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HAWKINS

ELECTRICAL GUIDE

NUMBER SEVEN

QUESTIONS ANSWERS & ILLUSTRATIONS

A PROGRESSIVE COURSE OF STUDY FOR ENGINEERS, ELECTRICIANS, STUDENTS AND THOSE DESIRING TO ACQUIRE A WORKING KNOWLEDGE OF

ECTRICITY AND ITS APPLICATIONS

A PRACTICAL TREATISE

by

HAWKINS AND STAFF

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TABLE OF CONTENTS
GUIDE NO. 7.

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LIGHTNING PROTECTION DEVICES—*Continued*

INDICATING DEVICES—*Continued*

CHAPTER LV

ALTERNATING CURRENT SYSTEMS

The facility with which alternating current can be transformed from one voltage to another, thus permitting high pressure transmission of electric energy to long distances through small wires, and low pressure distribution for the operation of lighting systems and motors, gives a far greater variety of systems of transmission and distribution than is possible with direct current.

Furthermore, when the fact that two phase current can be readily transformed into three phase current, and these converted into direct current, and vice versa, by means of rotary converters and rectifiers, is added to the advantages derived by the use of high tension systems, it is apparent that the opportunity for elaboration becomes almost unlimited. These conditions have naturally tended toward the development of a great variety of systems, employing more or less complicated circuits and apparatus, and although alternating current practice is still much less definite than direct current work, certain polyphase systems are now being generally accepted as representing the highest standards of power generation, transmission and distribution.

A classification of the various alternating current systems, to be comprehensive, should be made according to several points of view, as follows:

1. With respect to the arrangement of the circuit, as

   a. Series;
   b. Parallel;
   c. Series parallel;
   d. Parallel series.

2. With respect to transformation, as

   Transformer;

3. With respect to the mode of transmitting the energy, as

   a. Constant pressure;
   b. Constant current.

4. With respect to the kind of current, as

   a. Single phase { two wire; three wire;

   b. Monocyclic

   c. Two phase { four wire; three wire; five wire;

   d. Three phase { six wire; three wire; four wire; star connection; delta connection; star delta cnnnection; delta star connection;

   e. Multi-phase { of more than three phases;

5. With respect to transmission and distribution, as

   a. Frequency changing;
   b. Phase changing;
   c. Converter;
   d. Rectifier.

In order to comprehend the relative advantages of the various *alternating current systems*, it is first necessary to understand the *principle of vector summation.*

[redacted]

Vector Summation.—This is a simple geometrical process for ascertaining the pressure at the free terminals of alternating current circuits. The following laws should be carefully noted:

1. *If two alternating pressures which agree in phase are connected together in series, the voltage at the free terminals of the circuit will be equal to their arithmetical sum, as in the case of direct currents.*

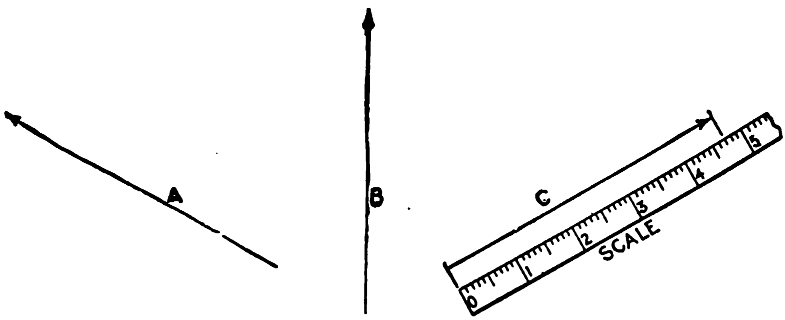


FIG. 2,123.—*Vectors.* **A vector is defined as:** *a line, conceived to have both a fixed length and a fixed direction in space, but no fixed position.* Thus A and B are lines, each having a fixed length, but no fixed direction. **By adding an arrow head** the direction is fixed and the line becomes a vector, as for example vector C. The fixed length is usually taken to represent a definite force, thus the fixed length of vector C is 4.7 which may be used to represent 4.7 lbs., 4.7 tons, etc., as may be arbitrarily assumed.

When there is phase difference between the two alternating pressures, connected in series, the following relation holds:

2. *The value of the terminal voltage will differ from their arithmetical sum, depending on the amount of their phase difference.*

When there is phase difference, the value of the resultant is conveniently obtained as explained below.

Ques. How are vector diagrams constructed for obtaining resultant *electric pressure?*

Ans. On the principle of the parallelogram of forces.

Ques. What is understood by the parallelogram of forces?

Ans. It is a graphical method of finding the resultant of two forces, according to the following law: *If two forces acting on a point be represented in direction and intensity by adjacent sides of a parallelogram, their resultant will be represented by the diagonal of the parallelogram which passes through the point.*

Thus in fig. 2,124, let OA and OB represent the intensity and direction of two forces acting at the point O. Draw AC and BC, respectively parallel to OB and OA, completing the parallelogram, then will OC,

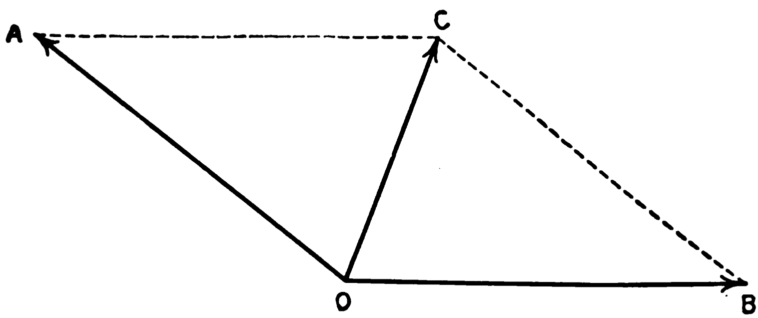


FIG. 2,124.—Parallelogram of forces. OC is the resultant of the two forces OA and OB. The length and direction of the lines represent the intensity and direction of the respective forces, the construction being explained in the accompanying text.

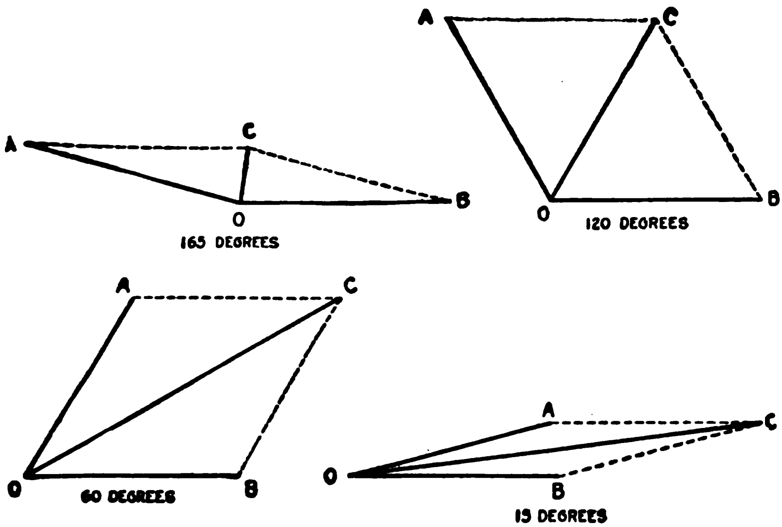
the diagonal from the point at which the forces act, represent the intensity and direction of the resultant, that is, of a force equivalent to the combined action of the forces OA and OB, these forces being called the *components* of the force OC.

Ques. Upon what does the magnitude of the resultant of two forces depend?

Ans. Upon the difference in directions in which they act, *as shown in figs 2,125 to 2,128.*

Ques. Is the parallelogram of forces applied when the difference in direction or "phase difference" of two forces is 90 degrees?

Ans. It is sometimes more conveniently done by calculation according to the law of the right angle triangle.



FIGS. 2,125 to 2,128.—Parallelograms of forces showing increase in magnitude of the resultant of two forces, as their difference of direction, or electrically speaking, their *phase difference* is diminished. The diagrams show the growth of the resultant of the two equal forces OA and OB as the phase difference is reduced from 165° successively to 120, 60, and 15 degrees.

According to this principle, if two alternating pressures have a phase difference of 90 degrees they may be represented in magnitude and direction by the two sides of a right angle triangle as OA and OB in fig. 2,129; then will the hypotenuse AB represent the magnitude and direction of the resultant pressure. That is to say, the resultant pressure

$$AB = \sqrt{\overline{OA}^2 + \overline{OB}^2} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

EXAMPLE.—A two phase alternator is wound for 300 volts on one phase and 200 volts on the other phase, the phase difference being 90°. If one end of each winding were joined so as to form a single winding around the armature, what would be the resultant pressure?

By calculation, substituting the given values in equation (1),

$$\text{Resultant pressure} = \sqrt{300^2+200^2} = \sqrt{130,000} = 360.6 \text{ volts.}$$

This is easily done graphically as in fig. 2,129 by taking a scale, say, 1″ = 100 volts and laying off OA = 3″ = 300 volts, and at right angles OB = 2″ = 200 volts, then by measurement AB = 3.606″ = 360.6 volts.

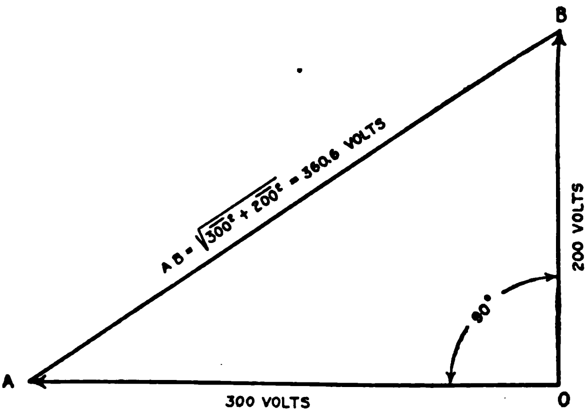


FIG. 2,129.—Method of obtaining the resultant of two component pressures acting at right angles by solution of right angle triangle. The equation of the right angle triangle is explained at length in Guide No. 5, page 1,070.

Ques. When the two pressures are equal and the phase difference is 90°, is it necessary to use equation (1) to obtain the resultant?

Ans. No. The resultant is obtained by simply multiplying one of the pressures by 1.41.

This is evident from fig. 2,130. Here the two pressures OA and OB *are equal as indicated by the dotted* arc. Since they act at right angles, *OB is drawn at 90° to OA. According* to the equation of the right angle *triangle, the resultant* $AB = \sqrt{1^2+1^2} = \sqrt{2} = 1.4142$ which ordinarily *is taken as 1.41.*

[redacted]

This value will always represent the ratio between the magnitude of the resultant and the two component forces, when the latter are equal, and have a phase difference of 90 degrees.

Forms of Circuit.—Alternating current systems of distribution may be classed, with respect to the kind of circuit used, in a manner similar to direct current systems, that is, they

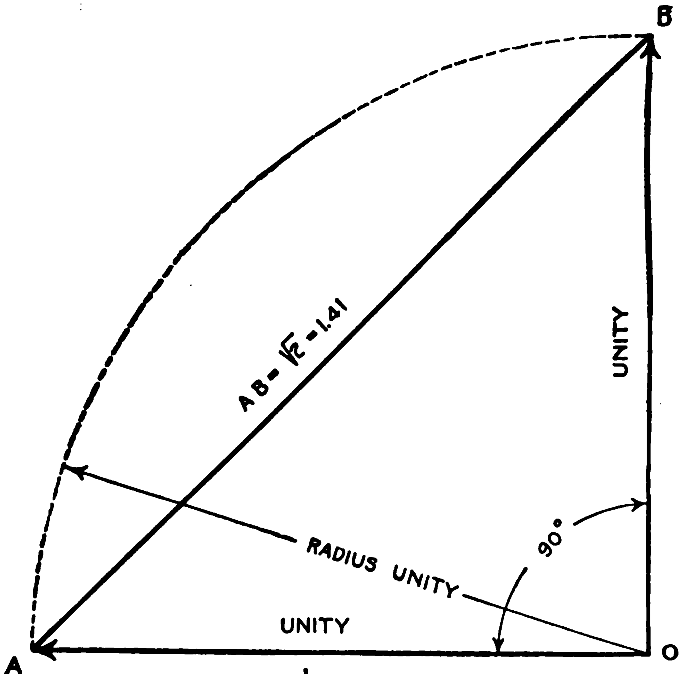
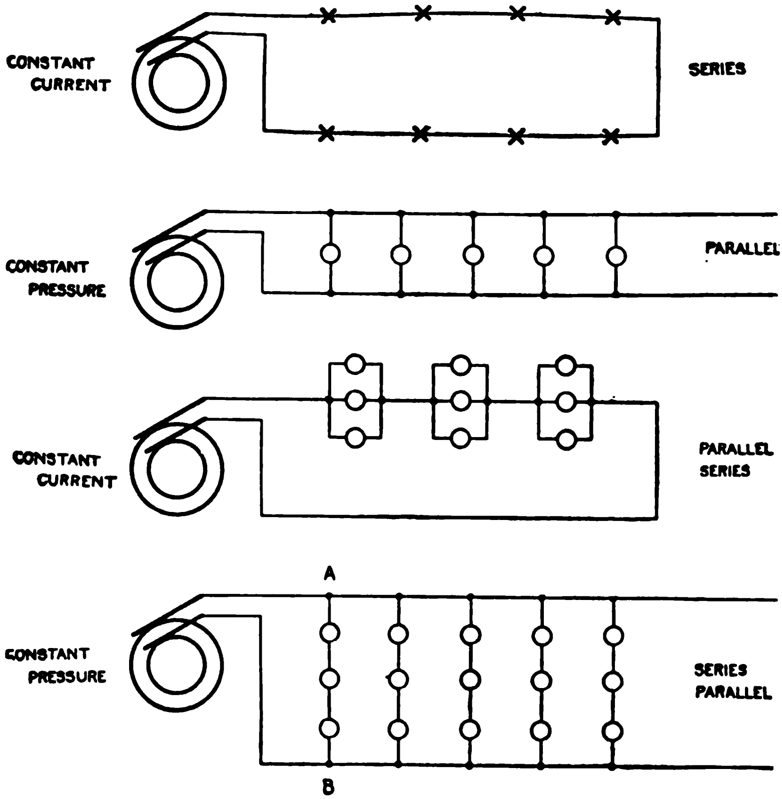


FIG. 2,130.—Diagram for obtaining the resultant of two equal component pressures acting at right angles.

may be called series, parallel, series parallel, or parallel series systems, as shown in figs. 2,131 to 2,134.

Series Circuits.— *These are used in arc lighting, and series incandescent lighting, a constant current being maintained; also fc* constant current motors and generators supplying secondary circuits.

Several forms of constant current alternator, analogous to the Thompson-Houston and Brush series arc dynamos, have



FIGS. 2,131 to 2,134.—Various forms of circuit. These well known forms of circuit are used in both alternating and direct current systems. The simple series circuit, fig. 2,131, is suitable for constant current arc lighting. Fig. 2,132, shows the parallel constant pressure circuit; this form of circuit is largely used but is seldom connected direct to the alternator terminals, but to a step down transformer, on account of the low pressure generally required. Fig. 2,133 illustrates a parallel series circuit, and 2,134, a series parallel circuit.

ıtroduced. In the design of such alternators self-induction mature reaction are purposely exaggerated; so that the t does not increase very much, even when the machine rt circuited. With this provision, no regulating device iired.

35.—Typical American overhead 6,600 volt single phase interurban trolley line, Balti- e and Annapolis short line, Annapolis, Md.

objectionable feature is that the voltage of a constant .t alternator will rise very high if the circuit be opened, se it is then relieved of inductance drop and armature on.

guard against a dangerous rise of voltage, a film cut out or ilent device is connected to the terminal of each machine so t will short circuit the latter if the voltage rise too high.

Ques. What advantage have constant current alternators over constant current dynamos?

Ans. The high pressure current is delivered to the external circuit without a commutator, hence there is no sparking difficulty.

The above relates to the revolving field type of alternator. There are, however, alternators in which the armature revolves, the current being delivered to the external circuit through collector rings and brushes. This type of alternator, it should be noted, is for moderate pressures, and moreover there is no interruption to the flow of the current such as would be occasioned by a tangential brush on a dynamo in passing from one commutator segment to the next.

