers should not be fastened down because if they are and accumulated gas in a manhole explodes, the vault will be shattered. If the manhole tends to fill with gas, holes should be made in the cover for ventilation. Dirt and water will get into the hole, but the dirt can be cleaned out and the water will drain out and no harm will result. If ventilation is not provided an explosion of gas may occur and do great damage.

95. **Draining Manholes.**—Where feasible, a sewer connection should lead from the bottom of every manhole. (See Fig. 74.) The mouth of the trap should be protected by a strainer, made of non-corrodable wire, such as that used for leader pipes. Where a sewer connection cannot be made there should be a hole in the manhole floor so that water can drain out. A pocket, filled with broken rock, under the hole will promote effective drainage. (See Fig. 75.)

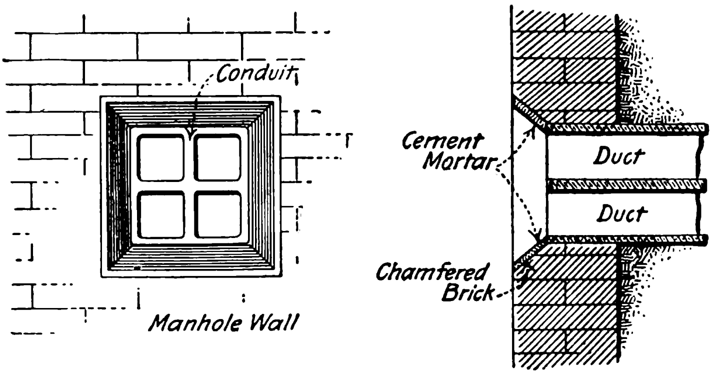


FIG. 79.—Chamfered wall at conduit entrance.

96. **At the point where a conduit line** enters a manhole the walls should be chamfered off as shown in Fig. 79 to prevent the damage that might occur if a cable is bent over a sharp corner.

97. **A manhole hook,** a convenient tool for removing manhole heads, is shown in Fig. 80. A common pick can be used, but the tool shown is much more convenient.

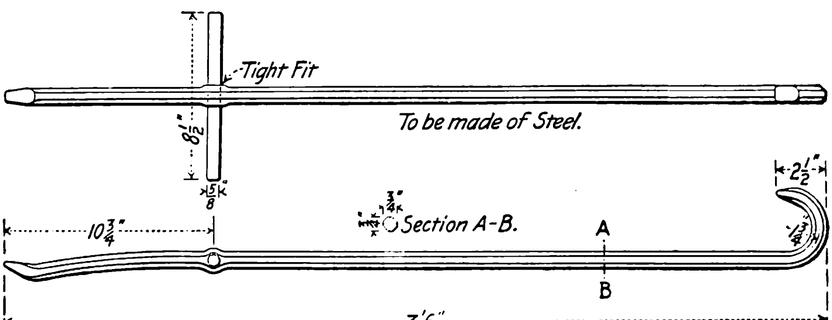


FIG. 80.—A manhole hook.

98. **Cement mortar** for building brick manholes or for conduit construction can be made by mixing together 1 part of cement and 3 parts of sand and about ⅓ part of water, all by volume.

99. **In installing cables in conduit,** if a pull-in wire was not installed at the time the ducts were placed, the conduit is rodded, a pull-in wire or the drawing-in-cable is drawn through, cleaners are pulled through and then the cable is drawn in.

100. Average Cost of Manholes in Dollars

(*Standard Handbook*)

Brick with brick roof

Item	Amount	Rate ($) Min.	Rate ($) Ave.	Rate ($) Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	12.6	$11.25	11.8	$ 15.00	11.2
Concrete	0.7 cu. yd.	5.00	7.00	9.00	3.50	5.9	4.90	5.1	6.00	4.4
Brick	2,200	12.00	15.00	18.00	26.40	44.5	33.00	34.6	39.60	29.4
Cover	1	5.00	10.00	15.00	5.00	8.4	10.00	10.4	15.00	11.2
Iron	500 lb.	0.015	0.03	0.05	7.50	12.6	14.00	14.6	25.00	18.6
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	7.6	15.00	15.7	24.00	17.8
Cleaning	....	0.50	0.75	1.00	5.00	8.4	7.50	7.8	10.00	7.4
Totals	....	....	....	....	$59.40	100.0	$95.65	100.0	$134.60	100.0
Brick with concrete roof										
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	14.8	$11.25	14.4	$15.00	13.8
Concrete	1.9 cu. yd.	5.00	7.00	9.00	9.50	18.7	13.30	17.0	17.10	15.7
Brick	1,600	12.00	15.00	18.00	19.20	37.8	24.00	30.7	28.80	25.7
Cover	1	5.00	10.00	15.00	5.00	9.9	10.00	12.8	15.00	13.8
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	8.9	12.00	15.4	24.00	21.9
Cleaning	....	0.50	0.75	1.00	5.00	9.9	7.50	9.5	10.00	9.1
Totals	....	....	....	....	$50.70	100.0	$78.05	100.0	$109.90	100.0
Concrete manhole										
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	16.8	$11.25	15.5	$ 15.00	14.3
Concrete	4.5 cu. yd.	5.00	7.00	9.00	22.50	50.5	31.50	43.6	40.50	38.8
Cover	1	5.00	10.00	15.00	5.00	11.2	10.00	13.9	15.00	14.4
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	10.2	12.00	16.6	24.00	23.0
Cleaning	....	0.50	0.75	1.00	5.00	11.3	7.50	10.4	10.00	9.5
Totals	....	....	....	....	$4.50	100.0	$72.25	100.0	$104.50	100.0

101. Cost of Sewer Connection in Dollars

Item	Amount	Rate ($) Min.	Rate ($) Ave.	Rate ($) Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	225 cu. ft.	0.02	0.03	0.04	$ 4.50	35.1	$ 6.75	26.0	$ 9.00	21.4
Concrete	5 cu. yd.	0.75	2.00	4.00	3.75	29.2	10.00	38.8	20.00	47.0
Cover	1	1.00	2.50	4.00	1.00	7.6	2.50	9.6	4.00	9.3
Repaving	16 ft.	0.04	0.07	0.10	0.64	5.0	1.12	4.4	1.60	3.6
Brick	....	0.50	0.75	1.00	1.00	7.6	1.50	5.8	2.00	.47
Cleaning	1	2.00	4.00	6.00	2.00	15.5	4.00	15.4	6.00	14.0
Totals	....	....	....	....	$12.89	100.0	$25.87	100.0	$42.60	100.0

102. Rodding.—Rods are pieces of round hickory about $\frac{3}{4}$ in. in diameter and 3 ft. long. (See Fig. 81.) The ends of the rods are equipped with brass knuckle-joint fittings so the rods can be readily joined together and disjoined. In rodding, a rod is pushed into the duct and a second rod is coupled to it. The two are pushed into the duct and a third rod joined on and the process is repeated until the rods extend from manhole to manhole. A galvanized-iron wire is attached to the last rod and the wire is drawn into the duct.

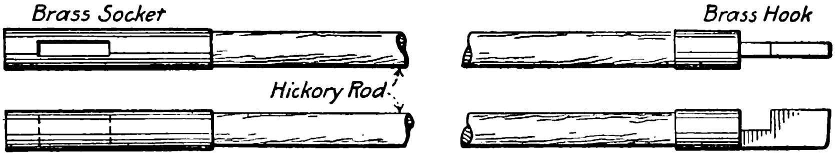


FIG. 81.—Rods for conduit.

A rope or flexible steel cable to which are attached a scraper and a brush (Fig. 69) is drawn through to insure that the duct is clear and clean. To the end of this rope or cable another is attached which is used to pull in the electrical conductor cable.

Where the conduit is short, a steel fish wire or ribbon, like that used by electricians in wrought-iron conduit work, can be inserted instead of the rods. Sometimes a "fish" made of lengths of flexible bamboo is used instead for laterals and other short runs.

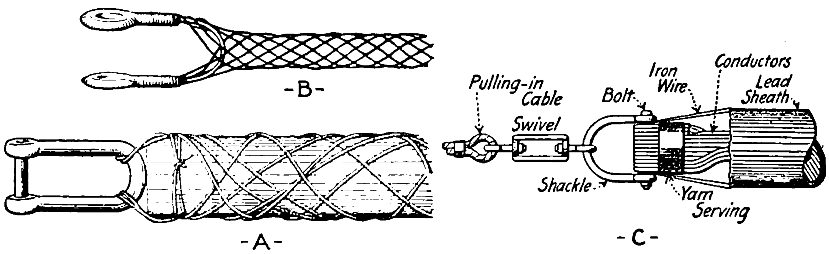


FIG. 82.—Methods of attaching cable to drawing-in line.

103. Pulling in Cable.—The cable can be attached to the pulling-in wire by any one of several methods. Fig. 82, *C* shows one that was formerly much used. Probably the best methods are those illustrated in Fig. 82, *A* and *B*. At *A*, a galvanized iron wire is laced around the cable in such a way that the harder it is pulled the tighter it grips. At *B* is shown a "grip" spirally laced from flexible steel strands. It slips over the cable sheath readily, but when tension is applied it effectively grips the cable. A swivel should always be inserted in any pulling-in line to prevent the untwisting of the drawing-in line under tension from twisting the cable.

After the cable is fastened to the pulling-in line a "protector" is placed in the mouth of the duct to prevent abrasion of the cable. Metal protectors can be purchased, but a good one can be formed from a piece of sole leather.

The cable is bent, as shown in Fig. 83, from the cable reel to the mouth of the duct and the pulling in commences. In the far manhole sheaves are arranged over which the pulling-in line passes. (See Fig. 83.) If eye bolts were built in the manhole sides the sheaves (snatch-blocks) can be fastened to them. Otherwise a guide-sheeve-rack (see Fig. 84 for detail and Fig. 83 for application) can be set up in the manhole.

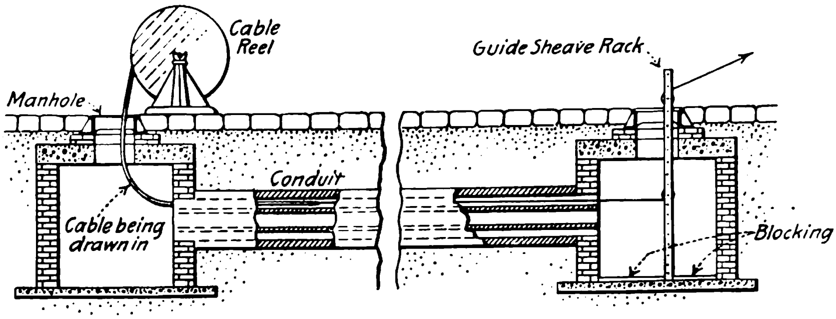


FIG. 83.—Drawing in cable with winch.

A winch or horses can be used for the pulling. Men can pull a cable in if the run is not too long. The cable sheath should be greased as it is drawn in to insure easy pulling. Where a length of cable longer than the distance between manholes is to be pulled through, it can pass over the sleeves on the guide sleeve rack, provided they are large enough in diameter. A cable should not be bent to any radius smaller than 10 times its diameter. A manhole capstan, Fig. 85, is sometimes used instead of a winch on the surface of the ground. Enough cable should be pulled into the manhole to allow for forming it around the hole and splicing it. Do not permit a cable to hang over the sharp edge of a duct. Support it in the rack.

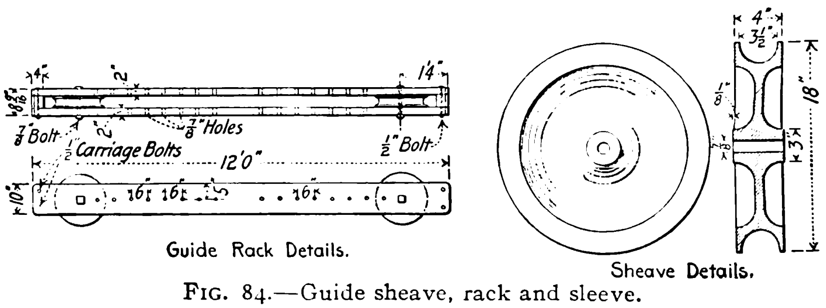


FIG. 84.—Guide sheave, rack and sleeve.

104. Supporting Cables in Manholes.—Some provision must be made. Creosoted planks, Fig. 86, are sometimes bolted to the manhole sides and the cables are held to the cleats with pipe straps. In other cases metal supports are used several forms of which are on the market. One that can be readily made is shown in Fig. 87. Shelves around the sides of the manholes can be formed of bricks as shown in Fig. 88. This is an excellent and probably the best method.

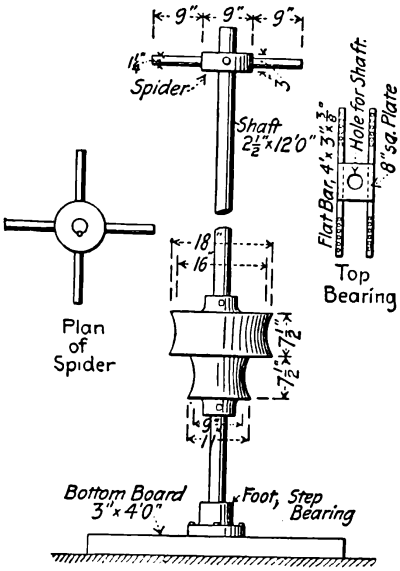


FIG. 85.—Manhole capstan.

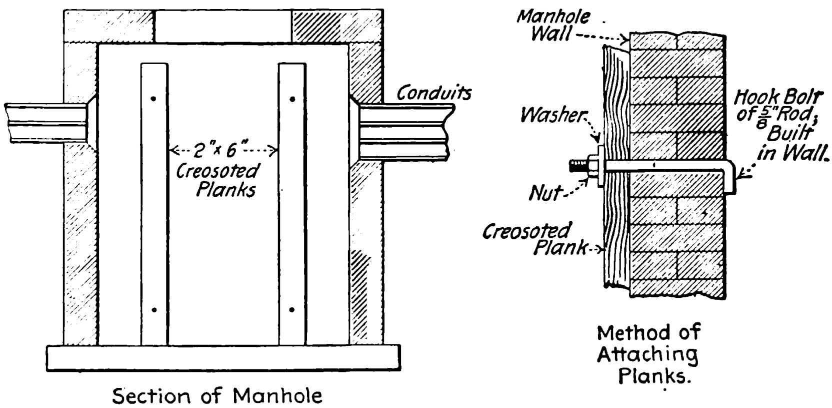


FIG. 86.—Creosoted plank cable supports.

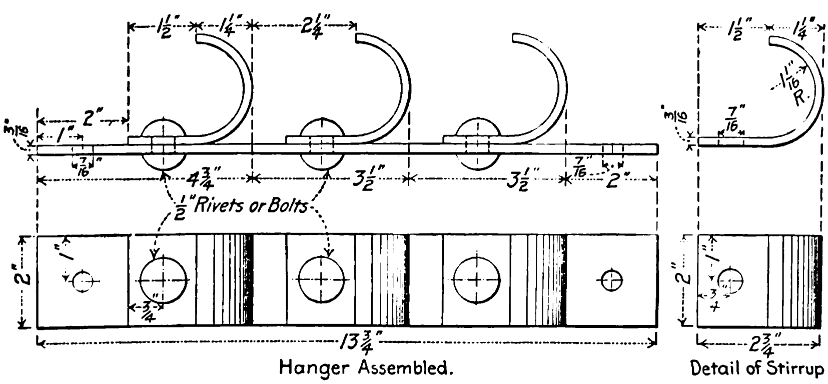


FIG. 87—Iron cable support.

105. Eyebolts or stirrups should be set in manhole walls to provide means of attachment for the tackle used in pulling in cable. (Fig. 88.) An eyebolt or stirrups should be set opposite the point of entrance of each subway. Fig. 89 shows the dimensions of a suitable stirrup.

106. Several Cables Should not be Placed in One Duct.—Experience has shown that while it is easy enough to install cables under such conditions and mechanically easy to withdraw them, the removal almost invariably ruins the cable, because after long lying in a duct the cables become so impacted with dust and grit that when one is drawn out the sheath is either stripped from the cable itself, or from one of its companions. Consequently conduits are now almost exclusively built by arranging a sufficient number of ducts so that each cable may have its own exclusive compartment.

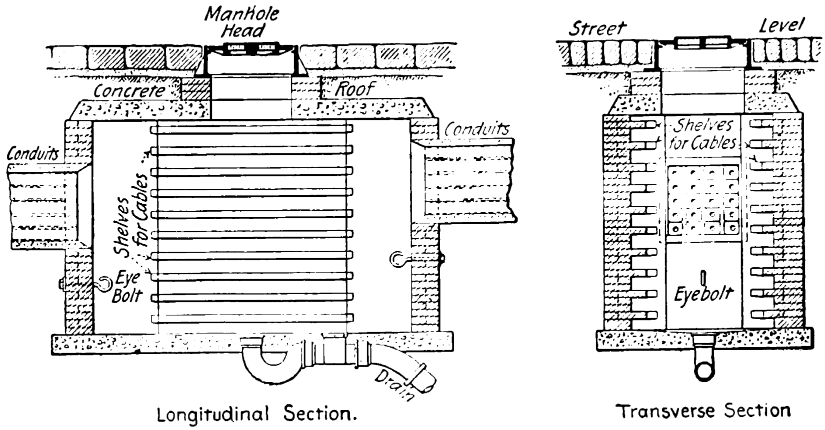


FIG. 88.—Cable shelves of brick.

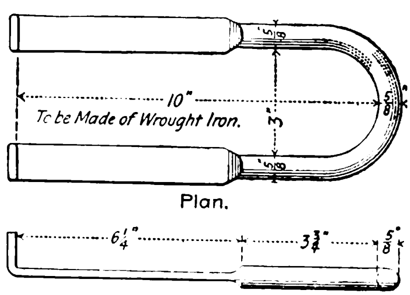


FIG. 89.—Stirrup for manhole wall.

107. In manholes and ducts cables should be so arranged that there will be a minimum of crossing and recrossing. An underground cable system should be carefully planned and the ducts should be so chosen for the cables that, insofar as feasible, a cable will take the duct in the same relative position throughout the subway.

DESIGN OF DISTRIBUTION INSTALLATIONS

108. In designing an installation of conductors for the distribution of electricity there is no royal road. It is rather a "cut-and-try" process and frequently, for a reasonably large installation, many tentative lay-outs must be made before the most suitable one is found. The design of such lay-outs is affected by so many conditions that only the most general suggestions can be given. Review the information on distribution in the "Fundamentals" section of this book.

109. In laying out any electrical distribution system the first step, if the system is of any consequence, is to note on a scale map of the territory to be served, the locations at which electricity will be required and the amount of power that will be taken at each. In general, each building in the area to be served is considered as a unit as it is seldom advisable to install more than one

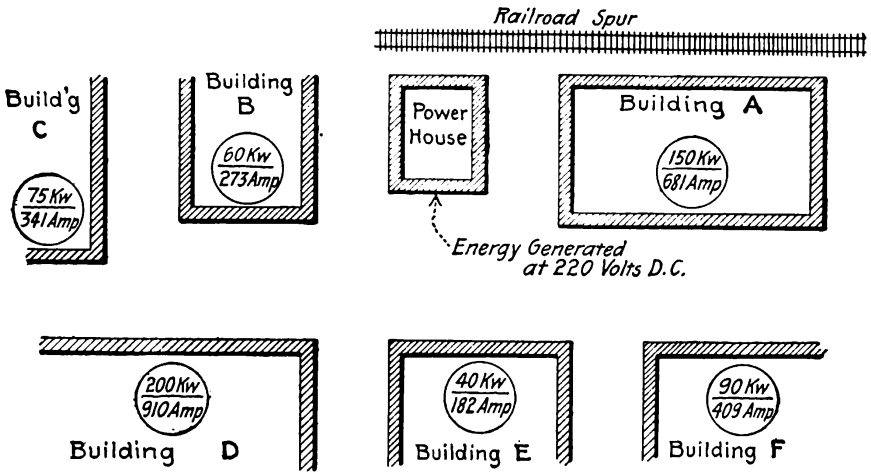


FIG. 90.—Power and current demands in an industrial plant.

service to a building. Fig. 90 shows such a lay-out for an imaginary industrial plant and Fig. 91 for a portion of a town. The values within the circles indicate the maximum power demands. That above the horizontal line is the power demand in kilowatts and the value below the line is the current, the power factor being considered if the system is to be alternating current. If separate circuits are to be maintained for light and for power, which is usual practice, the power demand for each circuit should be noted. In the illustrations (Figs. 90 and 91) it is assumed, for simplicity, that power and lighting devices are served from the same circuits. The current is noted in addition to the power demand because it is necessary to know the current to determine the capacities of fuses and switches and to check conductor sizes for current-carrying capacity.

110. Lay-out of Feeders and Mains.—After the locations of the points where energy will be required have been plotted and the amount of power that will be required at each has been noted, the feeders and mains can be laid out and the conductor sizes for them calculated. No hard and fast directions can be given. Each case must be treated individually in accordance with the conditions to be satisfied. The desideratum is to so plan the lay-out that the cost of the conductors and their supports will be a minimum and that, at the same time, the energy loss in the conductors will be reasonably small, and the whole system will be as reliable in operation and the voltage regulation will be as close as conditions warrant. Sometimes considerable expense is justified to secure reliability and close voltage regulation, but in other cases reliability and close voltage regulation are unimportant and the cheapest lay-out that will give service is the most desirable. Whether the distribution conductors are to be carried overhead—on poles or buildings—or underground will affect their routing.

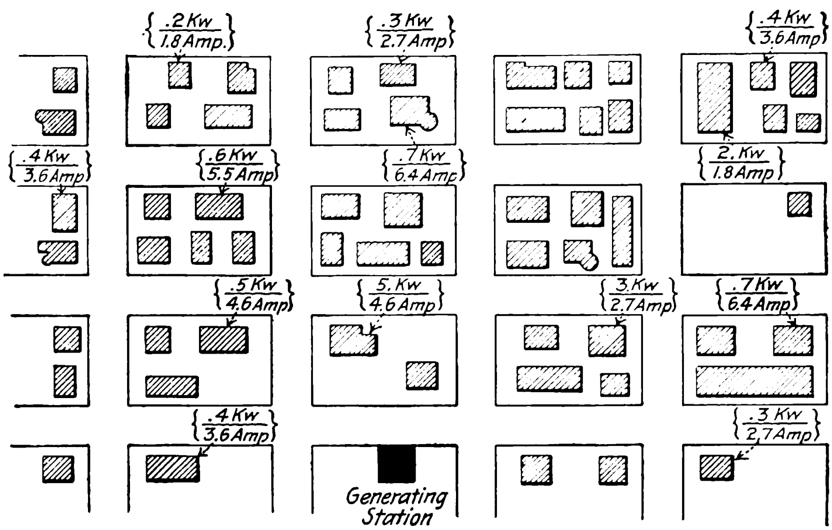


FIG. 91.—Power and current demands in a small town.

111. **The magnitude of load that should be served by one feeder or main** is altogether a relative matter and depends to an extent upon the flexibility of control and of metering desired and on the station capacity. In industrial plant installations if it is desired to meter in the generating station the energy supplied to different departments or buildings, obviously an individual circuit must be carried from the switchboard to every such building. It should be possible to disconnect portions of the load at the powerhouse, in case of trouble with the generators or in case a heavy load increase is thrown suddenly on the station, to tide over an emergency without shutting down the entire plant. In general, in a small station, the load on any feeder should not be larger than can be readily carried by any one of the generating units and it is better to have the load further subdivided. Usually a load divides itself naturally into convenient units because of the arrangement of buildings, groups of buildings, departments or other topographical or commercial considerations.

112. **Mains are Sometimes Tapered.**—A tapered main is one in which the conductor size diminishes from the point of source of energy outward. (See Fig. 92.) It is usual, and ordinarily the best, practice to use a main of the same size conductor throughout its length. Splices and intermediate cut-outs are thereby avoided. Theoretically, a tapering main, assuming a given maximum drop, does not effect a saving in copper as is often but erroneously believed. See Crockers, *Electric Lighting*, Vol. I, page 32.

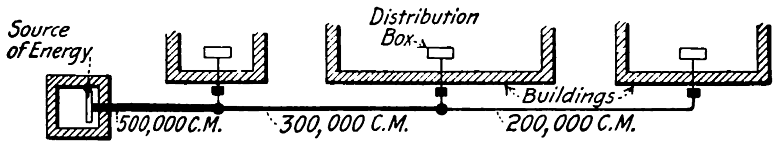


Fig. 92.—A tapered main.

113. **The calculation of wire sizes for feeders and mains** for distribution installations are made similarly to those for interior circuits. Methods and examples of calculation for the different systems are given in the "**Fundamentals**" section of this book.

114. **Overhead vs. Underground Distribution.**—Whether an overhead or underground distribution should be used depends in the case of small or medium-sized installations very largely on how much can be spent for appearances. An overhead system, properly installed, can be made thoroughly reliable and will usually cost much less than an equivalent underground system. Sometimes in

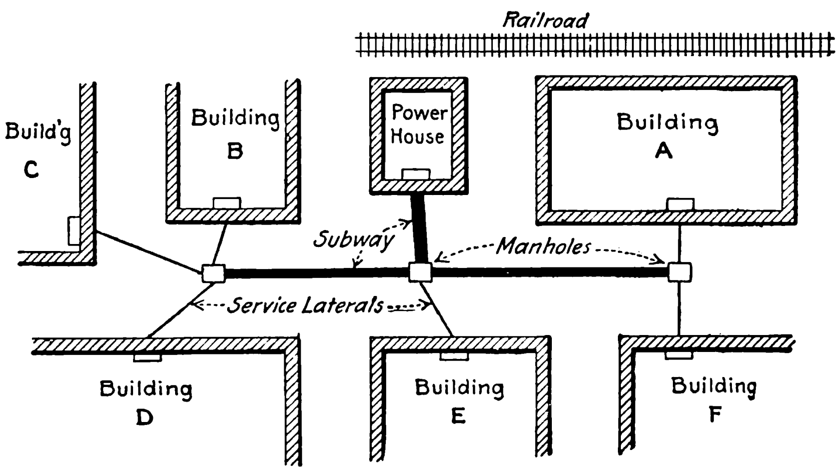


Fig. 92A.—Conduit system for underground distribution.

industrial plant work it is necessary to build subways for pipes in any event and when such subways can also be utilized for electrical conductors a low installation cost may be possible.

115. **If the distribution conductors are to be carried underground** in conduit it is necessary to group the runs insofar as possible, as suggested in Fig. 92, *A*, to insure minimum cost for excavation and manholes.

116. If the distribution conductors are to be carried overhead, more direct routes can be selected, as with overhead distribution conductors can, in industrial plant work, be carried over buildings in the most direct routes.

118. A combination main feeder or other circuit is one that serves all energy consuming devices, motors, lights and minor miscellaneous equipment.

119. An independent main, feeder or other circuit is one that serves only motors and similar equipment or only lighting devices.

120. Independent vs. Combination Circuits for Lights and for Motors.—One of the first things to be decided is whether individual circuits from the switchboard out will be used for lighting and for motors. It is desirable to use independent circuits because it is then possible, at reasonable expense, to maintain a much closer voltage regulation, hence steadier illumination on the lighting circuits. Furthermore, since troubles such as heavy short circuits and grounds occur more often on motor circuits than on lighting circuits, the possibility of such troubles throwing a building or an area in darkness is a minimum with independent motor and lighting circuits.

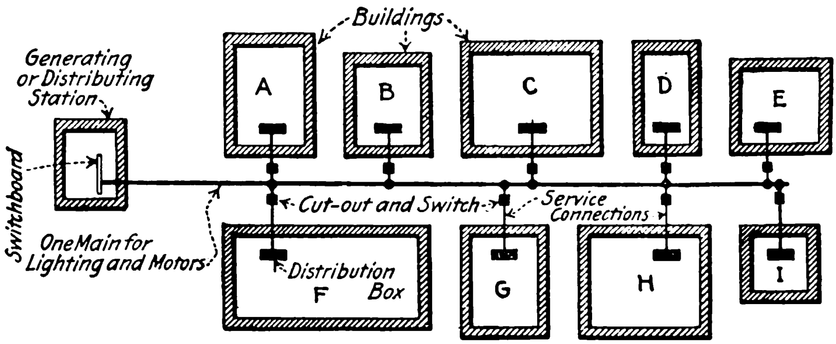


FIG. 93.—Combination main for lighting and motors.

121. Main and feeder lay-outs for industrial plants are shown diagrammatically in Figs. 93 to 99. While these apply principally to industrial plant installations, the principles involved are the same as for municipality electricity distribution. However, because of the different conditions, municipality distributions are handled somewhat differently. In these diagrams, which illustrate principles rather than actual installations, *A*, *B*, *C*, *D*, etc., represent the buildings in an industrial plant. A single line represents an entire circuit, two wires for a direct-current, two-wire circuit; three wires for a three-wire circuit, etc. The diagrams apply to any system of distribution. The service wires from the distribution circuits enter the buildings and terminate in distribution boxes—panel boxes or groups of cut-outs. From the distribution boxes the interior motor and lighting circuits, which are not shown, are supposed to radiate. For information regarding the lay-out of interior wiring circuits, refer to the section on *Interior Wiring*. See Index.

122. **A combination main for lighting and motors** (Fig. 93) can be used where the installation must be of minimum expense. In the illustration a single main, which may be either carried underground on poles or on fixtures attached to the buildings, extends from the switchboard. Service connections are tapped from the main for each building or group of buildings and are terminated in a distribution box—a panel box or a group of porcelain cut-out fittings—within the buildings. Since the service conductors will

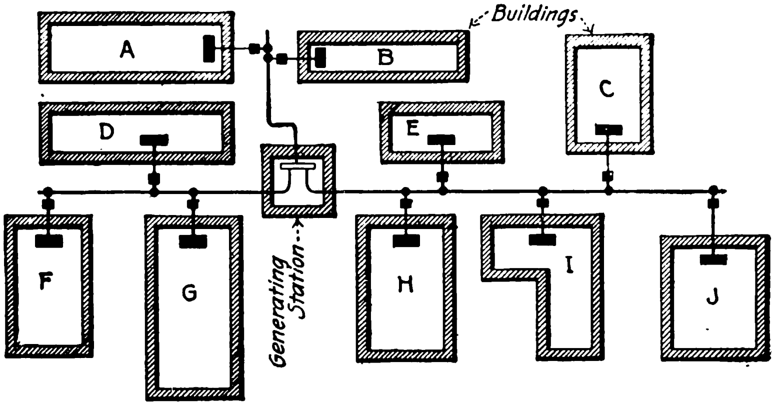


FIG. 94.—Combination mains serving groups.

be smaller than the main conductors a cut-out and, preferably, a switch are inserted in each. The only thing to commend a lay-out like that of Fig. 93 is its low first cost. With such a lay-out the voltage regulation on the lighting circuits is apt to be bad and a ground or short-circuit on any circuit may put the entire plant out of commission. With this arrangement the station operator has no control over the use of the power and if he wishes to decrease the load on the generators by cutting off certain portions of the plant he has no means of doing so. It is an example of "all of the eggs in one basket."

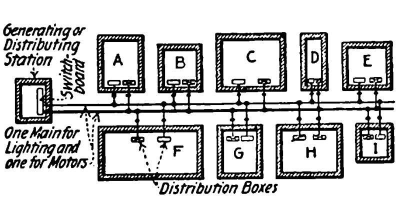


FIG. 95.—Independent main for lighting and one for motors.

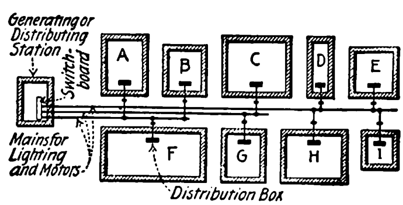


FIG. 96.—Combination mains serving groups.

123. **Independent mains for lighting and motors** (Fig. 95) are sometimes used. This is a better arrangement than that of Fig. 93 in that the lighting circuits are entirely separate from the motor circuits. But, if many lights or many motors are served by one main, trouble is apt to occur. Furthermore, it is not possible to control the power supply of each building from the generating or distributing station.

124. Combination Mains Serving Groups (Fig. 96).—This is a modification of a single combination main lay-out and is sometimes used and is permissible in certain instances where the installation cost must be low. It is better than a single combination main arrangement, but is not very good as no arrangement is good where lights and motors are fed from the same circuit, unless the motor load is relatively unimportant. The station operator has some control over his load and the load is sufficiently sectionalized so that all "eggs are not in one basket." Fig. 94 shows another example of combination mains serving groups.

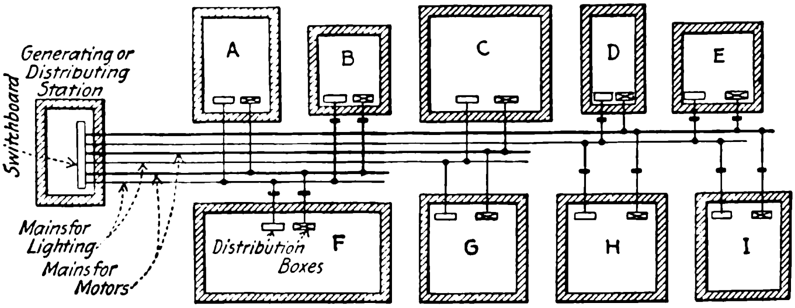


FIG. 97.—Independent mains serving groups.

125. Independent Mains Serving Groups (Fig. 97).—This is a fairly good arrangement if the groups are not too large. Its possible disadvantages are that with it it is not feasible to meter the energy to each unit in the group at the generating station nor is it possible to disconnect each unit from the generating station. These are not always disadvantages. Such an arrangement judiciously laid out will give excellent service.

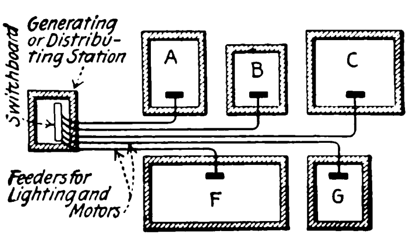


FIG. 98.—Combination feeders for lighting and motors.

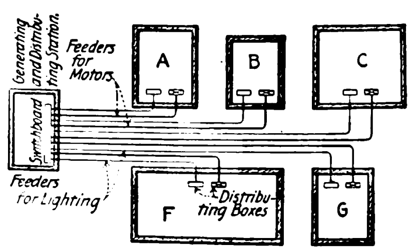


FIG. 99.—Independent feeders for lighting and independent feeders for motors.

126. Combination feeders (Fig. 98) possess the advantages that the load is well divided—"few eggs in a basket"—and that each feeder circuit can be readily controlled and metered at the generating station. But they possess the disadvantages, already enumerated, that always obtain where lighting appliances and motors are served by the same circuit. As a general proposition, such a lay-out is not to be recommended, though it may give satisfactory service where the conditions are not exacting.

127. Individual feeders (Fig. 99) provide the ideal lay-out for reasons that have been suggested in preceding paragraphs. It is seldom that it is advisable to run a feeder to every building in a group. A combination of the methods of Figs. 97 and 99 is usually used. Individual feeders are carried to the principal buildings and mains are arranged on the group plan to serve the buildings having small loads.