In the revolving field machine, though the armature current be of very high pressure, the field current which passes through the brushes and slip rings is of low pressure and accordingly presents no transmission difficulties.

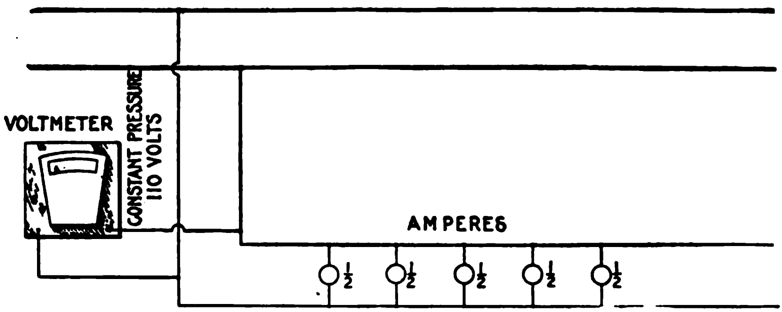


Fig. 2,136.—Diagram of parallel circuit. *It is a constant pressure circuit* and is very widely used for lighting and power. If each lamp take say ½ ampere, the current flowing in the circuit will vary with the number of lamp in operation; in the above circuit with all lamps on, the current is ½ × 5 = 2½ amperes.

Ques. State a disadvantage.

Ans. Some source of direct current for field excitation is required.

Ques. In a constant current series system, upon what does the voltage at the alternator depend?

Ans. *The number of devices connected in the circuit, the volts required for each, and the line drop.*

[redacted]

Parallel Circuits.—These are used for constant pressure operation. Such arrangement provides a separate circuit for each unit making them independent so that they may vary in size and each one can be started or stopped without interfering with the others. Parallel circuits are largely used for incandescent lighting, and since low pressure current is commonly used on such circuits they are usually connected to step down transformers, instead of direct to the alternators.

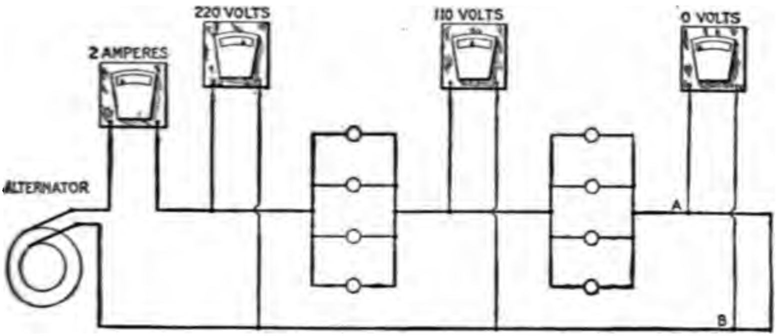


FIG. 2,137.—Diagram of **parallel series circuit**, *showing fall of pressure between units.* **This system** *is very rarely used;* it has the disadvantage that if a lamp filament break, the resistance of the circuit is altered and the strength of the current changed. The voltmeter shows the fall of pressure along the line. **It should be noted** that, although the meter across AB is shown as registering zero pressure, there is, strictly speaking, a slight pressure across AB, in amount, being that required to overcome the resistance of the conductor between A and B.

Parallel Series Circuits.—Fig. 2,137 shows the arrangement of a parallel series circuit and the pressure conditions in same. Such a circuit consists of groups of two or more lamps or other devices connected in parallel and these groups connected in series.

Such a circuit, when used for lighting, obviously has the disadvantage that if a lamp filament break, the resistance of the group is *increased, thus reducing* the current and decreasing *the brilliancy of the lamps.* This arrangement accordingly does *not admit of turning* off any of the lights.

Series Parallel Circuits.—The arrangement of circuits of this kind is shown in fig. 2,134; they are used to economize in copper since by joining groups of low pressure lamps in series they may be supplied by current at correspondingly higher pressure.

Thus, if in fig. 2,134, 110 volt, ½ ampere lamps be used, the pressure on the mains, that is, between any two points as A and B would be 110×3=330 volts. Each group would require ½ ampere and the five groups ½×5=2½ amperes.

FIG. 2,138.—44,000 volt lines entering the Gastonia sub-station of the Southern Power Co The poles used are of the twin circuit two arm type, built of structural steel, their height varying from 45 to 80 feet, the latter weighing 9,000 pounds each. These poles have their bases weighted with concrete.

Transformer Systems.—Nearly all alternating current systems are transformer systems, since the chief feature of alternating current is the ease with which it may be transformed from one pressure to another. Accordingly, considerable economy in copper may be effected by transmitting the current at high pressure, especially if the distance be great, and, by means of step down transformers; reducing the voltage at points where the current is used or distributed.

Ordinarily and for lines of moderate length, current is sent out direct from the alternator to the line and transformed by step down transformers at the points of application.

With respect to the step down transformers, there are two arrangements:

1. Individual transformers;
2. One transformer for several customers.

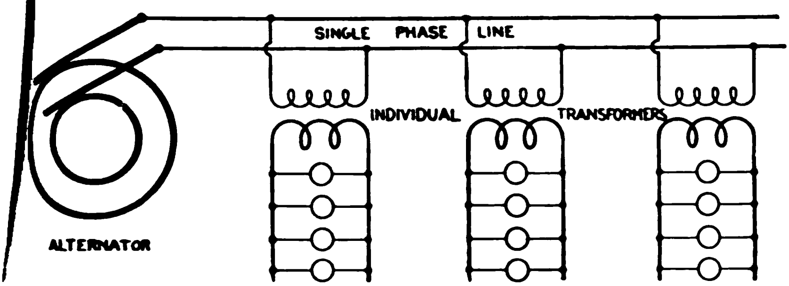


FIG. 2,139.—Diagram of transformer system with individual transformers. The efficiency is low, but such method of distribution is necessary in sparsely settled or rural districts.

Individual transformers, that is, a separate transformer for each customer is necessary in rural districts where the intervening distances are great as shown in fig. 2,139.

Ques. What are the objections to this method of distribution?

Ans. It requires the use of small transformers which are necessarily less efficient and more expensive per kilowatt than large transformers. The transformer must be built to carry within its overload capacity, all the lamps installed by the customer, since all may be used occasionally.

Usually, however, only a small part of the lamps are in use, and those only for a small part of the day, so that the average load on the transformer is a very small part of its capacity. Since the core loss continues whether the transformer be loaded or not, but is not paid for by the customer, the economy of the arrangement is very low.

In the second case, where one large transformer may be placed at a distribution center, to supply several customers, as in fig. 2,140, the efficiency of the system is improved.

Ques. Why is this arrangement more efficient than when individual transformers are used?

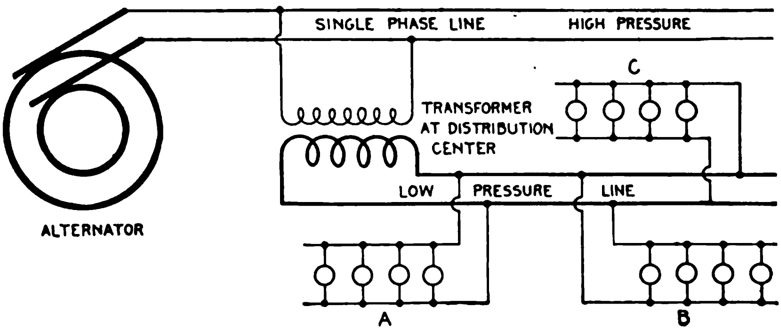


FIG. 2,140.—Diagram of transformer system with one transformer located at a distribution center and supplying several customers as A, B, and C. Such arrangement is considerably more efficient than that shown in fig. 2,139, as explained in the accompanying text.

Ans. Less transformer capacity is required than with individual transformers.

Ques. Why is this?

Ans. With several customers supplied from one transformer it is extremely improbable that all the customers will burn all their lamps at the same time. It is therefore unnecessary to install a transformer capable of operating the full load, as is *necessary* with individual transformers.

Ques. Does the difference in transformer capacity represent all the saving?

Ans. No; one large transformer is more efficient than a number of small transformers.

Ques. Why?

Ans. The core loss is less.

For instance, if four customers having 20 lamps each were supplied from a single transformer, the average load would be about 8 lamps, and at most not over 10 or 15 lamps, and a transformer carrying 30 to 35 lamps at over load would probably be sufficient. A 1,500 watt transformer would therefore be larger than necessary. At 3 per cent.

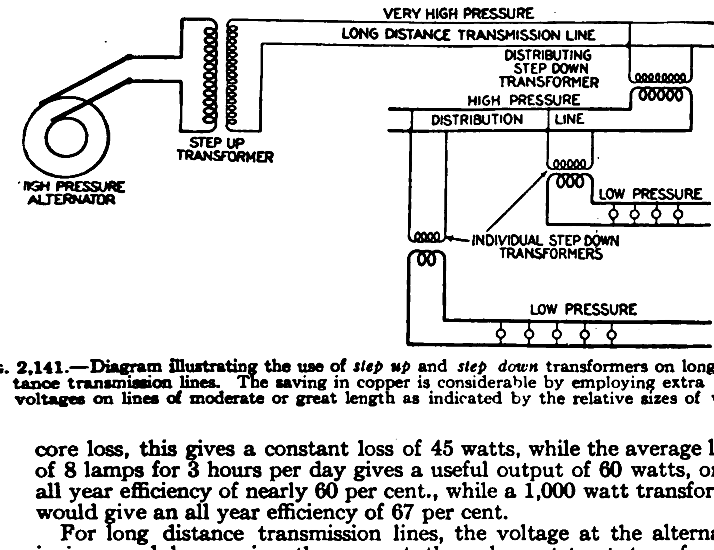


FIG. 2,141.—Diagram illustrating the use of *step up* and *step down* transformers on long distance transmission lines. The saving in copper is considerable by employing extra high voltages on lines of moderate or great length as indicated by the relative sizes of wire.

core loss, this gives a constant loss of 45 watts, while the average load of 8 lamps for 3 hours per day gives a useful output of 60 watts, or an all year efficiency of nearly 60 per cent., while a 1,000 watt transformer would give an all year efficiency of 67 per cent.

For long distance transmission lines, the voltage at the alternator is increased by passing the current through a *step up* transformer, thus transmitting it at very high pressure, and reducing the voltage at the points of distribution by step down transformers as in fig. 2,141.

Ques. In practice, would such a system as shown in fig. 2,141 be used?

Ans. *If the greatest economy in copper were aimed at, a three phase system would be used.*

The purpose of fig. 2,141 is to show the importance of the transformer in giving a flexibility of voltage, by which the cost of the line is reduced to a minimum.

Ques. Does the saving indicated in fig. 2,141 represent a net gain?

Ans. No. The reduction in cost of the transmission is partly offset by the cost of the transformers as well as by transformer losses and the higher insulation requirements.

FIG. 2,142.—Single and twin circuit poles (Southern Power Co.). The twin circuit pole at the right is used for 11,000 volt circuits, while the single circuit poles at the left carry 44,000 volt conductors, being used on another division for 100,000 volt line.

Every case of electric transmission presents its own problem, and needs thorough engineering study to intelligently choose the system best adapted for the particular case.

Single Phase Systems.—There are various arrangements for transmission and distribution classed as single phase systems. *Thus, single phase current* may be conveyed to the various

[redacted]

receiving units by the well known circuit arrangements known as series, parallel, series parallel, parallel series, connections previously described and illustrated in figs. 2,131 to 2,134.

Again single phase current may be transmitted by two wires and distributed by three wires. This is done in several ways, the simplest being shown in fig. 2,143.

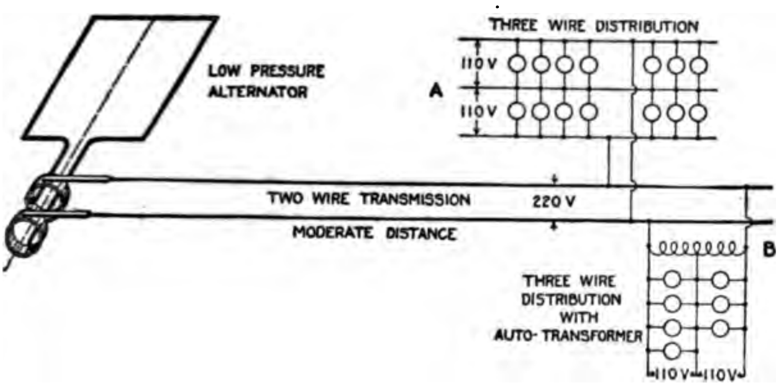


FIG. 2,143.—Diagram illustrating single phase two wire transmission and three wire distribution. The simplified three wire arrangement at A, is not permissible except in cases of very little *unbalancing*. Where the difference between loads on each side of the neutral may be great some form of balancing as an auto-transformer or equivalent should be used, as at B.

Ques. Under what conditions is the arrangement shown in fig. 2,143 desirable?

Ans. This method of treating the neutral wire is only permissible where there is very little unbalancing, that is, where the load is kept practically the same on both sides of the neutral.

Ques. What advantage is obtained by three wire distribution?

Ans. The pressure at *the alternator* can be doubled, which *means, for a given number of lamps*, that the current is reduced

FIG. 2,144.—100,000 volt "Milliken" towers with one circuit strung (Southern Power Co.). These towers are mounted on metal stubs sunk 6 feet in the ground. Where the angle of the line is over 15 degrees, however, these stubs are weighted with rock and concrete, and where an angle of over 30 degrees occurs, two and sometimes three towers are used for making the turn. The weight of the standard "Milliken" tower is 3,080 lbs., and its height from the ground to peak is 51 feet. The towers are spaced to average eight to a mile and a strain tower weighing 4,250 lbs. is used every mile. For particularly long spans a special heavy tower weighing 6,000 lbs. is used. The circuits are transposed every 30 miles. Multiple disc insulators are used, four discs being used to suspend each conductor from standard towers and ten discs to each conductor on strain towers. The *standard span is 600 feet, sag 11 ft at 50° Fahr.*

to half, the permissible drop may be doubled, the resistance of the wires quadrupled, and their cost reduced nearly 75 per cent.

Ques. What modification of circuit A (fig. 2,143), should be made to allow for unbalancing in the three wire circuit?

Ans. An auto-transformer or "balance coil" as it is sometimes called should be used as at B.

This is a very desirable method of balancing when the ratio of transformation is not too large.

Ques. For what service would the system shown in fig. 2,143 be suitable?

Ans. For short distance transmission, as for instance, in

[redacted]

the case of an isolated plant because of the low pressure at which the current is generated.

The standard voltages of low pressure alternators are 400, 480, and 600 volts.

Ques. In practice are single phase alternators used as indicated in fig. 2,143?

Ans. Alternators are wound for one, two or three phases. Three phase machines are more commonly supplied and in

FIG. 2,145.—View of a typical isolated plant. The illustration represents an electric lighting plant on a farm showing the lighting of the dwelling, barn, tool house and pump house. The installation consists of a low voltage dynamo with gas engine drive and storage battery together with the necessary auxiliary apparatus.

many cases it will pay to install them in preference to single phase, even if they be operated single phase temporarily.

For a given output, three phase machines are smaller than single phase and the single phase load can usually be approximately balanced between the three phases. Moreover, if a three phase machine be installed, polyphase current will be available in case it may be necessary to operate polyphase motors at some future time.

Standard three phase alternators will carry about 70 per cent. of their rated kilowatt output when operated single phase, with the same temperature rise.

Ques. How are three phase alternators used for phase circuits?

Ans. The single phase circuit is connected to any two o three phase terminal leads.

Ques. What form of single phase system shoul used where the transmission distance is considerable

Ans. The current should be transmitted at high pres a step down transformer being placed at each distribu

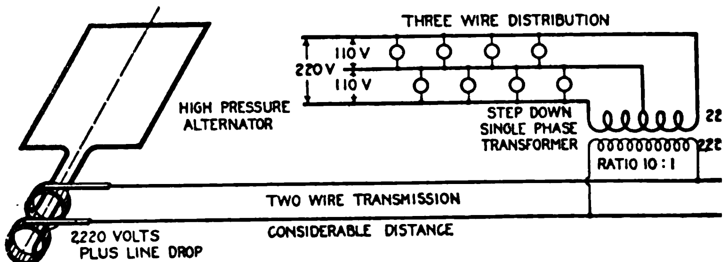


FIG. 2,146.—Diagram showing **arrangement of single phase system** for two wire transı and three wire distribution, *where the transmission distance* **is considerable.** In **to reduce the cost** of the transmission line, *the current must be transmitted at hig sure;* this necessitates the use of a step down transformer at the distributing as shown in the illustration.

center to reduce the pressure to the proper voltage to suit service requirements as shown in fig. 2,146.

Thus, if 110 volt lamps be used on the three wire circuit, the pr between the two outer wires would be 220 volts. A transforn ratio of say 10:1 would give 2,220 volts for the primary circuit. current required for the primary with this ratio being only .1 used in the secondary, a considerable saving is effected in the cost transmission line as must be evident.

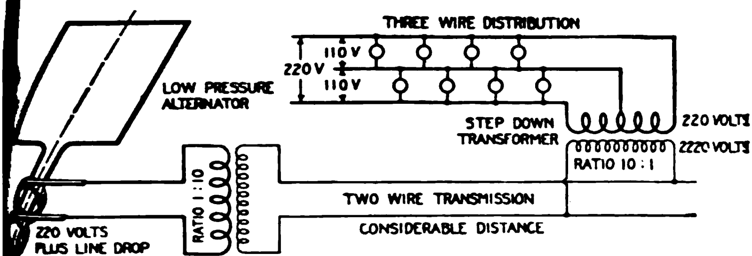
With the high pressure alternator only one transformation c current is needed, as shown at the distribution end.

In place of the high pressure alternator, a low pressure alte could be used in connection with a step up transformer as sho fig. 2,147, but there would be an extra loss due to the additional former, rendering the system less efficient than the one shown i *2,146. Such an arrangement* **as shown in the fig. 2,147 might be ju** l the case of a station having a low pressure alternator already in use nd it should be desired to transmit a portion of the energy a considerle distance.

ues. How could the system shown in fig. 2,147 be e more efficient than that of fig. 2,146.

s. By using a high pressure alternator in order to conbly increase the transmission voltage.

Thus, a 2,200 volt alternator and 1:10 step up transformer would give a line pressure of 22,000 volts, which at the distribution end could be reduced, to 220 volts for the three wire circuit, using a 100:1 step down transformation.



. 2,147.—Diagram illustrating how electricity can be economically transmitted a considerable distance with low pressure alternator already in use.

Ques. Would this be the best arrangement?

Ans. No.

Ques. What system would be used in practice for aximum economy?

Ans. Three phase four wire.

Ques. What are the objections to single phase generation and transmission?

Ans. It does not permit of the use of synchronous conrters, self-starting synchronous motors, or induction motor rting under load. *It is poorly adapted* to general power

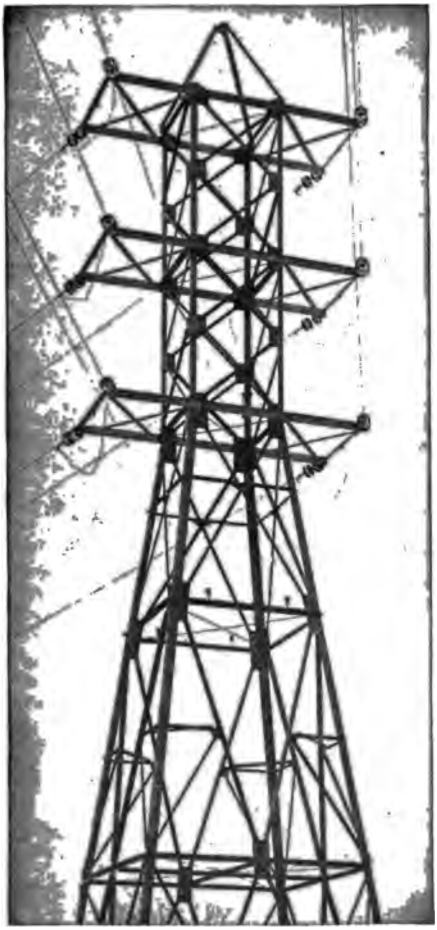


Fig. 2,148.—Angle tower showing General Electric strain insulators. The tower being subject to great tortional strains is erected on a massive concrete foundation. The construction is similar to the standard tower but of heavier material, and having the same vertical dimensions but with bases 20 ft. square.

distribution, hence it is open to grave objections of a commercial nature where there exists any possibility of selling power or in any way utilizing it for general converter and motor work.

Ques. For what service is it desirable?

Ans. For alternating current railway operation.

There are advantages of simplicity in the entire generating, primary, and secondary distribution systems for single phase roads. These advantages are so great that they justify considerable expense, looked at from the railway point of view only, the single phase system throughout may be considered as offering the most advantage.

Ques. What are the objectionable features of single phase alternators?

Ans. This type of alternator has an unbalanced armature reaction which is the cause of considerable flux variation in the

[redacted]

ield pole tips and in fact throughout the field structure.

In order to minimize eddy currents, such alternators must accordingly be built with thinner laminations and frequently poorer mechanical construction, resulting in increased cost of the machine. The large armature reaction results in a much poorer regulation than that obtained with three phase alternators, and an increased amount of field copper is required, also larger exciting units. These items augment the cost so that

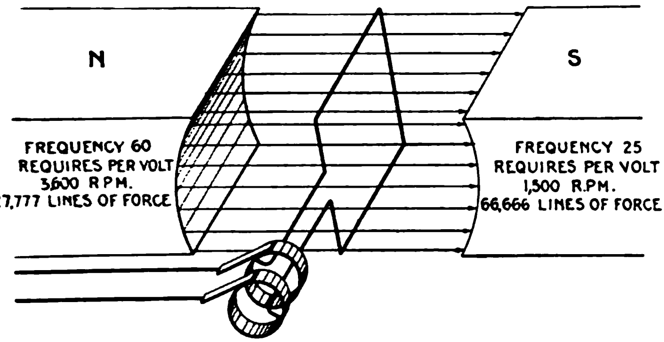


FIG. 2,149.—**Elementary alternator developing one volt at frequencies of 60 and 25, showing the effect of reducing the frequency.** Since for the same number of pole, the R.P.M. have to be decreased to decrease the frequency, increased flux is required to develop the same voltage. **Hence in construction,** low frequency machines require *larger magnets, increased number of turns in series on the armature coils, larger exciting units* as compared with machines built for higher frequency.

the single phase machine is considerably more expensive than the three phase, of the same output and heating.

Ques. What factor increases the difficulties of single phase alternator construction?

Ans. The difficulties appear to increase with a *decrease* in frequency.

The adoption of any lower frequency than 25 cycles may result in serious difficulties in construction for a complete line of machine, especially those of the two *or four pole* turbine driven type where the field *flux is very large per pole.*

Monocyclic System.—In this system, which is due to Steinmetz, the alternator is of a special type. In construction, there is a **main** single phase winding an auxiliary or **teaser** winding connected to the central point of the main winding in quadrature therewith.

The teaser coil generates a voltage equal to about 25 per cent. of that of the main coil so that the pressure between the terminals of the main coil and the free end of the teaser is the resultant of the pressure of the two coils.

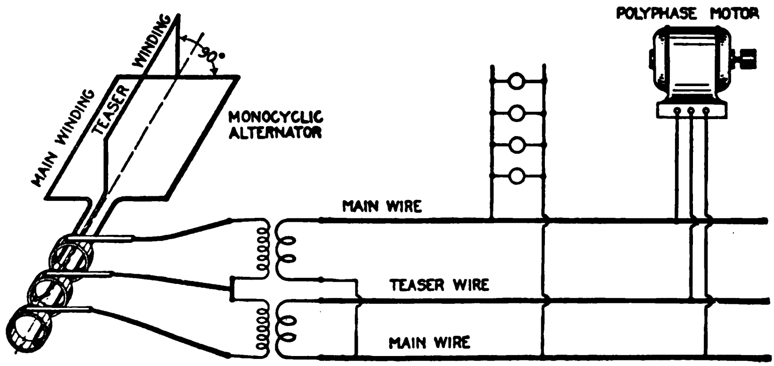


FIG. 2,150.—Diagram of monocyclic system, showing lighting and power circuits.

By various transformer connections it is possible to obtain a practically correct three phase relationship so that polyphase motors may be employed.

In this system, two wires leading from the ends of the single phase winding in the alternator supply single phase current to the lighting load, a third wire connected to the end of the teaser being run to points where the polyphase motors are installed as shown in fig. 2,150.

The monocyclic system is described at length in the chapter *on alternators, Guide No.* 5, pages, 1,156 to 1,159.

Two Phase Systems.—A two phase circuit is equivalent to two single phase circuits. Either four or three wire may be employed in transmitting two phase current, and even in the latter instance the conditions are practically the same as for single phase transmission, excepting the unequal current distribution in the three wires. Fig. 2,151 shows a two phase four wire system.

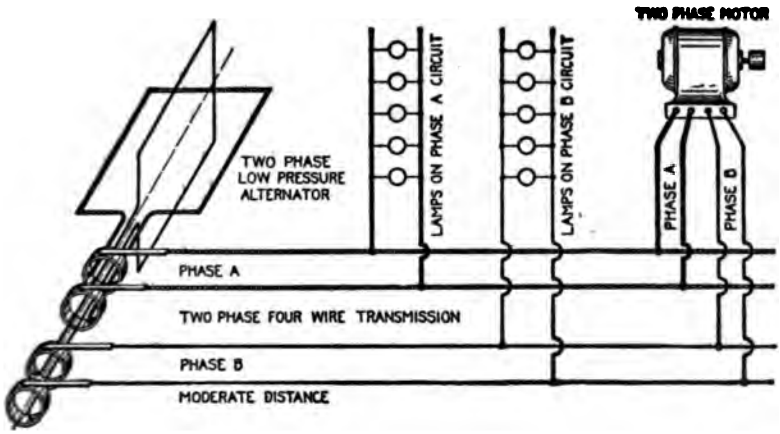


FIG. 2,151.—Diagram of two phase four wire system. It is desirable for supplying current for lighting and power. The arrangement here shown should be used only for lines of short or moderate length, because of the low voltage. Motors should be connected to a circuit separate from the lighting circuit to avoid drop on the latter while starting a motor.

Ques. For what service is the system shown in fig. 2,151 desirable?

Ans. It is adapted to supplying current for lighting and power at moderate or short distances.

Either 110 or 220 volts are ordinarily used which is suitable for incandescent lighting and for constant pressure arc lamps, the lamps being connected singly or two in pairs.

Ques. Where current for both power and light are obtained from the same source how should the circuits be arranged?

Ans. A separate circuit should be employed for each, in order to avoid the objectionable drop and consequent dimming of the lights due to the sudden rush of current during the starting of a motor.

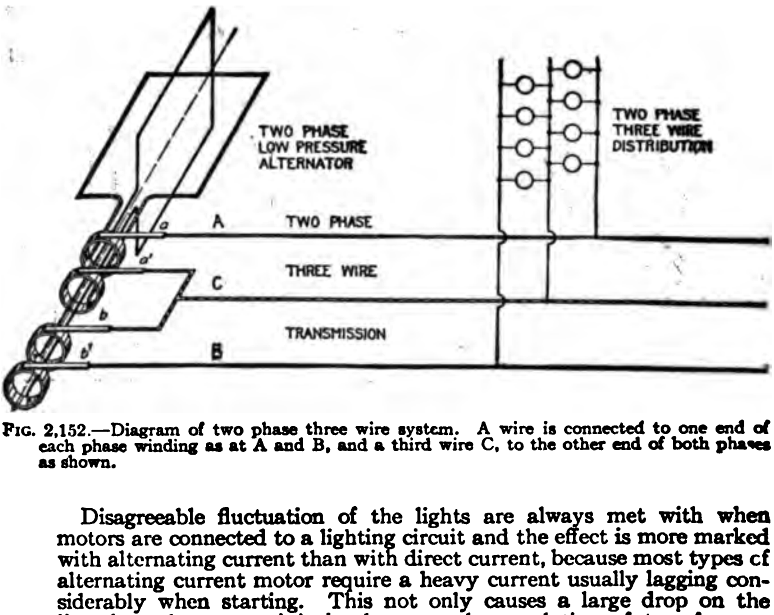


FIG. 2,152.—Diagram of two phase three wire system. A wire is connected to one end of each phase winding as at A and B, and a third wire C, to the other end of both phases as shown.

Disagreeable fluctuation of the lights are always met with when motors are connected to a lighting circuit and the effect is more marked with alternating current than with direct current, because most types cf alternating current motor require a heavy current usually lagging considerably when starting. This not only causes a large drop on the line, but also reacts injuriously upon the regulation of transformers and alternators, their voltage falling much more than with an equal non-inductive load.

Ques. What voltages are ordinarily used on two phase lines of more than moderate length?

Ans. For transmission distances of more than two or three miles, pressures of from 1,000 to 2,000 volts or more are employed to economize in copper. For long distance transmission of over fifty miles, from 30,000 to 100,000 volts and over are used.

Ques. For long distance transmission at 30,000 to 40,000 volts, what additional apparatus is necessary?

Ans. Step up and step down transformers.

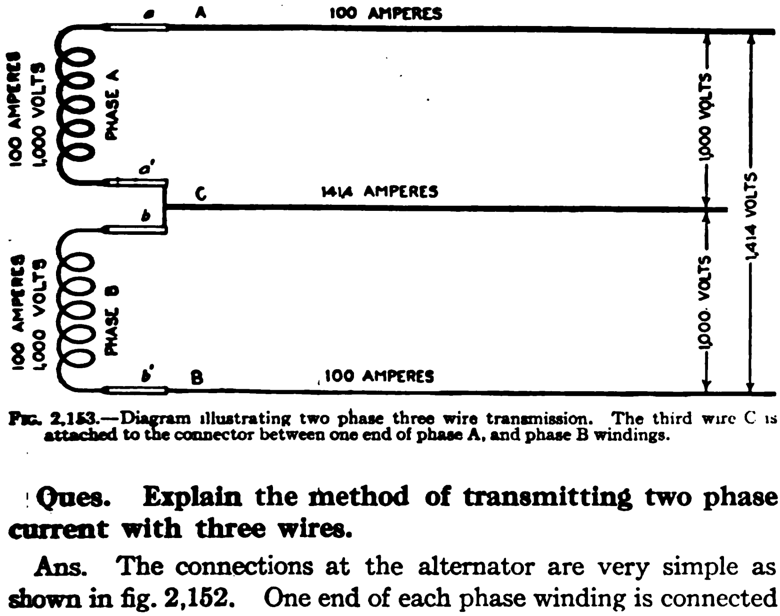


FIG. 2,153.—Diagram illustrating two phase three wire transmission. The third wire C is attached to the connector between one end of phase A, and phase B windings.

Ques. Explain the method of transmitting two phase current with three wires.

Ans. The connections at the alternator are very simple as shown in fig. 2,152. One end of each phase winding is connected by the brushes *a* and *b'*, to one of the circuit wires, that is to A and B respectively. The other end of each phase winding is connected by a lead across brushes *a'* and *b*, to which the third wire C is joined.

The current and pressure conditions of this system are represented diagramatically in fig. 2,153. The letters correspond to those in fig. 2,152, with which it should be compared.

As shown in the figure each coil is carrying 100 amperes at 1,000 volts pressure. Since the phase difference between the two coils is 90°, the voltage between A and B is $\sqrt{2} = 1.414$ times that between either A or B and the common return wire C.

The current in C is $\sqrt{2} = 1.414$ times that in either outside wire A or B, as indicated.

Ques. How should the load on the two phase three wire system be distributed?

Ans. The load on the two phases must be carefully balanced.