128. **A direct-current, two-wire distribution** is seldom used for any installation except a small industrial plant. The voltage may be either 110 or 220. If most of the load is lighting 110 volts may be used. But, if the load is of any consequence, the conductors will be very large for 110 volts hence 220 is more often used. The feeders and mains in an industrial plant can be laid out in accordance with any of the methods of Figs. 93 to 99 but, as outlined in connection with those illustrations, the methods of Figs. 97 or 99 are to be preferred. See the First Section for information in regard to the disadvantages of operating incandescent lamps at any other voltage than 110. If a direct-current two-wire system is used for a municipality the feeders and mains can be laid out somewhat as suggested in Fig. 100.

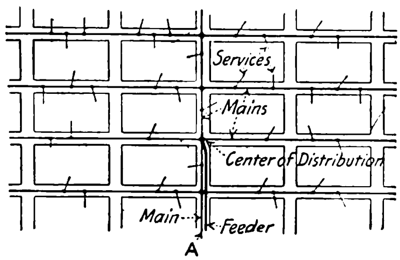


FIG. 100.—Primary distribution in a municipality.

129. **Direct-current, three-wire distributions** are frequently used in industrial plants where there are many adjustable-speed motors for machine tool drive and the like. Direct-current, three-wire distributions are also sometimes used in small municipalities.

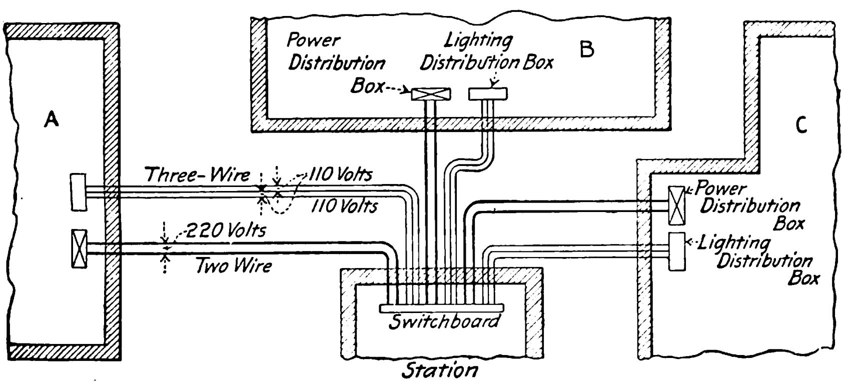


FIG. 101.—Three-wire distribution.

In either case the voltages are almost invariably 110 and 220. The best method for an industrial plant is suggested in Fig. 101 wherein separate feeders are carried from the switchboard to each building or group of buildings for lighting and for power service. The lighting feeders are three-wire so that the incandescent lamps can be operated at 110 volts. The motor feeders are usually 220 volts, two-wire unless some scheme of motor speed control is used that requires all three wires. In municipalities, since the load is usually mainly lighting, all feeders and mains are three-wire and are laid out as suggested in Fig. 100. This represents the arrangement in a small town or that in one of several similar districts of a large one.

130. Single-phase, alternating-current, high-voltage distributions are seldom used in industrial plants, but are often used in municipalities. The voltage is usually 2,200; 1,100 was at one

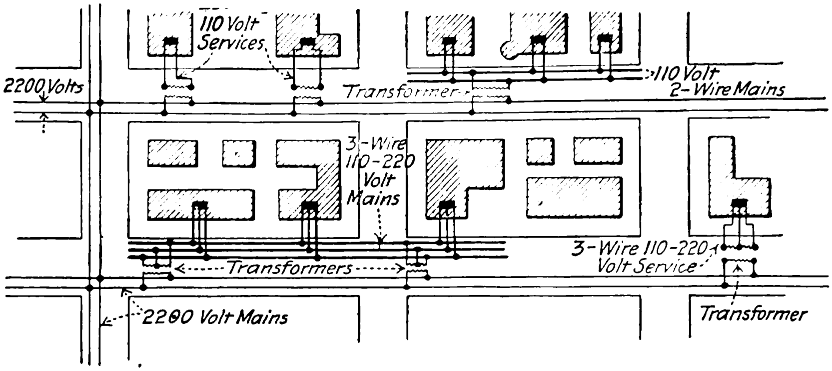


FIG. 102.—Single-phase, high-voltage distribution.

time popular, but was found to be too low for economy. In a municipality, a feeder can be installed to serve each district (Fig. 100) and an automatic potential regulator can, if necessary, be cut into the feeder and so arranged to maintain the voltage constant at the center of distribution. If no regulator is used the feeder might connect into the nearest point as A (Fig. 100) of the distribution system. Consumers are served through transformers which

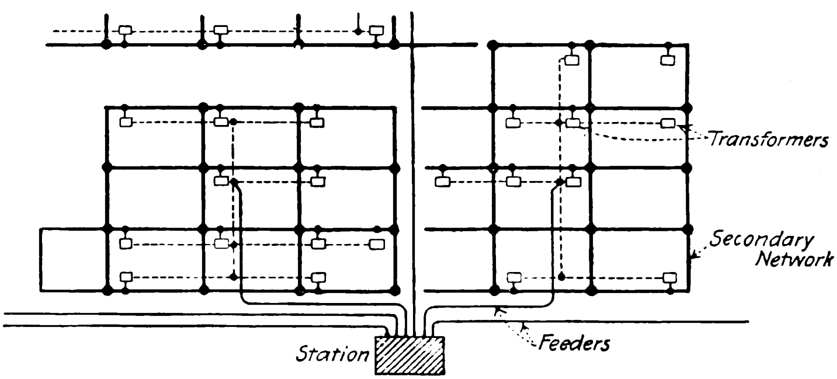


FIG. 103.—An alternating-current secondary network.

reduce the voltage (see Fig. 102) from 2,200 to 110 or 110–220 three-wire. (See section on *Transformers*.) Small single-phase motors, of capacities smaller than say 5 h.p. can be supplied from the secondary conductors, but a separate service should be run for motors of capacities greater than 1 h.p. If motors larger than 5 h.p. are used it is well to serve them with a separate feeder.

Fig. 102 shows methods of serving subscribers. Single transformers are used for detached subscribers. Where several subscribers are grouped it is good practice to run a secondary main supplied by one or more transformers. Through this arrangement the use of small transformers is avoided and the investment in transformers is decreased. Large transformers are more efficient than small ones.

Secondary mains are usually made three-wire (Fig. 102) and the advantages of the three-wire system (see *First Section*, Index) are thereby realized. Where the load is dense the secondary mains are tied together into a network (Fig. 103). Closer regulation is thereby assured. Such a network is usually 110–220 volts, three-wire. In modern practice, single-phase generators are seldom built. Alternating-current generators are usually three-phase, but feeders may be single-phase and they are tapped from three-phase bus-bars as suggested in Fig. 104. The single-phase loads should be, approximately, balanced on the three phases.

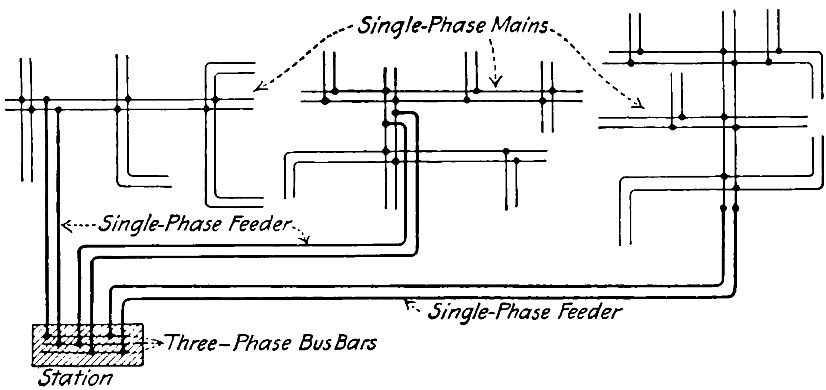


FIG. 104.—Single-phase distribution in a municipality.

131. Single-phase Distribution in Denver, Colo. (*Elec. World*, Dec. 2, 1911).—See Fig. 105. The lighting service is fed by multiple, single-phase, 2,200-volt primary feeders and mains, supplying energy to secondary networks throughout the urban districts through step-down transformers located at important centers of distribution and feeding individual consumers at 110 volts and 220 volts, according to the local load requirements.

The single-phase alternating-current system consists of twenty-six two-wire, 2,200-volt feeders extending from the station bus-bars to the electrical center of a definite section of the city which is electrically independent of any other section or feeder. The primary mains extend from the center of distribution in each section in the form of laterals or branches supplying energy to the most remote transformers of the district with the usual inclusion of intermediate transformers bunched, so far as practicable, to secure economy of operation and reasonable first cost. Any feeder may be fed from a special auxiliary bus in the station in case repairs, adjustments or inspection are necessary in connection with the switches and regulators in routine service.

Within a given section, the secondaries of all transformers are connected by three-wire tie lines forming low-tension bus-bars from which the leads to the various consumers are tapped. The transformers used on the lighting system vary in size from ½ kw. to 50 kw., and all above 1-kw. rating are connected for 2,200 volts

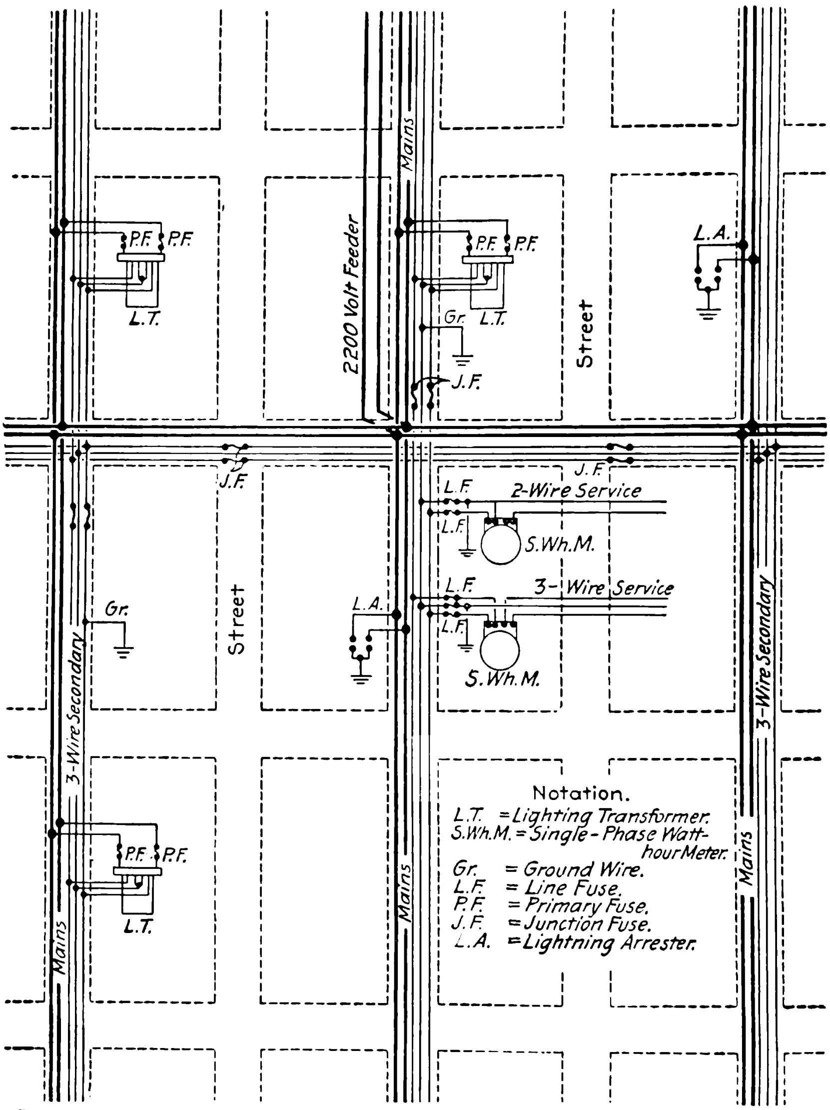


FIG. 105.—Single-phase feeder with high- and low-tension distributions.

on the primary. Each of the two secondary coils is connected so as to give 110 volts between the middle or neutral line and either of the outside lines and 220 volts between outers. The company has found that with the load well balanced considerable saving in secondary copper results from the three-wire method of operation.

Each transformer is connected to the primary main through outside-type primary fuses of double the transformer rating in amperes. The secondary network is sectionalized between each pair of transformers by a set of fuses or junction cut-outs. These are placed approximately at the point of zero current between the adjacent transformers on each secondary section. (See Fig. 105.) The object of this fusing of secondary sections is to prevent the transformers on either side of a defective unit or secondary service from assuming heavy overloads. As soon as any abnormal conditions occur the junction fuses on either side of a defective section blow, as well as the primary fuses on the transformers, and the section is automatically cleared from the system. The junction fuses are of copper wire, being about 50 per cent. larger than the rating of the smaller of the two transformers between which they are in each instance placed, and varying from about 60 amp. between 5-kw. transformers to 400 amp. between 50-kw. units. No fuses are installed in the neutral lines of the secondary networks, although fuses are placed in all leads running from any wire of the secondary service to consumers' premises. The secondaries are grounded; see **138.**

132. **Three-phase low-voltage distribution systems** are largely used in industrial plants. The generated voltage is either 220 or

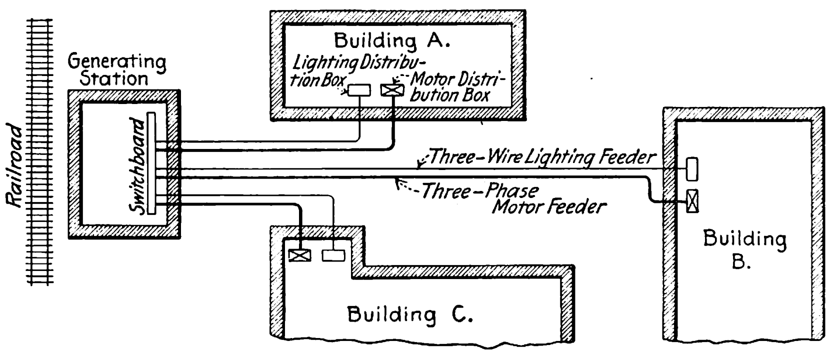


FIG. 106.—Three-phase individual feeder layout.

440. It is probable that 220 is to be preferred inasmuch as 440 is too high a voltage for safety around cranes and other motored machines in a shop. Figs. 106 and 107 illustrate what is probably the best lay-out for a three-phase industrial-plant system. Individual-motor feeders operate at either 220 or 440 volts and three-wire, single-phase lighting feeders at 110 and 220 volts are supplied through balance coils. (See section on *Transformers.*) The lighting load must be reasonably well-balanced among the phases. Any of the schemes of distribution suggested in Figs. 93 to 99 could be used with the three-phase system, but that of Figs. 106 and 107 is probably the best. Where balance coils are not used, single-phase incandescent-lamp circuits can be taken from three-phase circuits as suggested in Fig. 108. The lamp load should be balanced among the phases. However, any series-multiple scheme of connecting incandescent lamps should be avoided

and incandescent lamps should always, where possible, be operated at 110 volts. (See *First Section*, Index.) Occasionally it is advisable to carry the lighting feeders three-phase to the building or group of buildings served and to the balance coils, providing three-wire circuits are installed within the buildings. See also section on *Transformers*.

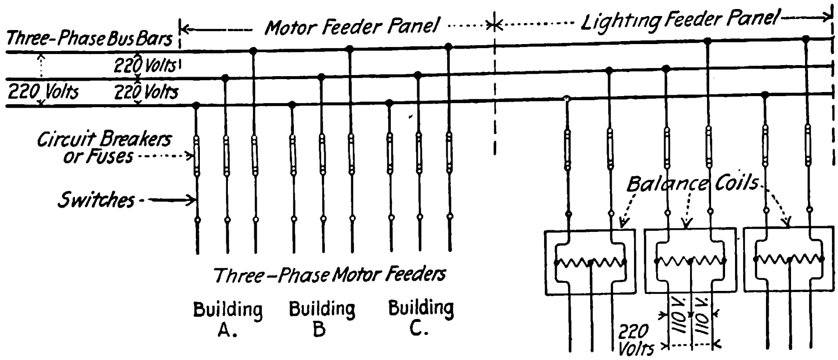


FIG. 107.—Connections at three-phase switchboard.

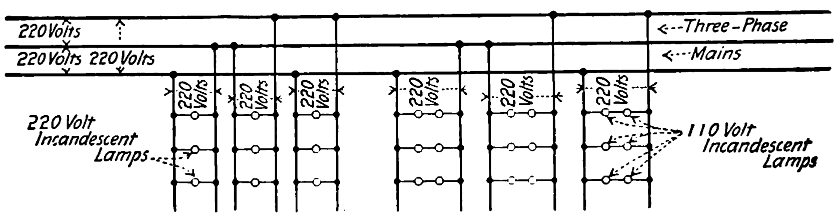


FIG. 108.—Single-phase lighting circuit from three-phase circuit. (*Note.*—Where two lamps are shown connected in series across 220 volts, 110-volt lamps must be used.)

133. **Three-phase, high-voltage distribution** (Fig. 109) is used considerably for municipalities and is probably the best method for average conditions. The voltage for three-wire three-phase systems is almost always 2,200 so that standard transformers can be used. Where a four-wire three-phase system is used the voltage between outer wires is, approximately, 3,800, but the voltage from any one of the outer wires to the neutral wire is 2,200 so standard transformers can be used. Single-phase transformers are used to serve the lighting loads. The transformers are so distributed on the three phases that the total load on the generator is approximately balanced. The secondaries of the lighting transformers are connected as are those of a system with single-phase primary conductors and may, as suggested in Fig. 102, be either two-wire or three-wire. All three wires of the three-phase circuit are not carried to all parts of the district served. Where the load is not dense only two wires—giving a single-phase circuit—are used. (See Fig. 109.)

Motors exceeding 5 h.p. in capacity should be at least 220-volt and should be three-phase rather than single-phase and separate services should be provided for motors exceeding 1 h.p. in capacity. The methods of connecting transformers served by a three-phase system are given in the section on *Transformers*. It is best practice to provide individual feeders and mains for the motor and the lighting loads, but this cannot always be done. The three-phase four-wire distribution system (Fig. 110) is used in several of the larger cities. Its advantage is that it saves copper as the transmission voltage is 3,800 rather than 2,200. For further information see section on *Transformers*.

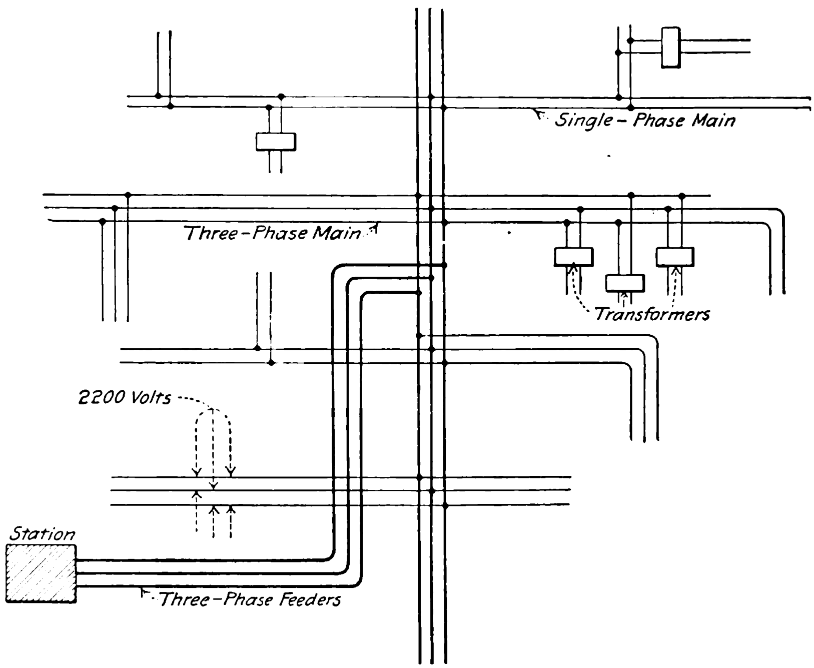


FIG. 109.—Three-phase feeder and mains in a municipality.

134. Protection and Switches on Distribution Systems.—In 131 a description is given of the methods used for overload protection for the overhead three-wire secondary network used in Denver, Colo. In general, it may be said that it is the practice of practical operating men to use but very few fuses or other protective cut-outs in overhead distribution systems. Where at all feasible, branch circuits are tapped to main circuits with soldered joints or with a disconnective pot-head. Fuses are used as seldom as possible because it has been found that they make more trouble than they are worth. Porcelain high-tension fuse blocks are almost invariably interposed in the primary leads to distributing transformers to protect the transformer against overload.

Fig. 111 suggests the practice sometimes followed for protecting alternating-current distribution systems against overload. Fuses are used only on unimportant mains. They are not used at important points because they are apt to rupture at the wrong time. A short-circuit on one of the principal conductors will usually burn itself clear and throw the station circuit-breaker simultaneously, so restoring the breaker restores service. If it does not burn itself clear it is necessary to send a man out to open the disconnectives in succession until the fault is located. This method has been found superior to one involving the use of many fuses.

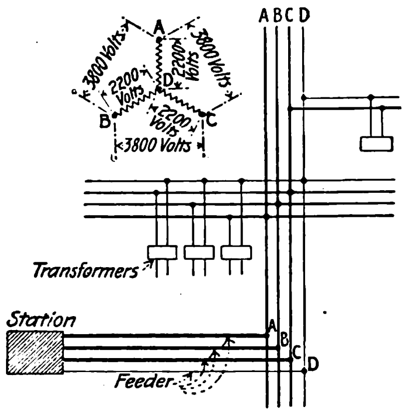


FIG. 110.—Three-phase four-wire distribution system.

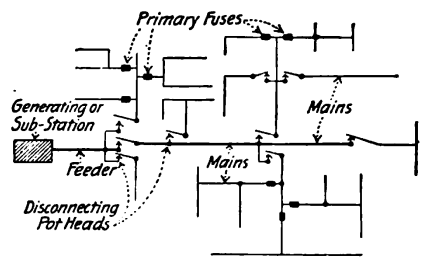


FIG. 111.—Overload protection on alternating-current overhead distribution.

In networks, such as that of Fig. 103, usually, each conductor is, fused wherever it joins another so that any faulty section will "burn itself clear." Copper fuses—stamped sheet metal or wire—are best for this service.

In industrial plants, where the Underwriters have jurisdiction, all conductors must be fused in accordance with the code rules which require protection wherever a conductor changes in size from large to small. (See *Fuses*, Index.)

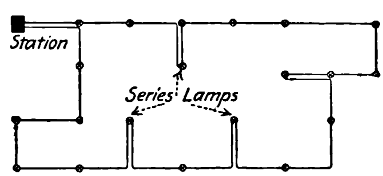


FIG. 112.—Open loop series circuit.

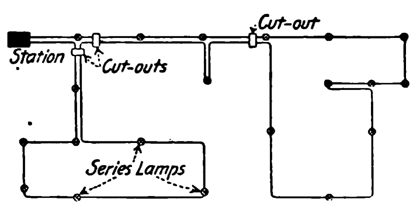


FIG. 113.—Mixed loop series circuit.

135. **Series circuits** (see "*Fundamentals*" section, Index, for further information) are used for series arc and incandescent lighting and for fire-alarm and watchman's circuits.

136. **In laying out a series circuit** the open-loop system of distribution (Fig. 112) can be used if the circuit covers a relatively small area. If a large area is covered the system suggested in Fig. 113 should be used because with it, if an open-circuit occurs in some section, the section can be quickly isolated by throwing the cut-out switch at the point where the section joins the main circuit. Series cut-out switches, especially designed, can be purchased from

electrical supply dealers. Obviously the open-loop plan requires a minimum of poles and wire, hence is the most economical to install. When laying out series circuits consideration should be given to future additions of lamps to the series circuit and the circuit should be so routed that they can be included with the least expense. These notes apply for either series incandescent or series arc-lighting circuits.

137. Series Circuits on Pole Lines (*From report of Committee on Overhead Line Construction, National Electric Light Association*, 1911).—Every series circuit should start from station, substation, or other point of distribution, on a given pin and cross-arm, and follow the same relative pin and cross-arm throughout its course. Circuits should not jump from one location on a cross-arm to another location on the same cross-arm, nor to a different cross-arm, but should always be placed on their proper pin. Such a system renders trouble hunting and repair work much simpler than they otherwise would be and is the only possible way in which circuits can be constructed, maintained, operated and extended in a satisfactory systematic manner. As series arc and series incandescent circuits are cut dead during the daytime and will not, therefore, hamper linemen working on a pole, these circuits can often be run to advantage on the pole-pins of the cross-arm. Such an arrangement is also convenient for making lamp loop connections. As it is usual practice to ground all constant-current series circuits in the station, these wires should be considered as grounded by linemen when working on the poles, this in addition to the general rule that all wires should be treated as being alive at all times.

138. Alternating-current, low-voltage, secondary circuits should be grounded. This is the recommendation of the National Electrical Code and the practice of progressive central station companies. Grounding prevents accidents to persons and damage, by fire, to property. If some point of a low-voltage secondary circuit is grounded, no point of the circuit can rise above its normal potential (except under unusual conditions) in case of a breakdown between primary and secondary windings of the transformer, or of other accidental connection between the primary and secondary circuits.

If the secondary is not grounded and the transformer breaks down, the primary voltage is impressed on the secondary circuit. A person touching any bare part of the secondary circuit would probably receive the primary voltage if he were grounded by contact with, say, a radiator or a gas fixture. Furthermore, the secondary not being grounded and there being a ground on the primary circuit, the primary voltage impressed on the low-voltage fittings of the secondary circuit might cause a fire. With the secondary grounded, a transformer breakdown will often reveal itself through the blowing of the primary fuses. Where a normal voltage in excess of 250 is possible between any wire of a secondary circuit and ground, it is doubtful whether the secondary should be grounded, because shocks to ground from such a system might cause death. See The National Electrical Code for further information regarding grounding.

139. Ground connections can be made in many ways. They may be made inside of buildings by connecting to pipes or may be installed at the poles which support the transformers or the secondary networks. Central-station practice favors grounds at poles. Figs. 114 and 115 show the method of making a pole ground used by the Allegheny County Light Company. The lower end of the pipe is pointed, the upper end is "tinned" inside and the wooden plug is inserted in the upper end of the pipe in the Company's shop. In making a ground, the pipe is driven into the earth next to the

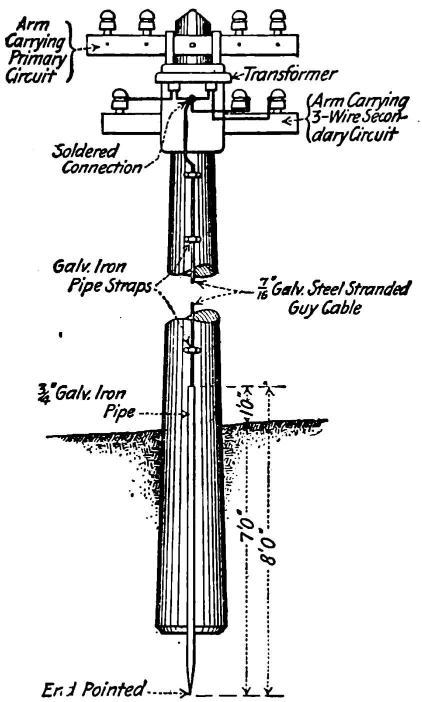


FIG. 114.—Method of grounding secondary circuit.

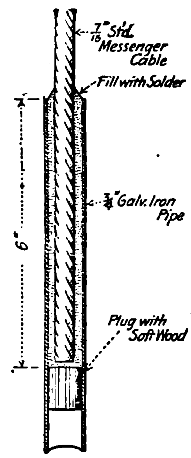


FIG. 115.—Method of connecting cable to pipe.

pole and the steel-cable ground conductor, its end having been tinned, is soldered into the upper end of the pipe by pouring molten solder in around it. An excellent feature of this method is that the $\frac{7}{16}$-in. ground conductor is so strong that it will never be disturbed. It is secured to the pole with pipe straps. (See **140**.)

The ground-pipe cap illustrated in Fig. 116 is used by several large central-station companies for connecting the ground wire to the ground pipe. Soldering is not necessary. The cap with the wire in position is placed over the top of the pipe and the pipe driven. In driving, the wire is firmly wedged between the cap and the pipe. The cap protects the top of the pipe. The cap fits $\frac{1}{2}$-in. pipe or $\frac{3}{4}$-in. rod, with a No. 6 ground wire. Where No. 4 wire is used, it is not necessary to double it. Ground pipes must be long enough to reach permanently moist soil, and in driving care must be taken not to drive them into the pole and thereby insulate them. Some companies ground to fire hydrants. The ground wire is supported down the pole by cleats or straps, and carried in a trench possibly 18 in. deep, to the fire hydrant. It is connected thereto by clamping it under a footing bolt. In Denver this method costs \$4.50 per ground, the average length of ground wire required from pole top to ground being 60 ft.

140. Ground wires should be incased by wooden molding, for a distance of at least 7 ft. from the surface, to protect against shocks to passersby. Under certain conditions of soil moisture, a shock can be received from a ground wire by a person standing on the earth's surface. The ground pipe extends about a foot above ground and is not usually protected. Some companies incase the entire length of the ground wire in molding to protect the linemen.

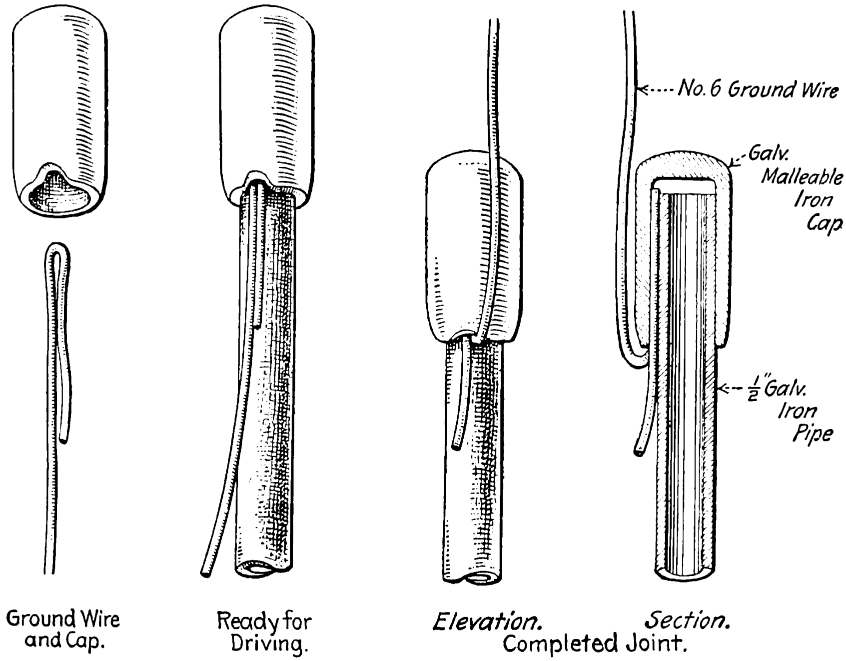


FIG. 116.—Making connection with ground-pipe cap.

No copper wire smaller than No. 6 should be used for a ground wire and some companies use nothing smaller than No. 4. Copper wire is preferable. Bare wire is satisfactory and should be attached to the poles with cleats or straps. Staples, although used, should not be. The National Electrical Code requires for three-phase systems that the ground wire be of the same carrying capacity as any one of the three mains. There should be a ground for each transformer or group of transformers, and when transformers feed a network with a neutral wire, there should, in addition, be a ground at least every 500 ft.

141. Ground-wire connections to transformer secondaries should be made to the neutral point or wire if one is accessible. Where no neutral point is accessible, one side of the secondary circuit may be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts (*National Electrical Code*). Fig. 117 shows theoretical diagrams of ground connections to transformer

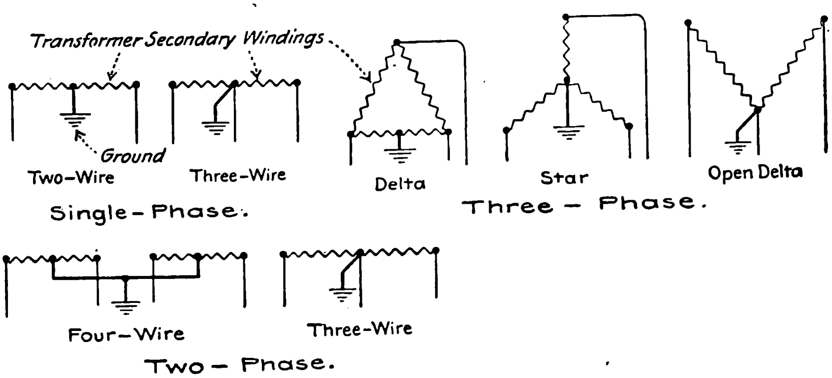


FIG. 117.—Theoretical diagrams of secondary ground connections.

secondaries and Fig. 118 illustrates how some of these connections are arranged with commercial transformers. The neutral point of each transformer feeding a two-phase, four-wire secondary, should be grounded, unless the motors taking energy from the

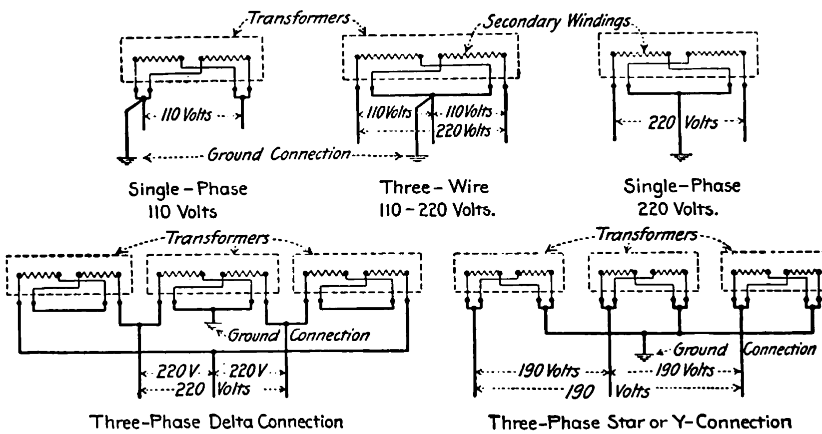


FIG. 118.—Ground connections to secondaries of commercial transformers.

secondary have interconnected windings. Where they are interconnected, the center or neutral point of only one transformer is grounded. No primary windings are shown in Figs. 117 and 118. Fig. 118 the secondary winding of each transformer is shown divided into two sections, as it is in commercial transformers.

SECTION IV

INTERIOR WIRING

GENERAL

1. **The National Electrical Code Rules,** the recommendations of The National Fire Protection Association, should be followed in installing all interior wiring. These rules are revised every two years (odd-numbered years) so it is inadvisable to include them in this book. A copy of these rules can be obtained by applying to any local fire inspection bureau or to The Underwriters' Laboratories, Chicago, Ill. The Factory Mutual Fire Insurance Companies of 31 Milk St., Boston, Mass., publishes an illustrated edition of the rules. The author's "*Wiring for Light and Power,*" in addition to being a general treatise on the wiring of buildings, contains the National Electrical Code and much data in explanation thereof.

2. **There are local regulations covering the installation of wiring,** in force in many localities, which have been enacted by city or state governments. Sometimes these differ from the National Code regulations so it is always well to be familiar with all of the regulations in force before starting any work. The city and state rules are in reality laws and therefore take precedence over the *National Electrical Code Rules* which have no legal status.