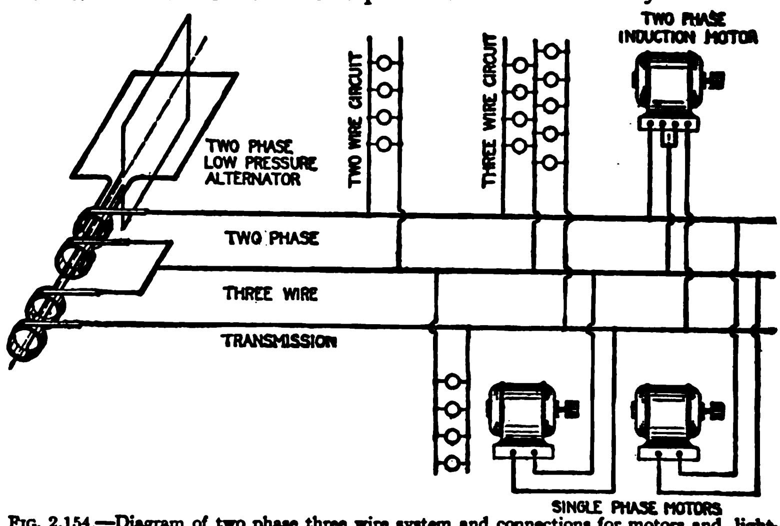


FIG. 2,154.—Diagram of two phase three wire system and connections for motors and lighting circuits.

Ques. Why should the power factor be kept high?

Ans. A high power factor should be maintained in order to keep the voltage on the phases nearly the same at the receiving ends.

Ques. How should single phase motors be connected and what precaution should be taken?

Ans. *Single phase* motors may be connected to either or

[redacted]

both phases, but in such cases, no load should be connected between the outer wires otherwise the voltages on the different phases will be badly unbalanced.

Fig. 2,154 shows a two phase three wire system, with two wire and three wire distribution circuits, illustrating the connection for lighting and for one and two phase motors.

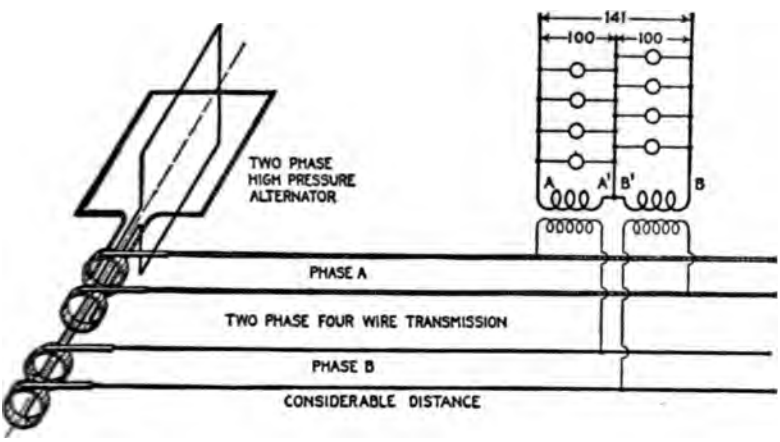


FIG. 2,155.—Diagram of two phase system with four wire transmission and three wire distribution. In the three wire circuits the relative pressures between conductors are as indicated; that is, the pressure between the two outer wires A and B is 141 volts, when the pressure between each cuter wire and the central is 100 volts.

Ques. Describe another method of transmission and distribution with two phase current.

Ans. The current may be transmitted on a four wire circuit and distributed on three wire circuit as in fig. 2,155.

The four wire transmission circuit is evidently equivalent to two independent single phase circuits.

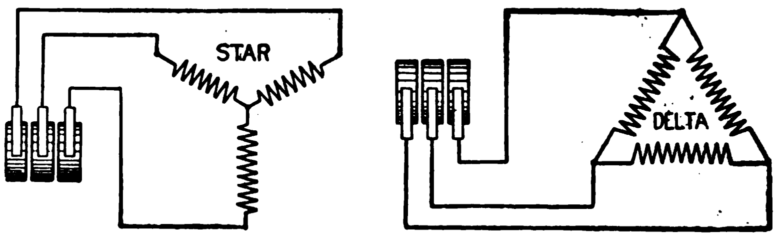
In changing from four to three wires, it is just as well to connect the two outside wires A and B together (fig. 2,152), as it is to connect *a'* and *b*. It makes no difference which two secondary wires are joined together, *so long as the other wires of each transformer are connected to the outside wires of the secondary system.*

Ques. For what service is the two phase three wire system adapted?

Ans. It is desirable for supplying current of minimum pressure to apparatus in the vicinity of transformers. It is more frequently used in connection with motors operating from the secondaries of the transformers.

Ques. How should the third or common return wire be proportioned?

Ans. Since the current in the common return wire is 41.4 per cent. higher than that in either of the other wires it must be of correspondingly larger cross section, to keep the loss equal.



FIGS. 2,156 and 2,157.—Conventional diagrams illustrating star and delta connected three phase alternator armatures.

Ques. What is the effect of an inductive load on the two phase three wire system and why?

Ans. It causes an unbalancing of both sides of the system even though the energy load be equally divided. The self-induction pressure in one side of the system is in phase with the virtual pressure in the other side, thus distorting the current distribution in both circuits.

Ques. Describe the two phase five wire system.

Ans. A two phase circuit may be changed from four to five *wires by arranging the* transformer connections as in fig. 2,158.

As shown, the secondaries of the transformers are joined in series and leads brought out from the middle point of each secondary winding and at the connection of the two windings, giving five wires.

With 1,000 volts in the primary windings and a step down ratio of 10 : 1, the pressure between A and C and C and E will be 100 volts and between the points and the connections B or D at the middle of the secondary coils, 50 volts.

The pressure across the two outer wires A and E is, as in the three wire system, $\sqrt{2}$ or 1.41 times that from either outer wire to the middle wire C, that is 141 volts.

The pressure across the two wires connected to the middle of the coils, that is, across B and D, is $50 \times \sqrt{2} = 70.5$ volts.

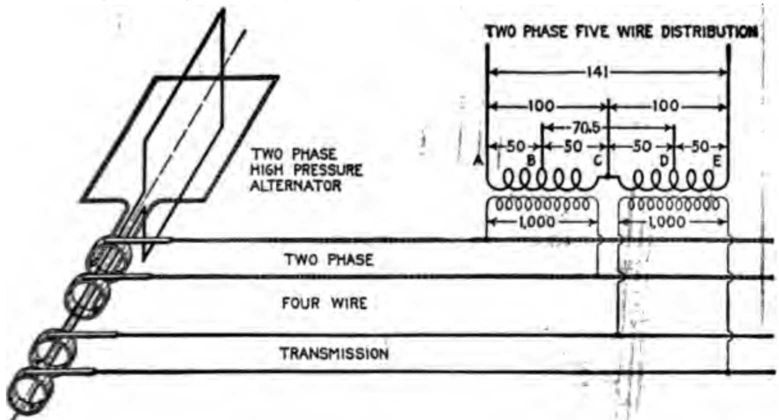


FIG. 2,158.—Two phase four wire transmission and five wire distribution system. The relative pressures between the various conductors are indicated in the diagram.

Three Phase Systems.—There are various ways of arranging the circuit for three phase current giving numerous three phase systems.

1. With respect to the number of wires used they may be classified as

a. Six wire;
b. Four wire;
c. Three wire.

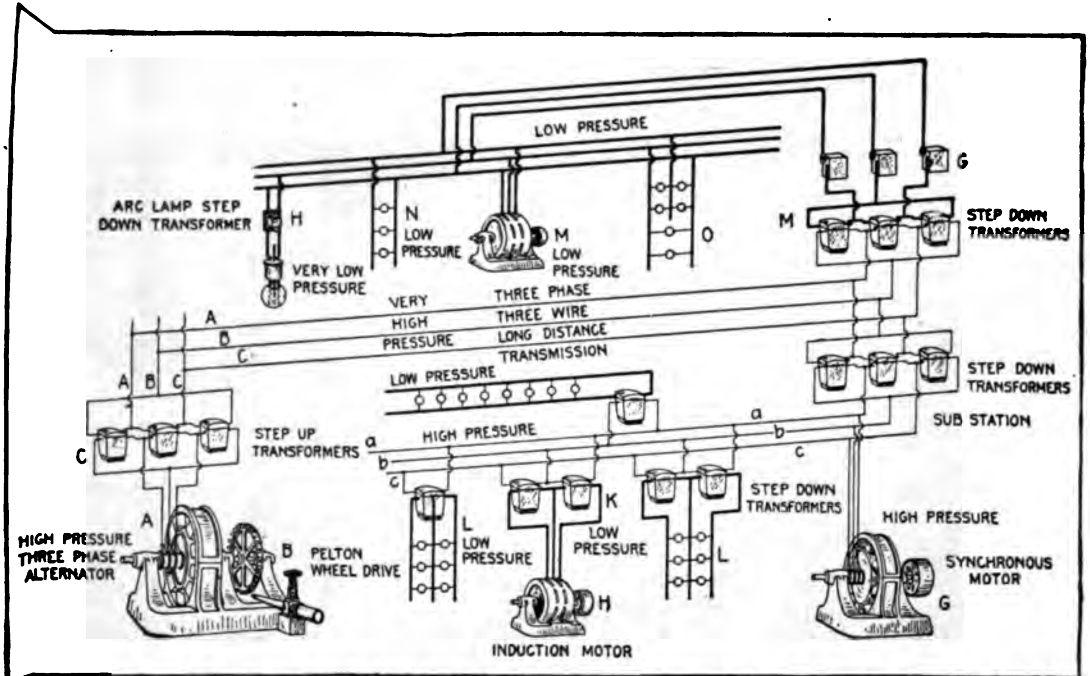


FIG. 2,159.—Line connections of three phase three wire long distance transmission, and distribution system. The three phase alternator A, is driven by the water wheel B, and furnishes current at say 2,200 volts plus sufficient pressure to compensate for line drop. With 1: 10 step up transformers C, this would give a transmission pressure of 22,000 volts plus line drop. ***It is* this transformation *that secures the* copper economy *of the system.*** At the distribution end are the step down transformers; one set reducing the voltage down to 2,200 volts, and supplying current direct to the synchronous motor, and through another set of other step down transformers, as L and K, to lighting and power circuits at 220 volts. Another set of step down transformers M reduce the pressure directly to 120 volts for power and lighting, the pressure being regulated by the regulators G. Arc lamps with individual transformers further reducing the pressure to 50 volts are connected to this circuit as shown.

[redacted]

2. With respect to the connections, as

a. Star;
b. Delta;
c. Star delta;
d. Delta star.

The six wire system is shown in fig. 2,160. It is equivalent **to three** independent single phase circuits. Such arrangement **would only be** used in very rare instances.

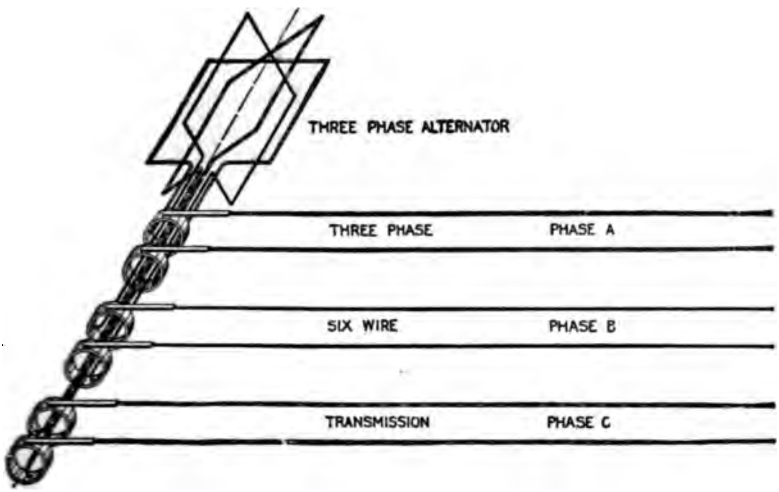
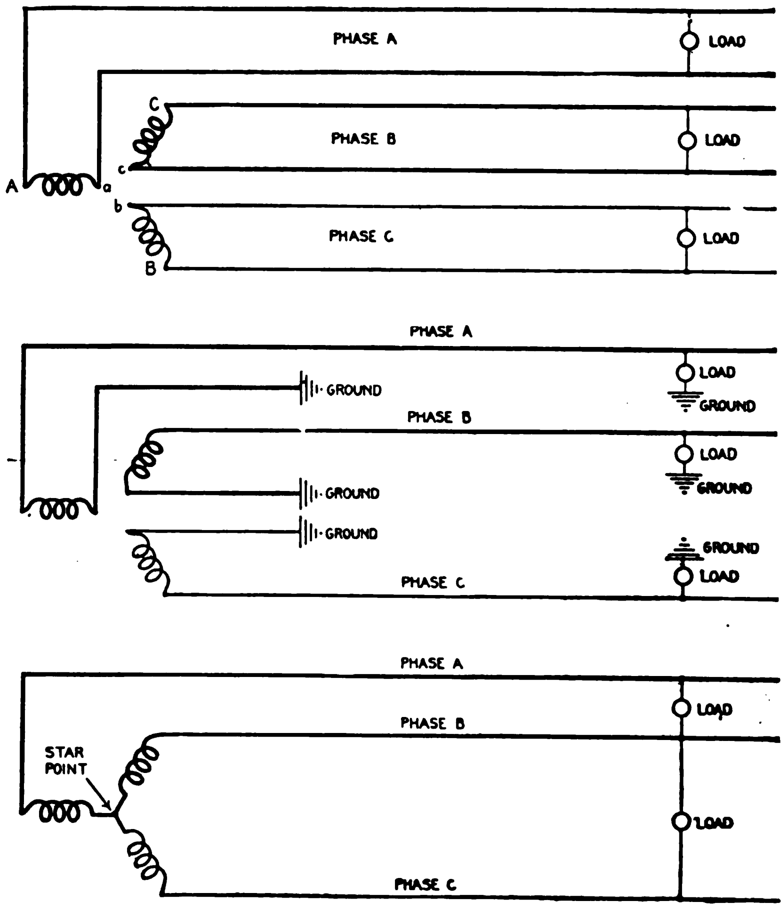


Fig. 2,160.—Three phase six wire system. It is equivalent to three independent single phase circuits and would be used only in very rare cases.

Ques. How can three phase current be transmitted by three conductors?

Ans. The arrangement shown in fig. 2,160 may be resolved **into three** single circuits with a common or grounded return.

When the circuits are balanced the sum of the current being zero no current will flow in the return conductor, and it may be dispensed with, thus giving the ordinary star or Y connected three wire circuit, as shown *in fig. 2,163. The transformation* from six to three wires *being shown in figs. 2,161 to 2,163.*

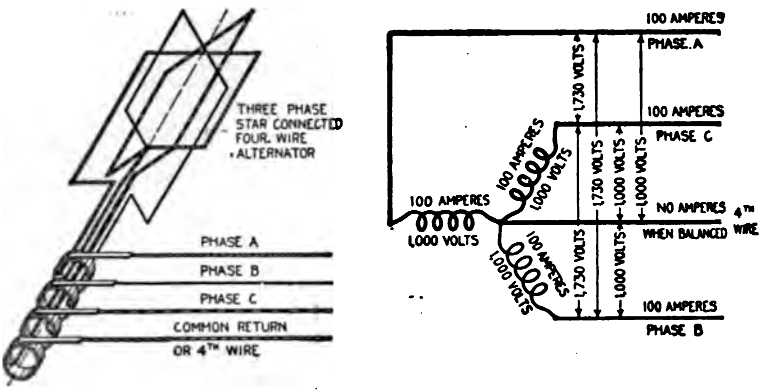


FIGS. 2,161 to 2,163.—Evolution of the three phase three wire system. Fig. 2,161 is a conventional diagram of the three phase six wire system shown in fig. 2,160. A wire is connected to both ends of each phase winding, giving six conductors, or three independent two wire circuits. In place of the wires running from A, B, and C, they may be removed and each circuit provided with a *ground* return as shown in fig. 2,162. The sum of the three currents being zero, or nearly zero, according to the degree of unbalancing, the *ground return may be eliminated* and the ends A, B, and C of the three phase winding *connected, as in fig. 2,163, giving* the so called *star point.*

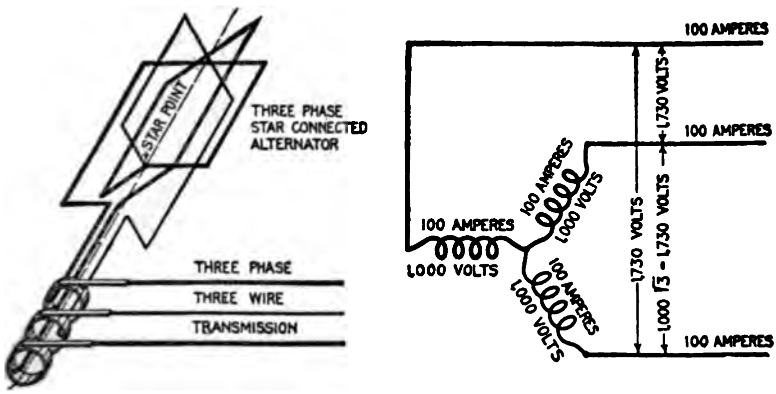
Fig. 2,166 is a view of an elementary three phase three wire star connected alternator.