3. **General Suggestions** (*Factory Mutual Fire Insurance Rules*).—In all electric work, conductors, however well insulated, should always be treated as bare to the end that under no conditions existing or likely to exist, can a ground or short-circuit occur, and so that all leakage from conductor to conductor, or between conductor and ground, may be reduced to the minimum. Special attention must be paid to the mechanical execution of the work. Careful and neat running, connecting, soldering, taping of conductors, and securing and attaching of fittings, are specially conducive to security and efficiency.

In laying out an installation, except for constant-current systems, every reasonable effort should be made to locate distribution centers in easily accessible places, at which points the cutouts and switches controlling the several branch circuits can be grouped for convenience and safety of operation. The load should be divided as evenly as possible among the branches, and all complicated and unnecessary wiring avoided. The use of wire-ways for rendering concealed wiring permanently accessible is most heartily endorsed and recommended; and this method of accessible concealed construction is advised for general use.

4. **Inside Wiring Rules in Brief** (*Factory Mutual Rules*).—Rubber-covered wire must be used in all damp places, in all conduit, molding, or concealed work, and throughout all systems on which the voltage exceeds 550. For "open" work in dry places where the voltage is not over 550, slow-burning wire is recommended, as it fulfills ever requirement for such work, is less expensive and will not carry fire. This wire has special merit for use in linty and

dusty places, for lint does not readily adhere to the hard, smooth, outer surface, as is the case with wires having a weather-proof braid on the outside which in warm rooms becomes sticky. Moreover, what little lint may collect upon it can be easily brushed off, so that when "sweeping down" there is much less liability of breaking the insulators or badly deranging the wires.

Where of necessity a considerable number of "open" wires are brought close together as, for example, about the ordinary distributing switchboard, the wires should have either the slow-burning insulation as just described, or if a rubber insulation is necessary it should be protected by a heavy "slow-burning" outer braid. The weather-proof and rubber insulations in common use contain a large amount of inflammable material, which ignites easily and produces a fierce fire and dense smoke. It is therefore desirable to reduce, as far as possible, the amount of this inflammable material and to surround it with a tight, "slow-burning" cover to prevent rapid combustion. To still further reduce the amount of combustible material, the porcelain insulators by which the wires are held in place may be supported on an iron frame.

Before beginning work the circuits should be carefully mapped out and the work so planned as to secure the very simplest arrangement.

In mill work, "open" wiring securely supported on porcelain insulators is generally best. Mains of No. 8 B. & S. gage wire and larger are usually most conveniently carried through space from timber to timber and supported at each timber only. Smaller wires thus supported would be liable to be broken, and should therefore be wrapped around the beams or carried through them in holes bushed with porcelain, or they may be fastened to strong running-boards, well put up. The idea is to have the wires so rigidly supported on proper insulators that, even if they were bare, the insulation of the system would be perfect. All joints should be securely made and then carefully soldered and taped.

Wires should be carefully protected where liable to be deranged or injured, as in passing from story to story up side walls or columns, or near belts, or over shelves and similar places where anything is likely to be piled against them. Excellent protection can be secured by carrying them through iron pipe, first reinforcing the insulation of each wire by enclosing it in flexible insulating tubing (also referred to as "standard flexible tubing") unless the wire is double braided rubber covered in which case the insulating tubing is unnecessary. On alternating-current systems, the two or more wires of the same circuit should be run in the same pipe to avoid induction effects. (See Figs. 56 and 57.) Even on direct-current systems this arrangement is best, as then the expense and inconvenience of rewiring is avoided when it is desired to change such systems to alternating current which frequently happens. Protection may also be obtained by strong wooden boxing, with a slanting top to keep out dirt, the holes through which the wires enter the top being bushed with short porcelain tubes. (See Fig. 56.)

The use of incandescent lamps in series on constant-potential systems is not approved.

5. Brief of Underwriters' Rules for Wiring in Especially Hazardous Places (such as Picker and Carding Rooms, Napping Rooms, Dust Chambers, Etc.) (*Factory Mutual Wiring Rules*).—For incandescent lamps in these more hazardous places, an excellent pendant can be secured by using reinforced flexible cord and a keyless socket with an outlet threaded for $\frac{3}{8}$-in. pipe and properly bushed, as advised for "Portable Lamps" in **6.** The cord should be securely supported from the ceiling by a porcelain cleat or split knob, and the two conductors should then be separated and soldered to the overhead circuit. (See Fig. 76.) The regular "Water-proof Pendant" described in 98 could also be used. As far as possible cut-outs should not be located in these rooms, but if this cannot be avoided they should be of the plug or cartridge type and should be enclosed in dust-tight cabinets of approved construction. (See Code rules governing the construction of dust-proof switch cabinet.) If it is desired to control the lights from points in these rooms, it should be done by snap switches, which should be either enclosed in dust-tight cabinets or located where lint and flyings cannot accumulate around them.

Drop cords can be effectively supported from a ceiling with the ceiling buttons shown in Fig. 76A. The cord is passed through the hole in the button and then soldered to the conductors that feed it. Some inspectors consider the ceiling button a much better support at a ceiling than either a rosette or a split knob. Knobs are not generally considered good supports for flexible cord. Ceiling buttons are particularly desirable in industrial plant work because there is no chance for the conductors to get loose from them. Where a drop cord is subject to vibration it should always be soldered to the conductors that feed it. If the connection is effected with the screw clamps of a rosette, the vibration is likely to loosen the screws and cause a loose connection.

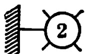
6. Brief of Underwriters' Rules Covering the Arrangement and Use of Portable Lamps (*Factory Mutual Fire Insurance Company's Wiring Rules*).—In this class of work the fittings are subjected to much hard usage, and the very best possible construction is therefore necessary. Instead of the ordinary flexible cord made for pendant lamps, a special cord having an extra covering of rubber, reinforced by a tough outer braid, should be used. (See *Section I* for dimensions of this cord.) The cord should be securely fastened to the wall or ceiling by a cleat or split knob near the point at which it connects to the rosette or supply wires, so that no strain can come on this connection. (See Fig. 76.) It should also be knotted inside the socket, as explained elsewhere. An approved metal shell socket with an outlet threaded for $\frac{3}{8}$-in. pipe should be used, so that the whole cable may be drawn into the socket and still permit the use of a proper socket bushing.

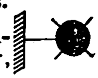
The bulb of an incandescent lamp frequently becomes hot enough to ignite paper, cotton and similar readily ignitible materials, and in order to prevent it from coming in contact with such materials, as well as to protect it from breakage, every portable lamp should be surrounded with a substantial wire guard. Many of the lamp-

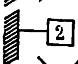
STANDARD SYMBOLS ADOPTED BY THE NATIONAL CONTRACTORS' ASSOCIATION AND THE AMERICAN INSTITUTE OF ARCHITECTS

 Ceiling outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

 Ceiling outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only, 

 Bracket outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

 Bracket outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only, 

 Wall or baseboard receptacle outlet. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

 Floor outlet. Numeral in center indicates number of Standard 16 c-p. incandescent lamps.

 Outlet for outdoor standard or pedestal, electric only. Numeral indicates number of standard 16 c-p. incandescent lamps.

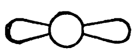
 Outlet for outdoor standard or pedestal; combination. $\frac{6}{6}$ indicates 6-16 c-p. standard incandescent lamps; 6 gas burners.

 Drop cord outlet.

 One-lamp outlet, for lamp receptacle.

 Arc lamp outlet.

 Special outlet for lighting, heating and power-current, as described in specifications.

 Ceiling fan outlet.

S^1 S. P. switch outlet.

S^2 D. P. switch outlets.

S^3 3-way switch outlet.

S^4 4-way switch outlet.

S^D Automatic door switch outlet.

S^E Electrolier switch outlet.

Show as many symbols as there are switches. Or in case of a very large group of switches, indicate number of switches by a roman numeral, thus; S′ XII; meaning 12 single pole switches.

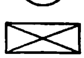
Describe type of switch in specifications, that is, flush or surface, push button or snap.

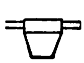
 Meter outlet.

 Distribution panel.

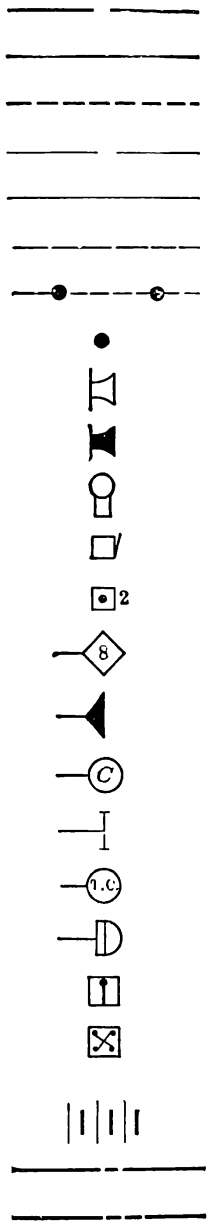
 Junction or pull box.

 Motor outlet. Numeral in center indicates horsepower.

 Motor control outlet.

 Transformer.

STANDARD SYMBOLS ADOPTED BY THE NATIONAL CONTRACTORS' ASSOCIATION AND THE AMERICAN INSTITUTE OF ARCHITECTS.—*Continued*



Main or feeder run concealed under floor.

Main or feeder run concealed under floor above.

Main or feeder run exposed.

Branch circuit run concealed under floor.

Branch circuit run concealed under floor above.

Branch circuit run exposed.

Pole line.

Riser.

Telephone outlet; private service.

Telephone outlet; public service.

Bell outlet.

Buzzer outlet.

Push button outlet. Numeral indicates number of pushes.

Annunciator. Numeral indicates number of points.

Speaking tube.

Watchman clock outlet.

Watchman station outlet.

Master time clock outlet.

Secondary time clock outlet.

Door opener.

Special outlet for signal systems, as described in specifications.

Battery outlet.

Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service wanted ascertained by symbol to which line connects.

Circuit for clock, telephone, bell or other service, run under floor above, concealed. Kind of service wanted ascertained by symbol to which line connects.

Heights of center of wall outlets (unless otherwise specified):

Living Rooms	5 ft. 6 in.
Chambers	5 ft. 0 in.
Offices	6 ft. 0 in.
Corridors	6 ft. 3 in.
Height of switches (unless otherwise specified)	4 ft. 0 in.

FIG. 1.—Standard Wiring Symbols.—*Continued.*

guards now on the market are very flimsy and utterly worthless.

7. **Light Wiring in Industrial-plant Storehouses** (*Factory Mutual Rules*).—The best and safest light for storehouses is the incandescent lamp. Special care should be taken to so locate and protect the wires that the handling of storage in the building could never derange them. The pendants should be of the type advised for "Especially Hazardous Places" in **5**. The cut-outs and switches should be grouped and enclosed in dust-tight cabinets of approved construction. (See **48**.) Standard lamp-guards should be provided, as advised for "Portable Lamps" in **6**.

8. **Fire Light Wiring in Industrial Plants** (*Factory Mutual Fire Insurance Company's Wiring Rules*).—It is a good plan, where possible, to arrange in yards and buildings, on circuits entirely out of the way of ladders or fire streams, a few lights which may be thrown on at the time of a fire when the main lights are off, enabling firemen to move about quickly and safely.

Such lights can generally be best arranged on entirely separate circuits, and will often be useful for repair work and for lighting the help into and out of the mill, when the main lights are off. These circuits may take current from a small, separate generator, driven by an independent engine or waterwheel; or from outside lines; or possibly from a storage battery, so isolated from the main buildings as not to be affected by a fire in them.

9. **Application of Flexible Cord.**—With the exception of wet rooms, storehouses, and specially hazardous rooms of textile mills and the like, flexible cord may be used for pendants hanging freely in the air. If the lamp is to be moved about, so that the cord is liable to come in contact with surrounding objects, reinforced flexible cord like that described for "Portable Lamps" should be provided. The two conductors which form the cord should be carefully knotted together, as shown in Fig. 9, in both socket and rosette, to prevent any strain from coming on the small binding screws in these fittings. The entire weight of the socket and lamp should be assumed, by some approved method, so that all mechanical strain is removed from electrical joints and binding screws.

10. **The standard wiring symbols** adopted by the National Contractors' Association and the American Institute of Architects are given in Fig. 1. These are quite generally used.

WIRING FITTINGS AND MATERIALS

11. **Wire nails** are formed from steel wire of the same diameter as the shank of the nail is to be. Ordinary nails have a "bright" finish. Copper, brass and galvanized steel nails can be obtained. The wire from which nails are made, hence the nail diameters are measured by the American Steel & Wire Co's. Gage (see table in *Section I*) which is the same as the Washburn & Moen gage, and which is used by practically all nail manufacturers, though it is sometimes given a different name. Some of the principal wire manufacturers have decided to call it the United States Steel Wire Gage.

12. Dimensions of Casing, Finishing, Shingle and Fine Nails

(American Steel & Wire Company)

Nail diameters are measured by the A. S. & W. gage. See Section I for table. Equivalent B. & S. gage numbers and inch fractional equivalents are given in Table 12.

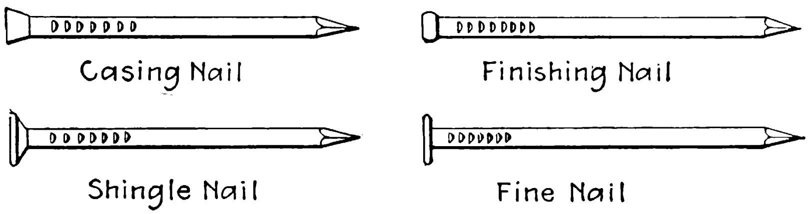


FIG. 2.—Casing, finishing, shingle and fine nails.

Size	Length, inches	Casing		Finishing		Shingle		Fine	
		Gage	Approx. No. per pound	Gage	Approx. No. per pound	Gage	Approx. No. per pound	Gage	Approx. No. per pound
2 d	1	15½	1,010	16½	1,351	.....	....	16½	1,351
3 d	1¼	14½	635	15½	807	13	429	[2]15	778
3½d	1⅜	.....	....	.....	....	12½	345	.....	....
4 d	1½	14	473	15	584	12	274	14	473
5 d	1¾	14	406	15	500	12	235	.....	....
6 d	2	12½	236	13	309	12	204	.....	....
7 d	2¼	12½	210	13	238	11	139	.....	....
8 d	2½	11½	145	12½	189	11	125	.....	....
9 d	2¾	11½	132	12½	172	11	114	.....	....
10 d	3	10½	94	11½	121	10	83	.....	....
12 d	3¼	10½	87	11½	113	.....	....	.....	....
16 d	3½	10	71	11	90	.....	....	.....	....
20 d	4	9	52	10	62	.....	....	.....	....
30 d	4½	9	46	.....	....	.....	....	.....	....
40 d	5	8	35	.....	....	.....	....	.....	....
[1]2 d	1	.....	....	.....	....	.....	....	17	1,560
[1]3 d	1⅛	.....	....	.....	....	.....	....	16	1,015

[1]These sizes are called "Extra Fine."
[2]This nail is only 1⅛ in. long.

13. Wood Screws.—Diameters are measured by the American Screw Company's Gage (see Wire Gage Table in Section I), and range in size from No. 0 to No. 30. They range in length from ¼ in. to 6 in. The increase in length is by eighths of an inch up to 1 in., then by quarters of an inch up to 3 in. and by half inches up to 5 in. Manufacturers' standards vary, but generally the threaded portion is approximately seven-tenths of the total length. There is no standard number of threads per inch for the products of all manufacturers.

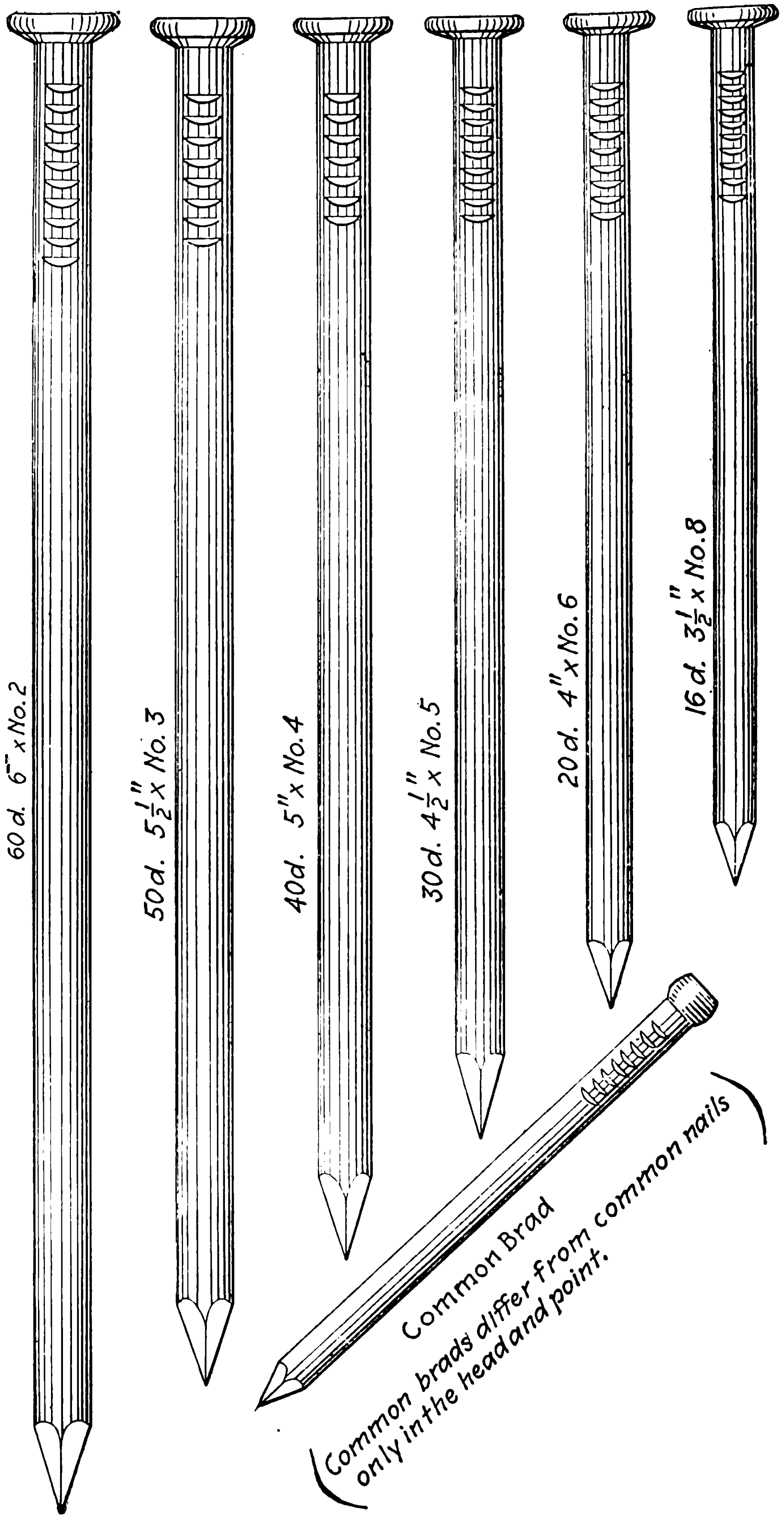


FIG. 3.—Common nails (actual size).

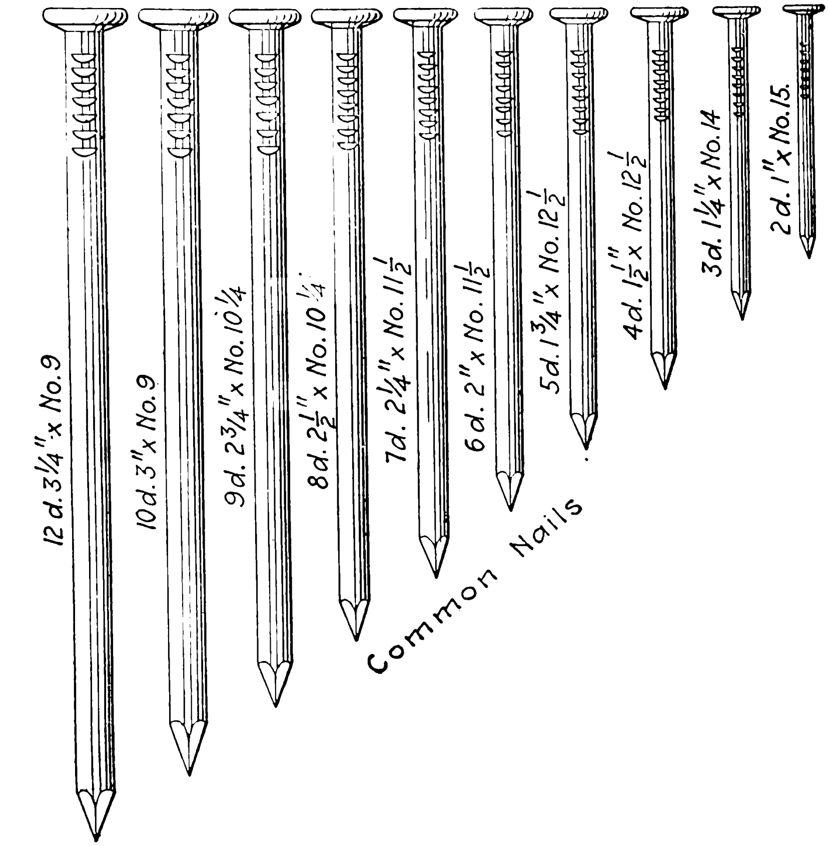


FIG. 3A.—Common nails (*Continued*).

14. Dimensions of Common Nails and Brads

(American Steel & Wire Company)

Size	Length, inches	A. S. & W. gage No.	Approx. No. to lb.	Diam. in decimals, inches	Approx. diam. in inches	Nearest B. & S. gage
2d	1	15	876	0.0720	$\frac{5}{64}$	13
3d	$1\frac{1}{4}$	14	568	0.0800	$\frac{5}{64}$	12
4d	$1\frac{1}{2}$	$12\frac{1}{2}$	316	0.0985	$\frac{7}{64}$	10
5d	$1\frac{3}{4}$	$12\frac{1}{2}$	271	0.0985	$\frac{7}{64}$	10
6d	2	$11\frac{1}{2}$	181	0.1130	$\frac{7}{64}$	9
7d	$2\frac{1}{4}$	$11\frac{1}{2}$	161	0.1130	$\frac{7}{64}$	9
8d	$2\frac{1}{2}$	$10\frac{1}{4}$	106	0.1314	$\frac{1}{8}$	8
9d	$2\frac{3}{4}$	$10\frac{1}{4}$	96	0.1314	$\frac{1}{8}$	8
10d	3	9	69	0.1483	$\frac{9}{64}$	7
12d	$3\frac{1}{4}$	9	63	0.1483	$\frac{9}{64}$	7
16d	$3\frac{1}{2}$	8	49	0.1620	$\frac{5}{32}$	6
20d	4	6	31	0.1920	$\frac{3}{16}$	6
30d	$4\frac{1}{2}$	5	24	0.2070	$\frac{13}{64}$	4
40d	5	4	18	0.2253	$\frac{7}{32}$	3
50d	$5\frac{1}{2}$	3	14	0.2437	$\frac{1}{4}$	2
60d	6	2	11	0.2625	$\frac{17}{64}$	2

15. Dimensions of Wood Screws

Round-head wood screws do not measure full length, but are from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. short. For example: a No. 4 by $\frac{1}{2}$ in. round-head wood screw measures about $\frac{7}{16}$ in. long under the head and a No. 20 by 2 in. screw measures about $1\frac{7}{8}$ in. under the head.

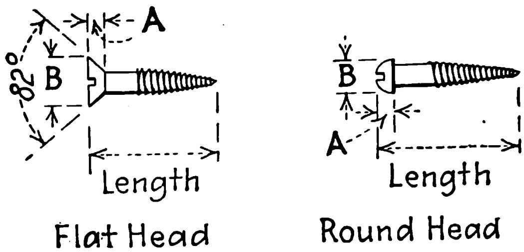


FIG. 4.—Wood screws.

Screw gage No.	Diameter			Flat head		Round head				Clearance drill		Greatest length obtainable, inches
	In decimals	In fractions	Nearest B. & S. gage	A	B	A	B	Counterbore for head	Depth of hole = height of head A	No.	Diameter	
0	.05784	1/16 −	15	1/16	7/64 +	..	..	......		....	......	3/8
1	.07100	5/64 −	14	1/16	9/64 −	..	..	......		....	......	1/2
2	.08416	5/64 +	12	1/16	5/32 +	1/16	13/64	7/32		44	.086	7/8
3	.09732	3/32 +	11	1/16	3/16	5/64	11/64	......		....	......	1 1/2
4	.11048	7/64 +	9	1/16	7/32 −	5/64	13/64	7/32		33	.113	1 1/2
5	.12364	1/8 −	8	1/16	15/64 +	3/32	15/64	......		....	......	2 1/2
6	.13680	9/64 −	7	5/64	17/64 +	3/32	1/4	17/64		28	.1415	3
7	.14996	5/32 −	7	3/32	19/64 −	7/64	3/32	......		....	......	3
8	.16312	5/32 +	6	7/64	5/16 +	7/64	19/64	5/16		18	.1695	4
9	.17628	11/64 +	5	7/64	11/32 +		21/64	......		....	......	4
10	.18944	3/16 +	5	7/64	3/8 −	1/8	11/32	23/64		10	.1935	4
11	.20260	13/64 −	4	1/8	25/64 +	9/64	3/8	......		....	......	4
12	.21576	7/32 −	4	1/8	27/64	5/32	25/64	13/32		7/32	.2188	6
13	.22892	15/64 −	3	1/8	29/64	5/32	27/64	......		....	......	6
14	.24208	1/4 −	3	9/64	15/32 +	5/32	29/64	29/64		1/4	.250	6
15	.25524	1/4 +	2	9/64	1/2	11/64	29/64	......		....	......	6
16	.26840	17/64 +	2	5/32	17/32 −	11/64	31/64	......		....	......	6
17	.28156	9/32	1	5/32	35/64 +	11/64	1/2	......		....	......	6
18	.29472	19/64 −	1	11/64	37/64	3/16	17/32	35/64		....	.302	6
19	.30788	5/16 −	0	3/16	39/64 −	..	17/32	......		....	......	6
20	.32104	21/64 −	0	13/64	5/8 +	13/64	9/16	37/64		....	.323	6
21	.33420	21/64 +	0	13/64	21/32	13/64	19/32	......		....	......	6
22	.34736	11/32 +	0	13/64	11/16 −	7/32	5/8	......		....	......	6
23	.36052	23/64 +	2/0	7/32	45/64 +	7/32	41/64	......		....	......	6
24	.37368	3/8 −	2/0	7/32	47/64	15/64	21/32	43/64		....	.377	6
25	.38684	25/64 −	3/0	7/32	49/64 −	15/64	11/16	......		....	......	6
26	.40000	13/32 −	3/0	15/64	25/32 +	1/4	45/64	......		....	......	6
27	.41316	13/32 +	3/0	15/64	13/16	1/4	23/32	......		....	......	6
28	.42632	27/64 +	3/0	1/4	27/32	1/4	47/64	......		....	......	6
29	.43948	7/16 +	4/0	1/4	55/64 +	17/64	3/4	......		....	......	6
30	.45264	29/64	4/0	17/64	57/64	9/32	25/32	......		....	......	6

16. Toggle bolts, which are used for fastening molding and electrical devices to hollow tile or plaster-on-metal-lath surfaces, are of two general types. The screw type (Fig. 5) is the most frequently used but has the disadvantage that if it is ever necessary to entirely remove the screw, the toggle is lost within the wall. Where the object fastened must be removed and replaced a nut-type toggle bolt (Figs. 6 and 7) can be used. With that of Fig. 6 it is usually necessary, after the device is in place, to cut off the part of the bolt that extends so that the thing will look well. The so-called plumber's toggle bolt (Fig. 7) has a removable, hexagonal cap so that the device can be inserted in the wall before the object to be fastened is slipped over the bolt. Then, on putting the cap in place, the whole bolt is backed into the wall, hiding the surplus

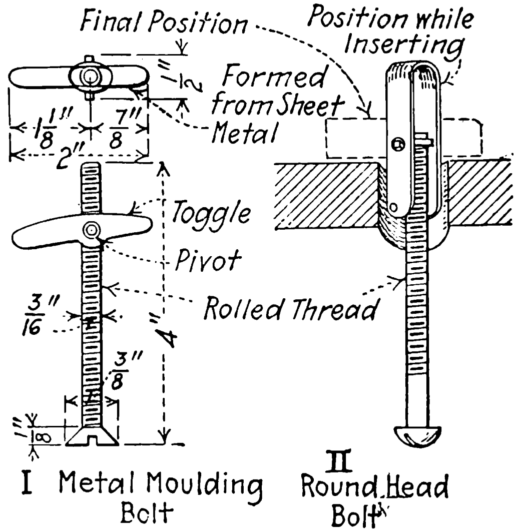


FIG. 5.—Screw-type toggle bolts.

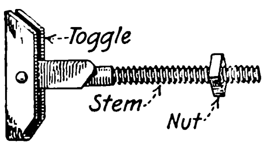


FIG. 6.—Nut-type toggle bolt.

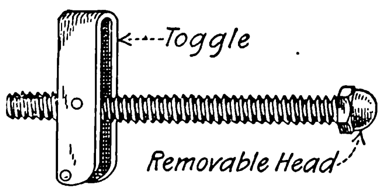


FIG. 7.—Plumbers' toggle bolt.

thread from view. Cone-head toggles, Fig. 8, are used principally for the erection of metal molding and have the advantage that the toggle head will readily pass through the hole in the molding backing. Toggle bolts are made in several diameters and lengths. That of Fig. 5, *I* and Fig. 8 are made by the National Metal Molding Co., Pittsburg. The others illustrated are made by the Chicago Nut Co., Chicago, Ill.

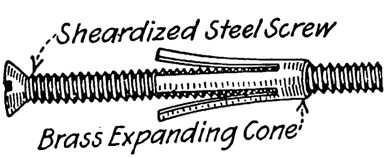


FIG. 8.—Toggle bolt for metal molding.

16A. Knobs, the small porcelain insulators used for supporting interior conductors, are of two general types, the solid (Fig. 8, B) and the split (Fig. 8, A). The solid knob is required by the Underwriters for certain work and is the cheaper of the two, but the additional cost of the tie-wire required with it and the labor of tying makes the cost installed about equal to that of the split knob. The split or confining knob is unquestionably superior to the solid knob, as no tie-wires are required with it. In some places inspectors require with the larger size wires that a tie-wire be used even with the split knob, because Code rules specify tie-wires. The rule is not always strictly enforced. Knobs of the same kinds are used for both open and for knob and tube wiring.

16B. As to the Use of Screws or Nails with Split Knobs.—Nails hold better than screws in certain woods. The breaking of knobs at the time of putting them up with screws is not the only source of trouble, for the binding tension applied often acts to crack the knob a considerable time after it has been put in place. It is an objectionable practice of many wiremen in putting up knobs with screws to drive the screws in nearly all the way with a hammer, giving them only a couple of turns with a screwdriver to tighten them. The principal argument in favor of the use of the nail is the great saving of the wiremen's time that results as compared with that required for putting in screws. The insulating value of either construction is practically the same.

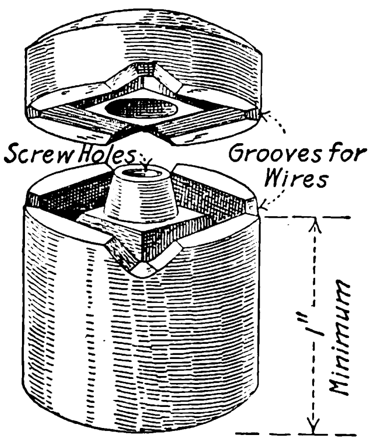


FIG. 8A.—Split knob.

16C. A split knob which clamps the conductor between its two halves is shown in Fig. 8, A. Split knobs must be used for conductors smaller than No. 8, B. & S. gage.

16D. Dimensions of Standard Porcelain Knobs

(*R. Thomas & Sons Company*)

All dimensions are in inches

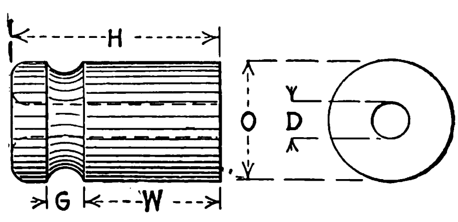


FIG. 8B.—Standard porcelain knob.

Trade number	H Height	O Outside diameter	D Hole diameter	G Width of groove	W Height of wire
0	$2\frac{1}{4}$	3	$1\frac{1}{4}$	1	$\frac{9}{16}$
1	3	$2\frac{1}{4}$	$\frac{7}{16}$	$\frac{3}{4}$	$1\frac{3}{4}$
2	2	2	$\frac{1}{2}$	$\frac{1}{2}$	1
3WG	$1\frac{1}{4}$	2	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{9}{16}$
3	$1\frac{1}{4}$	2	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{3}{4}$
$3\frac{1}{2}$	2	2	$\frac{7}{16}$	$\frac{7}{16}$	1
4	$1\frac{11}{16}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{8}$
Midway	$1\frac{7}{8}$	$1\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	1
$4\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{16}$	1
5	$1\frac{1}{4}$	1	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{11}{16}$
$5\frac{1}{2}$	$1\frac{9}{16}$	1	$\frac{1}{4}$	$\frac{5}{16}$	1
6	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{1}{2}$
7	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{7}{16}$	$\frac{1}{8}$
8	$\frac{15}{16}$	1	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$
9	$1\frac{1}{8}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{4}$
10	$1\frac{3}{4}$	$1\frac{5}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{5}{16}$
$10\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	1

16E. Tubes for knob and tube work can be obtained in many lengths and sizes, as indicated by Table **16F**. A tube $3\frac{1}{2}$ in. long, $\frac{5}{8}$ in. external diameter and $\frac{5}{16}$ in. internal diameter, is the size most frequently used in ordinary house wiring.

16F. Dimensions of Code Standard Unglazed Porcelain Tubes

(*R. Thomas & Sons Company*)

All dimensions are in inches. An allowance of one sixty-fourth of an inch for variation in manufacturing is permitted, except in the thickness of the wall.

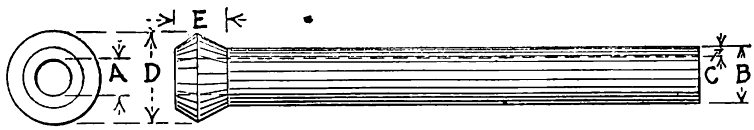


FIG. 8C.—Standard porcelain tube.

A	B	C	D	E		
Diameter of hole	External diameter	Thickness of wall	External diameter of head	Length of head	Greatest length made	Shortest length made
$\frac{5}{16}$	$\frac{9}{16}$	$\frac{1}{8}$	$\frac{13}{16}$	$\frac{1}{2}$	24	$\frac{1}{2}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{5}{32}$	$\frac{15}{16}$	$\frac{1}{2}$	24	$\frac{1}{2}$
$\frac{1}{2}$	$\frac{13}{16}$	$\frac{5}{32}$	$1\frac{3}{16}$	$\frac{1}{2}$	24	1
$\frac{5}{8}$	$\frac{15}{16}$	$\frac{5}{32}$	$1\frac{5}{16}$	$\frac{1}{2}$	24	1
$\frac{3}{4}$	$1\frac{3}{16}$	$\frac{7}{32}$	$1\frac{11}{16}$	$\frac{5}{8}$	24	1
1	$1\frac{7}{16}$	$\frac{7}{32}$	$1\frac{15}{16}$	$\frac{5}{8}$	24	$1\frac{1}{2}$
$1\frac{1}{4}$	$1\frac{13}{16}$	$\frac{9}{32}$	$2\frac{5}{16}$	$\frac{5}{8}$	24	$2\frac{1}{2}$
$1\frac{1}{2}$	$2\frac{3}{16}$	$\frac{11}{32}$	$2\frac{11}{16}$	$\frac{3}{4}$	24	$2\frac{1}{2}$
$1\frac{3}{4}$	$2\frac{9}{16}$	$\frac{13}{32}$	$3\frac{1}{16}$	$\frac{3}{4}$	24	$2\frac{1}{2}$
2	$2\frac{15}{16}$	$\frac{15}{32}$	$3\frac{7}{16}$	$\frac{3}{4}$	24	$2\frac{1}{2}$
$2\frac{1}{4}$	$3\frac{5}{16}$	$\frac{17}{32}$	$3\frac{13}{16}$	1	24	$2\frac{1}{2}$
$2\frac{1}{2}$	$3\frac{11}{16}$	$\frac{19}{32}$	$4\frac{3}{16}$	1	24	$2\frac{1}{2}$

16G. Approximate Dimensions of Two- and Three-wire Porcelain Cleats

(The R. Thomas & Sons Company, East Liverpool, Ohio)
All dimensions are in inches

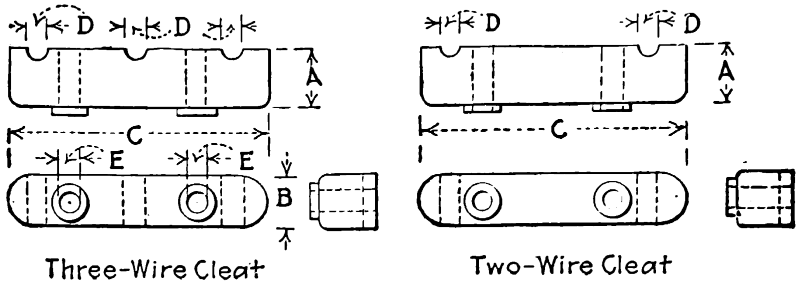


FIG. 8D.—Two- and three-wire porcelain cleats.

Standard No.	No. of wires	For size wires	A Height	B Width	C Length	D Groove	E Diameter screw hole
333	1	18–10	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{16}$
[1] 333½	....	....	$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{3}{16}$	....	$\frac{3}{16}$
334	2	18–10	$1\frac{1}{8}$	$\frac{5}{8}$	$3\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{32}$
335	2	18– 8	$1\frac{1}{8}$	$\frac{3}{4}$	$3\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{32}$
336	2	18–10	$1\frac{1}{8}$	$\frac{5}{8}$	$3\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{32}$
[2] 337	3	....	....	....	....	....	....
350	2	4– 2	$1\frac{1}{2}$	$\frac{3}{4}$	$3\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{16}$

[1] No. 333½ has no groove and of itself could not be used as a cleat. It is simply a flat piece of porcelain to be used in combination with No. 333, the screw holes of the two corresponding.

[2] No. 337 is a three-wire cleat and can be made of the dimensions of Nos. 334, 335 or 336.

16H. B. & D. Porcelain Cleats

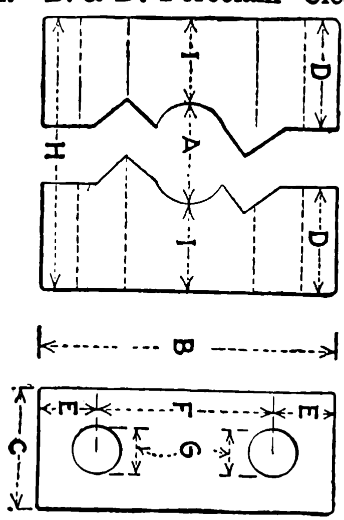


FIG. 8E.—Showing cleats the dimensions of which are given in Table 16I.

161. Dimensions of Regular Style B. & D. Porcelain Cleats

(See Fig. 8E for key to reference letters.)

No.	Std. No.	Size wire R. C. B. & S.	Dimensions A Min in.	A Max. in.	B in.	C in.	D in.	E in.	F in.	G in.	H Min. in.	H Max. in.	Approx. price each
1	328	14 to 16	$\frac{3}{16}$	$\frac{3}{8}$	$1\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{7}{16}$	0.01
$1\frac{1}{2}$	329	10 to 2	$\frac{3}{16}$	$\frac{7}{16}$	$2\frac{1}{4}$	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{15}{32}$	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{2}$	$1\frac{3}{4}$	0.016
2	....	2 to 0	$\frac{3}{8}$	$\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{1}{16}$	$\frac{13}{16}$	$\frac{15}{32}$	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{5}{8}$	$1\frac{3}{4}$	0.019
$2\frac{1}{2}$	330	0 to $\frac{3}{10}$	$\frac{1}{2}$	$\frac{5}{8}$	$2\frac{11}{16}$	$1\frac{3}{16}$	1	$\frac{17}{32}$	$1\frac{5}{8}$	$\frac{5}{16}$	2	$2\frac{1}{8}$	0.024
3	331	$\frac{3}{10}$ to 200,000 cm.	$\frac{1}{2}$	$\frac{3}{4}$	$3\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$\frac{5}{8}$	$1\frac{7}{8}$	$\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{5}{8}$	0.032
$3\frac{1}{2}$	$331\frac{1}{2}$	200,000 cm. to 500,000 cm.	$\frac{3}{4}$	1	$3\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{8}$	$\frac{5}{8}$	$1\frac{15}{16}$	$\frac{3}{8}$	$2\frac{1}{4}$	3	0.049
4	332	500,000 cm. to 1,000,000 cm.	$\frac{7}{8}$	$1\frac{3}{8}$	$3\frac{11}{16}$	$1\frac{3}{8}$	$1\frac{7}{16}$	$\frac{11}{16}$	$2\frac{5}{16}$	$\frac{3}{8}$	$2\frac{7}{8}$	$3\frac{3}{8}$	0.065
$4\frac{1}{2}$	$332\frac{1}{2}$	1,000,000 cm. to 2,000,000 cm.	$1\frac{3}{8}$	$1\frac{15}{16}$	$5\frac{3}{8}$	2	$1\frac{15}{16}$	$\frac{7}{8}$	$3\frac{5}{8}$	$\frac{9}{16}$	$3\frac{3}{4}$	$4\frac{3}{16}$	0 .164

NOTE.—Nos. 1 to 3 inclusive, regular cleats (as tabulated), approved for 300 volts and Nos. $3\frac{1}{2}$ to $4\frac{1}{2}$ regular cleats (as tabulated), approved up to 550 volts. If cleats Nos. 1 to 3 are desired for service above 300 volts "style A" should be specified, in which Dimension I is 1 in. in every case.

16J. Flexible tubing or circular loom (Fig. 8, *F*) finds application in mixed wiring, where short sections of rigid conduit are installed, being used as additional insulation and protection for the entire length of conductor within the rigid conduit. When metal outlet boxes are used, or switch boxes, flexible tubing is required from the last porcelain support and extending into the outlet box. Another application for flexible tubing is in buildings already completed where the wires are fished in between the walls and ceilings. The tubing is used as a covering on such wires separately encased. In concealed knob and tube work it is frequently impracticable to place wires 5 in. apart and 1 in. from the surface wired over as required by the code, and in such cases the wires may be separately encased in flexible tubing. In open wiring where the amount of separation required by the code from the surface wired over cannot be maintained, the wires may also be encased in flexible tubing.

The following is a list of places where flexible tubing is applicable: In open work where wires are exposed nearer each other than $2\frac{1}{2}$ in.; on wires crossing other wires; on wires crossing gas pipes, water pipes, iron beams, wood work, brick or stone; on wires at chandeliers and bracket outlets; on gas pipe back of insulating joints; on wires under the edges of canopies; and at distributing centers or where space is limited and the 5-in. separation required cannot be maintained, each wire must be separately encased in a continuous length of flexible tubing. In many other places flexible tubing is employed as an added protection to wires; as for instance on portable wires around machinery and in show windows, etc., where added protection although not required is often desirable.

Knox in his *Electric Light Wiring* says: The use of flexible tubing is becoming more limited every year and as a separate method of wiring is only approved by certain inspectors. It is used in non-fireproof buildings and is frequently used in conjunction with other methods of wiring, such as knob-and-tube wiring, exposed wiring on insulators, molding work, etc. It is also used at the backs of switchboards to cover conductors where they emerge from conduit, or where the conductors pass through walls, etc. It must be used on the loop system and be continuous from outlet to outlet. It must not be installed in damp places or in any way subjected to moisture (such as being placed in contact with damp mortar, plaster, etc.). Wires should not be drawn into flexible tubing until after the rough work in the building is finished as the tube is not strong mechanically and would not protect the wires from nails, etc. Duplex wires are not permitted in flexible tubing, although single-braided conductors are allowed.

Owing to the fact that flexible tubing is neither moisture-proof nor mechanically strong, it compares unfavorably with metallic conduits. Wiring with it is, however, cheaper than either rigid or flexible conduit wiring.

Flexible tubing should be used only in dry places.

16K. Properties of Flexible Tubing or Loom

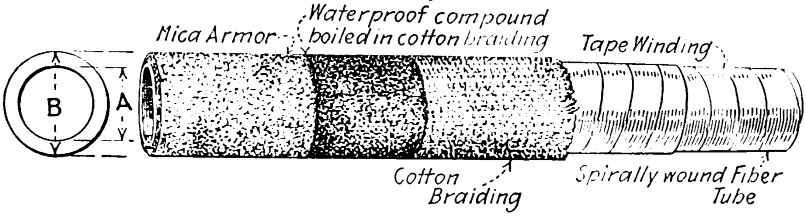


FIG. 8F.—Flexible tubing.

A Inside diam., inches	B Outside diam., inches	Ft. per coil	Largest wire, B. & S. and cir. mils	Weight per 1,000 ft.-lb.
$\frac{1}{4}$	$\frac{17}{32}$	250	No. 14	75 lb.
$\frac{3}{8}$	$\frac{5}{8}$	250	No. 12	110 lb.
$\frac{1}{2}$	$\frac{3}{4}$	200	No. 8	125 lb.
$\frac{5}{8}$	$\frac{7}{8}$	200	No. 4	155 lb.
$\frac{3}{4}$	$1\frac{1}{16}$	150	No. 2	200 lb.
1	$1\frac{3}{8}$	100	No. 00	275 lb.
$1\frac{1}{4}$	$1\frac{11}{16}$	100	200,000	360 lb.
$1\frac{1}{2}$	$2\frac{1}{16}$	100	400,000	400 lb.
$1\frac{3}{4}$	$2\frac{1}{2}$	100	600,000	440 lb
2	$2\frac{3}{4}$	Odd lengths	800,000	600 lb.
$2\frac{1}{4}$	3	Odd lengths	1,100,000	700 lb.
$2\frac{1}{2}$	$3\frac{1}{4}$	Odd lengths	1,300,000	700 lb.

17. Insulating tape for the United States Navy Department is purchased under the following specifications:

1. Tape to be classified as follows:

(a) Rubber tape.
(b) Cotton tape.

2. Both classes must meet the following requirements:

(a) Deliveries shall contain full specified weight of tape, exclusive of wrapping and boxes. Net weight only of tape shall be paid for.
(b) All tapes shall be of recent manufacture.
(c) The surface shall be smooth, the body entirely free from holes, the edges straight without selvage and widths even. When held before a strong light there must be no evidence of pin holes.
(d) The wrappings shall be secure and protect the contents fully.

3. The cotton tape must be well saturated and frictioned, but compound shall not be put on in excess. Separation under a pull of 2 lb. per inch width applied to the material when wound from the original in a coil on a $\frac{1}{4}$-in. mandrel under a tension of 10 lb. shall not exceed 8 in. per minute at 75 deg. fahr.

4. When unwinding from the original coil there must be no tendency to leave a thread sticking to the next layer in the case of cotton tape, nor shall the separator show any tendency to stick in the case of rubber tape. Rubber tape, when wrapped to a thickness of $\frac{1}{4}$ in. and heated to 150 deg. fahr. for 20 min., shall fuse into a homogeneous mass.

5. Cotton tape, when exposed in strip to dry heat at 210 deg. fahr. for 16 hr. shall stand the following separation test immediately

after removal from the heat. Test similar to that in paragraph three will be made, except that the pull shall be two ounces per inch width and the separation shall not exceed 3 in. per minute.

6. The weight of the compound applied to the cloth shall be about 0.65 lb. per square yard.

7. To possess the following physical and chemical characteristics:

Width, inches: Rubber, $\frac{1}{2}$, $\frac{3}{4}$, and 1; cotton, $\frac{1}{2}$, $\frac{3}{4}$ and 1.

Thickness, inches: Rubber, 0.035, approximately; cotton, 0.015, approximately.

Package, pounds: Rubber, $\frac{1}{4}$, $\frac{1}{2}$, and 1; cotton, $\frac{3}{8}$ to $\frac{2}{3}$ (all widths).

Length of tape per pound weight (minimum): Rubber, 27, 18, and 13.5 yards; cotton, 72, 48, and 36 yards.

Para rubber: Rubber, not less than 30 per cent.

Sulphur: Rubber, not more than $3\frac{1}{2}$ per cent. total.

Ash by burning: Rubber, not to exceed 65 per cent.; cotton, not to exceed 45 per cent.

Tensile Strength: Rubber, 400 lb. per square inch at 75 deg. fahr.; cotton, 40 lb. per inch of width.

Dielectric Strength: Rubber, 250 volts per millimeter of thickness (5 minims); cotton, 1,000 volts (5 minims).

Color: Rubber, black; cotton, black.

Layer separation: Rubber, linen or glazed cloth.

Packing: Rubber, oil paper or tinfoil; and in pasteboard box; cotton, tissue paper or tinfoil and in tin box.

Markings of package: Rubber, maker's trade name, width, weight, directions; cotton, maker's trade name, width.

The test for tensile strength of the rubber tape shall be performed on a rubber testing machine, the rate of separation of the jaws which clamp the test piece being 3 in. per minute. The initial distance between the jaws shall be 3 in. The test for tensile strength of the cotton tape shall be conducted with a textile testing machine or by lifting the specified weight.

The dielectric strength tests to be conducted as follows: The test piece to be placed between two electrodes consisting of two brass balls, each 2 cm. in diameter, and the specified alternating potential having an effective value, at a frequency of 60 cycles, shall be continuously applied for 5 min. and no break-down shall result. The electrodes must be brought close together so that the tape will just move between them.

17A. Rosettes may be either fused or unfused. Fused rosettes are seldom used now. The usual practice is to connect 16 sockets to a branch circuit, through fuseless rosettes, so that the total wattage of the lamps will not exceed 660. Sockets are usually considered as requiring not less than 40 watts each. The branch circuit can then be properly fused at the point where it connects to the main circuit. Fused rosettes are used, with the underwriters' approval only for open work. Link-fused rosettes can be used for voltages not exceeding 125 and enclosed fused rosettes for voltages not exceeding 250. Where rosettes are fused 30 or 40 lamps may be connected to one branch circuit.

The rosette fuse must not exceed 3 amp. capacity and the fuse protecting the branch must not exceed 25 amp. capacity. It is not now considered good practice to load any incandescent lamp circuit to more than 660 watts. If there are too many lamps on one fuse, its blowing will render too great an area dark.

18. Insulating socket bushings must be used where a cord enters a socket to protect it against abrasion and grounding against the shell. The most popular bushings are of hard rubber or of a compound resembling it. Patented bushings which automatically grip the cord by a wedging action can be purchased.

19. Sockets made with a $\frac{1}{8}$-in. or a $\frac{3}{8}$-in. pipe thread. The so-called $\frac{1}{8}$-in. sockets are used only on fixtures. The $\frac{3}{8}$-in. sockets can be used with reinforced lamp cord. In connecting a cord to a socket, the cord should always have a knot (Fig. 9) tied in it that will lie within the socket to insure against its pulling out and to take the strain from the binding screw.

20. Key sockets should not be used in places where they are in an atmosphere filled with an inflammable dust. Weather-proof or keyless sockets should be installed in such places.

21. Brass-shell or key sockets should never be used out of doors or in damp places. Sometimes, even in bath-rooms, moisture will get into the shell and ground a socket. Occasionally the water comes from the hand of a person that has just washed and turns the key before his hand is dry. The water enters through the slot in the shell. A keyless or a pull-chain socket should be installed in bath-rooms.

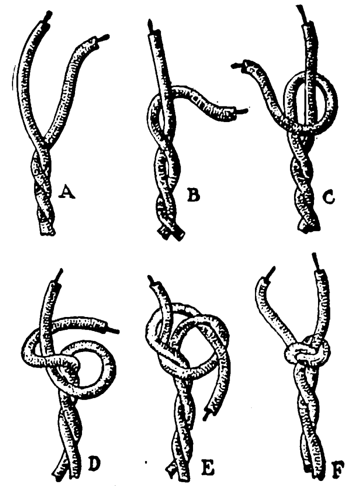


FIG. 9.—Method of tying supporting knot in flexible cord. (See Par. 9 for description.)

22. Weather-proof sockets are used out of doors and in damp places as suggested in **95.**

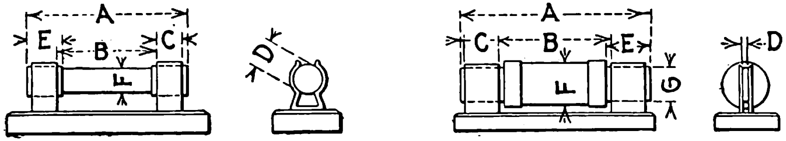
23. Brief of Underwriters' Rules Covering Cut-outs (*Factory Mutual Rules*).—Link fuses are not suitable for general use about a factory and will not be approved unless mounted on slate or marble bases made to conform to the specifications given in the Code and enclosed in dust-tight, fire proofed cabinets. (See Fig. 23.) The ordinary porcelain link-fuse cut-outs are not permissible. Approved plug and cartridge fuses may be used almost anywhere in the ordinary manufacturing plant without the enclosing cabinet, such cabinets being necessary only in specially hazardous places, or where persons would be liable to come in contact with the bare live parts. These fuses of the enclosed type are strongly recommended for general use.

In 1903 the enclosed fuse was standardized by a special committee of the underwriters in consultation with the fuse manufacturers. (See specifications in **25.**) This was found necessary in order to secure an interchangeable fuse for any given capacity regardless of the make. This feature had previously been sadly lacking, and the result had been great inconvenience or the use of dangerous substitutes, such as fuse wire, wire nails, etc. The great advantages of an interchangeable fuse are evident.

24. Relative cost of fuses of capacities up to 25 amp. is given in Knox's *Electric Light Wiring* as follows: Open-link fuse with copper terminals, $\frac{3}{4}$ cent each; Edison fuse plug, 5 cents each; Edison fuse plug casing with cartridge fuse complete, 15 cents each; cartridge fuse, 8 cents each. These costs are approximate.

25. Dimensions of National Electrical Code Standard Enclosed Fuses

(0 to 60 Amperes)
I Cartridge Fuse-Ferrule Contact



(61 to 600 Amperes)
II Cartridge Fuse-Knife Blade Contact

FIG. 10.—National electrical code standard fuses and holders.

Voltage	Rated capacity, amperes		A Length over terminals, inches	B Distance between contact clips, inches	C Width of contact clips, inches	D Diameter of ferrules or thickness of terminal blades, inches	E Min. length of ferrules or of terminal blades outside of tube, inches	F Diameter of tube, inches	G Width of terminal blades, inches		Rated capacity, amperes
0–250	0–30	Form 1	2	1	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$		Form 1	0–30
	31–60		3	$1\frac{1}{4}$	$\frac{5}{8}$	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{3}{4}$			31–60
	61–100	Form 2	$5\frac{7}{8}$	4	$\frac{7}{8}$	$\frac{1}{8}$	1	1	$\frac{3}{4}$	Form 2	61–100
	101–200		$7\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$		101–200
	201–400		$8\frac{5}{8}$	5	$1\frac{3}{4}$	$\frac{1}{4}$	$1\frac{7}{8}$	2	$1\frac{5}{8}$		201–400
	401–600		$10\frac{3}{8}$	6	$2\frac{1}{8}$	$\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	2		401–600
251–600	0–30	Form 1	5	4	$\frac{1}{2}$	$\frac{13}{16}$	$\frac{1}{2}$	$\frac{3}{4}$		Form 1	0–30
	31–60		$5\frac{1}{2}$	$4\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{5}{8}$	1			31–60
	61–100	Form 2	$7\frac{7}{8}$	6	$\frac{7}{8}$	$\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{3}{4}$	Form 2	61–100
	101–200		$9\frac{5}{8}$	7	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{1}{8}$		101–200
	201–400		$11\frac{5}{8}$	8	$1\frac{3}{4}$	$\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{5}{8}$		201–400

26. **A cartridge fuse** consists of a tube of vulcanized fiber, paper or some similar material (Fig. 11) within which the fuse is mounted. The fuse terminals are connected with contact pieces at the ends of the tube. An insulating, porous powder resembling chalk surrounds the fuse and fills or nearly fills the tube. When the fuse blows the powdered material disrupts the arc. Sometimes the fuse is surrounded by a small air chamber as shown in the illustration.

The formation of an arc is prevented in a cartridge fuse, therefore fuses of this type are more reliable than those of any other.

27. **National Code Standard Ferrule Contact Cut-out vs. Edison Plug Cut-out.**—The following objections have been raised against the code standard fuse-and-holder combination, for currents of less than 60 amp., which is illustrated in Fig. 10.

1. The fuses are difficult to remove with the fingers. Tools are required in some cases for their removal and the tools sometimes cause short-circuits.
2. The spring clips on the cut-outs are sometimes bent and broken off.
3. Frequently the contact between the fuse ferrules and the spring clips is bad due to soft metal in the clips or bending by unskilled persons.
4. The ferrules of the 0–30 amp. fuse are so close together that a shock is likely to be received when a fuse is being taken out or removed, when the workman is standing on grounded conducting material.

The combination of a National Electrical Code standard fuse (Fig. 12, *I*) enclosed in a porcelain Edison plug fuse casing (Fig. 12, *II*) and held in an Edison plug cut-out (*III*) is believed by many practical men to be much superior to the combination illustrated in Fig. 10.

The Edison plug arrangement, if it has any of the four disadvantageous features tabulated above, certainly has them to a lesser ex-

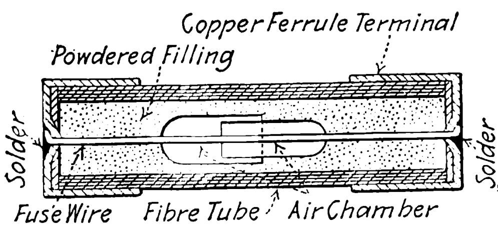


FIG. 11.—Cartridge-type enclosed fuse.

tent than does the spring-clip holder and ferrule fuse arrangement. Edison plug cut-outs are not approved by the underwriters for pressures exceeding 125 volts or currents exceeding 30 amp.

An approved Edison plug cut-out and a fuse-plug casing of the 0–30 amp. size are made by the Bryant Electric Company for 250 volts. The threads of the cut-out socket and those of the casing are left-hand instead of the usual right-hand. Therefore fuse plugs designed for 125-volt service (and which have a right-hand thread) cannot be used in the 250-volt cut-outs.

28. Approximate Cost of Enclosed Fuses in Place (*Nelson S. Thompson, Electrical World*, Sept. 9, 1911).—5 to 65 amp., $0.10

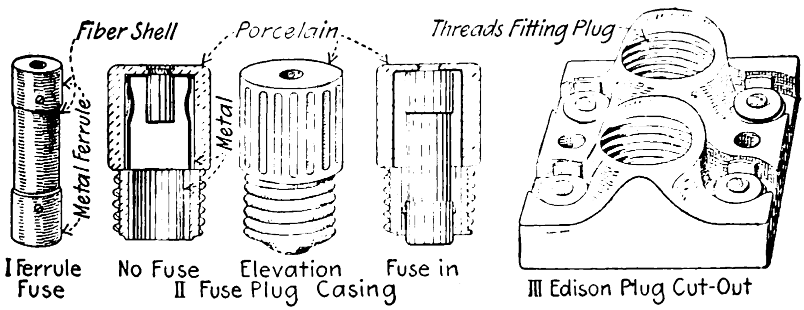


FIG. 12.—Edison plug cut-out and Edison fuse plug casing.

each; 65 to 100 amp., $0.25 each; 110 to 200 amp., $0.50 each; 225 to 400 amp., $0.90 each; 450 to 600 amp., $1.30 each.

29. Open-link fuses (Fig. 13) have the disadvantage of disrupting violently when short-circuited and may burn a person that is near. They blacken the panel that supports them. They are permitted by the Underwriters only when supported on slate bases and enclosed in iron cabinets. When so arranged they will give good satisfaction in industrial plant service where they are handled by journeyman electricians.

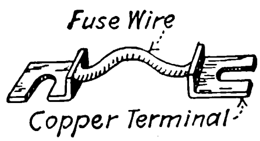


FIG. 13.—Link fuse.

30. Melting Points of Commercial Fuse Wire

From Knox's *Electric Light Wiring*. Table by Mr. Bathurst

The following values are approximate as the fusing point of metals depends on the proportion and kind of alloys used, kind and form of terminal, length of fuse and on other things.

Fusing current in amperes	Diameter in thousandths of an inch	Nearest B. & S. gage
1.7	0.010	30
4.9	0.020	24
9.0	0.030	20
11.3	0.035	19
13.3	0.040	18
19.8	0.050	16
25.4	0.060	14
32.0	0.070	13
39.1	0.080	12
54.1	0.100	10
63.1	0.110	9
81.1	0.130	8
90.6	0.140	7
100.5	0.150	7
110.7	0.160	6
132.1	0.180	5
154.7	0.200	4

31. Diameters of Wires of Various Materials That will be Fused by a Current of a Given Strength

Knox's *Electric Light Wiring*. Derived from tables of W. H. Preece

Current in amp.	Copper		Aluminum		German silver		Iron	
	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage
1	0.0021	43	0.0026	41	0.0033	39	0.0047	37
2	0.0034	39	0.0041	38	0.0053	35	0.0074	33
3	0.0044	37	0.0054	35	0.0069	33	0.0097	30
4	0.0053	35	0.0065	34	0.0084	31	0.0117	29
5	**0.0062**	**34**	**0.0076**	**32**	**0.0097**	**30**	**0.0136**	**27**
10	0.0098	30	0.0120	28	0.0154	26	0.0216	24
15	0.0129	28	0.0158	26	0.0202	24	0.0283	21
20	0.0156	26	0.0191	24	0.0245	22	0.0343	19
25	0.0181	25	0.0222	23	0.0284	21	0.0398	18
30	**0.0205**	**24**	**0.250**	**22**	**0.0320**	**20**	**0.0450**	**17**
35	0.0227	23	0.0277	21	0.0356	19	0.0498	16
40	0.0248	22	0.0303	20	0.0388	18	0.0545	15
45	0.0268	21	0.0328	20	0.0420	18	0.0589	15
50	0.0288	21	0.0352	19	0.0450	17	0.0632	14
60	**0.0325**	**20**	**0.0397**	**18**	**0.0509**	**16**	**0.0714**	**13**
70	0.0360	19	0.0440	17	0.0564	15	0.0791	12
80	0.0394	18	0.0481	16	0.0616	14	0.0864	12
90	0.0426	18	0.0520	16	0.0667	14	0.0935	11
100	0.0457	17	0.0558	15	0.0715	13	0.1003	10
120	**0.0516**	**16**	**0.0630**	**14**	**0.0808**	**12**	**0.1133**	**9**
140	0.0572	15	0.0698	14	0.0895	11	0.1255	8
160	0.0625	14	0.0763	13	0.0978	10	0.1372	7
180	0.0676	14	0.0826	12	0.1058	10	0.1484	7
200	0.0725	13	0.0886	11	0.1135	9	0.1592	6
225	**0.0784**	**12**	**0.0958**	**10**	**0.1228**	**8**	**0.1722**	**5**
250	0.0841	12	0.1028	10	0.1317	8	0.1848	5
275	0.0897	11	0.1095	9	0.1404	7	0.1969	4
300	0.0950	11	0.1161	9	0.1487	7	0.2086	4

32. Switches may be classified thus: (1) Surface switches, arranged for mounting on the surface of a wall, which may be of either the open knife-blade or of the enclosed snap-switch types. (2) Flush switches arranged for mounting in a wall or partition with their face plates and operating buttons practically flush with the surface of the wall. (3) Canopy switches which are mounted in wall bracket, electrolier or portable lamp canopies. (4) Pendent switches arranged to hang from a two-conductor cord and open and close the circuit of the cord.

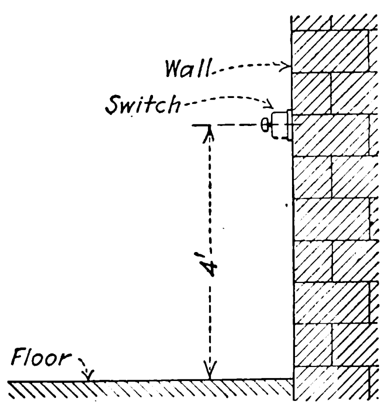


Fig. 14.—Location of wall switch.

33. Copper fuses (Fig. 15) stamped from sheet copper are used for the protection of underground and aerial circuits. They have the disadvantage of becoming very hot before they rupture. At 75 per cent. of their fusing capacities they often become so hot as to heat terminals or switches to which they are connected to undesirably high temperatures. Copper fuses should always be enclosed in iron boxes. The General Electric Company marks its copper fuses with the current that they will carry without undue heating and recommends them for the protection of underground circuits against dead short-circuits only. Many thousand are in use in this service and for it give excellent satisfaction.

34. Data on Dimensions of Copper Fuses
(From *Electric Light Wiring*—Knox)

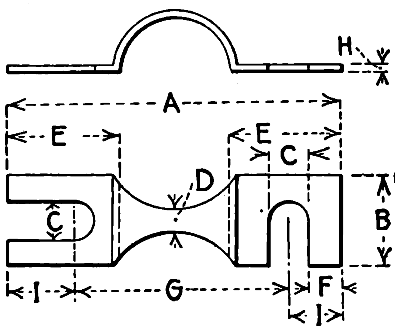


FIG. 15.—Stamped copper fuse.

Amperes	A	B	C	D	E	F	G	I	H
25	$1\frac{15}{16}$	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{17}{32}$	$\frac{1}{8}$	$1\frac{1}{2}$	$\frac{7}{32}$	0.0071
50	$2\frac{1}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{11}{16}$	$\frac{3}{16}$	$1\frac{5}{8}$	$\frac{5}{16}$	0.0071
75	$2\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{16}$	$\frac{3}{32}$	$\frac{7}{8}$	$\frac{7}{32}$	$1\frac{7}{8}$	$\frac{3}{8}$	0.0126
100	$3\frac{1}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	$\frac{1}{8}$	1	$\frac{9}{32}$	$2\frac{1}{4}$	$\frac{7}{16}$	0.0126
150	$4\frac{1}{8}$	1	$\frac{3}{8}$	$\frac{3}{16}$	$1\frac{1}{8}$	$\frac{5}{16}$	$3\frac{1}{8}$	$\frac{1}{2}$	0.0126
200	$4\frac{1}{4}$	1	$\frac{7}{16}$	$\frac{1}{8}$	$1\frac{3}{16}$	$\frac{9}{32}$	$3\frac{1}{4}$	$\frac{1}{2}$	0.025
250	$4\frac{1}{4}$	1	$\frac{7}{16}$	$\frac{5}{32}$	$1\frac{3}{16}$	$\frac{9}{32}$	$3\frac{1}{4}$	$\frac{1}{2}$	0.025
300	$4\frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{16}$	$\frac{7}{32}$	$1\frac{3}{8}$	$\frac{11}{32}$	$3\frac{1}{2}$	$\frac{9}{16}$	0.025
350	$4\frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{16}$	$\frac{1}{4}$	$1\frac{3}{8}$	$\frac{11}{32}$	$3\frac{1}{2}$	$\frac{9}{16}$	0.025
400	$4\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{9}{32}$	$1\frac{7}{16}$	$\frac{3}{8}$	$3\frac{1}{2}$	$\frac{5}{8}$	0.025
450	$4\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{16}$	$1\frac{7}{16}$	$\frac{3}{8}$	$3\frac{1}{2}$	$\frac{5}{8}$	0.025
500	$5\frac{1}{8}$	$1\frac{3}{8}$	$\frac{1}{2}$	$\frac{11}{32}$	$1\frac{5}{8}$	$\frac{7}{16}$	$3\frac{3}{4}$	$\frac{11}{16}$	0.025
600	$5\frac{1}{4}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{16}$	$1\frac{11}{16}$	$\frac{15}{32}$	$3\frac{3}{4}$	$\frac{3}{4}$	0.051
700	$5\frac{1}{4}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{7}{32}$	$1\frac{11}{16}$	$\frac{15}{32}$	$3\frac{3}{4}$	$\frac{3}{4}$	0.051
800	$5\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{1}{4}$	$1\frac{13}{16}$	$\frac{15}{32}$	$3\frac{3}{4}$	$\frac{7}{8}$	0.051
900	$5\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{5}{16}$	$1\frac{13}{16}$	$\frac{19}{32}$	$3\frac{3}{4}$	$\frac{7}{8}$	0.051
1,000	$5\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{11}{32}$	$1\frac{13}{16}$	$\frac{19}{32}$	$3\frac{3}{4}$	$\frac{7}{8}$	0.051
1,100	$6\frac{1}{2}$	$2\frac{1}{4}$	$\frac{9}{16}$	$\frac{3}{8}$	$2\frac{5}{16}$	$\frac{27}{32}$	$4\frac{1}{4}$	$1\frac{1}{8}$	0.051
1,200	$6\frac{1}{2}$	$2\frac{1}{4}$	$\frac{9}{16}$	$\frac{13}{32}$	$2\frac{5}{16}$	$\frac{27}{32}$	$4\frac{1}{4}$	$1\frac{1}{8}$	0.051
1,500	$7\frac{1}{2}$	$2\frac{3}{4}$	$\frac{9}{16}$	$\frac{1}{2}$	$2\frac{13}{16}$	$1\frac{3}{32}$	$4\frac{3}{4}$	$1\frac{3}{8}$	0.051

36. Switches should be located 4 ft. from the floor (Fig. 14) if they are to control lighting circuits. This is the practice recommended by The American Institute of Architects. Sometimes the character of the wood work or decorations makes it necessary to depart from this standard. Switches controlling the lights in a room should be located at the entrance to it and not behind the door. Consult the plans and find which way the doors open. Cellar lamp switches should be at the head of the stairs. Hall lamp switches should be near the door into the hall. In first class work three- and four-way switches should be used so the hall lights can be controlled from any floor.

37. Cost of Knife Switches in Place

(*Nelson S. Thompson, Electrical World,* Sept. 9, 1911)

The values are for 250-volt, single-break switches with extension for fuses, polished and without bases, but mounted on panels.

Rating, amperes	Double-pole	Triple-pole
30	$ 1.80	$ 2.30
50	3.05	4.35
100	4.65	6.75
200	7.45	10.95
300	10.45	15.20
400	13.00	19.55
500	18.10	27.00
600	23.10	34.45
800	27.95	41.80
1,000	53.35	63.65
1,200	67.25	87.40

The cost of mounting an unmounted switch not including the drilling of the tablet board is $1.00 per switch.