Ques. What are the pressure and current relations of the star connected three wire system?

Ans. These are shown in the diagram, fig. 2,166 and 2,167



FIGS. 2,164 and 2,165.—Three phase four wire *star connected* alternator and conventional diagram showing pressure and current relations.



FIGS. 2,166 and 2,167.—Three phase **star connected** alternator, and conventional diagram *showing pressure relations.*

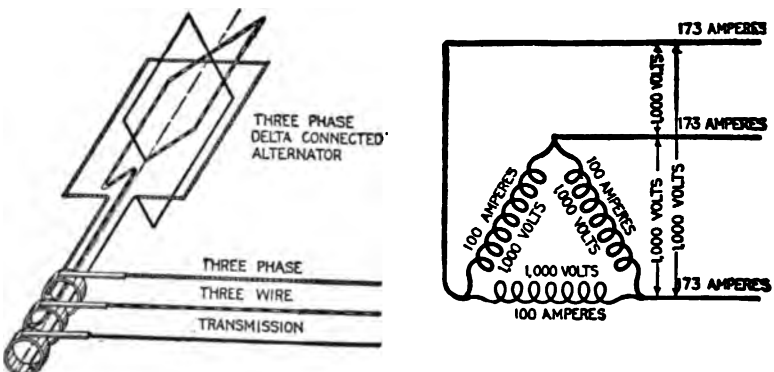
Assuming 100 amperes and 1.000 volts in each phase winding, the pressure between any two conductors is equal to the pressure in one winding multiplied by $\sqrt{3}$, that is $1,000 \times 1.732 = 1,732$ volts.

The current in each conductor is equal to the current in the winding, or 100 amperes.

Ques. Describe the delta connection.

Ans. In the delta connection, the three phase coils are connected together forming an endless winding, leads being brought out from these points.

Fig. 2,168 shows a delta connected three phase alternator, the pressure and current relation being given in fig. 2,169.



FIGS. 2,168 and 2,169.—Three phase delta connected alternator and conventional diagram showing pressure and current relations.

Ques. What are the pressure and current relations of the delta connected three wire system?

Ans. They are as shown in fig. 2,169.

Assuming 100 amperes and 1,000 volts in each phase winding, the pressure between any two conductors is the same as the pressure in the winding, and the current in any conductor is equal to the current in the winding multiplied by $\sqrt{3}$, that is $100 \times 1.732 = 173.2$ amperes, *that is, disregarding the* fraction, 173 amperes.

[redacted]

Ques. What are the relative merits of the star and delta connections?

Ans. The power output of each is the same, but the star connection gives a higher line voltage, hence smaller conductors may be used.

When it is remembered that the cost of copper conductors is inversely as the square of the voltage, the advantage of the Y connected system can be seen at once.

Assuming that three transformers are used for a three phase system

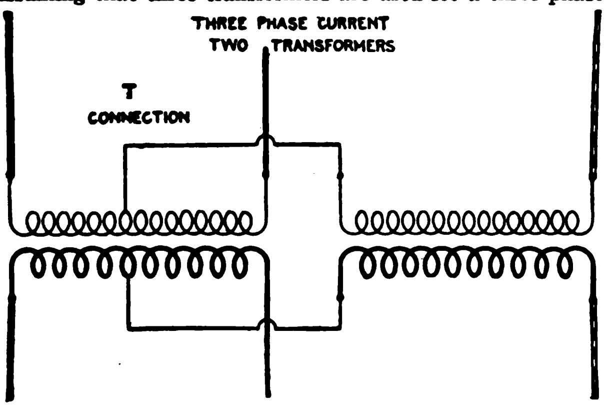


FIG. 2,170.—T connection of transformers in which three phase current is transformed with two transformers. The connections are clearly shown in the illustration. The voltage across one transformer is only 86.6% of that across the other, so that if each transformer be designed especially for its work one will have a rating of .866EI and the other EI. The combined rates will then be 1.866 as compared with 1.732 EI for three single phase transformers connected either star or delta.

of given voltage, each transformer, star connected, would be wound for $1 \div \sqrt{3} = 58\%$ of the given voltage, and for full current.

For delta connection, the winding of each transformer is for 58% of the current. Accordingly the turns required for star connection are only 58% of those required for delta connection.

Ques. What is the objection to the star connection for three phase work?

Ans. It requires the use of three transformers, and if anything happen to one, the entire set is disabled.

Ques. Does this defect exist with the delta connection?

Ans. No.

One transformer may be cut out and the other two operated at full capacity, that is at $\frac{2}{3}$ the capacity of the three.

Ques. Describe the T connection.

Ans. In this method two transformers are used for transforming three phase current. It consists in connecting one end of both windings of one transformer to the middle point of like windings of the other transformer as in fig. 2,170.

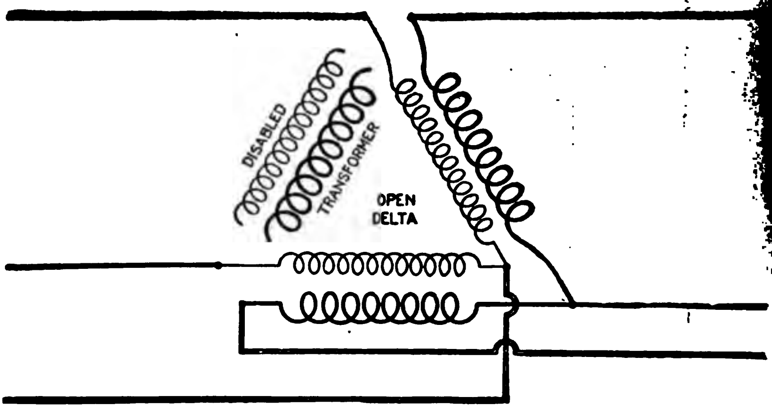


FIG. 2,171.—Open delta connection or method of connecting two transformers in delta for three phase transformation. It is used when one of the three single phase delta connected transformers becomes disabled.

Ques. What is the open delta connection?

Ans. It is a method of arranging the connections of a bank of three delta connected transformers when one becomes disabled as in fig. 2,171.

Change of Frequency.—There are numerous instances where it is desirable to change from one frequency to another, as for instance to join two systems of different frequency which

[redacted]

may supply the same or adjacent territory, or, in the case of a low frequency installation, in order to operate incandescent lights satisfactorily it would be desirable to increase the frequency for such circuits. This is done by motor generator sets, the motor taking its current from the low frequency circuit.

Synchronous motors are generally used for such service as the frequency is not disturbed by load changes; it also makes it

FIG. 2,172.—Course of the Schaghticoke-Schenectady transmission line of the Schenectady Power Co. This transmission line carries practically the entire output of the Schaghticoke power house to Schenectady, N. Y., a distance of approximately 21 miles. The line consists of two separate three phase, 40 cycle, 32,000 volt circuits, each of 6,000 kw. normal capacity. These circuits start from opposite ends of the power house, and, after crossing the Hoosic River, are transferred by means of two terminal towers, fig. 2,173, to a single line of transmission towers. The two circuits are carried on these on opposite ends of the cross arms, the three phases being superimposed. The power house ends of the line are held by six short quadrangular steel lattice work anchor poles with their bases firmly embedded in concrete, the cables being dead ended by General Electric disc strain insulators. This equipment, together with the lightning arrester horn gaps and the heavy line outlet insulators mounted on the roof of the power house, is shown in fig. 2,174. While each circuit carries only 6,000 kw. under normal conditions, either is capable of carrying the entire output of the station; in this case, however, the line losses are necessarily augmented. This feature prevents any interruption of the service from the failure of one of the circuits. There are altogether 197 transmission towers, comprising several distinct types.

possible to use the set in the reverse order, that is, taking power from the high frequency mains and delivering energy at low frequency.

Ques. In the parallel operations of frequency changing sets what is necessary to secure equal division of the load?

Ans. The relative angular position of the rotating elements of motor and generator must be the same respectively in each set.

FIG. 2,173.—Beginning of Schaghticoke-Schenectady transmission line; view showing 4 towers with power house in background.

Ques. How is this obtained?

Ans. Because of the mechanical difficulty of accurately

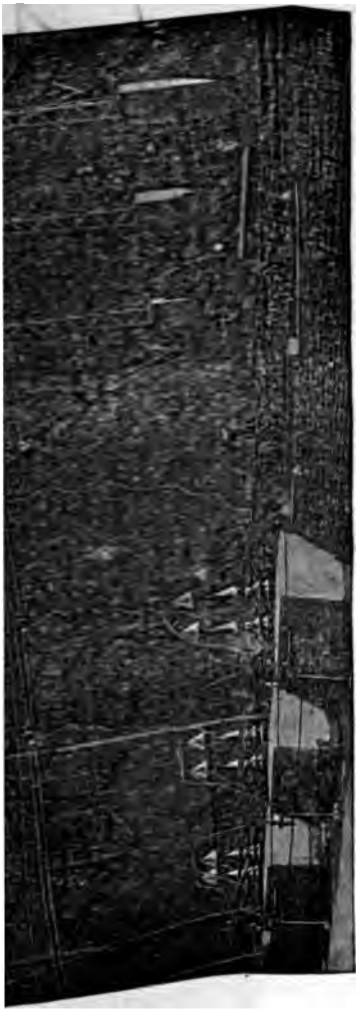


FIG. 2,174.—View from roof of power house of the Schaghticoke-Schenectady transmission line, showing anchor poles, strain insulators, lightning arrester horn gap and line entrance bushings.

locating the parts, the equivalent result is secured by arranging the stationary element in one of the two machines so that it can be given a small angular shift.

Transformation of Phases.—In alternating current circuits it is frequently desirable to change from one number of phases to another. For instance, in the case of a converter, it is less expensive and more efficient to use one built for six phases than for either two or three phases.

The numerous conditions met with necessitate various phase transformations, as

1. Three phase to one phase;

2. Three phase to two phase;

3. Two phase to six phase;
4. Three phase to six phase.

These transformations are accomplished by the numerous arrangements and combinations of the transformers.

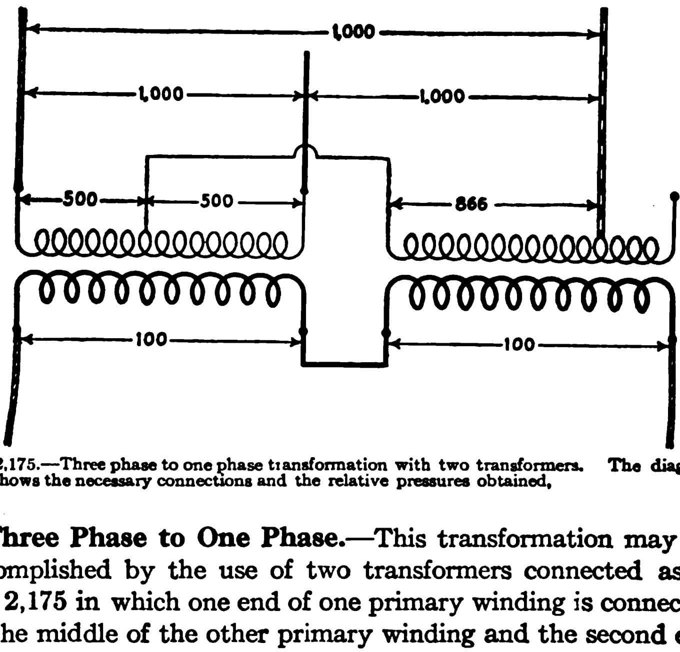


FIG. 2,175.—Three phase to one phase transformation with two transformers. The diagram shows the necessary connections and the relative pressures obtained.

Three Phase to One Phase.—This transformation may be accomplished by the use of two transformers connected as in fig. 2,175 in which one end of one primary winding is connected to the middle of the other primary winding and the second end of the first primary winding at a point giving 86.6 per cent. of that winding as shown. The two secondary windings are joined in series.

Three Phase to Two Phase.—The three phase system is *universally used for long distance transmission, because it requires less copper than either the single or two phase systems.*

[redacted]

or distribution, however, the two phase system presents rtain advantages, thus, it becomes desirable at the distribution nters to change from three phase to two phase. This may be one in several ways.

Ques. Describe the Scott connection.

Ans. Two transformers are used, one having a 10:1 ratio,

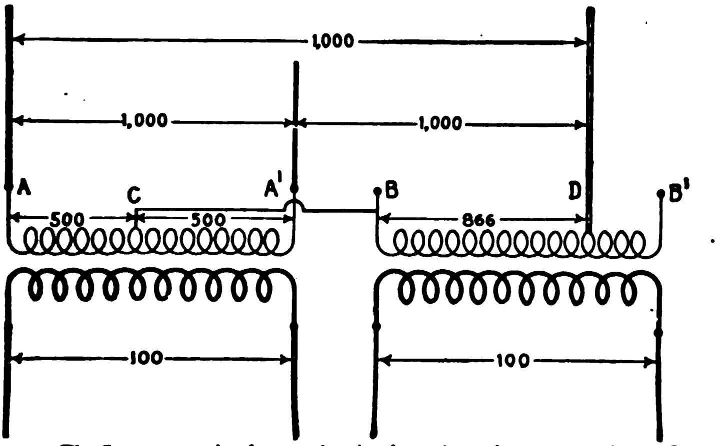


Fig. 2,176.—The Scott connection for transforming from three phase to two phase. In this method one of the primary wires B of the .866 ratio transformer is connected to the middle of the other primary as at C, the ends of which are connected to two of the three phase wires. The other phase wire is connected at D, the point giving the .866 ratio. The secondary wires are connected as shown.

nd the other, a $\frac{1}{2}\sqrt{3}$: 1, that is, an 8.66 : 1 ratio. The connections are arranged as in fig. 2,176.

It is customary to employ standard transformers having the ratios 10 : 1, and 9 : 1.

Ques. What names are given to the two transformers?

Ans. The one having the 10 : 1 ratio is called the **main** ansformer, and the other *with the 8.66* : 1 ratio, the **teaser** ansformer.

In construction, the transformers may be made exactly alike so that either may be used as main or teaser.

In order that the connections may be properly and conveniently made, the primary windings should be provided with 50% and 86.6% taps.

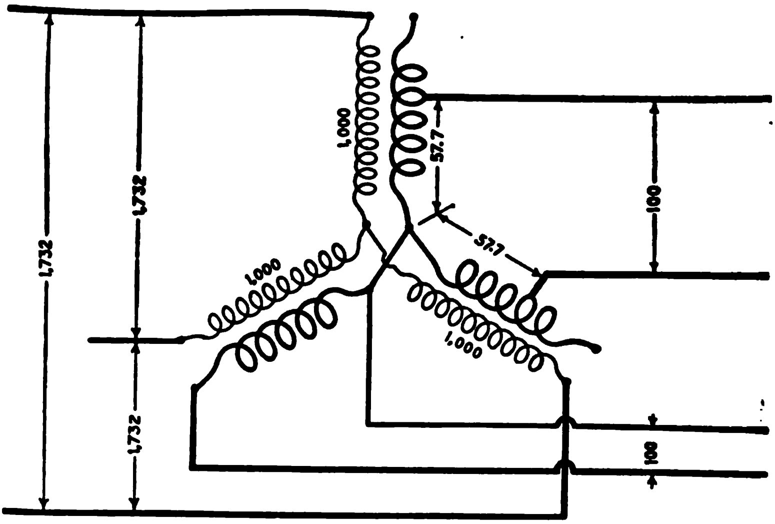


FIG. 2,177.—Three phase to two phase transformation with three star connected transformers. Two of the secondary windings are tapped at points corresponding to 57.7% of full voltage; these two windings are connected in series to form one secondary phase of voltage equal to that obtained by the other full secondary winding.