38. Knife switches (*Power*, April 23, 1912) made by reputable manufacturers are constructed in accordance with National Electrical Code requirements. This pretty effectively protects the buyer, but any switch should be carefully inspected before it is purchased.

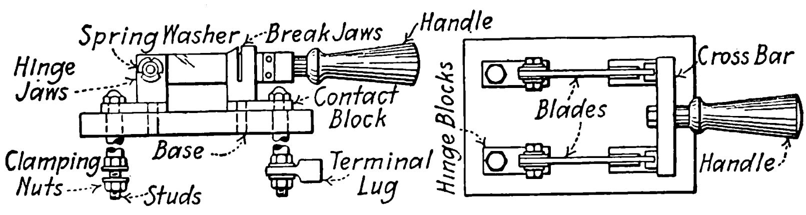


FIG. 16.—Names of knife blade switch parts.

Fig. 16 gives the names of knife switch parts. The contact between the break-jaws and the blade should be carefully inspected, as it is at this point that knife switches are most apt to give trouble by overheating. The contact between the hinge-jaws and the blade seldom limits the capacity of a switch, because it is under pressure from the hinge bolt and the spring washers. The capacity of a switch is determined by its temperature rise. The Code specifies a maximum rise in any part of 50 deg. fahr. at full-load.

39. To make a contact between switch blade and jaws considerable skill is required. After a switch is assembled, the jaws are first bent into correct position either by hand or by driving a block of wood against the distorted portion with a hammer. Then they are "ground in" with vaseline and fine (FF) pumice stone. Often the "fit" of a switch is reasonably good at the start, and merely working the blade in and out of the jaws by hand will grind them in. Before the grinding process is started, the portion of the blade that wipes the jaws should be daubed with the vaseline and pumice stone compound. The abrasive not only "grinds in the fit" but wears off the lacquer, which, if it remained, might be the cause of a bad contact. The surplus compound should be removed with a rag.

40. A test for good blade contact can be made by trying to insert a "feeler," which is a leaf of very thin steel, mica or paper, between the jaws and blade at the corners and sides. About 0.001 in. to 0.004 in. is about the right thickness for a "feeler." An excellent feeler can be made by hammering down to a knife edge, the edges of a strip of very thin metal possibly 4 in. long and $\frac{3}{4}$ in. wide. If the feeler slips in at any point, it is evident that the "fit" is poor at that point and the contact bad. Proper forming of the jaw will correct the difficulty. There have been cases where switches have been made to carry, without excessive temperature rise, currents 50 per cent. greater than their normal ratings, by merely carefully fitting their jaws to their blades.

41. Knife Switch Ratings.—About 1,000 amp. per square inch of copper section and 50 to 75 amp. per square inch of sliding contact surface is usually allowed in designing switches.

A switch that will carry, possibly, 1,000 amp. with a 20 deg. temperature rise, will carry possibly 2,000 amp. with about a 60 deg. rise. The radiation of heat from the switch increases more rapidly than does the rise in temperature, and as the heat generated varies as the square of the current, it is evident that the temperature rise will be somewhat less than proportional to the square of the current.

A switch will break about double the voltage, with a given current with alternating current as with direct current. This is due to the fact that an alternating current decreases to a zero value during each cycle. The Code recognizes this and specifies that "for 100-amp. switches and larger, the spacings for 250 volts, direct current, are also approved for 250 volts alternating current."

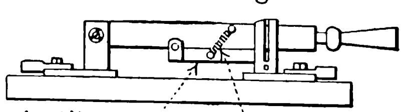


FIG. 17.—A quick-break switch.

The voltage drop from contact-block to hinge-block of a good switch should not exceed about 12 milli-volts with full-load current.

42. Quick-break switches (Fig. 17) have an auxiliary breaking arrangement, actuated by a spring, making it difficult to draw an arc even if the switch is opened slowly. Usually the quick-break attachment is relatively delicate and is apt to get out of order. Where feasible, it is always better to use a switch without a quick-break attachment.

43. Single-throw knife switches should be so mounted that gravity will tend to open rather than to close them. Double-throw switches can be mounted horizontally, but often when so mounted, it is inconvenient to connect to them, and they do not work in well with many switchboard arrangements; hence they are often mounted vertically and an insulating guard, possibly of wood, is arranged that may be slipped over the jaws on the lower terminals of the switch, to prevent accidental contact. Usually it is best to so connect a switch that the break-jaws will be "alive" and the blades dead when the switch is open. The blades expose more surface and extend further than do the jaws, hence are more liable to accidental contact and short-circuits than are the jaws.

44. **Enclosed snap switches are usually preferable to knife switches,** where it is feasible to use them. Snap switches can be obtained for breaking currents as great as 30 amp. at 250 volts. The unskilled person in opening and closing a knife switch is apt to draw an arc between the contacts, or only partially close the switch, which will pit the metal and ultimately ruin the switch. This condition cannot occur with a good snap switch. Only indicating switches should be installed.

45. **The remote control switch** can often be advantageously used. One manufacturer gives the following as a list of its desirable properties as applied to theater, large building and general wiring:

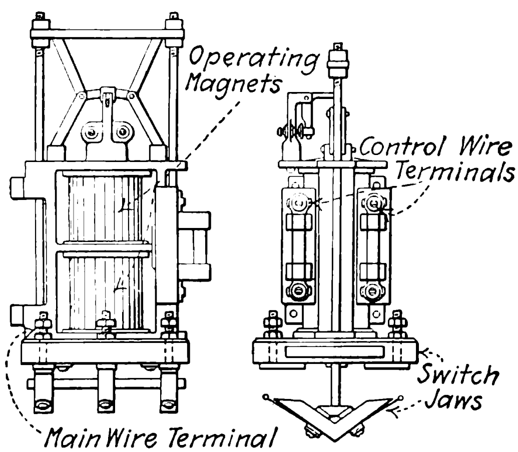


FIG. 18.—A three-pole remote control switch.

1. Simplifies wiring. Main wires can be run in most direct routes, without considering the locations of switch outlets.

2. Often saves money. It takes much less conduit and wire to properly wire some buildings and control the lights with remote control switches than with any other method.

3. Saves annoyance after the building is wired. All lights, or any groups of lights, in a building can be absolutely controlled at all times from any part of the building. Considerable advantages result and great savings are thereby effected in public building and in apartment house light wiring.

4. Enables the owner or custodian of a building to positively cut off the entire current supply of the building by merely pressing a flush push button when leaving the building. This prevents waste of current by lights that have been accidentally left burning, and it eliminates danger of electrical fires.

5. Permits a watchman to control show-window or other store lights without entering the premises.
6. Makes possible the control of current distribution from distant points.

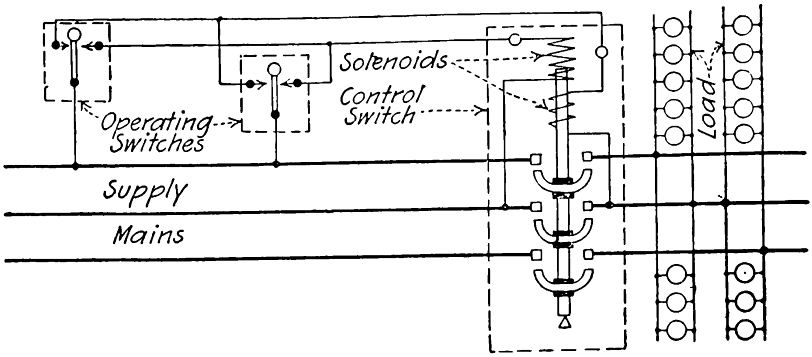


FIG. 19.—Remote control switch circuits.

46. A remote control switch is shown in Fig. 18, its circuits in Fig. 19, and the operating switch in Fig. 20. When the white button of the operating switch is pressed, it permits current to flow through the solenoid that closes the switch. It pulls the jaws together, which closes the main circuit and the jaws are locked in the closed position by the toggle arrangement. The operating current is discontinued by the closing movement. When the black button is pressed, the opening solenoid is energized and the switch opens and severs the operating circuit. Operating switches of several forms are for sale. The principles of all are essentially as described above.

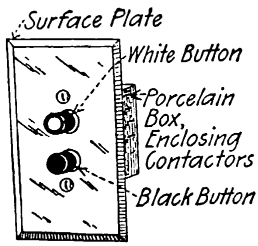


FIG. 20.—Momentary contact switch.

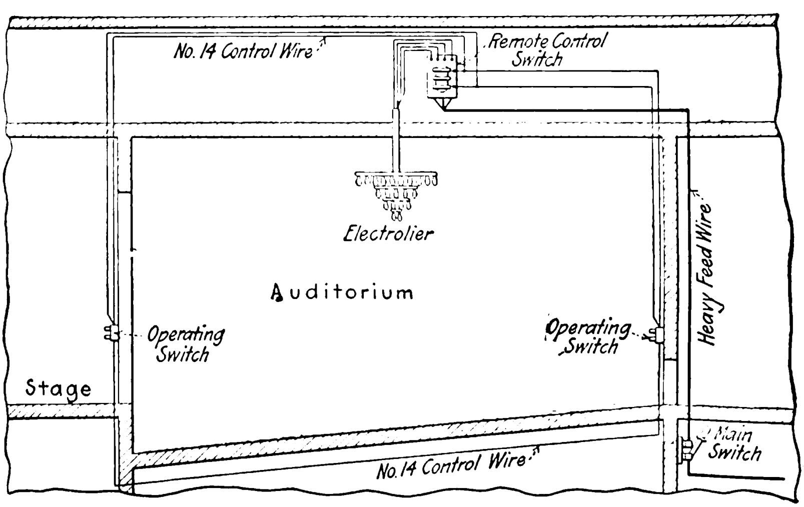


FIG. 21.—Remote control switch installation in a theater.

47. A typical remote control-switch installation is shown in Fig. 21. The main conductors serving the electrolier are carried to the remote control switch near it. Branch lighting circuits from the remote control switch pass to the electrolier. The electrolier is controlled by two conveniently located operating switches—there could be as many more operating switches as desired—but the heavy conductors are not carried to the operating switches. A saving in the cost of conductors thereby results. The operating circuits are of No. 14 wire. Many other applications will suggest themselves wherein circuits may be controlled from various points without its being necessary to carry the main conductors to those points.

48. An iron switch box can be readily made as illustrated in Fig. 22 of sheet metal. It is probably always cheaper to buy a switch box than to make one. When the homemade article must be used, the box is bent from the sheet metal which is indicated

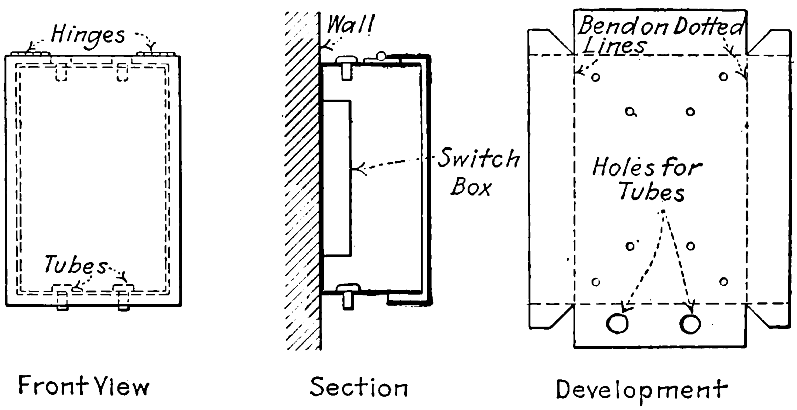


FIG. 22.—A homemade iron switch box.

at *Development.* The cover is formed in the same way. After being bent, the sides are held in position with rivets. Holes are punched for conductor outlets and ordinary tubes are used in them for insulation. The boxes must be painted and be made of metal not less than No. 12 B. & S. gage (approx. $\frac{3}{32}$ in.) thick to comply with Code requirements. The hinges for the door are riveted on. Holes are provided in the back for securing the box to the wall and for supporting the switch within it with stove bolts. (*Electrical World*, March 9, 1912.)

49. Wooden Switch Boxes can be Readily Made (*Electrical World*, May 4, 1912).—Iron ones are preferable and can now be secured from jobbers at costs that compare favorably with or are less than those for homemade wooden boxes. Wooden boxes (Fig. 23) should be of $\frac{7}{8}$-in. well-seasoned wood and lined with $\frac{1}{8}$-in. asbestos, secured in place with tacks and shellac. Sheet iron $\frac{1}{16}$ in. thick or two $\frac{1}{32}$-in. sheets may be used instead of asbestos. The door should close against a rabbet so as to be dust-tight. Where a door is wider than, say, 12 in., it should be paneled with either wood or glass, to insure against distortion due to warping. A space of 2 in. should be allowed between fuses and the door. A reliable catch should be provided on the door. Porcelain tubes or bushings should be used for insulating where wires enter the box, and should fit the holes snugly. Where necessary, wires should be taped so as to completely fill the holes in the bushings. Bushings reaching just to the inside of the box should be used, as longer ones will be broken. It is recommended that, for factory use, the top of the box be slanted as at III, so that it will not be used as a shelf. A box should be thoroughly filled and painted before it is lined.

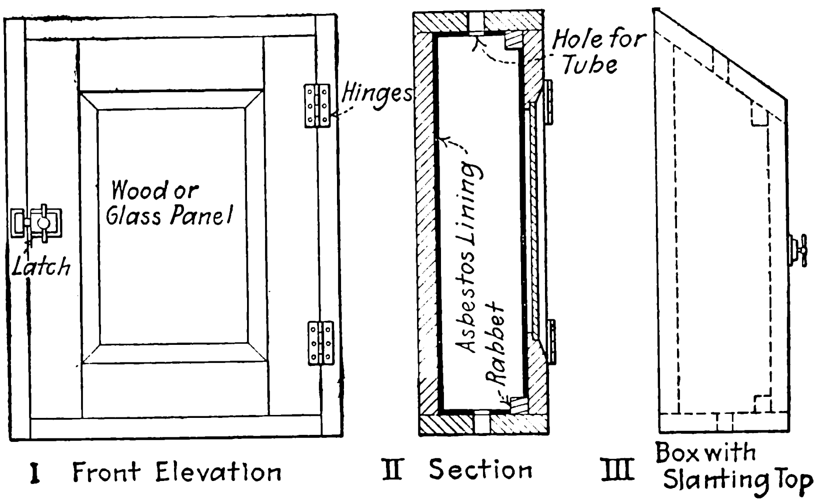


FIG. 23.—A homemade wooden switch box.

Several switches either snap or knife can be mounted in a box like that shown; in fact it might be used as a panel box. A box or cabinet similar to that of Fig. 24 is often convenient, in that it is not necessary to open the door to manipulate the switch. The heavy iron wire handle can be attached to the switch by bending it around the wooden handle, or the wooden handle can be removed and the wire fastened with a nut or a screw eye. If iron conduits, armoured cable or metal moulding terminate in a box, it should be of sheet iron.

50. **Tablet or panel boards** are made in many standard forms and capacities to fit the panel boxes made by their respective manufacturers. Practically all are constructed in accordance with the requirements of the National Electrical Code. One can be reasonably sure that the construction of the tablet boards that have been approved in accordance with the code will be of good construction. Plain black finished slate is probably the best and most serviceable material for a board and a plain lacquered finish on the copper is probably as good as any. In general, plug cutouts are to be preferred and also snap switches are better than knife switches, particularly where they are to be manipulated by persons unskilled electrically. Tablet boards can be assembled

from standard porcelain fittings, as suggested in Fig. 25, held with wood screws.

51. Panel boxes are cabinets arranged to contain cut-outs or cut-outs and switches for protecting and controlling branch circuits where they branch from a main. The miniature switchboard within the box supporting the cut-outs and fuses is called the panel board or the tablet board. It has been found desirable, in so far as possible to group cut-outs in a wiring system and

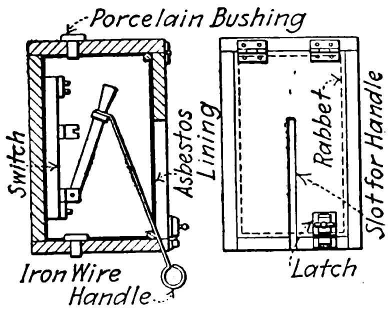


FIG. 24.—An enclosed wooden switch box.

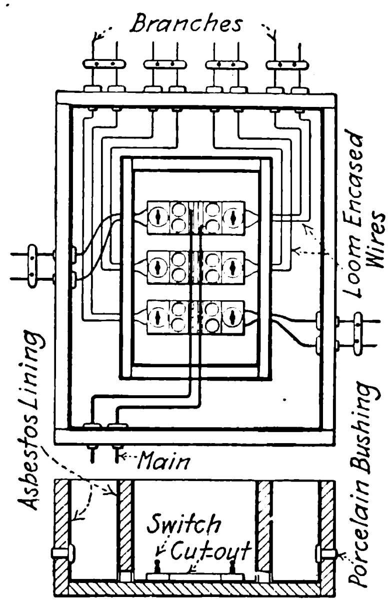


FIG. 25.—A homemade panel box.

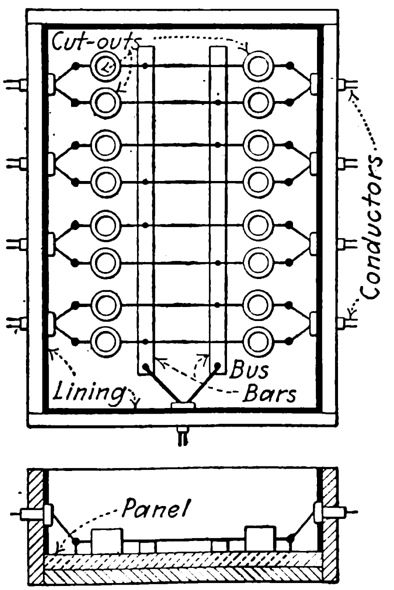


FIG. 26.—A panel box without gutter.

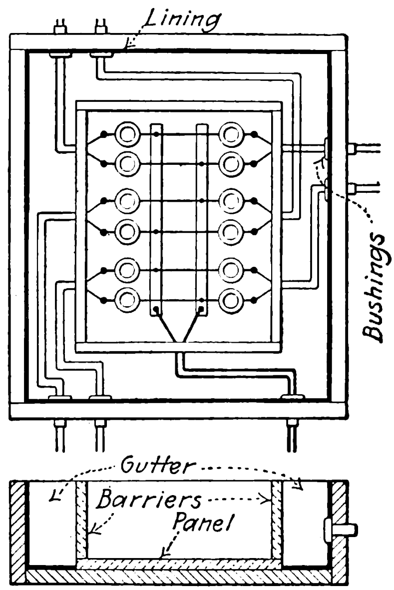


FIG. 27.—Panel box with gutter.

this accounts partially for the popularity of panel boxes. The first panel boxes were made without gutters (Fig. 26) and boxes of this type are still used to some extent. Their disadvantage is that it is necessary to carry the wires for each branch circuit to a point of the box opposite the proper cut-out. This is often inconvenient and expensive. To obviate this disadvantage panel boxes are now most often made with wiring gutters (Fig. 27). With this arrangement conductors can enter the box at any point on the sides or top and can be carried in the gutter to a point opposite the cut-out.

Panel boxes may be of either the flush or surface type (Fig. 28). The flush type is obviously preferable because it extends but little beyond the surface of the wall. Flush type boxes are always used in first-class residence and office building wiring. Surface type boxes are used principally for factory wiring and for conduit installations in old buildings.

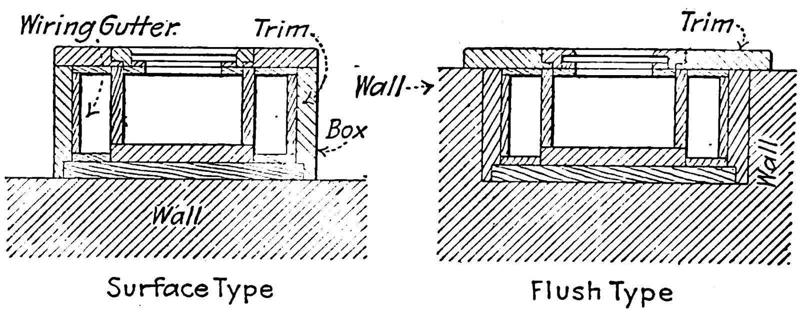


FIG. 28.—Boxes of the surface and flush types.

Panel boxes of sheet steel are suitable for factory work. The barriers in boxes with gutters are usually of slate or marble. The inside of a wooden box must be completely lined with a non-combustible insulating material. Slate or marble $\frac{1}{4}$ in. thick or asbestos board $\frac{1}{8}$ in. thick can be used. Where iron conduit, armoured cable or metal moulding enters the box it should be of painted sheet iron or steel. Boxes should be painted inside and out. An asbestos or steel lining is to be preferred because slate and marble break readily.

The "trim" of a panel box consists of the door and the frame in which it swings. Trims are held to the boxes with screws so they can be readily removed for manipulating wires. The door should close against a rabbet so as to be dust-tight. Glass panels may be used in doors instead of wooden ones and should be at least $\frac{1}{8}$ in. thick. A 2-in. space should be provided between the fuses and the door.

52. **Homemade panel boxes** can be constructed where necessary but it is probable that it is cheaper to buy ready made. See paragraph on *Homemade Switch Boxes* and National Electrical Code rules regarding the construction of cut-out boxes and cabinets. Figs. 23, 25, 26 and 27 illustrate the general construction of boxes. The barrier in a homemade box can be of wood in which case it must be covered on both sides with $\frac{1}{8}$-in. sheet asbestos. For a homemade box standard porcelain cut-out fittings and standard snap switches can be used. They are held with screws to the as-

bestos covered back of the box. Heavy wire can be used for bus-bars. Fig. 25 illustrates the appearance of such a box and the trim can be made as shown in Fig. 28, which illustrates a box with a barrier. One without a barrier would appear like that of Fig. 26.

MISCELLANEOUS WIRING METHODS

53. Service entrances may be made as suggested in Fig. 29 where the wires enter the attic and as in Fig. 30 where the entrance switch and meter are in the basement. The cut-out (fuse-block) should protect the switch. The conductors should be bushed with porcelain tubes where they pass through a wall. Tubes or conduit should be cemented in the wall. The tubes should slant outwardly and downwardly to prevent the entrance of water. A drip loop should be formed in the service wires. The main switch should be arranged to disconnect all of the equipment in the building, except the main cut-out, from the outside wires. Where conduit is used for an entrance two or three rubber-covered wires can be carried in one conduit.

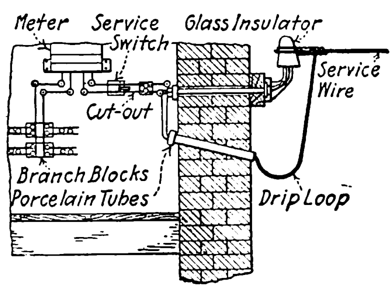


FIG. 29.—Entrance and service switch.

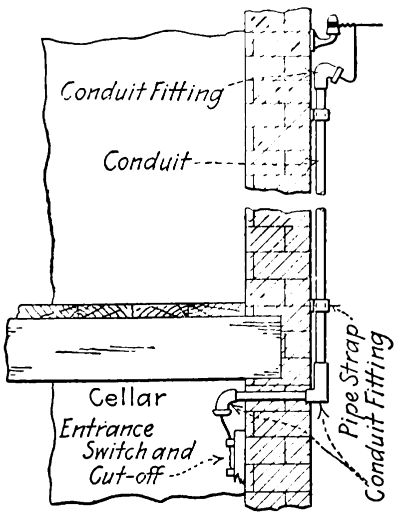


FIG. 30.—Conduit entrance.

54. A typical electric service board is shown in Fig. 31. (*Rules and Regulations of the Commonwealth Edison Co.*).—Service boards are used for installations of considerable capacity. The features of the board shown are: (1) The provision for the removal of links for meter testing and (2) the division of the elevator from the general power, and the lighting from the power. If energy is to be purchased a maximum demand form of contract, space and drilling must be provided for demand meters. Service boards of the general form shown are required by the Commonwealth Edison Company.

55. Brief of Underwriters' Rules Covering the Installation of Switchboards (*Factory Mutual Fire Insurance Co's Wiring Rules*).—Switchboards should be made of slate or marble, supported on metal frames, and should be located well away from combustible materials. They should always be open at the sides, and a space of at least 12 in. should be left between the floor and the board, and 3 ft., if possible, between the ceiling and the board, in order to lessen the danger of communicating fire to the floor or ceiling, and to prevent the formation of a partially concealed space, very liable to be used for the storage of rubbish, oily waste, etc. The instruments should be neatly arranged and the wiring on the back should be laid out in a careful and workmanlike manner.

It is recommended that all live parts, such as bus-bars and other conductors, be protected against accidental contact as far as practicable by suitable insulation, which shall be "flame-proof" or "slow-burning" and designed to withstand a reasonable amount of abrasion. The chances of accidental short-circuit and arcing

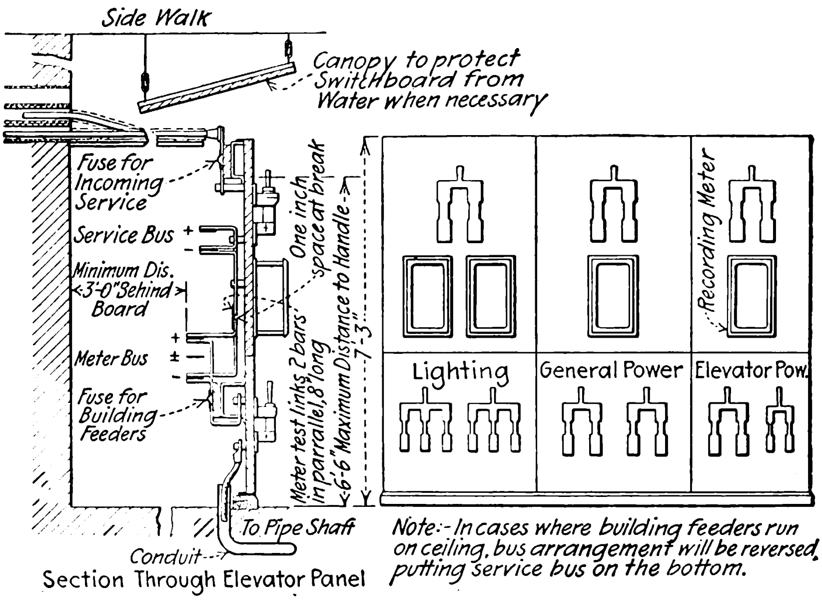


FIG. 31.—Service board.

at these points may thereby be greatly reduced. Insulated cable for bus-bars and connections is excellent for this purpose. However, the conductors could be wrapped or taped if this should be found more convenient, but this method should never be used unless it can be done *well*. Special precautions might also be necessary with either method if applied to high-voltage switchboards.

In addition to the usual measuring instruments and other apparatus, the switchboard should contain reliable devices for testing for grounds.

56. The following suggestions should be followed in wiring for watt-hour meters (*Rules and Regulations of the Commonwealth Edison Co., Chicago*): Meter loops should be provided in the mains at an accessible point, and so arranged that the meter may be mounted with ordinary wood screws on the wall. A meter board must be provided of sufficient size to allow the installation of a recording wattmeter and maximum demand meters. Two demand meters are installed on three-wire mains. Maximum meters will not be installed on installations under 1 kw. Sufficient space must be provided about the meters to allow the removal of the case.

Meter boards should not be erected on a wall which is subject to any considerable vibration, or in places subject to excessive moisture or heat. A pressure wire tap must be provided in all cases where all wires of the circuit are not looped out. On three-wire mains the pressure wire tap must be made on the neutral wire. The general arrangements of meter loops should be such that a meter can be installed without crossing any wires, if possible. If this is impracticable, sufficient flexible tubing should be left on the wires to make possible an installation which will be in accordance with the wiring rules.

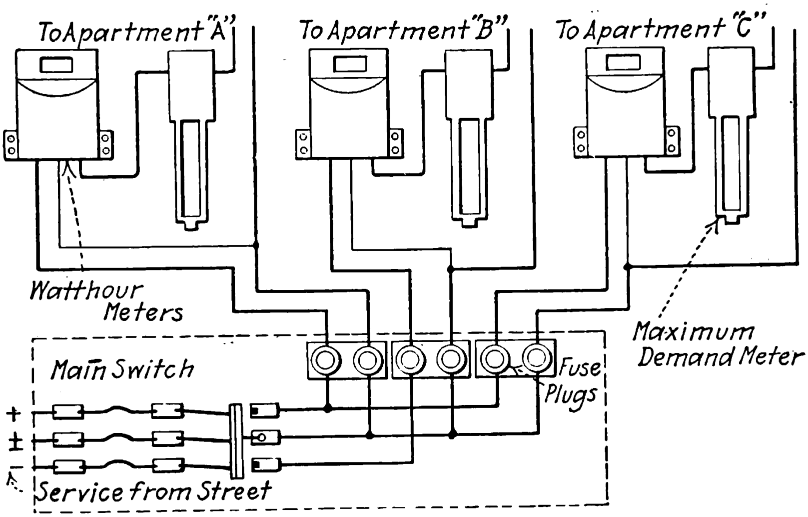


FIG. 32.—Diagram of meter connections and general wiring of meterboard for apartments requiring but one circuit.

Meter loops should not be placed above 7 ft. from the floor, and should be as near the point of entrance of the service as possible. In office buildings meter loops should be located at a central point in meter closets or public corridors, and in apartment buildings in the basement of the building, so that meters may be installed and maintained without annoyance to tenants.

Meter loops must be located relative to fuses so that meters are protected by the fuses. See Figs. 32 and 33. They must never be placed between the service and the service switch. Generally speaking, not more than one meter installation will be provided for the same class of service in any one building.

Meter loops for service to supply temporary lighting or power to new buildings during construction must be located on adjoining premises. No three-wire meters larger than 200 amp. are used. Installations requiring meters of larger capacity will be provided with two meters, one on each side of the three-wire main; space should be allowed accordingly in arranging meter boards.

57. In connecting Edison plug cut-outs, they should always be so arranged that the screw shells, which extend beyond the porcelain, will not normally be alive. Fig. 34, *I* and *II*, show the right

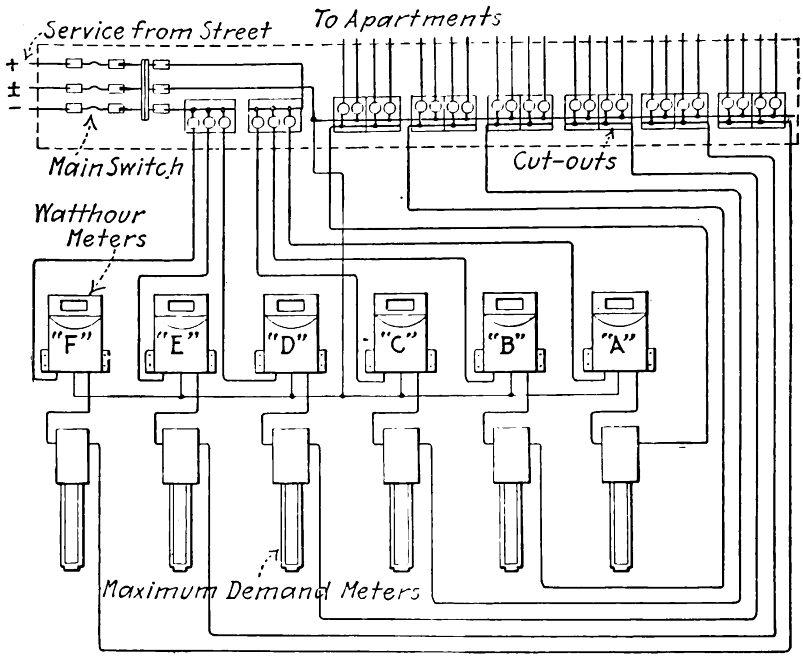


FIG. 33.—Design of meterboard connections for apartments requiring two circuits.

and wrong methods. If connected incorrectly, there is constant danger of short-circuit or shock when men are working about the cut-outs with bare wire ends or tools. Some makes of plug cut-outs are so constructed that the porcelain is higher than the screw shell which is thereby protected. Such cut-outs would be properly

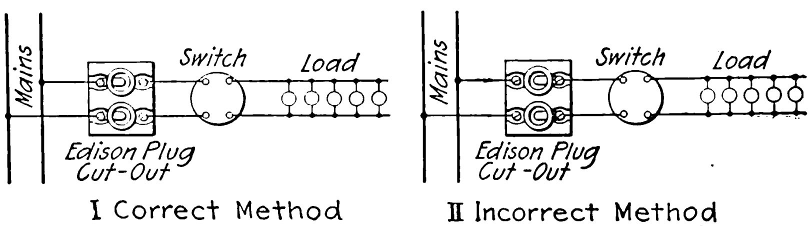


FIG. 34.—Correct and incorrect methods of connecting Edison plug cut-outs.

connected as shown in either *I* or *II* and should therefore be selected where possible. (*Electrical World*, May 4, 1912.)

58. In protecting reinforcing conductors, that is, in protecting conductors that are to operate in parallel with conductors already installed, the methods illustrated in Fig. 35 may be used. Where small wires are involved and are so located as to be apt to be broken, each reinforcing wire should be protected with its own cut-out, as shown in *I*. Where the wires are heavy and not liable to breakage, both the reinforcing and the reinforced wire can be connected in parallel and can be protected by one fuse, *II*. If the method of *II* were used for the conditions recommended for *I*, one of the wires might break and the remaining one would be

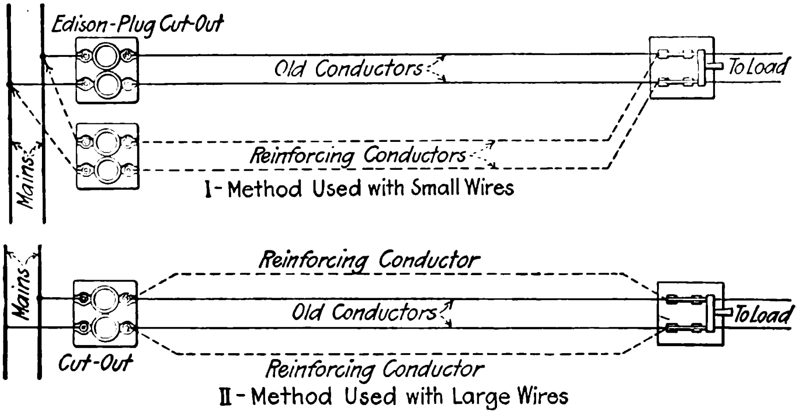


FIG. 35.—Methods of reinforcing conductors.

protected by a fuse too heavy for it. It might, therefore, become overheated and cause a fire. Where at all feasible, the method of *II* should be used, because with that of *I* there is apt to be unproportional division of current between the two conductors, due to differences in contact resistance at the terminals.

59. A single-pole switch should never be cut in the neutral wire of a three-wire system because the neutral is usually intentionally grounded and with a switch, cut in the neutral wire, open, the path to ground may be destroyed.