Ques. Describe another way of transforming from three to two phases.

Ans. The transformation may be made by three star connected transformers, proportioning the windings as in fig. 2,177, *from which it* will be seen that two of the secondary windings *are tapped at points* corresponding to 57.7 per cent. of full *voltage.*

[redacted]

Three Phase to Six Phase.—This transformation is usually made for use with rotary converters and may be accomplished in several ways. As these methods have been illustrated in the chapter on Converters (page 1,462), it is unnecessary to again discuss them here. Fig. 2,178, below shows the *diametrical* connection for transforming three phase to six phase.

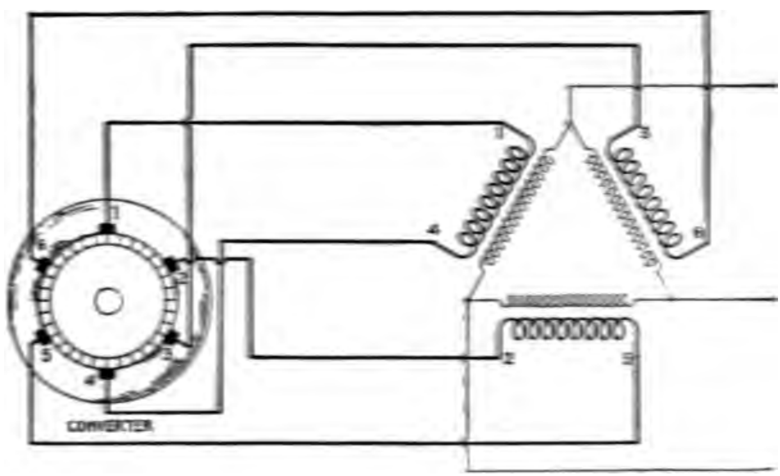


FIG. 2,178.—Diagram of diametrical connection, three phase to six phase. It is obtained by bringing both ends of each secondary winding to opposite points on the rotary converter winding, utilizing the converter winding to give the six phases. This transformation of phases may also be obtained with transformers having two secondary windings.

Alternating Current Systems.—The saving in the cost of transmission obtained by using alternating instead of direct current is not due to any difference in the characteristics of the currents themselves, but to the fact that in the case of alternating current very high pressures may be employed, thus permitting a given amount of energy to be transmitted with a *relatively small current.*

In the case of direct current systems, commutator troubles limit the transmission pressure to about 1,000 volts, whereas with alternating current it may be commercially generated at pressures up to about 13,000 and by means of step up transformers, transmitted at 110,000 volts or more.

FIG. 2,179.—End of Schaghticoke-Schenectady transmission line at Schenectady; view showing entrance bushings and lightning arrester horn gaps.

Relative Weights of Copper Required by Polyphase Systems.—A comparison between the weights of copper required by the different alternating current systems is rendered quite difficult by the fact that the voltage ordinarily measured is not the maximum voltage, and as the insulation has to withstand the strain of the maximum voltage, the relative value of copper obtained by calculation depends upon the basis of comparison adopted.

[redacted]

As a general rule, the highest voltage practicable is used for long distance transmission, and a lower voltage for local distribution. Furthermore, some polyphase systems give a multiplicity of voltages, and the question arises as to which of these voltages shall be considered the transmission voltage.

If the transmission voltage be taken to represent that of the distribution circuit, and the polyphase system has as many independent circuits as there are phases, the system would represent a group of several single phase systems, and there

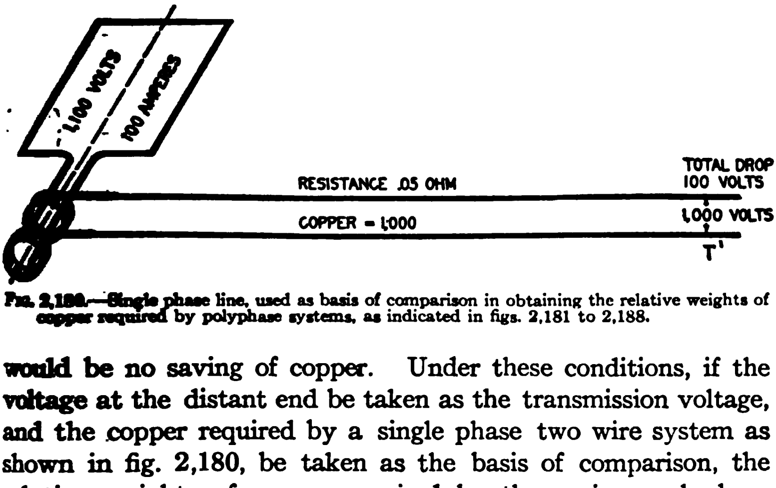
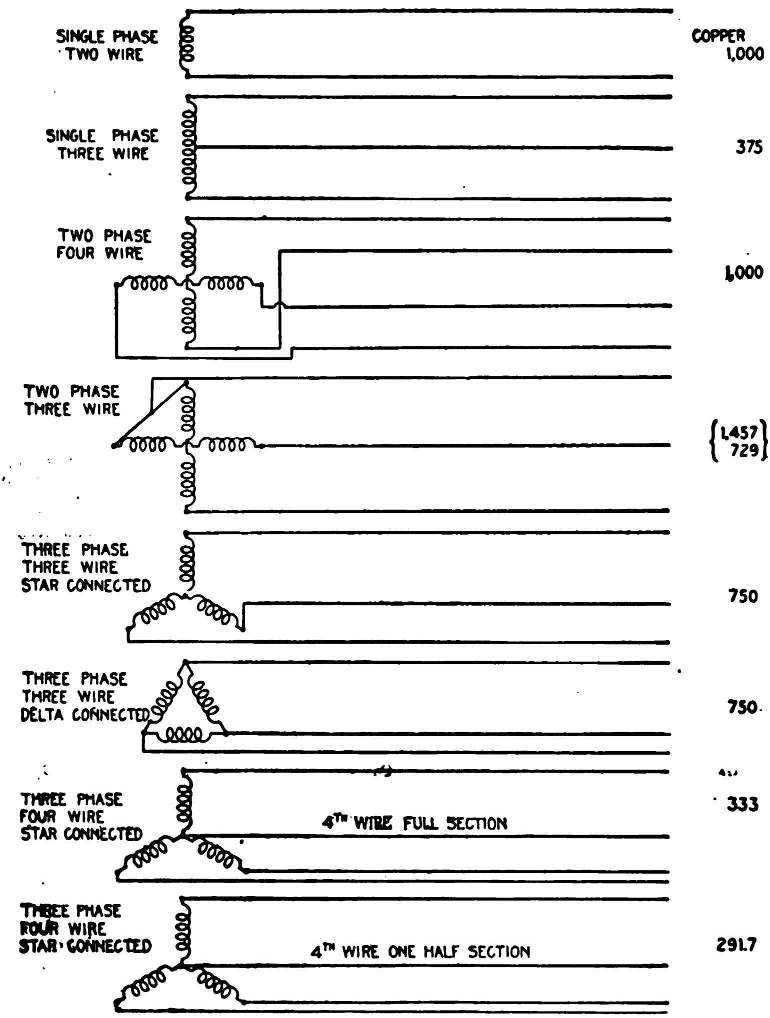


FIG. 2,180.—Single phase line, used as basis of comparison in obtaining the relative weights of copper required by polyphase systems, as indicated in figs. 2,181 to 2,188.

would be no saving of copper. Under these conditions, if the voltage at the distant end be taken as the transmission voltage, and the copper required by a single phase two wire system as shown in fig. 2,180, be taken as the basis of comparison, the relative weights of copper required by the various polyphase systems is given in figs. 2,181 to 2,188.

In the case represented in fig. 2,180, if the total drop on the line be 100 volts, the generated voltage must be 1,100 volts, and the resistance of each line must be 50 ÷ 1,000 = .05 ohms. Calculated on this basis, *a two phase four wire system is equivalent to two single phase systems and gives no economy of copper in power transmission over the ordinary single phase two wire*



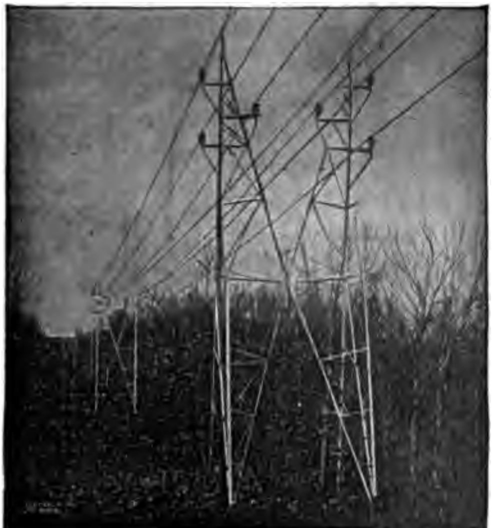
FIGS. 2,181 to 2,188.—Circuit diagrams showing relative copper economy of various alternating current systems.

[redacted]

ystem. This is the case also with any of the other two phase ystems, except the two phase three wire system.

In this system two of the four wires of the four wire two phase system are replaced by one of full cross section.

The amount of copper required, when compared with the single phase system, will differ considerably according as the comparison is based on the highest voltage permissible for any given distribution, or on the minimum voltage for low pressure service.



IG. 2,189.—Twin circuit "aermotor" towers carrying 44,000 volt conductors (Southern Power Co.). These towers vary in height from 35 to 50 feet, and the circuits are transposed every 10 miles. The towers are assembled on the ground and erected by means of gin poles. They are normally spaced 500 feet apart with a sag of 5 feet 8 inches. The minimum distance between towers is 300 feet and the maximum 700 feet.

If E be the greatest voltage that can be used on account of the insulation strain, or for any other reason, the pressure between the other conductors of the two phase three wire system must be reduced to $E \div \sqrt{2}$.

The weight of copper *required under this condition* is 145.7% that *of the single phase copper.*

On the basis of minimum voltage, the relative amount of copper *required is 72.9% that of the single* phase system.

Figs. 2,187 and 2,188 are two examples of three phase four wire systems. The relative amount of copper required as compared with the single phase system depends on the cross section of the fourth wire. The arrangement shown in fig. 2,188, where the fourth wire is only half size, is used only for secondary distribution systems.

Choice of Voltage.—In order to properly determine the voltage for a transmission system there are a number of

FIG. 2,190.—General Electric standard tower for high tension three phase transmission line.

FIG. 2,191.—General Electric transposition tower for high tension three phase transmission line.

[redacted]

conditions which must be considered in order that the economy of the entire installation shall be a maximum.

The nature of the diversely various factors which affect the problem makes a mathematical expression difficult and unsatisfactory.

Ques. What is the relation between the cross sectional area of the conductors and the voltage?

Ans. For a given circuit, the cross sectional area of the conductors, or weight varies inversely as the voltage.

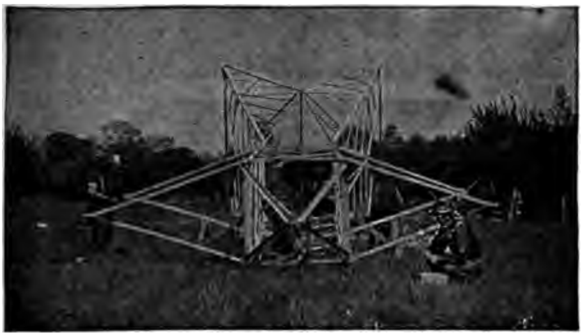


FIG. 2,192.—General Electric standard tower under construction.

Ques. Would the highest possible voltage then be used for a transmission line?

Ans. The most economical voltage depends on the length of the line and the cost of apparatus.

For instance, alternators, transformers, insulation and circuit control and lightning protection devices become expensive when manufactured for very high pressures. Hence if a very high pressure were used, it would involve that the transmission distance be great enough so that the extra *cost of the high pressure* apparatus would be offset by *the saving in copper effected by* using the high pressure.

In the case of the longest lines, from about 100 miles up, the saving in copper with the highest practicable voltage is so great that the increase in other expenses is rendered comparatively small.

In the shorter lines as those ranging in length from about one mile to 50 or 75 miles, the most suitable voltage must be determined in each individual case by a careful consideration of all the conditions involved. No fixed rule can be established for proper voltage based on the length, but the following table will serve as a guide:

FIG. 2,193.—Line of the Schenectady Power Company crossing the tracks of the Boston and Maine Railroad near Schaghticoke.

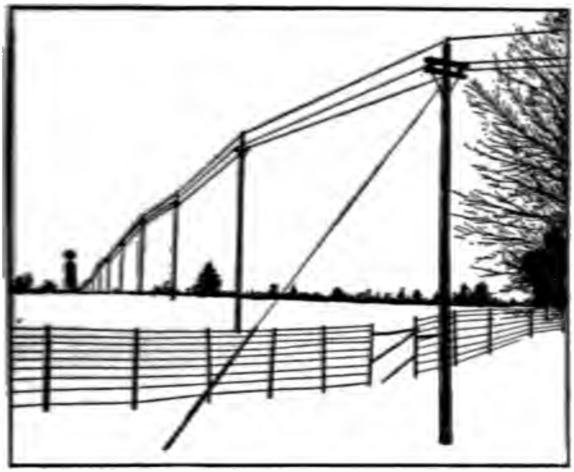
Usual Transmission Voltages

Length of line in miles	Voltage
1	500 to 1,000
1 to 2	1,000 to 2,300
2 to 3	2,300 to 6,600
3 to 10	6,600 to 13,200
10 to 15	13,200 to 22,000
15 to 20	22,000 to 44,000
20 to 40	44,000 to 66,000
40 o 60	66,000 to 88,000
60 to 100	88,000 to 110,000

ea. What are the standard voltages for alternating nt transmission circuits?

. 6,600, 11,000, 22,000, 33,000, 44,000, 66,000, 88,000.

The amount of power to be transmitted determines, in a measure, the nit of line voltage. If the most economical voltage considered from e point of view of the line alone, be somewhere in excess of 13,200, ep up transformers must be employed, since the highest voltage for

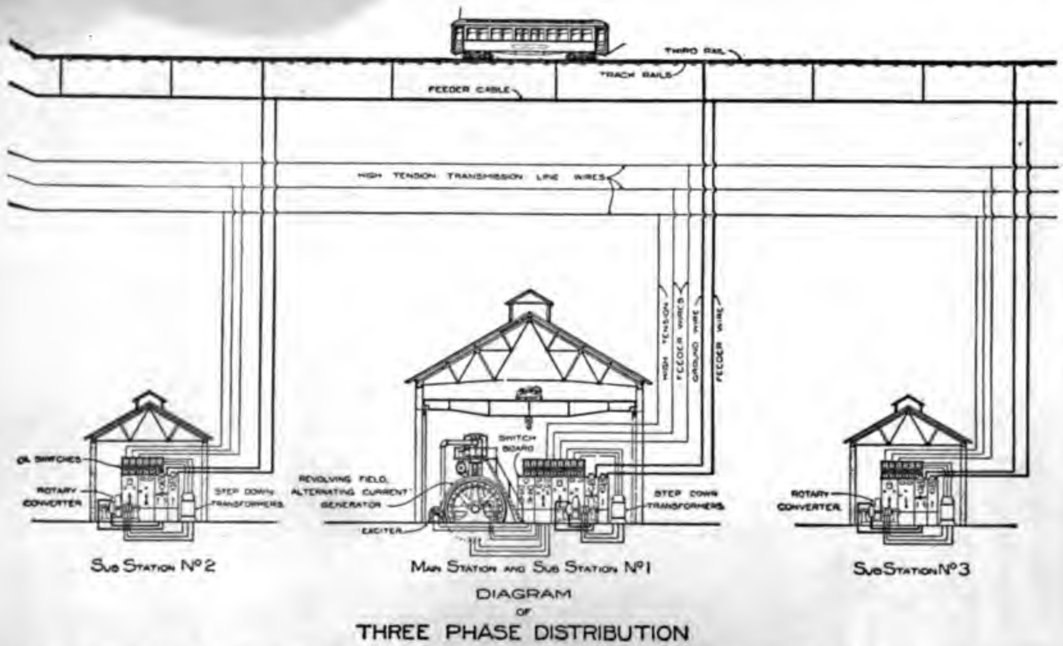


4.—View of a three phase, 2,300 volt, 60 cycle line at Chazy, N. Y. The current is smitted at the alternator voltage $2\frac{3}{4}$ miles over the single circuit pole line. The s are of cedar with fir cross arms, and are fitted with pin insulators. They are from) 40 feet high and are spaced at an average of about 120 feet. The conductors are copper wire No. 00 B. & S. The alternators consist of one 50 kw., and one 100 kw. eral Electric machines.

nich standard alternators are manufactured is 13,200. In a given case, e saving in conductor by using the higher voltage may be more than fset by the increased cost of transformers, and the question must be termined for each case.

ea. What are the standard transformer ratios?