60. A three-wire to two-wire change-over switch, or as it is sometimes called, a break-down switch, is connected as in Fig. 36. Such a switch is used when it is necessary to feed a three-wire system from a two-wire or from a three-wire source of energy. Where such a switch is installed the neutral of the three-wire system must have an area equal to the sum of the areas of the two outside wires because when operating from a two-wire source the current in the middle wire will be twice that (assuming the system to be balanced) in either of the outer wires. If arc lamps are used on such a three-wire system they must all be connected between the neutral and a certain one of the outside wires or some special scheme of connection must be adopted. If they are not so connected, polarities will be reversed when the change-over switch is thrown.

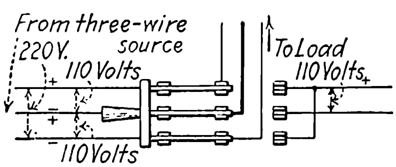


FIG. 36.—Three-wire to two-wire switch.

61. Connections are sometimes reversed in double-pole, snap switches, even by experienced wiremen. Many makes of snap switches "cross-connect" (Fig. 37), that is, the contact bar, when the switch is closed, connects each terminal with the one diagonally opposite. If, through error, the leads are connected as at *II*, a short-circuit may be established through the switch.

62. Single-pole switches are permitted, by the Underwriters, on circuits carrying loads not exceeding 600 watts at pressures not exceeding 300 volts. This gives a maximum permissible current of 3 amp. at 220 volts, or 6 amp. at 110 volts. With these loads, single-pole switches will give good service in residences where the circuits are not apt to be disturbed, but in industrial plants, single-pole switches may give trouble, as described below, and it is good practice to use double-pole switches in such installations where reliability of service is important.

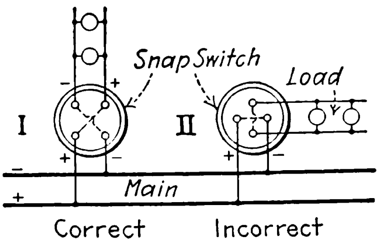


FIG. 37.—Snap switch connections.

63. Single-pole switches may cause trouble because they open but one side of the circuit. For example (Fig. 38 *I*), if one side of a two-wire main happens to be grounded, a ground on the side of opposite polarity, on a branch circuit controlled by a single-pole switch, will form a closed circuit. If the grounds are of sufficiently low resistance, enough current will flow to light the lamps,

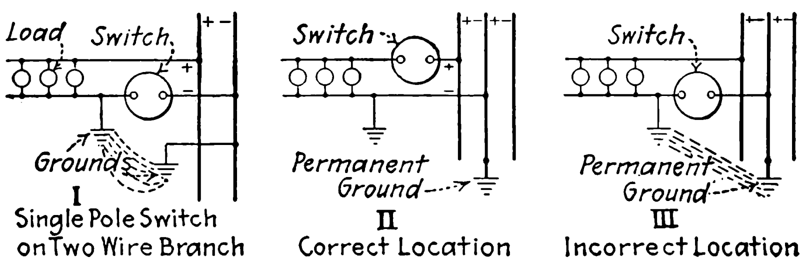


FIG. 38.—Connection of single-pole switch on branch circuits.

even with the switch open. If the resistance of the grounds is high, not enough current will flow to light the lamps. Furthermore, with conditions as shown at *I*. if a wireman accidentally touches a wire of the + side of the branch circuit to any grounded object, such as a gas pipe, a short-circuit would result.

64. Single-pole switches in two-wire branches from three-wire mains should not be inserted in the branch wire connected to the neutral wire of the three-wire system. (See Fig. 38, *II* and *III*.) The neutral of a three-wire system is usually permanently grounded at the central station as well as elsewhere, and with the switches in a neutral branch wire (*III*), trouble is more apt to occur than when the switch is in the other branch wire, as at *II*.

65. Where the switch must be at the opposite end of a room from the entrance the wiring should be arranged as shown at Fig. 39, *II* rather than as at *I*. The method of *I* requires four wires the length of the room while that of *II* requires but three.

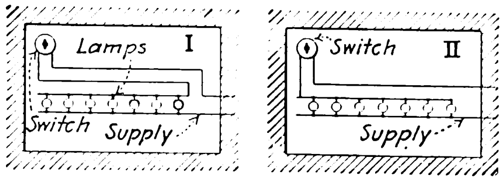


FIG. 39.—Switch at opposite end of room from entrance.

66. Wiring for a switch-controlled lighting circuit, which feeds from another circuit which is also controlled by a switch. Three methods are shown in Fig. 40. With that of *I*, when the main circuit is switched off the branch circuit is

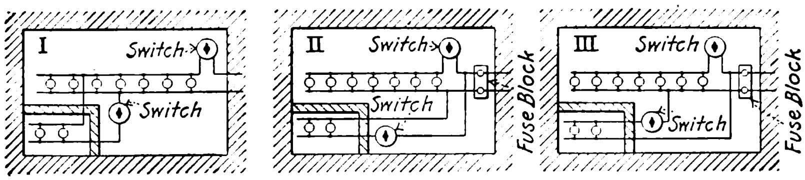


FIG. 40.—Control of lights on sub circuit.

extinguished also. With the methods of *II* and *III*, either the main or the branch circuit can be controlled independently but the arrangement of *II* requires four wires the length of the room, while that of *III* requires but three wires.

67. Where each half of the lamps in a room must be controlled independently the method of Fig. 41, which permits of such control with minimum wiring, can be used.

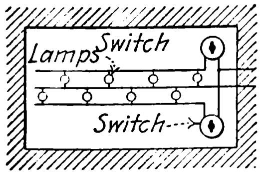


FIG. 41.—Each switch controls half of the lamps.

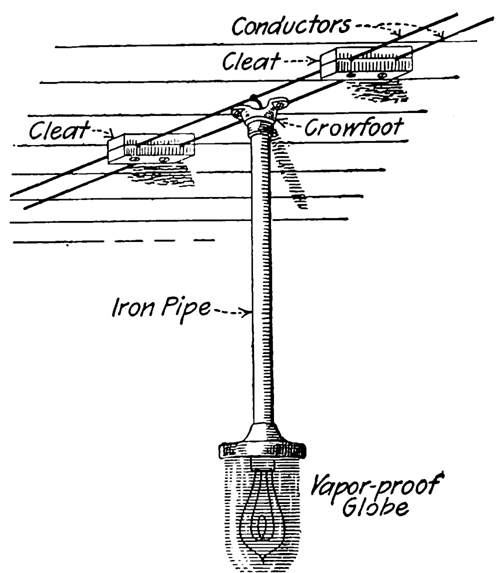


FIG. 42.—Vapor-proof globe on pipe hanger.

68. Sockets in rooms where inflammable gases may exist should be enclosed in a vapor-tight globe (Fig. 42) and supported on a pipe-hanger, wired with approved rubber-insulated wire soldered directly to the circuit. The upper end of the pipe should be sealed with compound if the room is damp.

69. **In fastening cords in sockets,** some precaution should be taken to prevent stray strands of wire from coming in contact with metal, and thereby causing short-circuits or grounds. This can be accomplished by dipping the bared conductor of the cord in molten solder before it is made up under the binding screw. Strips of tape, about $\frac{1}{4}$ in. wide, torn from wider pieces, are sometimes wound about the braid at the end of bared cord, to prevent

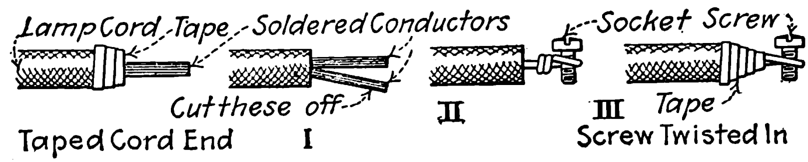


FIG. 43.—Method of connecting flexible cord in socket.

the braid from unraveling. See Fig. 43. A good method of fastening a cord in a socket (Fig. 43, *I*, *II* and *III*), is to cut half of the conductor away, twist the remaining strands into a little cable and then make it up about the screw. Tape should be applied as shown. (*Electrical World*, May 4, 1912.)

70. **Insulating joints** (*Electrical World*, June, 29, 1912) are used to insulate fixtures from grounded parts of a building. The wiring spaces within fixtures are so confined that grounds are very liable to occur in them. If the fixture is insulated from the grounded parts, one ground within it is not liable to do harm. Fig. 44 shows

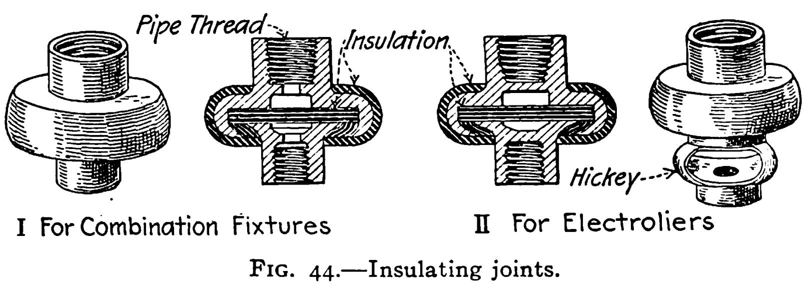


FIG. 44.—Insulating joints.

some insulating joints. That at *I* is used for combination gas and electric fixtures. It has a hole through it to permit the passage of gas. That shown at *II* is for electroliers, and has no hole through it.

71. **In insulating combination fixtures,** the insulating joint should be located as near as feasible to the ceiling, and the wire ends, left after connecting, should never be twisted around the supporting pipe above the joint. (See Fig. 45.) Flexible tubing is required on the wires in knob and tube work and it should extend to below the joint. The Code requires that the pipe above the joint be protected with insulating tubing, which may be either a heavy wrapping of tape or circular loom.

72. Fixtures can be supported in frame buildings by the method of Fig. 46. A wooden strip or cleat should be fastened just above the lath during the construction of the building to take the screws to hold a canopy block. The wooden canopy block supports, with wooden screws, the fixture crow-foot and insulates the canopy

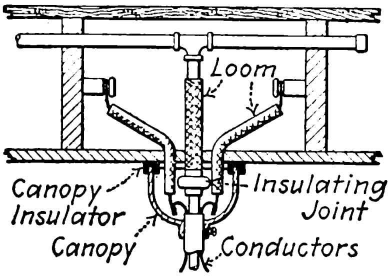


FIG. 45.—Insulating joint for a combination fixture.

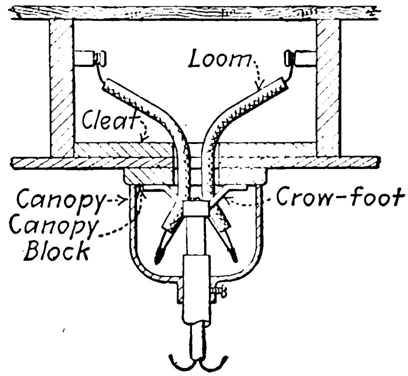


FIG. 46.—Electric fixture support.

from the ceiling. A screw hook turning into a joist (Fig. 47) can be used for sustaining heavy fixtures in frame buildings. A special insulating joint having an eye is screwed on the fixture stem to insulate the fixture from the ceiling or a chandelier loop can be used on a regular insulating joint. In fire-proof buildings, where

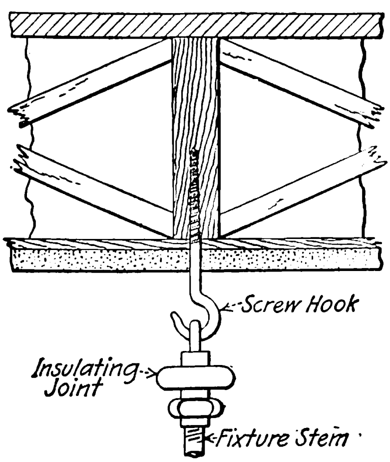


FIG. 47.—Supports for heavy fixtures.

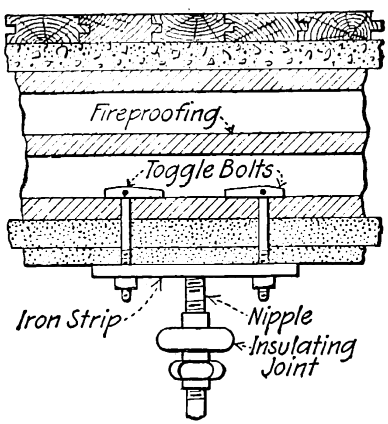


FIG. 48.—Support from a fireproof ceiling.

fixtures must be erected after the building is completed, an iron strap (Fig. 48) held to the surface of the ceiling with a couple of toggle bolts can be utilized for supporting a fixture. A pipe or conduit nipple, turning into a threaded hole in the strap, takes the weight of the fixture.

73. Fixture canopies can be insulated from ceilings and walls with commercial canopy insulators, of which there are many forms on the market. Canopies are usually supplied already fitted with insulating rings by the fixture manufacturers. Where canopy insulators must be "home-made," the method of Fig. 49 or that of Fig. 50 may be followed. In Fig. 49 a ring of fiber formed from the sheet material is bent to fit the interior of the canopy, and is held therein with wires or small rivets. The ring should extend about

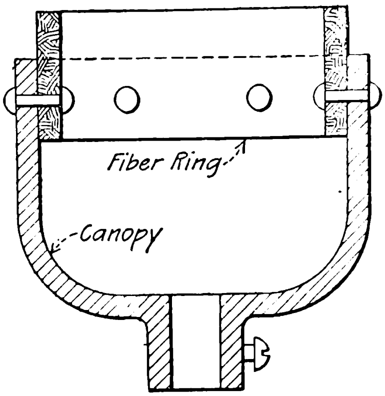


FIG. 49.—Fiber-ring insulator.

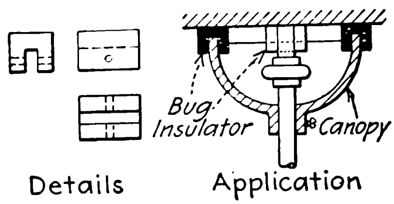


FIG. 50.—Bug insulator.

$\frac{3}{8}$ in. above the top edge of the canopy. Another canopy insulator, sometimes termed a "bug" insulator, can be sawed from block fiber, as shown in Fig. 50. The upper edge of the canopy rests in a slot sawed in the "bug." At least three such insulators should be used for every canopy. A small nail or wire driven through a

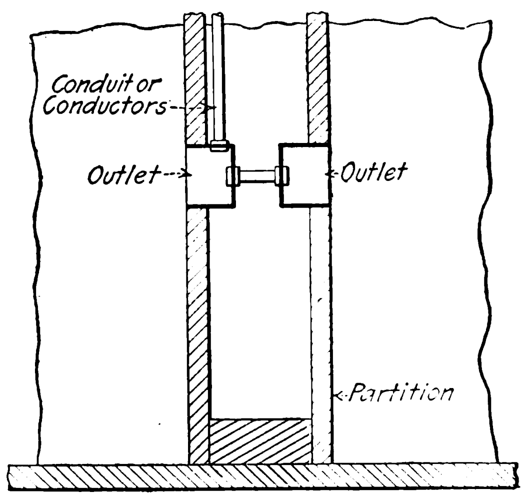


FIG. 51.—Outlets opposite one another in a partition.

hole in the insulator, and one in the canopy, holds each "bug" in position. This method of Fig. 50 is not approved by the Underwriters, whose rules require that the entire edge of the canopy be insulated.

74. Wall or partition outlets in adjoining rooms should always be located opposite one another (Fig. 51).—In general, this applies to both switch and fixture outlets. The reason is that in nearly every case a considerable amount of wiring can be saved by following this construction. This applies to conduit as well as to knob and tube wiring.

75. A method of making up a ground wire where it is to be connected to a pipe and no ground clamp is available. A length, possibly 3 ft., of the ground conductor is "skinned" and carefully scraped or cleaned with fine sandpaper. The pipe on which the connection is to be made is filed bright and clean for a distance of several inches and "tinned" if the connection is to be soldered. Then the bared end of the conductor is arranged, on the brightened portion of the ground pipe, as indicated in Fig. 52, *I*. The free end of the wire (c, c, c) is then served around the pipe as suggested at *II*, and the free end, c, of the wire is passed through the loop B

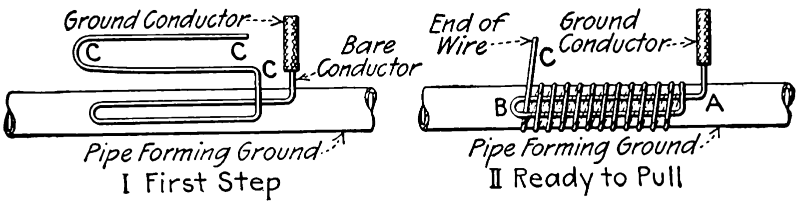


FIG. 52.—Making-up a ground wire.

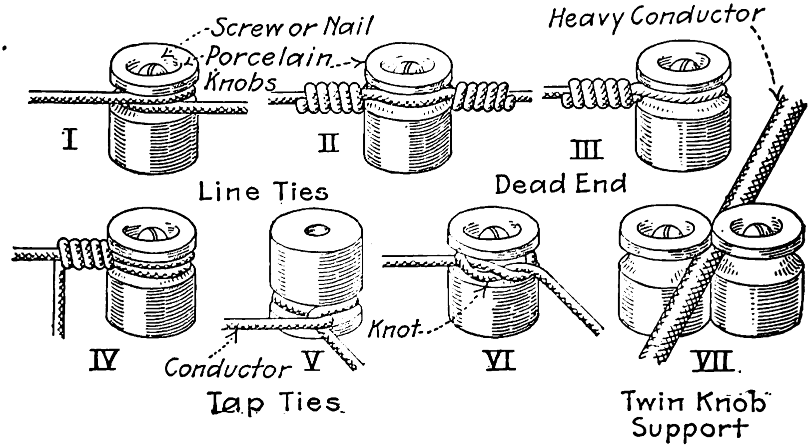
The end A is then pulled. This draws the loop B and the end c up tightly against the other turns and effectively prevents the wrapping from unwinding.

In an actual connection the turns on the pipe are wound closely together. They are shown separated better to illustrate the method. The connection can be soldered with a blow torch and wire solder using a paste flux or by pouring molten solder over the connection until it is hot enough for the solder to adhere.

Where soldering is not feasible the connection can be wrapped with a couple of layers of tin-foil and then with several layers of friction tape. These layers exclude moisture and prevent oxidization. One of the large telephone companies has used the tin-foil and tape method on many hundreds of ground connections for telephone subscribers' stations with excellent results. The tin-foil and tape should extend along the pipe for several inches on each side of the connection and should be wrapped firmly so that they will form a moisture-proof jacket.

76. Knobs and Methods of Supporting Conductors on Them.—Knobs for supporting conductors in interior work are of porcelain. Split knobs or cleats should be used for supporting conductors smaller than No. 8 B. & S. gage. Some methods of securing wires to knobs are shown in Fig. 53. The line tie of *I* is made by winding the conductor once around the knob so both ends of the wire must be under tension to hold the wire in position. A tie-wire is used at *II*. In making up the tie-wire the slack can be drawn out of the conductor. A dead end or termination is shown at *III*. Where it is necessary to change the direction of a run to get the conductor to an outlet or for any other reason, tap-ties

IV, *V* and *VI* are used. It is not practicable to tie large conductors so they may be supported as at *VII*. See following note.



NOTE.—Methods of tying shown at I, V and VI, are not approved by the *Code* and should not be used except in temporary installations not subject to inspection. They should never be used in permanent work.

FIG. 53.—Methods of attaching to knobs.

77. **Tie-wires** must have an insulation equal to that of the conductors they confine and may be used in connection with solid knobs for the support of wires of size No. 8 or larger.

EXPOSED KNOB AND CLEAT WIRING

78. **Exposed knob and cleat wiring** is one of the cheapest and best methods when properly installed (*Standard Handbook*). It finds wide application in factories and mills and in places where appearance is of little consequence. It is also used for running feeders in tunnels and in specially built feeder shafts in fireproof buildings. The wires may be rubber-covered or provided with a slow-burning weather-proof installation. Slow-burning wire cannot be used in cellars, basements, under roofs or in other places exposed to moisture. The wires must be supported at least every $4\frac{1}{2}$ ft., except in mill buildings where a support on each beam may be approved for wires No. 8 and larger if they are separated at least 6 in. The wires must, in dry places, be separated $\frac{1}{2}$ in. from the surface wired over and spaced $2\frac{1}{2}$ in. apart for voltages below 300. Above 300 volts and up to 550 volts, the wires must be separated from the surface wired over by at least 1 in. and must be spaced 4 in. apart. In wet places wires must be at least 1 in. from surface wired over for voltages below 300.

79. **Mechanical Protection of Exposed Surface Wiring.**—The wires must be protected on side walls from mechanical injury and, when crossing floor timbers in cellars or in rooms where they might be disturbed (Fig. 54), the wires must be attached by their insulating supports to the under side of a wooden strip or "running-

board" not less than ½ in. thick and 3 in. wide. Instead of running boards, guard strips on each side of and close to the wires may be substituted. The strips should be at least ⅞ in. thick and should be as high as the insulators. The wires should also be protected by porcelain tubes when passing over pipes (Fig. 55) or any other members.

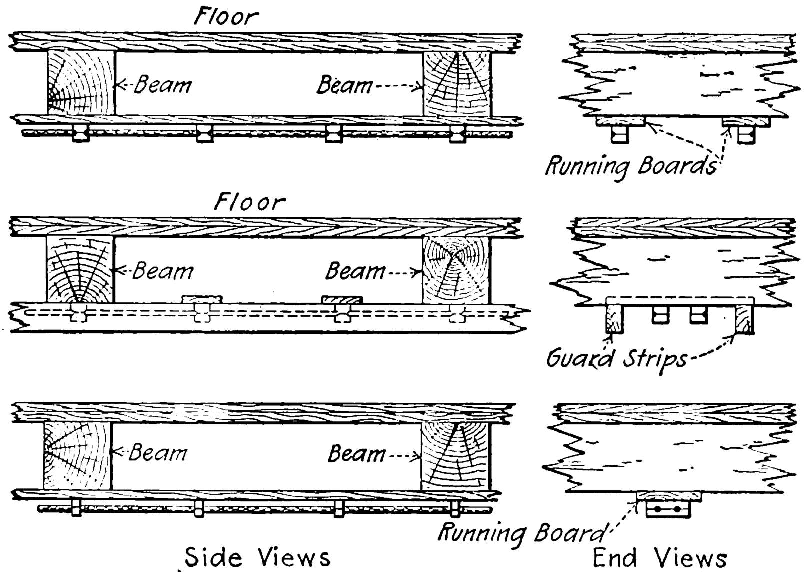


FIG. 54.—Protection of open-wiring on beams.

80. Suitable protection on side walls should extend not less than 7 ft. from the floor (Fig. 56). This may consist of substantial boxing, providing an air space of 1 in. around the conductors, closed at the top (the wires passing through porcelain bushed holes) or of approved wrought iron conduit or commercial wrought

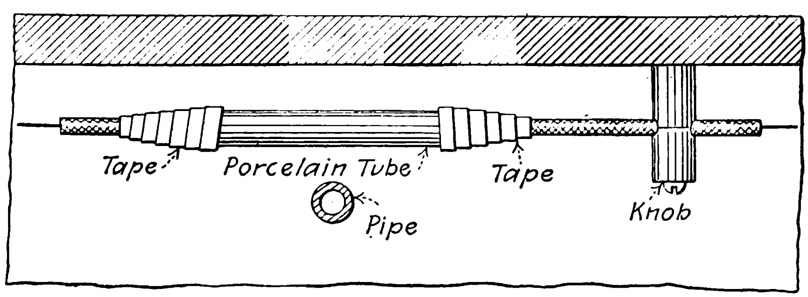


FIG. 55.—Protection of conductor passing over pipe.

iron pipe. When common pipe is used, the insulation of each wire must be reinforced by approved flexible tubing extending from the insulator next below the pipe to the one next above it. Where single-braid rubber-insulated wire is used in conduit the same protection must be provided. Where double-braid-insulated wire is used in conduit the flexible tubing can be omitted, but each end of the pipe must be provided with an approved outlet box.

The two or more wires of a circuit, each with its approved flex-

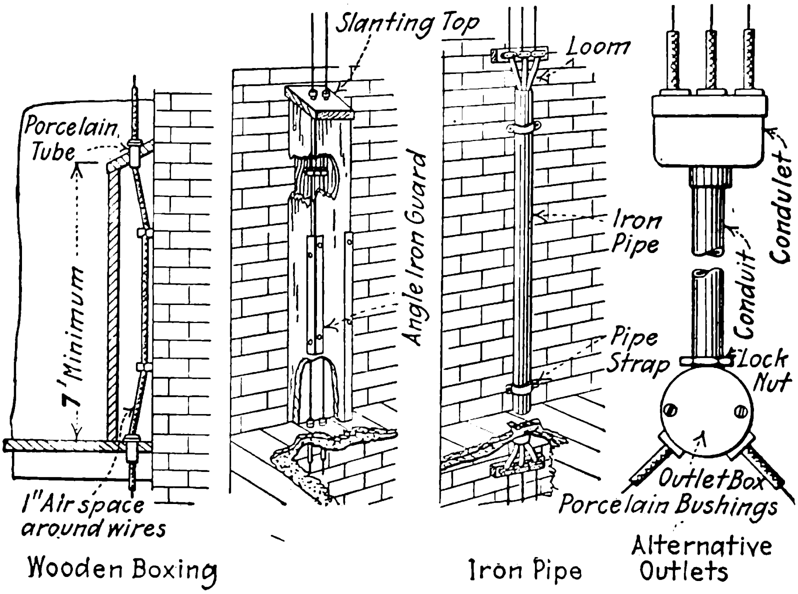


FIG. 56.—Protection of conductors on side walls.

ible tubing, if carrying alternating current, *must*, or if carrying direct current, may, be placed within the same pipe. In damp places the wooden boxing may be preferable because of the precautions which would be necessary to secure proper insulation if pipe were used. With this exception, however, iron pipe is considered preferable to wooden boxing, and its use is strongly urged. It is especially suitable for the protection of wires near belts, pulleys, etc. Fig. 57 shows an outlet arrangement for use at a floor that can be made with a square conduit outlet box.

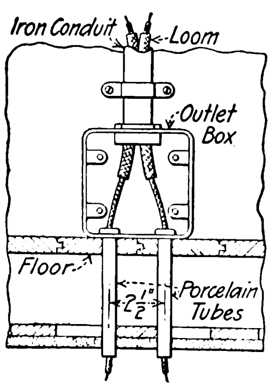


FIG. 57.—Another outlet arrangement.

81. **Where conductors pass through floors, walls or partitions they** must always be protected. Open-work wires can be protected with porcelain tubes (Fig. 58). The tube or bushing must be long enough to bush the entire length of the hole in one continuous piece or else the hole must first be bushed by a continuous water-proof tube. This tube may be a conductor, such as iron pipe, but in that case an insulating bushing must be pushed into each end of it, extending far enough to keep the wire absolutely out of contact with the pipe.

82. **A tube for protecting a wire where it crosses another wire** should always be so placed that the tube will not force the un-

protected wire against the surface supporting the conductors. The tube should always be on the inner wire (Fig. 59). If placed on the outer wire, the tube may force the unprotected wire against the surface as shown in Fig. 59, *I*. (*Electrical World*, April 6, 1912.)

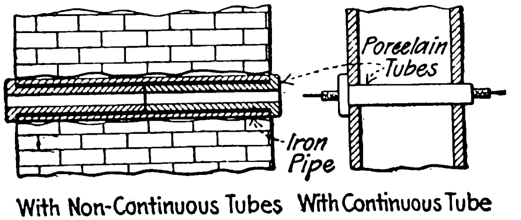


FIG. 58.—Protection through walls and partitions.

83. **A method of supporting open wiring in concrete buildings** is shown in Fig. 60. A round groove of $\frac{3}{8}$-in. radius is cast in the faces of the beams, by having $\frac{3}{4}$-in. half-round molding nailed in the forms. Wrought-iron yokes are bent to fit the grooves as

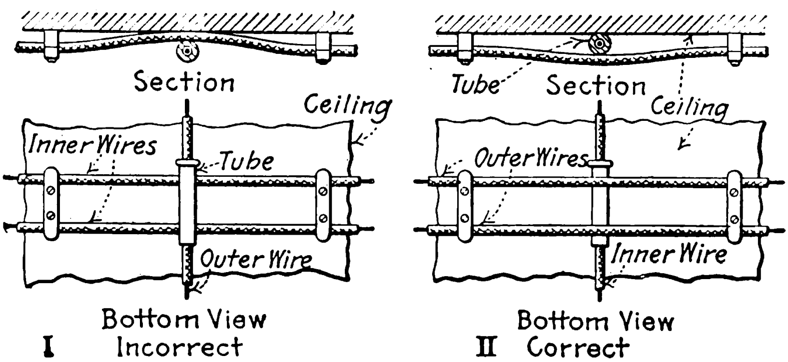


FIG. 59.—Methods of placing protecting tubes.

shown, and $\frac{1}{2}$-in. bolts clamp them in position. Although molding and conduit is shown supported in the illustration, wooden blocks can be bolted to the yokes and thereby open wiring can be supported.

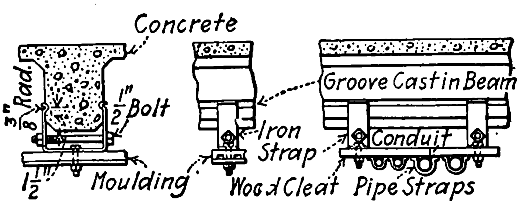


FIG. 60.—Supporting conductors on a concrete beam.

84. **Methods of carrying exposed wiring around and through beams** are illustrated in Fig. 61 which shows the tube and cleat arrangements. In Fig. 62 are shown some methods that can be used when wires are supported on knobs.

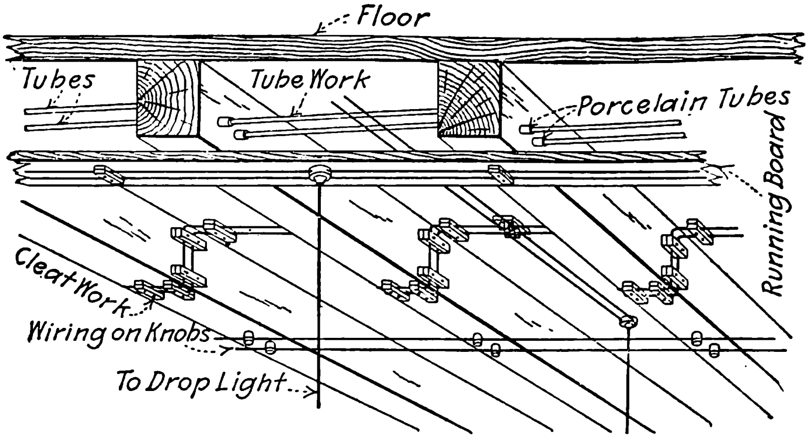


FIG. 61.—Open-work wiring in a mill building.

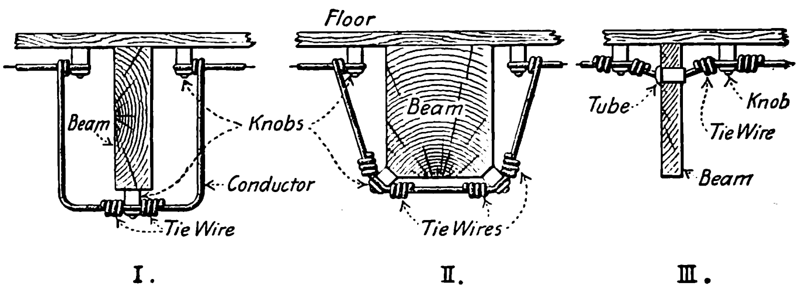


FIG. 62.—Open work wiring with knobs.

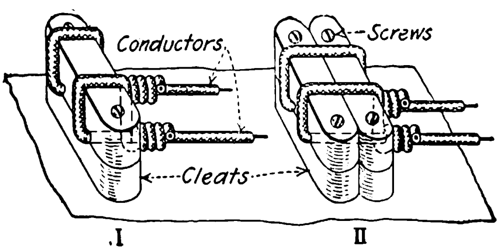


FIG. 63.—Dead-ending on cleats.

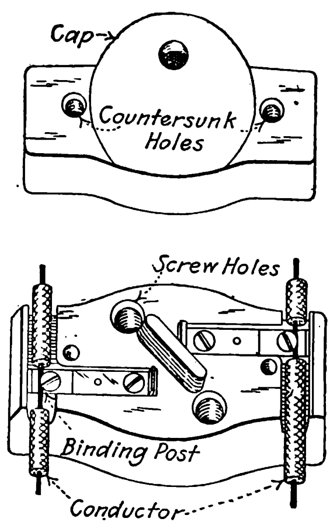


FIG. 64.—A cleat rosette.

85. The method of dead ending on a cleat at the end of a run is illustrated in Fig. 63, *I*. After the wire is passed through the groove the free end is given several short turns around the line. Where a long run is dead ended it is often advisable to so fasten two sets of cleats that one bears against the other so that both will assume the strain as shown at *II*.

86. Rosettes for open surface wiring are used to connect the drop cords for the incandescent lamps to the branch circuits. . A rosette with protected (concealed) contact lugs is preferable to one

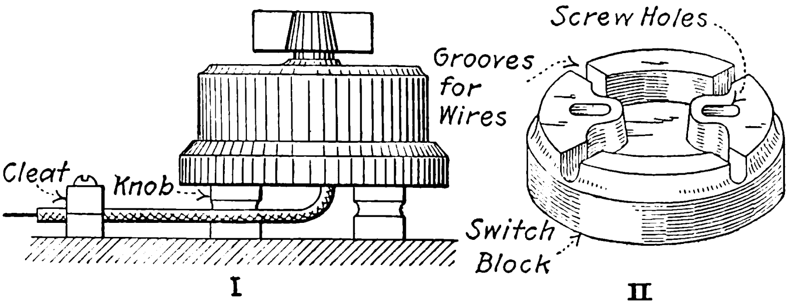


FIG. 65.—Supporting switches in exposed surface wiring.

with exposed lugs. Fig. 64 shows one good type. Another good method of supporting drop cords, particularly where there is vibration, is with the ceiling button described in 5 and illustrated in Fig. 76A.

87. Switches can be supported in exposed surface wiring as shown in Fig. 65. Small porcelain knobs may be used to support the switch (Fig. 65, *I*), which permits of the conductors being brought through the back of the switch without touching the supporting surface, however, this method is not approved by the National Code. Or the switch can be mounted on a commercial porcelain switch block (Fig. 65, *II*), which is an approved method.

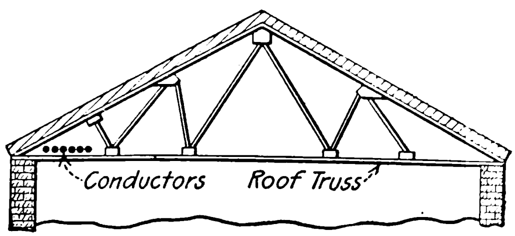


FIG. 66.—Conductors carried on roof truss.

88. The different approved methods of exposed surface wiring as arranged in a building of mill construction are illustrated in Fig. 61. Which method should be used in any particular case is a matter that is largely determined by the size of wire involved and other local conditions.