. ***Multiples of 5 or 10.***



FIGS. 2,195 to 2,197.—Diagram showing electric railway system. Three phase current is generated at the main station where it passes to **step up** transformers to increase the pressure a suitable amount for economical transmission. At various points along the railway line are *sub-stations*, where the three phase current is reduced in pressure to 500 or 600 volts by **step down** transformers, and converted into direct current by rotary converters. The relatively low pressure direct current is then conveyed by "feeders" to the rails, this resulting in a considerable saving in copper.

[redacted]

Mixed Current Systems.—It is often desirable to transmit electrical energy in the form of alternating current, and distribute it as direct current or vice versa.

Such systems may be classed as mixed current systems. The usual conversion is from alternating current to direct current because of the saving in copper secured by the use of alternating current in transmission, especially in the case of long

FIG. 2,198.—Example of converter sub-station, showing the Brooklyn Edison Co. Madison sub-station. The transformers are seen on the left, the converter shown at the right is a Westinghouse synchronous booster rotary converter, consisting of a standard rotary converter in combination with a revolving armature alternator mounted on the same shaft with the converter and having the same number of pole. *The function of the machine is to convert and regulate the pressure.* By varying the field excitation of the alternator, the A.C. voltage impressed on the rotary converter proper can be increased or decreased as desired. Thus, the D.C. voltage delivered by the converter is varied accordingly. This type of converter is well adapted for any application for which a relatively wide variation, either automatic or non-automatic, in direct current voltage is necessary. Also especially for serving incandescent lighting systems where considerable voltage variation is required for the compensation of drop in long feeders, for operation in parallel with storage batteries and for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

distance lines. Such conversion involves the use of a rotary converter, motor generator set, or rectifier, according to the *conditions of service.*

The suburban trolley forms a good example of a mixed system, in which alternating current is generated at the *central station* and transmitted to *sub-stations*, where it is transformed to low pressure, and converted into direct current for use on the line. Fig. 2,195 shows the interior of a sub-station of this kind.

Ques. What direct current pressure is usually employed on traction lines?

Ans. 500 volts.

Ques. Mention another important service performed by a mixed system.

Ans. If the generator furnish alternating current it must be converted into direct current in order to charge storage batteries.

[redacted]

CHAPTER LVI

AUXILIARY APPARATUS

For the proper control of the alternating current in any of the numerous systems described in the previous chapter, various devices, which might be classed as "auxiliary apparatus," are required. These may be grouped into several divisions, according to the nature of the duty which they perform, as

1. Switching devices;

   a. Ordinary switches;
   b. Oil break switches;
   c. Remote control switches.

2. Current or pressure limiting devices;

   a. Fuses;
   b. Reactances;
   c. Circuit breakers;
   d. Relays.

3. Lightning protection devices;

   a. Air gap arresters;
   b. Multi-gap arresters;
   c. Horn gap arresters;
   d. Electrolytic arresters;
   e. Vacuum tube arresters;
   f. Choke coils;
   g. *"Static" interrupters.*

4. Regulating devices;

   a. Induction voltage regulators;
   b. Variable ratio transformer regulators { drum type; dial type;
   c. Compensation shunts;
   d. Pole type regulators;
   e. Small feeder voltage regulators;
   f. Automatic voltage regulators;
   g. Line drop compensators;
   h. Starting compensators;
   i. Star delta switches.

5. Power factor regulating devices;

   a. Condensers;
   b. Synchronous condensers.

6. Indicating devices;

   a. Moving iron instruments { plunger type; inclined coil type; magnetic vane type;
   b. Hot wire instruments;
   c. Induction instruments { shielded pole type; repulsion type;
   d. Dynamometers;
   e. Instrument transformers;
   f. Watthour meters { commutator type; induction type; Faraday disc type;
   g. Frequency indicators { synchronous motor type; resonance type; induction type;
   h. Synchronism indicators { lamp type; voltmeter type; resonance type; rotating field type;
   i. Power factor indicators { wattmeter type; rotating field type;
   j. Ground detectors;
   k. Earth leakage cut outs;
   l. Oscillographs.

CHAPTER LVII

SWITCHING DEVICES

A switch is *a piece of apparatus for making, breaking, or changing the connections in an electric circuit.*

The particular form and construction of any switch is governed by the electrical conditions under which it must operate.

Since the electric current cannot be **stopped instantly** *when the circuit in which it is flowing, is broken,* **an arc is formed** *as the switch contacts separate;* this tends to burn the contacts, and to short circuit, the severity of such action depending on the voltage and the proximity of the switch terminals. Accordingly in switch design, provision must be made to counteract these tendencies. Thus,

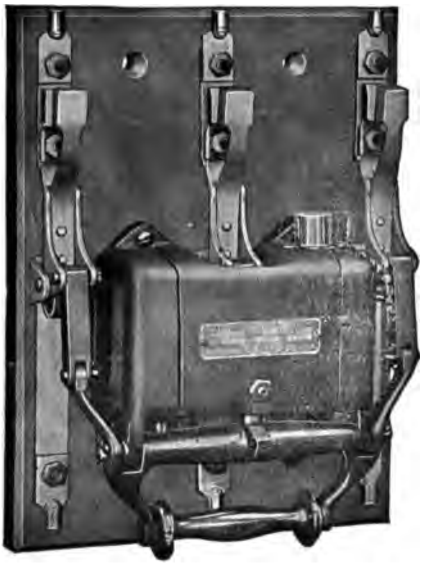
1. The contacts should separate along their entire length, rather than at a point;

2. The terminals should be far enough apart and properly protected to prevent short circuiting of the arcs;

3. The break should be quick;

4. The gap should be surrounded by the proper medium (air or oil) to meet the requirements of the electrical conditions.

A great variety of switches have been introduced to suit the different requirements. Knife switches are used for low pressure service, the multiple break form being used where it is desired *to reduce the arcing distance.*



Ques. How should single throw switches be installed?

Ans. They should open downward so gravity will keep them open.

FIGS. 2,199 and 2,200.—**General Electric triple pole solenoid operated, single throw remote control switch, and push button switch for operating same.** Switch is a self-contained unit with two sets of contacts, main laminated copper brushes, and carbon auxiliary contacts to take the arc on breaking the circuit. The main brushes are so made that each lamination makes an end on contact with the switch blade without any tendency to force the laminations apart. A wiping effect, given to the contacts every time the switch is closed, keeps the contact surfaces clean and insures good contact at all times. The carbon auxiliary contacts are made of blocks of carbon fastened without screws. **In operation,** the switch is actuated by a double coil solenoid, one coil for closing and one for opening, controlled by the single pole double throw push button switch shown in fig. 2,200, which is normally in the open position and remains closed only when held by the operator. One of these switches is furnished with each control switch and must always be used, as the solenoid coils are not intended for continuous service. The power required to operate the remote control switch is small, being approximately 1.6 amperes at 110 volts, 0.81 amperes at 220 volts direct current, and 10 amperes at 110 volts, and 6 amperes at 220 volts alternating current 60 cycles. The main switch can be closed and opened by hand, and the push button located at any point.

[redacted]

Ques. How should double throw switches be installed?

Ans. Horizontally.

FIGS. 2,201 and 2,202.—Palmer service switch and fuse box, for either plug, cartridge or open link fuses. Fig. 2,201 illustrates the box in open position for the inspection of fuses, etc. The cover is held open by a simple lock so that the switch cannot fall closed by gravity, the box may be mounted so that the service wires lead directly into a sealed terminal chamber from any direction, and all current carrying parts made accessible by the opening of the switch are dead. Fig. 2,202 illustrates the device with side of box and cover cut away to show interior and the normally sealed cover of terminal chamber removed. The switch contacts do not enter their contact clips until the flanged cover of the box has closed the switch opening, no current connections being made to line or load until the box is completely closed, and in consequence there is no opportunity to make improper connections to any live parts of switch, when conduit connections are used to the service and meter wires.

Ques. What is a plug switch?

Ans. A switch in which the current is ruptured in a tube enclosed at one end, thereby confining the arc and limiting the supply of air.

They are used on high pressure circuits of from 10,000 to 20,000 volts, *for transferring live circuits* and for voltmeter and synchronizing circuits where there is very little energy. The usual current capacity is from 4 to 7½ amperes.

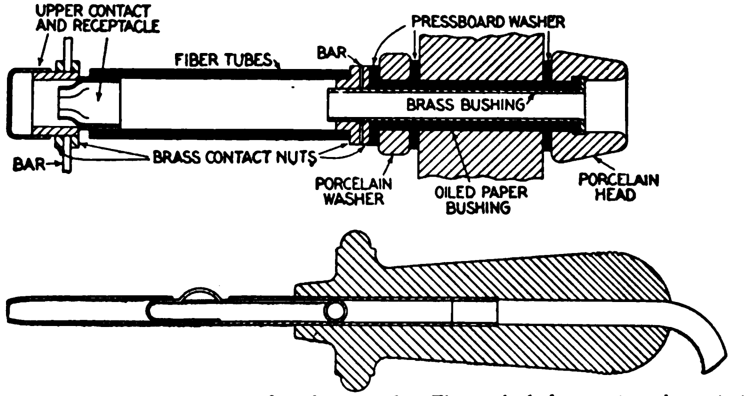


FIG. 2,203 and 2,204.—**Bus transfer plug switch**. The method of supporting the contact farthest from the panel consists of a porcelain pillar of the same height as the receptacle, clamped to a brass connecting or bus bar which in turn is fastened to the receptacle.

Forms of Break.—On high pressure circuits there are several types of switch: they are classified with respect to the break, that is to say, according as the break takes place,

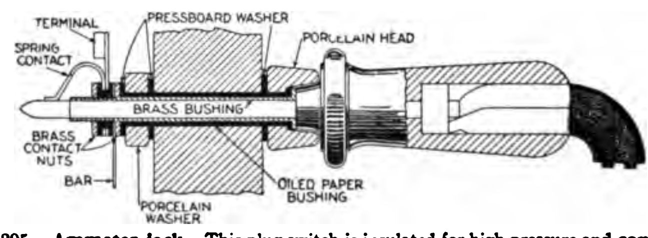


FIG. 2,205.—**Ammeter jack.** This plug switch is insulated for high pressure and **consists of two parts:** *the ammeter jack, and the ammeter jack plug, cable, and bushing.* The receptacle, which is simple in construction, consists of a brass bushing well insulated from the panel and protected on the front of the panel by a porcelain bushing. **On the end of this tube** and insulated from it, is a phosphor bronze spring which, when the plug is out, rests on the brass tube and keeps the circuit closed. **The plug** consists of a brass rod well insulated and set in a brass tube, both being fastened in a handle which is stained black and polished. Inside the handle is run a twin conductor cable, one side being soldered in the brass tube and the other to the brass rod. The other end of the cable is run through a bushing set in the panel and thence to the ammeter or current transformer. Where it is desired to remove *the plug and cable from the board, or to plug both ends of the cable in different receptacles, a plug instead of a bushing should be used.* In this case a cable should be provided *with a plug on each end.*

[redacted]

1. In open air;
2. In an enclosed air space;
3. Aided by a metal fuse;
4. Aided by a horn;
5. In oil.

FIG. 2,206.—Westinghouse fused starting switch for squirrel cage motors. It is arranged for National Electric Code fuses on one end only and has springs on the other end to open the switch automatically if left closed at this end. The corresponding terminals at both ends of the switch are connected in grooves in the back of the slate base so that the wiring need be connected to one set of these terminals only, thus decreasing the number of connections necessary, as shown in fig. 2,207. In starting an induction motor, the switch is thrown to the end that is not fused and held there until the motor is up to running speed; then it is quickly thrown to the fused position, thus protecting the circuit under running conditions.

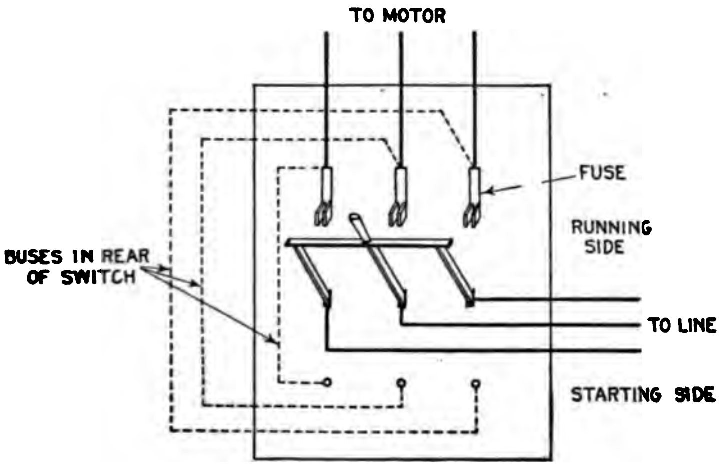


FIG. 2,207.—Diagram of connections of Westinghouse fused starting switch for squirrel cage motors. The starting current of induction motors is several times the normal running current and, when the controlling switch is fused to carry the running load only, the fuses are apt to blow when the motor is started. The fuses must be of a capacity to prevent overloads under *running conditions*. These switches are designed to meet this difficulty *and are used without auto-starters* to control motors up to 5 horse power rating.

Ques. What is the objection to open air break?

Ans. The relatively long gap required to extinguish the arc, limiting this form of switch to low or moderate pressure circuits.

The open air arc may cause very high voltage oscillations when the circuit contains inductance and capacity unless the break occur at zero value.

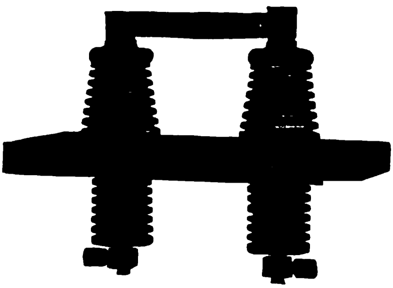
FIG. 2,208.—Westinghouse single pole disconnecting switch. Disconnecting switches are used primarily for isolating apparatus from the circuit for purposes of inspection and repair; also for sectionalizing feeders. They are not designed for opening under load, and therefore no attempt should be made to open them with current in the circuit. In connection with lightning arrester installations, disconnecting switches are particularly useful, providing a simple and effective means for isolating the arresters while cleaning and inspecting. The switch is opened and closed with a hook on the end of a wooden pole, which hook engages in a hole provided in the switch blade. This type of disconnecting switch is intended for wall mounting. The live parts are mounted on porcelain insulators carried on a cast iron yoke or base, forming a simple and substantial construction.

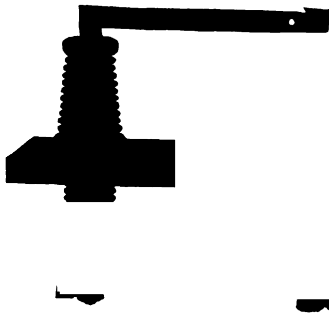
Ques. What are disconnecting switches?

Ans. Knife switches in series with other switches so that the apparatus controlled by the latter may be repaired in safety by entirely disconnecting it from the bus bars or live circuit.

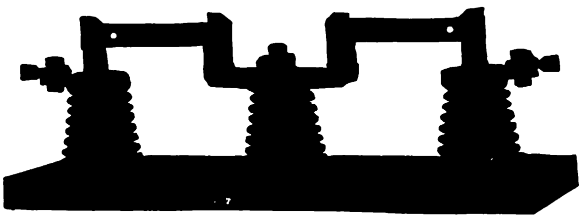
Such switches are not intended to rupture the load current.