89. In steel mill buildings heavy conductors may be carried on the lower chords of the roof trusses (Fig. 66). This is a good location as the conductors are out of the way and not liable to be disturbed. At each truss the conductors can be supported by one of the methods illustrated in Fig. 67. With the method of Fig. 67, *I*, the conductor merely rests in the insulator and the entire longitudinal strain is taken by strain insulators, attached to tightening bolts or turnbuckles, at the ends of the run. This method has the

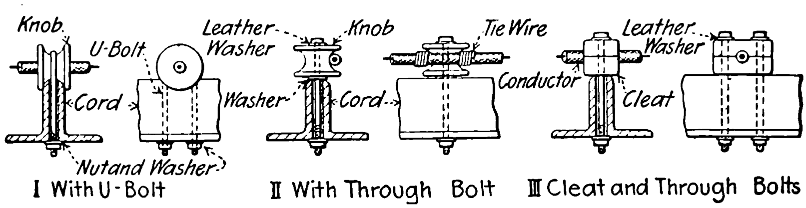


FIG. 67.—Attaching knobs to truss chords.

disadvantage that if the conductor breaks at any point or is burnt in two it will fall to the floor. The tie-wire method of *II* is seldom used, though it is satisfactory if cleats are not obtainable. (Split knobs or cleats must be used for conductors smaller than No. 8.) The cleat and through-bolt method of *III* is probably the best, all things considered. After the conductor has been drawn taut with the tightening bolts at the ends of the run the cleat bolts are tightened and each cleat then assumes its share of the strain. Tie-wires which are unreliable and which may cut into the insulation of the conductor are unnecessary. Leather washers should be used between the insulator and bolt to prevent breakage. Material that follows on Steel Mill Building Wiring is largely from an article in the *Southern Electrician*, December, 1912, by the compiler of this book.

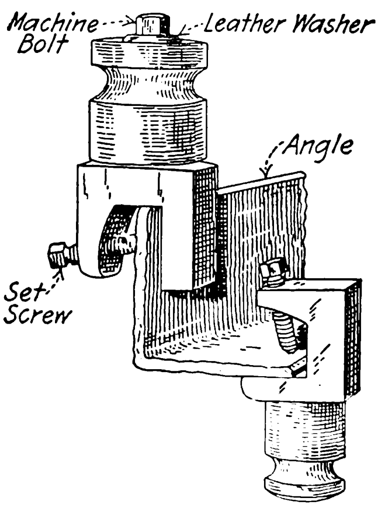


FIG. 68.—Universal insulator supports on an angle. (Note that split knobs must be used where conductors smaller than No. 8 are to be supported.)

90. For supporting conductors on steel angles the Universal Insulator Support (Figs. 68 and 69 and Table **91**) is a convenient fitting. It is of malleable iron and can be clamped on the flanges of steel beams, angles, channels, Z-bars, and on round, square and flat bars. It can be also attached to gas and water pipes, and to the edges of plates and tanks. Two insulators can be fastened to each support when necessary. Cup-pointed, case-hardened set screws are used. Leather washers should be used under the bolts that hold the insulators.

91. Dimensions of Universal Insulator Supports

(*Steel City Electric Co., Pittsburgh, Pa.*)

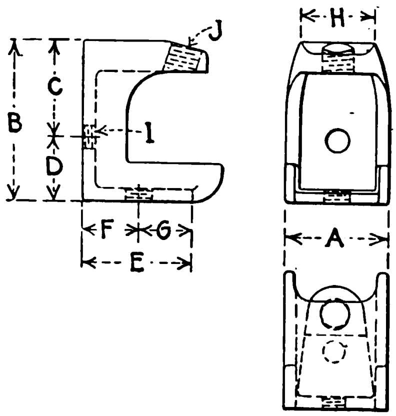


FIG. 69.—The universal insulator support.

A size in.	For insulators, numbers	B in.	C in.	D in.	E in.	F in.	G in.	H in.	I Dia. of tapped hole	J Dia. of set screw furnished
1	5, $5\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{5}{16}$
$1\frac{1}{2}$	10, 4, $4\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	$\frac{7}{16}$
2	1, 3, 3 W.G., $3\frac{1}{2}$, 24	2	1	1	2	1	1	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{1}{2}$
$2\frac{1}{2}$	25, 29, 34	$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{5}{8}$

92. For supporting conductors on steel columns a wooden base-board for the cleats clamped to the column with hook-bolts,

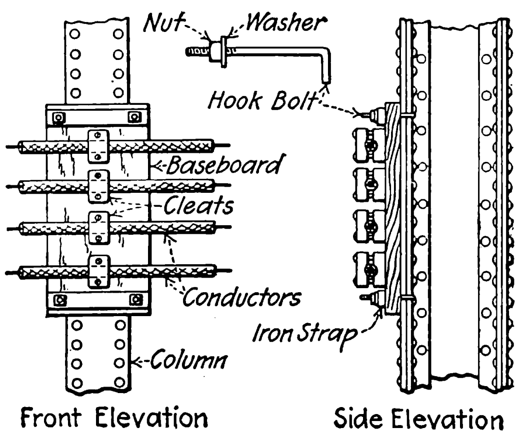


FIG. 70.—Attachment of wiring board to column.

Fig. 70, is a good arrangement. The board must be cut out in back for the rivet heads in the column. Strap iron cleats through which the hook-bolts pass prevent warping and splitting.

29

93. **Wire-racks** are used to support conductors, principally heavy ones, where there are many conductors in the run. The conductors should have flame-proof or slow-burning insulation. A wire-rack can be made of wood fashioned into a framework some-

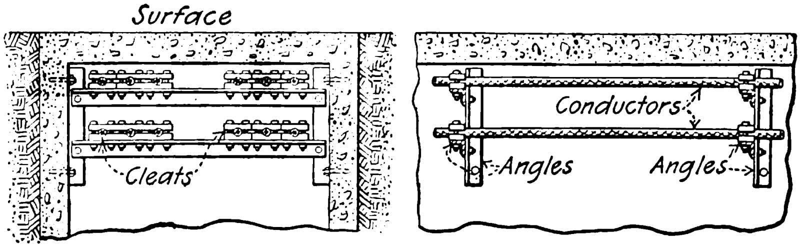


FIG. 71.—Angle iron rack for conductors.

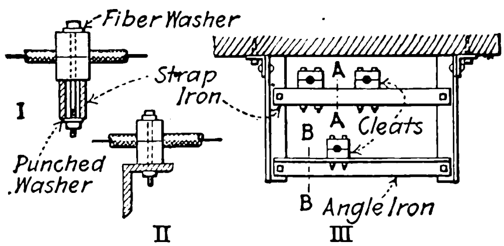


FIG. 72.—Rack composed of angles and strap iron.

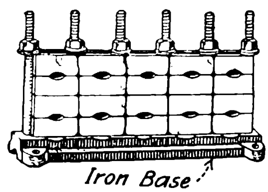


FIG. 73.—A commercial insulator rack.

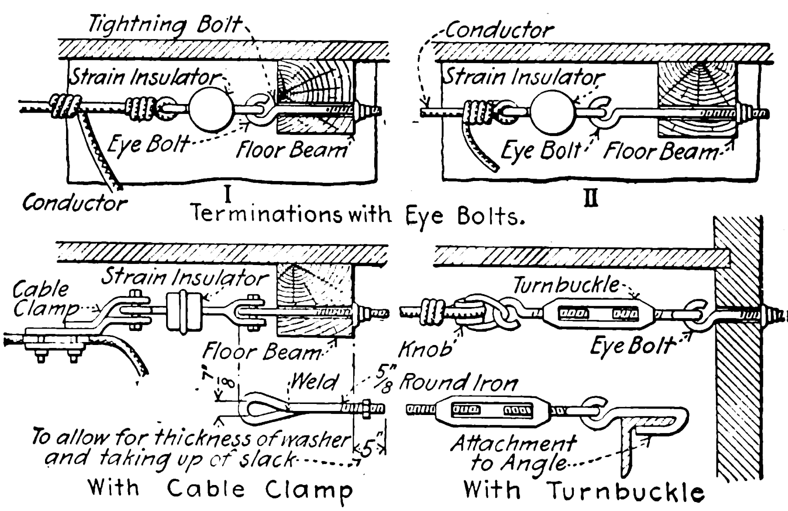


FIG. 74.—Methods of terminating conductors.

what along the lines of the steel ones of Figs. 71 and 72. The cleats insulating the conductors are held to the frame with wood screws or, preferably, with machine or stove bolts. A commercial wire rack with a cast-iron base that can be bolted to any surface is shown in Fig. 73. Generally a steel-frame rack is preferable to a wooden one. The rack of steel angles of Fig. 71 was designed for installation in the top of a pipe tunnel. The insulators are held to the cross angles with bolts with a leather washer under the head of each. The structural steel rack of Fig. 72, *III*, is arranged for supporting from a ceiling. Angle cross-arms can be used as at *II*, or the cross-arms can each be formed of two iron straps as at *I*. With the two-strap method, drilling for the cleat bolts is unnecessary and the cleats can be shifted along the arm into any desired position and there clamped fast. Strain insulators engaging in turnbuckles or tightening-bolts should be used at the ends of each straight run to assume the strain and to provide for tightening or else the arms and cleats at the run ends should be reinforced to assume the stress that will come on them.

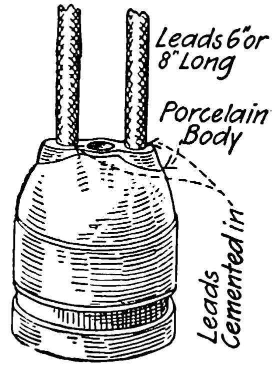


FIG. 75.—Weatherproof socket.

94. Methods of Terminating Heavy Conductors.—At the ends of all important open-wire runs of wires larger than, say, No. 8, strain insulators engaging in some wire-tightening device should be used. Fig. 74 illustrates some methods. Either tightening-bolts or turnbuckles can be used. The insulator may be of the type extensively used in trolley line construction as in *I*, *II* and *III*, or it may be a heavy knob (*IV*), held to the tightening device with stout wire. Where a run changes direction a cable clamp (see index for a further descrip-

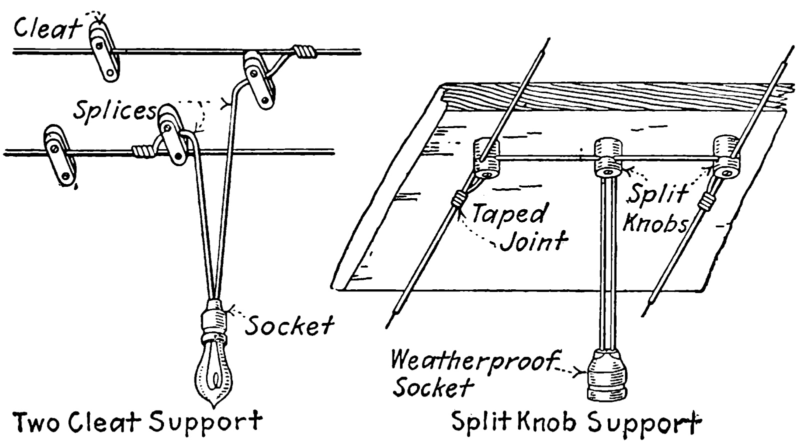


FIG. 76.—Short weatherproof pendant.

tion) can often be used with economy, particularly with large conductors. Where a cable clamp is used it is unnecessary to cut the conductor to change its direction and the necessity of making-up turns about the line wire as in *I* and *II* is eliminated.

95. Water-proof Pendants (*Factory Mutual Wiring Rules*).—For incandescent lamps in wet places, approved water-proof sockets should be used. These sockets should be suspended by separate, *stranded*, rubber-covered wires, soldered to the socket leads and also to the overhead wires. Where the pendant is over 3 ft. long, the wires should be twisted together. The entire weight of the pendant should be borne by cleats or some other independent means, in order to prevent any strain on the connection to the overhead wires. (See Figs. 75, 76 and 77.)

96. In wiring in damp places such as in dye-houses, stables and breweries, wires should be rubber insulated, and separated at least 1 in. from the surface wired over, preferably by knobs. Solid knobs are preferable to split ones, because there is more liability of current leakage to the screw of a split knob. They should be separated by at least $2\frac{1}{2}$ in. for voltages up to 300 and 4 in. for voltages up to 600. Greater separations

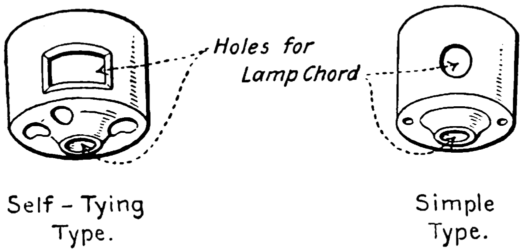


FIG. 76A.—Ceiling buttons.

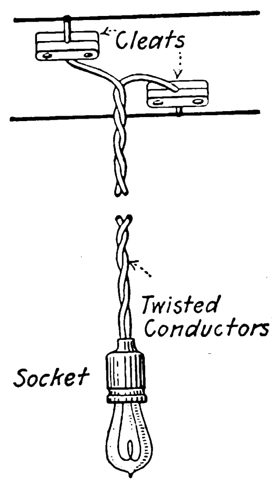


FIG. 77.—Long weather-proof pendant.

are preferable. Conductors **on side walls** should be protected preferably with well-painted wooden boxing (see 80), but conduit can be used. Molding is not permitted in damp locations. Sockets and other fittings in such places should be designed to withstand moisture.

97. Where conductors cross damp pipes they should be carried over rather than under, so that drippings will not strike the wires. Porcelain tubes, securely taped to the conductors, should be placed on the conductors over the point where they cross.

98. Sockets for damp places should be of porcelain and hard rubber, or composition weather-proof, or, as they are sometimes called "water-proof" (Fig. 75). Unless made up on fixtures they should be hung by separate stranded, rubber insulated wires, not smaller than No. 14 B. & S. gage, which should preferably be twisted together when the pendant is over 3 ft. long. The leads furnished in weather-proof sockets are 6 in. or 8 in. long, but longer ones can be supplied on special order. The socket leads should be soldered direct to the circuit wires but supported independently of them. Fig. 76 shows a short drop and Fig. 77 a long one; both figures illustrate the method of using cleats to remove the stress from the line conductors. Water-proof sockets are always keyless. Porcelain sockets are easily broken; hence, although their use is not formally approved by the Underwriters', brass-shell sockets thoroughly taped and coated with water-proof paint, are sometimes used. Where not liable to be broken, porcelain sockets are the best.

99. Receptacles for damp places are shown in Fig. 80. They are especially designed to withstand moisture, but should always be supported on porcelain knobs. The rubber insulated leads extend 6 or 8 in. from the body. The leads should be soldered directly to the line wires and the joint well taped.

100. Wiring troughs are sometimes used in damp places. (Fig. 78.) The troughs protect the conductors from drippings, but not from water that condenses on them out of the atmosphere. In assembling wiring troughs, abutting edges should be coated with

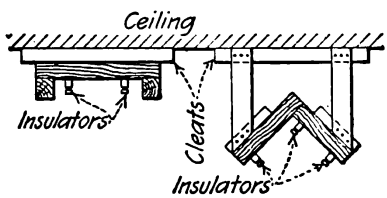


FIG. 78.—Wiring troughs.

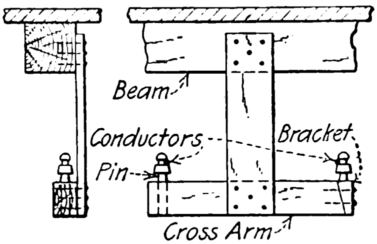


FIG. 79.—Cross-arm support.

tar or with a thick water-proof paint. Screws smeared with paint should be used to hold the pieces together and the screw heads should be painted. A wiring trough in addition to keeping drippings from the conductors, constitutes a mechanical protection for the conductors. The wiring trough serves the same purpose as a running board in this respect.

101. Porcelain or Glass Petticoat Insulators Probably Form the Best Support for Wiring in Damp Places.—These are the same insulators that are used on out-of-door pole lines. There is apt to be considerable electrical leakage in damp places with ordinary

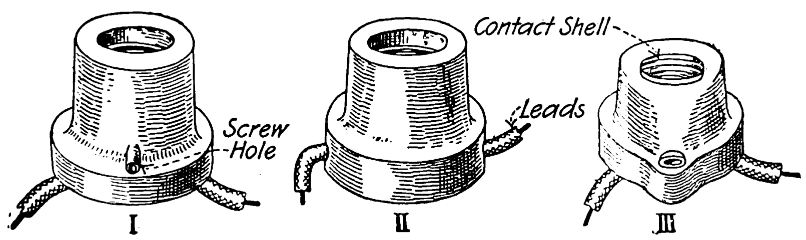


FIG. 80.—Receptacles for damp places.

knobs and cleats, and the long creepage distance provided by petticoat insulators constitutes good protection against this. The insulators are supported on thoroughly painted wooden pins or brackets, which are held by small cross-arms (Fig. 79). In no case should the insulator be mounted upside down. Glass or porcelain knobs, mounted on a small cross-arm, are sometimes used instead of insulators, but are not as good from an insulation standpoint. The advantage of mounting them on the arm is that an ample separation from the surface wired over is thus provided. The cross-arm and support should be thoroughly painted with a water-proof paint or tar.

102. Joints and splices in damp places must be soldered with great care and should be thoroughly taped. A thorough painting of the tape wrapping, with a water-proof compound, asphaltum or tar, will protect against the entrance of moisture. Splices should be avoided in damp places, but where necessary, they should be located at some distance from a point of support, because the insulation resistance of the insulation around a splice is less than that of equal length of perfect wire.

103. Switches and fuses for wiring in damp locations should, if possible, be located outside of the damp room and in a dry place. Where it is impossible to locate them outside of the damp room they should be mounted within a box that can be kept dry, or on porcelain knobs (Fig. 81). Cabinets thoroughly treated with water-proof compound are preferable to metal ones. A switch-and-fuse cabinet similar to that

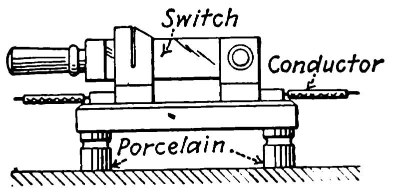


FIG. 81.—Knife switch mounted on porcelain knobs.

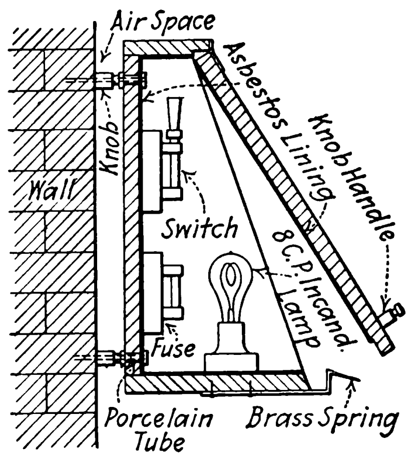


FIG. 82.—Switch and fuse box for damp places.

of Fig. 82 can be made of $\frac{7}{8}$-in. stock. It is lined with well-painted asbestos board and mounted away from the damp wall on porcelain knobs. The constantly burning incandescent lamp keeps the box dry. A glazed hole in the cover serves to show the location of the box in a dark room.

104. Wiring in Packing Houses.—Moisture, ammonia and other corrosive vapors are encountered, hence, fuses and switches cannot be installed exposed as in ordinary open-work wiring. There is also danger of mechanical injury to ordinary open-work wiring. Switches should be installed in cabinets similar to that described in 103. Ordinary brass sockets will give trouble; those of the keyless type of porcelain, hard rubber or composition may be used. Open wiring on knobs is usually preferable because of the trouble encountered with conduit due to corrosion, even if it is thoroughly painted. The rusting gives the most trouble at the threads in the couplings.

To support the knobs, blocks of wood impregnated with asphaltum, tar or shellac are nailed to the wall or ceiling. The blocks provide ample clearance between the surface and the conductors. A method of carrying conductors that largely prevents moisture from reaching them and the knobs is shown in Fig. 79. Tie knobs are considered preferable to split knobs for this work because of the better insulating properties of the tie knobs.

105. **Brewery wiring** is subject to conditions similar to, though less severe than, those affecting packing-house installations and in general should be treated accordingly. Conduit can be installed to advantage in many locations. In the others, open wiring on knobs can be effectively used, especially in the compressor rooms, the wash rooms and in the tank cellars. Weather-proof switch boxes of the type herein before described should be used unless switch cabinets are installed.

106. **Wiring in Flour, Cereal and Planing Mills.**—Switches and fuses should be installed in dust-tight cabinets, as should starting rheostats for the motors. There are on the market dust-proof switch cabinets, starting boxes and other appliances which should be used in preference to homemade ones. Lamps installed in sockets attached to side walls involve a fire risk as the dust may deposit on them and ignite. Suspend the lamps from the ceiling. Since the dust may get into them and be the cause of an explosion or a short-circuit, key sockets should not be used. Wrought-iron conduit work is probably the preferable type of wiring.

107. **Chemical Works Wiring.**—Lead cable sheaths, iron conduit and slate are usually attacked by the vapors, while porcelain, as a rule, is not. The following method of installing conductors has been used with success in one prominent works. Conductors having weather-proof insulation are installed in hard-wood molding and are buried in tar in the grooves. Both the molding base and the capping are served with a thick coating of tar before they are installed and also afterward. For lamp outlets, molding receptacles are used. Before each lamp is screwed into its socket, a ring of heavily tarred wire is slipped over the base. This ring seals the opening and prevents the entrance of corrosive vapors into the receptacle. The entire installation—molding and fittings—should be thoroughly coated with tar.

108. **Wiring in Dry Kilns** (H. G. Wilson, *Electrical Review*, Feb. 17, 1912).—Rubber-covered wire is of little practical value in these excessively hot places either on knobs or cleats or in conduit, as after a comparatively short time the rubber is thoroughly dried out and becomes brittle and crumbles. Dry kilns are usually constructed of brick with a structural steel framework. Experience has shown that wooden blocks fastened to the walls and framework shrink to quite an extent and in some places char with the heat. Consequently, they become loose and fail to sustain the wires. Profiting by experience, rubber-covered wire, wooden blocks and conduit were eliminated altogether from a certain dry-kiln job. Asbestos-covered wires with a 6-in. separation and not less than 1 in. from the surface wired over were installed. Supports were placed every $4\frac{1}{2}$ ft. Split knobs fastened securely to the iron framework with bolts were used, the holes being drilled through so that nuts held them in place and, where this was impossible, the holes were drilled and tapped with threads corresponding with those on the bolts. For supporting the wire on brick side walls, iron brackets were made which carried knobs.

Porcelain wall sockets were used where practicable. For drop lights another Code rule was "stretched," as No. 14 solid asbestos-covered wire had to be used. The drop wires were permanently separated, from their joints on the circuit wire to the porcelain sockets, by cleats held together by stove bolts, thus giving a $2\frac{1}{2}$-in. separation, and the taps were anchored by split knobs, one for each wire. Fuses, switches and cut-out cabinets were placed outside of the kilns.

109. Wiring in Metal Refineries (H. G. Wilson, *Electrical Review*, Mar. 2, 1912).—While, as a rule, the motors employed in plants of this kind can be placed beyond the reach of the detrimental effects of heat and acid fumes, the use of squirrel-cage induction motors is to be preferred, since these have no sliding contacts. When these are used it is best to paint the insulation of wires exposed to acid fumes with hot tar. If direct-current motors must be employed, these should be completely inclosed to protect them from the effects of dust, which is always prevalent.

Overhead wiring in furnace buildings, in which it is always very hot, should preferably be with asbestos-covered conductors on cleats or split knobs which hold them 1 in. from the surface wired over and 6 in. apart. Screws should be used rather than nails and leather washers in securing the knobs or the cleats, for in a room where the temperature is from 125° to 150°, as it is in these, leather-heads soon become practically worthless.

When installing wiring in metal refineries already completed, as much of the work as possible should be done outside the rooms, since on the inside the acid fumes and heat may be very trying to workmen. This outside work may include such jobs as loosely screwing the insulators to the supporting blocks, cutting conductors to the proper length, and making splices and taps for drop lights. With this done, the installation can be rapidly completed.

Only the best workmanship and material should be employed; for, since the making of repairs is apt to be very trying, the highest possible degree of permanency is desirable. Contractors, in submitting bids on jobs of this kind, should make a generous allowance for labor, as only about half the work can be accomplished as it would be under better conditions. This precaution applies only where the wiring must be done after the plant is running.

Wiring in furnace buildings for switch legs and on sidewalls should be placed in rigid conduit as a protection from mechanical injury. Porcelain sockets seem to withstand the conditions better than others. Single-wire cleats or split knobs should be used rather than rosettes, with each wire anchored separately. Steel cut-out cabinets are preferable, as wooden asbestos-lined boxes soon dry out and become defective unless they are thoroughly seasoned. All openings around wires should be filled to prevent the entrance of dust, which will, in time, cause poor contacts, and for this same reason snap switches are preferred to knife switches. No. 14 rubber-covered stranded wire for drop cords can be used to good advantage.

A permanent method for wiring the copper sulphate houses is still being sought, as the sulphuric acid fumes rot the braiding on the wire and also have a dehydrating effect on the rubber, which soon dries it out and renders it useless as an insulator. The atmosphere is moist due to the escaping steam from the vats. This may render other insulations than rubber unreliable. Conduit work and lead-covered twin wiring on insulators have been used with only fair results. However, the conduit does not protect the insulation from the acid fumes. The difficulty of readily making a good joint in the lead-covered cable has made its use undesirable.

A certain metal refinery which had been annoyed with breakdowns in the electric wiring due to the causes indicated, tried the following construction. The first cost was high, but several years' use of the system has shown the investment to be a wise one. Sound hard-wood molding was thoroughly warmed and generously painted on all surfaces with hot tar, so that the pores were well filled. The rubber-covered wire was coated with tar. Care was taken that no uncovered spots were left. The wires then were placed in the grooves in the molding and the space that then remained unfilled was also tarred with as much tar as could be made to adhere. The capping was then put in place after receiving a coat of tar on all surfaces. The molding was placed on its supporting surface at a time when it was comparatively dry and a strip a little wider than the molding was painted with tar. Porcelain molding receptacles were used wherever practicable and for drop lights No. 14 rubber-covered stranded wire was employed.

MOLDING WIRING

110. **Wooden molding wiring** is frequently used for additions to existing installations and where a low-priced job of neat appearance is required. Its use is prohibited by the Underwriters in damp places, in rooms where there are fumes or in elevator shafts. (Iron conduit should always be used in elevator shafts.) Approved fittings are made whereby molding wiring can be used in combination with the other methods. Single-braid, rubber-insulated wire must be used in molding. Where a circuit in molding runs into conduit, double-braid wire, spliced to the single-braid molding wire, must be used in the conduit. Where wire from molding runs into flexible tubing or loom, single-braid wire may be used in both molding and flexible tubing. (The material that follows on Molding Wiring is taken largely from articles on the subject written by the complier of this book and printed in *The Practical Engineer* and in *Electrical Engineering*.)

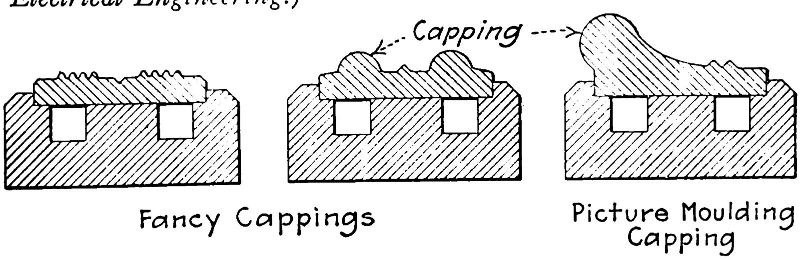


FIG. 83.—Special cappings.

111. **Wooden molding** is made in many forms. The standard designs are shown in Fig. 86 for two-wire, and Fig. 87 for three-

wire. For first-class work hard-wood molding and capping matching in finish the trim of the room in which it is installed can be used. Capping of various designs can be purchased (Fig. 83). When buying molding one should see that it conforms to code requirements. Second-rate material which may be cross-grained or knotty should be avoided because it will be more expensive in the long run than first-class stock. Patented moldings (Fig. 84) are

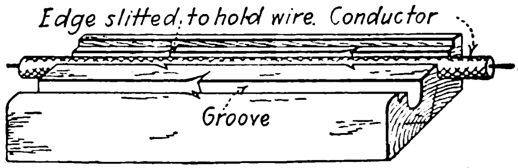


FIG. 84.—Kirkpatric's hold-wire molding.

obtainable which will retain the wire when it is pressed into the grooves, making the use of brads for temporary support unnecessary. Although it is recommended by the Code, hard-wood molding is little used. Georgia pine, oak or similar hard-wood moldings cost about twice as much as the ordinary white wood (soft wood) stock. Table 114 gives the dimensions of standard molding.

112. **Molding is supported** on lath and plaster with long, small-diameter, flat-head screws. Nails are permissible when running over a wooden surface. On brick walls, the wall is drilled and plugged and a wood screw turning into the plug supports the molding. In fire-proof buildings using hollow tile partitions and arches toggle bolts (Fig. 85) are used. Wood screws have been used for this work by drilling holes, of a slightly smaller diameter than the screw, in the tile. Then turning the screw into the hole causes it to cut its own thread. Base should be supported every $1\frac{1}{2}$ ft. to every 3 ft. and the capping somewhat more frequently. With very large molding support points should be even closer together.

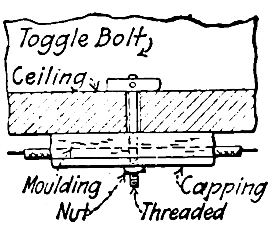


FIG. 85.—A toggle bolt supporting molding.

Either screws or nails can be used to support capping and they should, if feasible, pass entirely through the capping and into the wall. The saw cuts for two pieces of base where they abut should be at an angle and so that one piece will support the other. Where feasible, the nut on a toggle-bolt should be placed outside the capping. If placed under the capping there is a possibility, particularly with the smaller moldings, of cutting away so much of the tongue that the toggle-bolt nut will bridge across the conductors.

113. **When erecting wooden molding on side walls or partitions,** it should never be installed where it will be subjected to mechanical injury and as a general proposition should not be used within 6 ft. from the floor. Conduit or pipe protection (see 80) is preferable in such locations.

114. Standard Two- and Three-wire Wooden Molding

(*Kirkpatric Manufacturing Company*)

The products of various manufacturers vary somewhat in dimensions. All dimensions are given in inches.

Two-wire molding

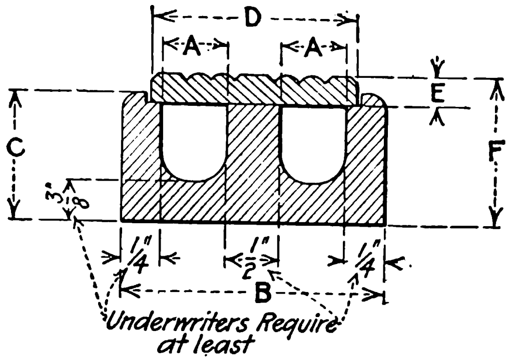


FIG. 86.—Section of two-wire molding.

A Size of groove	Will accommodate wires: Solid	Will accommodate wires: Stranded	B	C	D	E	F
1/4	14 to 12	......	1 1/2	5/8	1 1/8	3/16	13/16
3/8	10 to 8	8	1 3/4	3/4	1 3/8	3/16	15/16
1/2	9 to 4	5 to 6	2 1/8	1	1 5/8	7/32	1
5/8	3 to 0	4 to 1	2 1/2	1 3/16	1 7/8	7/32	1 1/8
3/4	.....	0 to 4/0	2 7/8	1 1/4	2 3/16	1/4	1 3/8
7/8	.....	4/0 to 250,000	3 1/8	1 3/8	2 7/16	1/4	1 1/2
1	.....	250,000 to 500,000	3 5/8	1 5/8	2 13/16	1/4	1 3/4

Three-wire molding

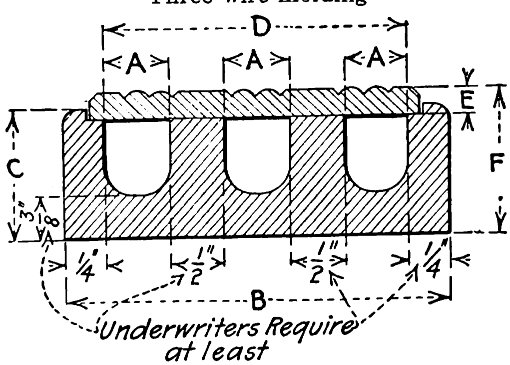


FIG. 87.—Section of three-wire molding.

A Size of groove	Will accommodate wires: Solid	Will accommodate wires: Stranded	B	C	D	E	F
1/4	16 to 12	......	2 3/8	11/16	1 7/8	3/16	13/16
3/8	10 to 8	8	2 3/4	13/16	2 1/4	3/16	15/16
1/2	8 to 4	5 to 6	3 1/8	1	2 11/16	1/4	1 1/8
5/8	3 to 0	4 to 1	3 5/8	1 3/16	3	1/4	1 1/4
3/4	.....	0 to 4/0	4 1/8	1 1/4	3 3/8	5/16	1 7/16
7/8	.....	4/0 to 250,000	4 1/2	1 3/8	3 7/8	1/4	1 1/2
1	.....	250,000 to 500,000	5 1/4	1 5/8	4 1/2	1/4	1 3/4

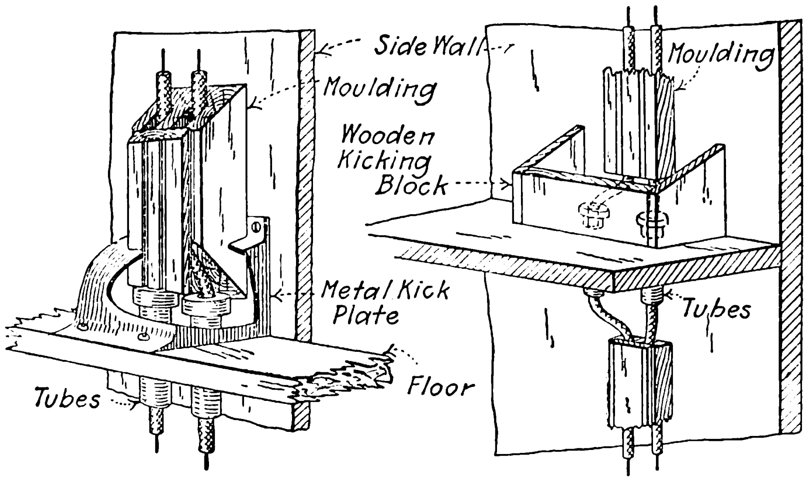


FIG. 88.—Molding kick plates.

115. **In running molding circuits through floors where no interference is probable, the molding can be run almost to the floor** provided protection such as a kick plate (Fig. 88) is installed at the floor. This construction is permissible in residences, offices and similar places. An iron pipe may be used instead of a kick plate to protect wires from molding where they pass through a floor (Fig. 89), provided the wire within the pipe is encased in loom. The pipe should extend 4 to 6 in. above and below the floor.

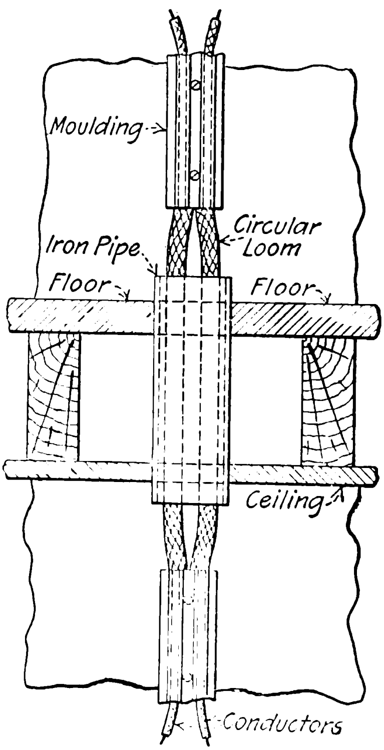


FIG. 89.—Iron pipe protection through floor.

116. **When running wooden molding on outside brick walls** a cleat or backing of wood $\frac{1}{2}$ in. or $\frac{7}{8}$ in. thick, thoroughly painted with a moisture-proof paint, should be first nailed to the wall (Fig. 90) to which the base can be fastened. The backing protects the molding from the moisture which often exists in the outer walls of brick buildings.

117. **Mitering molding at turns** should be done as suggested in Fig. 91, *I*. A fine-tooth miter saw and a miter-box, preferably a metal one, can be used to advantage. A rough and ready method that cannot be considered safe wiring is shown at Fig. 91, *II*. The capping hides the botch job.

118. **Molding can be bent** around the curved surfaces often

found in modern office buildings as shown in Fig. 92. Saw cuts are made in the base with the miter-saw. Moistening the base and capping renders it more easily bent. For first-class work, glue painted into the saw cuts before the base is formed to position will tend to better hold the base in shape.

119. The molding lay-out should conform to symmetrical designs in first-class work even if it is necessary to place "dead" molding to complete the design. It may be necessary to run

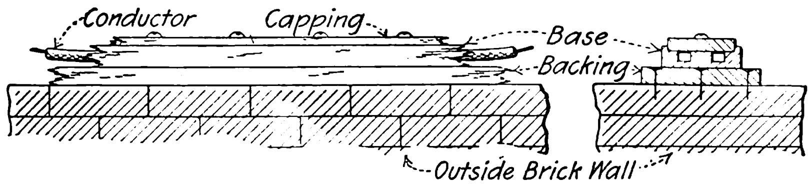


FIG. 90.—Molding on an outside brick wall.

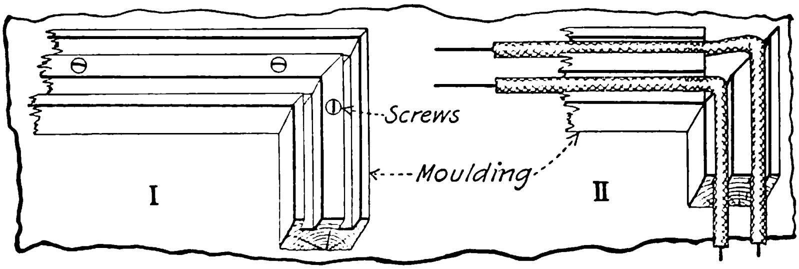


FIG. 91.—Right-angle molding turns.

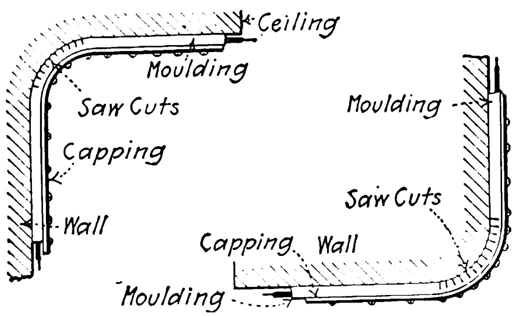


FIG. 92.—Methods of bending molding.

molding with picture-molding capping around the walls of an entire room even if that on three walls is dead. Fig. 93 shows an arrangement of dead molding on a ceiling.

120. To support wooden molding to the lower flanges of I-beams in fire-proof and structural steel buildings I-beam hooks, Fig. 94, which are punched from sheet metal and which can be purchased from supply dealers, are used. Wood screws passing through the hook enter the base and thus secure it in position. Where the span between beams is long it may be necessary to support a running board with the beam-hooks and then fasten the molding to the running board.

121. **When placing wires in molding** that does not have one of the

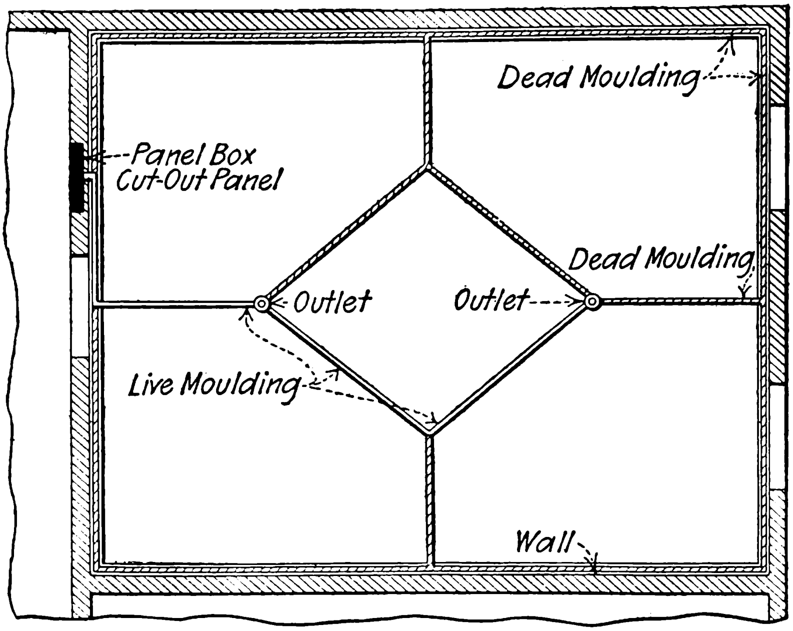


FIG. 93.—Dead molding to complete a design.

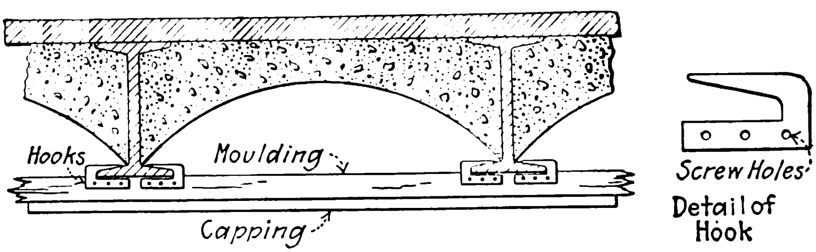


FIG. 94.—Method of supporting molding on I-beam flanges.

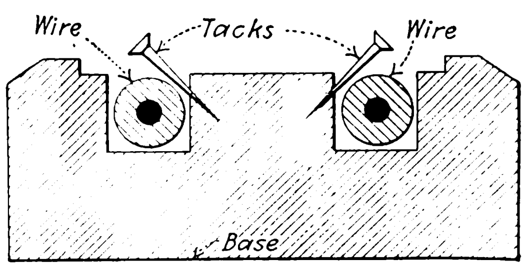


FIG. 95.—Brads holding wires.

patented "wire grip" features they can be temporarily held in the grooves with tacks or brads (Fig. 95) until the capping is placed.

122. **In tapping off a branch in wooden molding wiring** an approved "taplet" fitting (Fig. 96) must be used. It was formerly permissible to solder on the tap wires and bring one of them over the capping, but this is no longer permitted by the Underwriters. No joints or splices are permitted in molding wiring except at outlets or fittings.

123. **A cross-over in wooden molding wiring** is made with a fitting as in Fig. 97.

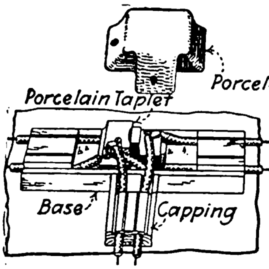


FIG. 96.—Molding taplet.

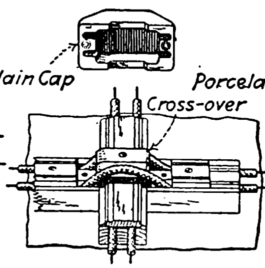


FIG. 97.—Molding cross-over.

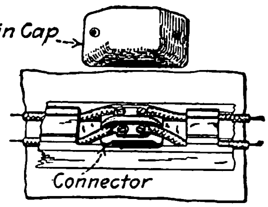


FIG. 98.—Molding connector.

124. **A joint in wires in wooden molding** must be made with an approved fitting (Fig. 98). No joints or splices are permitted within the molding itself, that is, the wires must be continuous from outlet to outlet.

125. **In wiring for side-wall outlets in a molding installation** the molding can often be advantageously carried around the base-board (Fig. 99) and the taps to the outlets carried down within the partition in loom. The taps are fished down within the partition.

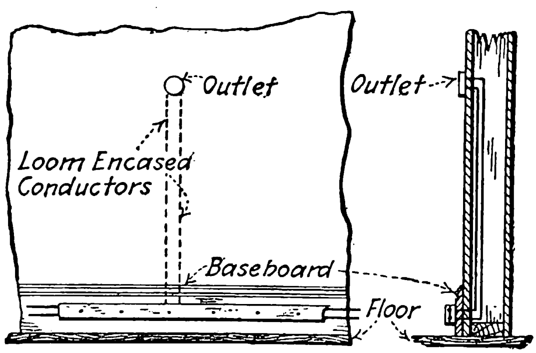


FIG. 99.—Molding on baseboard.

126. **Special Fittings are Made for Connecting Conduit Circuits to Molding Circuits.**—Fig. 100 illustrates one of the many forms. These compact fittings can be substituted for the bulky and unsightly pressed steel outlet boxes.

127. **In carrying wires from conduit to molding,** the single-braid molding wire must be spliced to the double-braid conduit wire

within an outlet box (Fig. 101). Flexible conduit or porcelain bushings must protect the molding wires where they enter the box. Where the junction between molding and conduit systems is on a wall or ceiling wherein the conduit is embedded, the connection may be made as at *II*. An additional outlet box is attached over the old one with long screws.

128. **When using molding in combination with flexible conduit or flexible steel armored cable for old building wiring,** flexible tubing or steel armored conductors are used for the portions of the installation where they can be readily drawn in and molding is used for the balance. Fig. 102 (Knox, *Electric Light Wiring*) shows such an installation. The circuits in the hall are carried in molding, but from the hall to the outlets they are in flexible tubing and are fished over from the hall. Where flexible fibrous conduit and molding are used steel outlet and splice boxes are not required so the work can be economically done and it looks well when finished. Auerbacher says (*Electrical Contracting*): "If ceilings are furred, an apartment of this kind should be wired in two days by a journeyman and helper without breaking walls or ceilings.

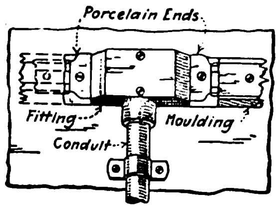


FIG. 100.—A "condulet" molding fitting.

129. **Molding receptacles and rosettes** (Fig. 103) should be of the types for which the backing does not have to be cut for their installation. Fittings are on the market which require the cutting of the backing and these should be avoided.

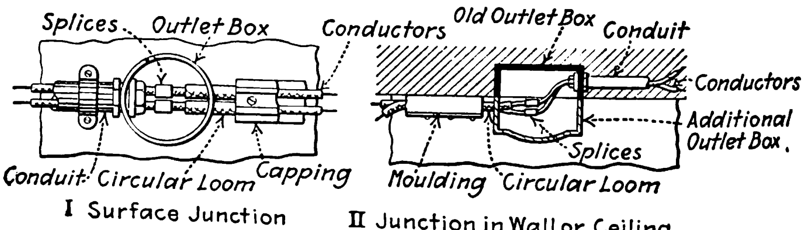


FIG. 101.—Molding-conduit junction.

130. **Switches for molding** are ordinary snap switches mounted on either a wooden (Fig. 104, *I*) or a porcelain (Fig. 104, *II*) switch block. Porcelain is preferable but a wooden block can be made on the job if a porcelain block is not available.

131. **Molding for store-window lighting** can be erected as in Fig. 105. This is a good method where expense must be a minimum. (Auerbacher, *Electrical Contracting*.) An aluminum reflector requiring no shade-holder can be used. The reflectors are spaced 6 in. to 12 in. The molding can be made up complete with wires and receptacles in the shop and can be erected in a short time. For further information see the section on *Illumination*.

132. **In wiring in molding for drop lights on a fire-proof ceiling** (*Electrical Contracting*, Auerbacher) (Fig. 106), if the panel has no

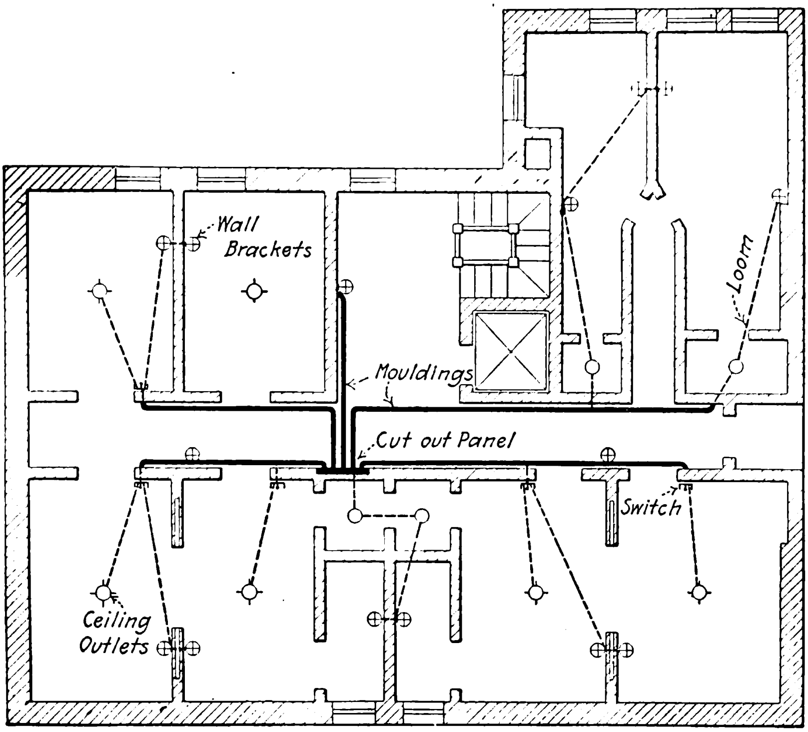


FIG. 102.—Combined molding and circular loom job.

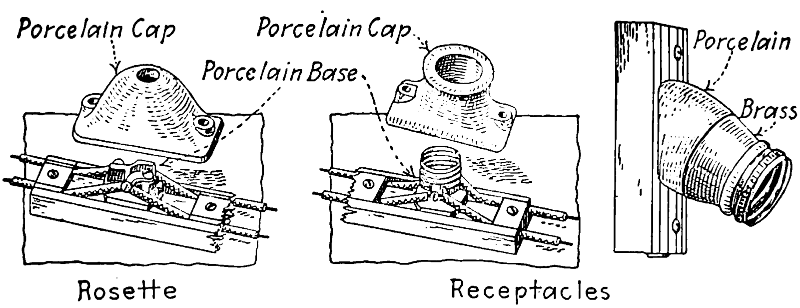


FIG. 103.—Molding rosette and receptacles.

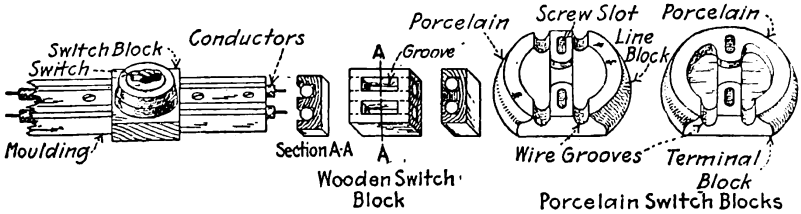


FIG. 104.—Switches on molding.

directory it is necessary to make a diagram of the circuits and to tap the outlets in such a manner that the 660-watt limit per branch circuit is not exceeded. When estimating on such work the wireman should ascertain the capacity of the existing outlets so that his estimate will include any additional circuit runs to the panel that may be required. The molding circuits are tapped to the

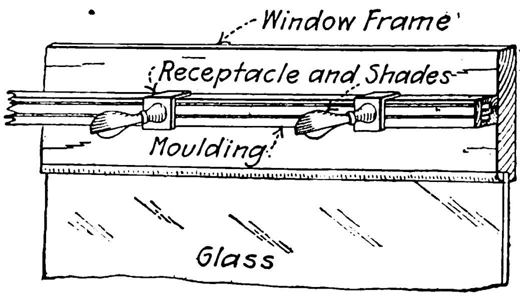


FIG. 105.—Show-window wiring in molding.

conduit outlets as described elsewhere. Fig. 106 shows the wiring plan of a fire-proof building ceiling for which the existing outlets have been tapped and wire run in the molding as described. The dead portion of the molding is indicated by the shaded parts.

133. **Fixtures in molding wiring installations** should be supported on a wooden block (Fig. 107) about 5 in. in diameter. The block provides a substantial support for the fixture, constitutes a backing

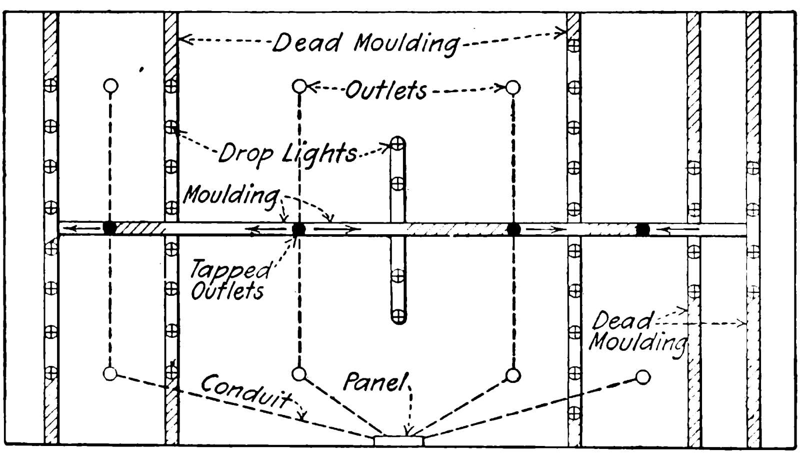


FIG. 106.—Molding wiring on fireproof ceiling.

for the canopy and the wires can be carried through the block eliminating the necessity of cutting the canopy.

134. **Wiring in approved metal molding** can be used for exposed work for circuits, where the difference of potential is not over 300 volts and where the power transmitted does not exceed 660 watts. Metal molding must be continuous from outlet to outlet, to junction

box or to approved fittings designed especially for use with metal molding. All outlets must be provided with approved terminal fittings which will protect the insulation of conductors from abrasion unless such protection is afforded by the construction of the boxes or fittings. Metal molding should not be used in damp places.

135. Wire for Metal Molding.—Single-braid, rubber-insulated wire is approved. In all cases wires must be laid in and not fished.

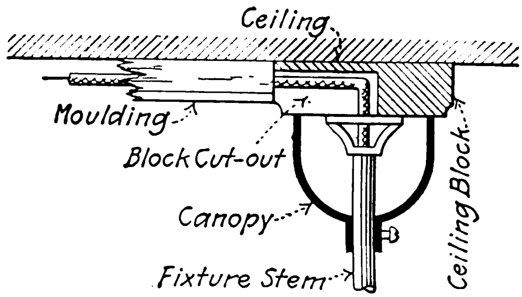


FIG. 107.—A molding-wiring fixture support

There is sufficient space in National Metal Molding for 4 No. 14 single-braid, rubber insulated wires. It is often necessary to insert this number at double-pole switch loops, etc. The two or more wires of an alternating-current circuit must be in the same molding and those of a direct-current circuit should be so that if a change is made to alternating-current reconstruction will not be necessary.

136. National metal molding is made by the National Metal Molding Company of Pittsburgh, Pa. It consists of channel

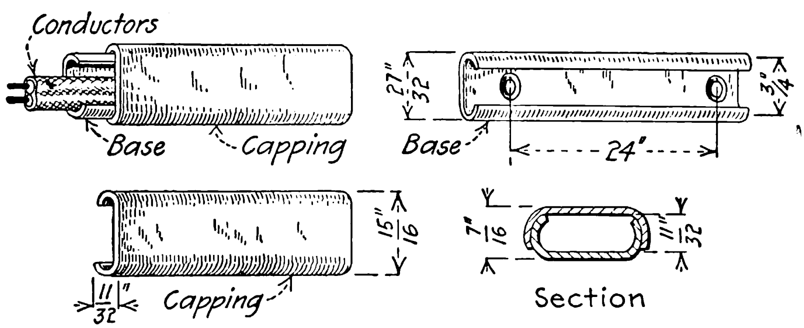


FIG. 108.—Dimensions of national metal molding.

capping that snaps over a channel base. The principal dimensions are given in Fig. 108. It is furnished in lengths of 8 ft. 6 in. It is Sherardized, a process whereby finely divided zinc is driven into the pores of the metal forming an iron-zinc alloy which is thoroughly rust-proof and which cannot be knocked off. Either water or oil paints adhere well to it. Because of the small space that it occupies it can be used to advantage on steel ceilings, in show-windows, in show-cases and in other locations where appearance is a factor and where safety is essential.

137. **The application of national metal molding and fittings** is illustrated in Fig. 109, an imaginary lay-out shown to indicate how the material may be used.

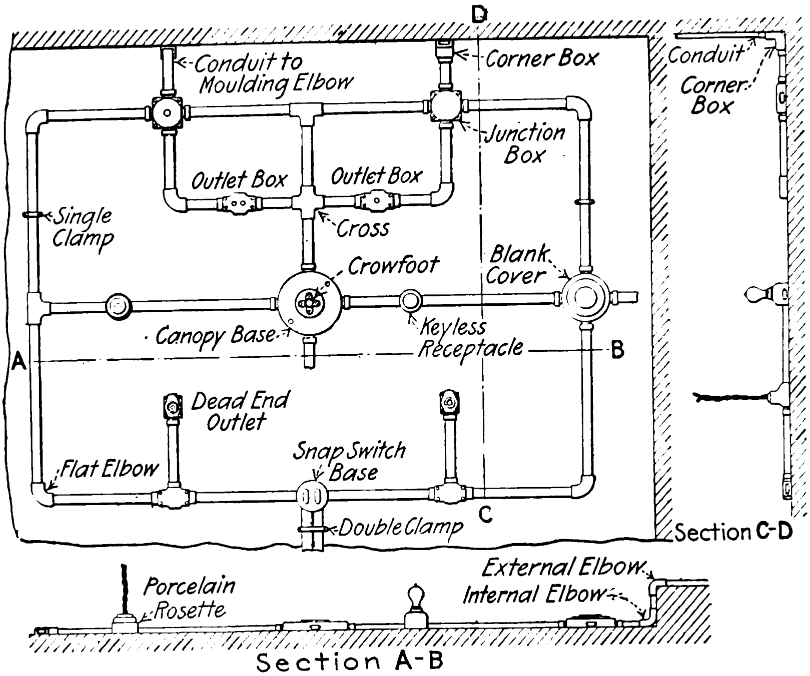


FIG. 109.—Application of metal molding and fittings.

138. **The cost of national metal molding** is $8.00 per 100 ft. list with a discount varying from 20 per cent. to 50 per cent. and with the point of delivery and the quantity purchased.

139. **The Cost of Metal Molding Fittings.**—The same discounts apply as those applying to molding. List prices for some are as follows: Cross, 17 cents each; base coupling, 2.5 cents; tee, 14 cents; elbows, internal, external and flat, 11 cents; outlet box, 20 cents; metal covers 5.5 cents; receptacles, 45 cents; bushings, 3.5 cents; snap switch bases, 25 cents; one-piece porcelain rosettes, 8 cents; two-piece porcelain rosettes, 25 cents.

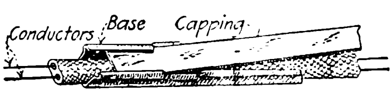


FIG. 110.—Lutz metal molding.

140. **Lutz metal molding** consists of a channel-shaped base and a strip of sheet metal that slips in, as illustrated in Fig. 110 which constitutes the capping. It is electro-galvanized and is furnished in 10 ft. lengths. Capping can be removed at either end or at any other point desired by making two hack-saw cuts with a fine-tooth (tubing) saw through the flanges of the base and slightly opening the cut portion to release the ends of the capping. It is

recommended that in making installations these hack-saw cuts be made at intervals to permit the future removal of the capping

141. **Fittings for Lutz molding** are made which are somewhat similar to those for the National. All fittings are arranged to insure electrical conductivity throughout the molding installation.

142. **Where metal molding passes through floors** it should be carried through an iron pipe extending from the ceiling below to a point 5 ft. above the floor, which will serve as an additional mechanical protection and exclude moisture. In residences, office buildings and similar locations where appearance is an essential feature, and where the mechanical strength of the molding itself is adequate, the iron pipe can extend from the ceiling below to a point 3 in. above the floor

143. **Metal molding must be grounded permanently** and effectively and so installed that adjacent lengths of molding will be mechanically and electrically secured at all points. It is essential

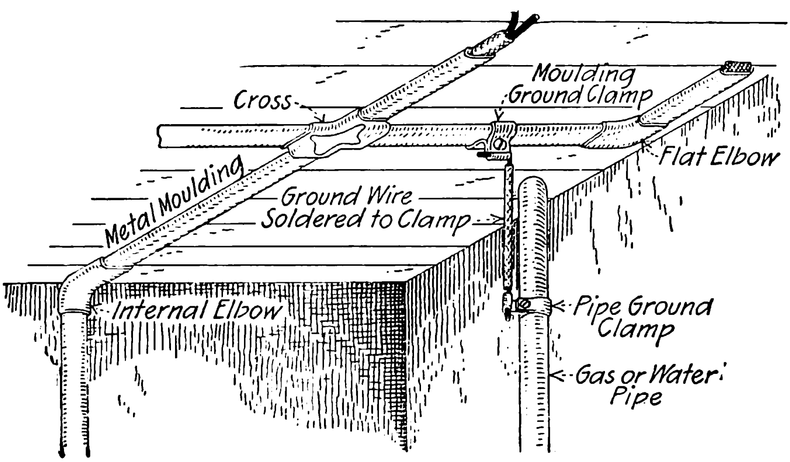


FIG. 110A.—Grounding metal molding.

that the metal of such systems be joined so as to afford electric conductivity sufficient to allow the largest fuse in the circuit to operate before a dangerous rise of temperature in the system can occur. Moldings and gas pipes must be securely fastened in metal outlet boxes, so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection the metal molding must be joined around them by suitable bond wires. Where sections are installed without being fastened to the metal structure of the building or grounded metal piping, they must be bonded together or joined to a permanent and effective ground connection.

The metal molding manufacturers provide fittings suitable for joining adjacent lengths of backing together and ground clamps (Fig 110, *A*) for grounding. Lapping the capping from one length to the adjacent one constitutes an electrical connection. Ground wires must be at least No. 10 B & S gage.

144. Installing National Metal Molding. *Separating.*—Reasonable care should be exercised in separating the backing and capping preparatory to installation. As the quickest, most satisfactory method, hooking one of the punched holes in the backing over a convenient nail or screw and drawing the capping off is recommended. *Cutting.*—Except in cases where the backing of the molding passes through under the fittings and is not cut, backing and capping should be cut before being separated in all cases. Because of the light stock, hack-saw blades having fine teeth and commonly known as "tube saws" should be used for cutting. Some construction men recommend marking deeply with a file and breaking. *Bending.*—The molding is readily bent and, with reasonable care, may be worked to any radius down to one of 4½ in. Bends must be made in all cases before backing and capping are separated. *Supporting.*—The backing is punched and countersunk every 2 in. for the supporting screws or bolts. The support so afforded will usually be found more than ample, but further support may be secured either through additional punching with a special punch or by using a metal molding clamp. Fig. 111 shows a toggle bolt support for metal molding. When the metal molding is installed on uneven surfaces, such as the ceilings of old buildings, the capping has a tendency to spring away from the backing. This may be overcome by the use of two or three straps fastened over each length.

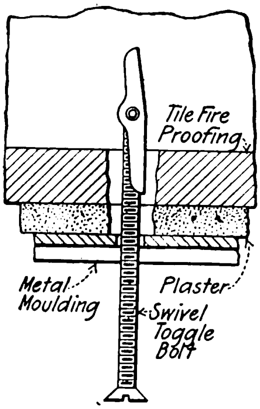


FIG. 111.—Toggle bolt being inserted.

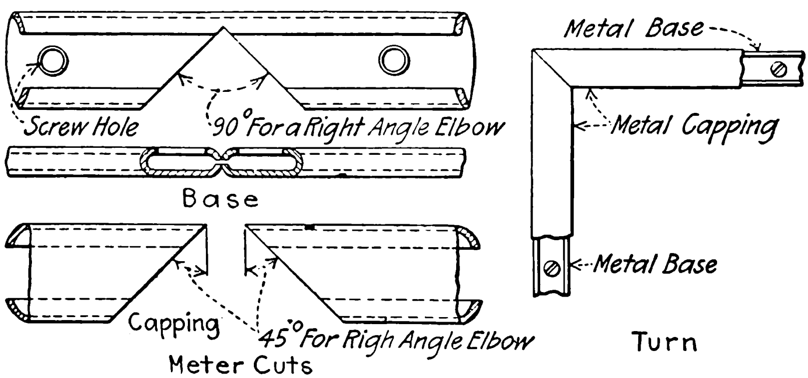


FIG. 112.—Mitered turn.

Loose Capping.—If the capping of the molding is loose, it should be removed from the backing and tightened by tapping it with a mallet or hammer at points about 8 in. apart but on one edge only.

145. Metal molding can be mitered for elbows and bends by cutting it with a hack-saw. Elbows and bends thus made have the advantage that they fit into corners more closely than do the purchased fittings. Electrical conductivity is preserved by always leaving a portion of the backing intact. Fig. 112 shows how a turn can be made and Fig. 113 the method for an elbow.

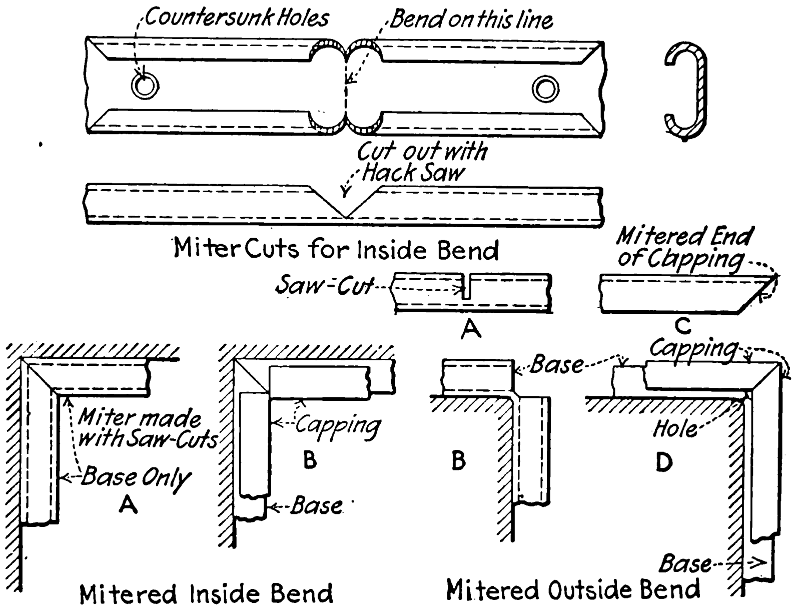


FIG. 113.—Mitered elbows.

KNOB-AND-TUBE WIRING

146. Concealed knob-and-tube wiring is used in frame houses where a low cost of installation is essential. The wires are concealed within floors and partitions. Concealed wiring can be installed cheaper by the knob-and-tube method than by any other (unless wooden moulding wiring be considered as concealed wiring), but the cost is greater than for open work on knobs and cleats. (Much of the matter on knob and tube wiring is from articles on this subject published in the *Pract. Eng.* commencing Sept. 1, 1912.)

147. The use of knob-and-tube work should be discouraged in so far as possible (Knox, *Electric Light Wiring*), as it is subject to mechanical injury and is liable to interference from rats and mice. The wires may sag against beams, laths, etc., or may be covered by shavings or other inflammable building material. Knob-and-tube work is prohibited by municipal ordinances in many cities and is being superseded by flexible steel and rigid iron conduit installations.

148. The wires are run just after the floors and studding are in place and before the lathing is done. This principal part of the work is called the "roughing in," and comprises the installation of the mains and the branches and the taps to the outlets. Frequently the basement wiring is not done until the building is practically completed. The "finishing," which comprises the installation of the switches, fixtures, meter board, distributing panels, etc., is not usually done until the building is otherwise completed.

149. **Wire and tie-wires** for concealed knob-and-tube wiring must have an approved rubber insulation, but may be single-braid. Tie-wires should have an insulation equal to that of the conductors they support, and must not be smaller than No. 14. (Tie wires are not permitted for conductors smaller than No. 8. B. & S. gage. Where conductiors smaller than No. 8 are used they must be supported on split knobs except at the ends of runs where solid knobs should be used.)

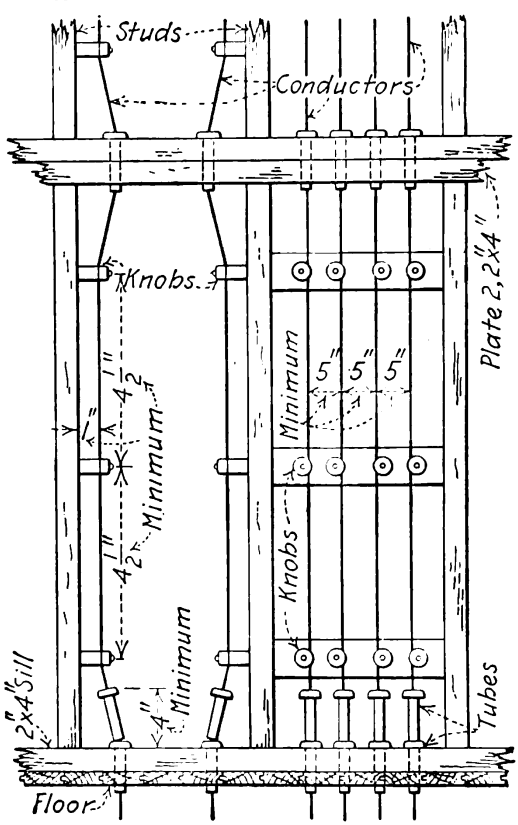


FIG. 114.—Knob-and-tube vertical run.

150. **In making joints and splices** in concealed knob-and-tube work, a serving of rubber tape and then one of friction tape are made around the splice. Inasmuch as most of the joints are inaccessible after the completion of the building, they should be very carefully made.

151. **Wires must be supported in knob-and-tube wiring by approved porcelain knobs,** which separate the wires at least 1 in. from the surface wired over. The wires must be maintained at least 5 in. apart, and when possible should be run (Fig. 114) on separate timbers and studding. Knobs are located at least every $4\frac{1}{2}$ ft. where the wire run is parallel to the supporting timber. Where it is impossible to maintain the 5 in. separation, the wires can be run closer together, provided each is encased in a continuous length of flexible tubing, or as it is often termed, "loom." When passing through floors, walls, etc., the wires must be protected by glass or porcelain tubes, as outlined in Fig. 114. Flexible tubing may in dry places be used to insulate the wires where projecting members of the building interfere with them. Porcelain tubes should be used where the wires cross each other or cross pipes (Fig. 115).

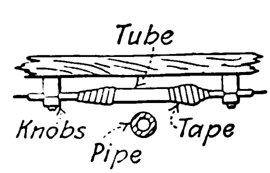


FIG. 115.—Wire crossing pipe.