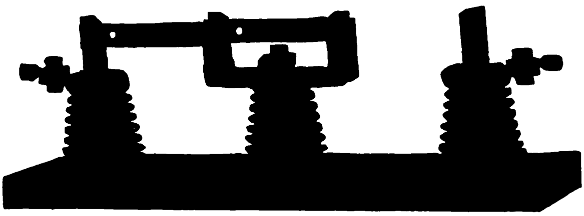
[redacted]





Figs. 2,209 and 2,210.—Westinghouse disconnecting switches for pressures over 3,300 volts





Figs. 2,211 and 2,212.—Westinghouse selector type disconnecting switch. Fig. 2,211, view showing both sides closed; fig. 2,212, view with one side open. The selector type of disconnecting switch is a transfer switch which does not require the circuit to be interrupted while making the change. It can also be used to connect two independent circuits in parallel. In construction, it is in effect two single throw, single pole disconnecting switches with the hinge jaws connected together and mounted on the same insulator. The hinge jaw is also provided with dummy jaws to hold either blade of the switch in the open position. Except for these differences in the hinge jaws, the construction is similar to the switch shown in fig. 2,209. It should not be used to open the circuit when loaded.

Fig. 2,213.—Hook stick for operating a disconnecting switch.

Ques. What are the features of the enclosed air break?

Ans. The switch is more compact than the open air break type, but pressure oscillations are caused on opening the circuit the same as with the open air break, and it is not desirable for heavy current.

FIG. 2,214.—Baum 35,000 volt, 200 ampere, double break pole type switch. While designed for disconnecting purposes only, it can break considerable amperage. The levers and couplings are fastened with tape pins. The control shaft coupling is adjustable to any angle, and the switch can be locked in the open or closed position. A removable wooden handle is supplied and the switch can be handled in any weather. The arms can be extended to hold fuse fittings, or dead end insulators in the event of a heavy strain, but it is preferable to have fuses on another structure as a precaution against coming in contact with the energized portion of the switch, and it is also preferable to take the strain of the line on a pole a few feet from the switch, rather than on the switch structure, particularly in the larger sizes. An insulating wood section in the control shaft separates the control handle from the remainder of the switch. Discharging horns can be fitted to this type of switch and when so equipped they have been found capable of breaking considerable loads.

Ques. How is the fuse arranged in the metal fuse break type of switch?

Ans. It is placed in a tube fitted with powdered carbonate of lime or some other insulating powder.

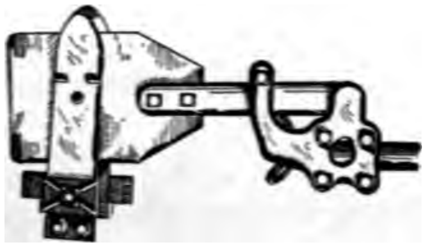


FIG. 2,215.—Pacific swivel type blade for Baum pole top switches. The **twist type** *of blade*, **here shown**, is especially adapted to switches operating in freezing or sleety weather. **It will be seen** that the first few degrees through which the rotating insulator is moved *have the effect of twisting the blade between the shoes of the contact*, which breaks any seal through freezing, or corrosion.

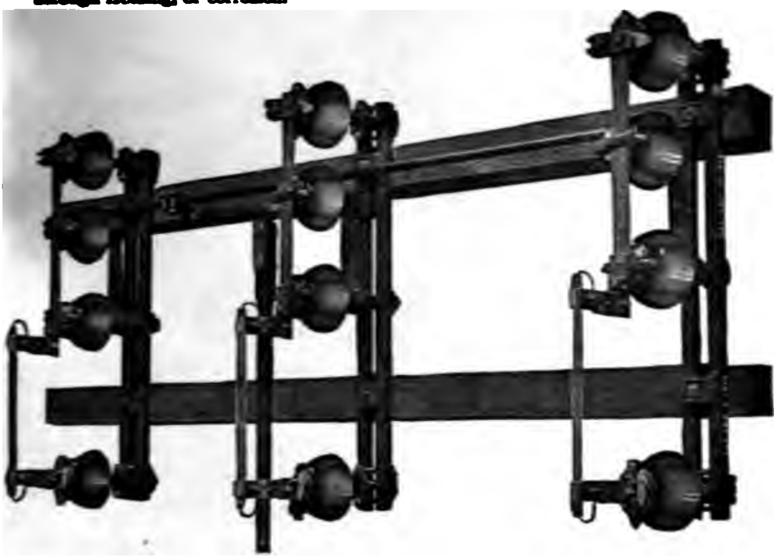


FIG. 2,216.—Pacific 22,000 volt, 100 ampere, **pole top switch** equipped with fuse tubes; designed to meet the need for a small group controlled disconnecting switch, having several features making it suitable for use with service transformer installations and line branches. **The switch is made** with clamped pipe arms permitting adjustment. It is equipped with fuse tubes and fittings, but should the fuses be not desired, the arm may be shortened. Provision is made for fitting insulator pins to the top of the arms, when the switch is mounted vertically, which will hold insulators at right angles to the switch, making it possible to end a line on the *top* of these arms and then drop down through the switch *to the bank of transformers. The switch is so constructed that* **gravity tends to** *hold it in either the open or the closed position.* Provision can be made for locking.

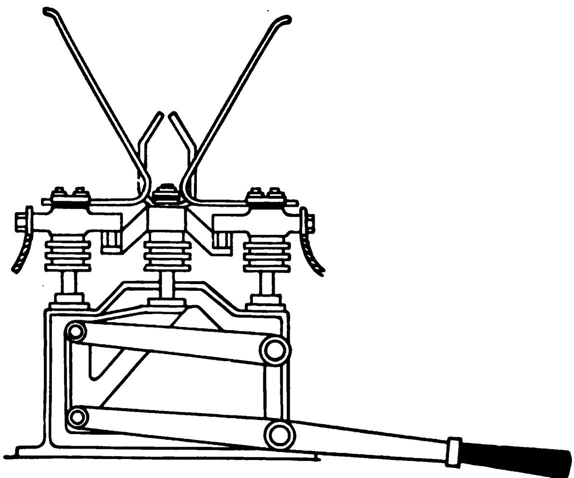


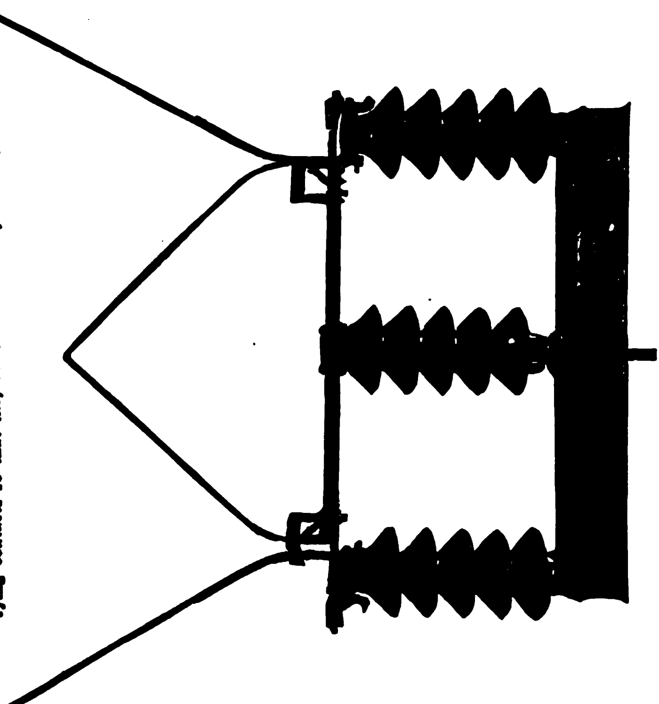
FIG. 2,217.—Horn break switch. **In operation**, the arc formed at break, will travel toward the extremities of the horns because of the fact that a circuit will tend to move so as to embrace the largest possible number of lines of force set up by it. Hence, the arc that starts between the horns where they are near together rises between them until it becomes so attenuated that it is extinguished.

FIG. 2,218.—Westinghouse rear connected motor starting switch, for pressures up to 600 volts. It is used for starting rotary converters and direct current motors of large capacity having starting torque small enough to permit cutting out the starting resistance in few steps. The clips can be connected to any type of resistor, the steps of which are successively short circuited as the switch closes; the amount of resistance in the armature circuit is thus gradually reduced. A pause should be made after each step of resistance is thrown in to allow the motor speed to accelerate. *If the starting switch do not have to carry the full load current and can be short circuited by another switch, a starting switch of smaller capacity* equivalent to 50 per cent of running current of the machine *can be used.* The switch is of the single pole, single throw, rear connected, four point, *knife blade type.*

[redacted]

. Describe its operation.

The moving arm of the switch draws the fuse through e, thus opening the circuit without much disturbance.



rying contacts so that they are not attacked by the arc.

. What is the objection to the metal fuse switch?

The powder is set flying by the explosion of the arc, which, as it settles, gets into the bearings of any machine that may be in the vicinity.

Ques. What is a horn break switch?

Ans. One provided with horn shaped extensions to the contacts, as shown in fig. 2,219.

The arc formed on breaking the circuit, as it travels toward the extremities of the horns, becomes attenuated and is finally ruptured.

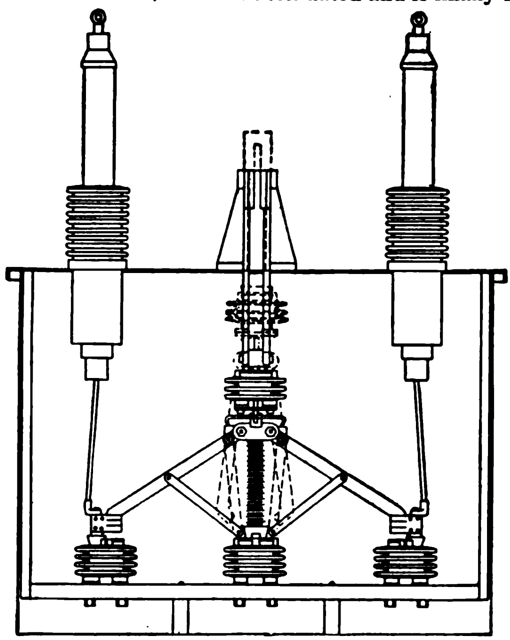
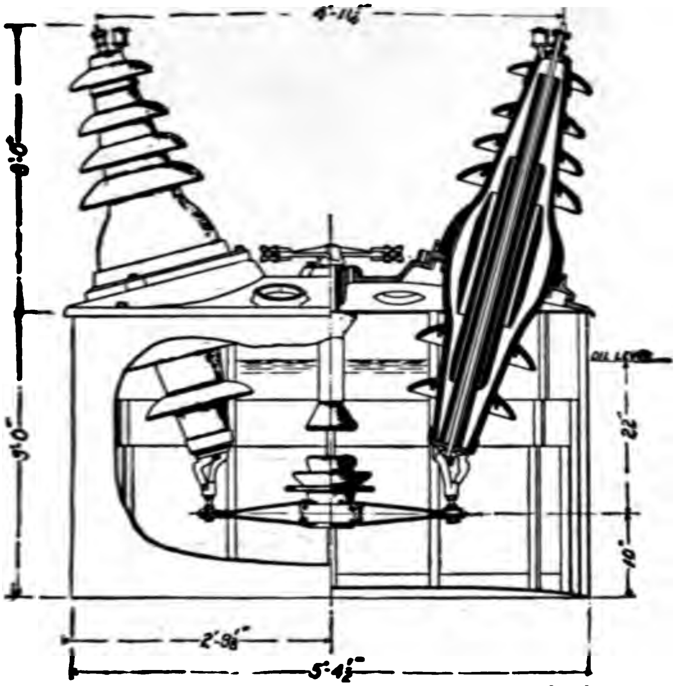


FIG. 2,220.—Kelman switching mechanism. The pantograph arrangement of the contact blades gives a double horizontal break deep down in the oil. This gives over the break a heavy head of oil which immediately closes in around the thin blades as they leave the contacts in opening, thus effectually extinguishing the arc. The opening spring acts within the pantograph itself without any intervening mechanism, and the light weight of the few moving parts enables the spring to accelerate the blades rapidly, thus obtaining a quick break. The contacts are of the return bend type, which makes a flexible contact, to obtain alignment with the blades at all times. The pantograph and contacts are supported on corrugated porcelain insulators on a hardwood base or insulator board. The insulators are fitted with iron ends for securing the different parts. At each end of the insulator board is an upright or lifting board which serves to lift the switching mechanism out of the tank. The leads are heavily insulated.

Ques. What are the objections to this type of switch?

Ans. The considerable space required for the horns and cs, and the line surges caused by the arc.

Horn switches were used extensively for high pressure alternating current circuits before the introduction of oil switches.



c. 2,221.—Sectional view of Pacific weatherproof oil switch for use in places exposed to the weather. All moving and contact parts are supported from the cast iron top and are readily removable for inspection or repair

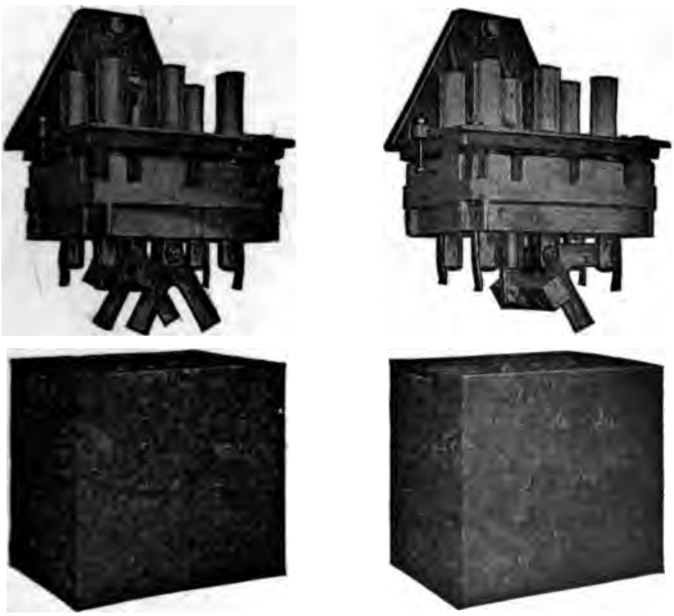
Oil Switches.—The extensive use of high pressure currents d alternating current motors and other devices introducing ductance make it necessary to use switches radically different om the ordinary *air break types.*

The opening of circuits of considerable current value with inductive loads is not possible with old style switches which

FIG. 2,222.—General Electric central station triple pole single throw oil switch; view of switch in tank. This type is for pressures up to 110,000 volts, being adapted for stations employing open wiring, since the connections are made at the top of the switch and its construction obviates the need for isolating it in a cell. One tank with two breaks in series are used for each phase.

[redacted]

were quite adequate for the service for which they were designed. These circuits are controlled with ease and certainty by the oil switch.



FIGS. 2,223 to 2,226.—Westinghouse indoor, two pole double throw oil switch for pressures not over 6,600 volts. Fig. 2,223, open position; fig. 2,225, closed position. This type of switch is suited for a wide range of application, being made in both switchboard and wall mounting styles; also for remote mechanical control by the use of bell cranks and connecting rods. The wall mounting style is adaptable to motor installations on account of the facility with which it may be mounted on any support, convenient to the motor operator. The lever and handle extend outward over the oil tank, so that the switch may readily be mounted against a wall, post or any vertical support. The characteristic features of this type of switch are: knife blade contacts submerged in oil; live parts carried on a porcelain base affording a permanent insulation between adjacent poles, and between the frame and live parts; compactness and accessibility; enclosure of all live metal parts; and low first cost. Each contact jaw has attached to it an arcing piece which takes the final break, thus preventing any burning of the jaws. These arcing pieces are inexpensive and readily replaced when worn or burnt away. The contact making parts are enclosed in a sheet metal oil tank which has an insulating lining. The leads are brought out at the top. Connections to the outside circuit are made inside the switch and a porcelain insulator is slipped over the joint, thus providing a straight continuous connection from the line with maximum insulation. On the 6,600 volt switch, insulation is obtained by the use of porcelain bases for supporting the live parts. In the 2,300 volt switch specially treated wooden bases are used, suitable barriers being provided between the poles where necessary to prevent arcs communicating.

Ques. What is an oil switch?

Ans. One in which the contact is broken under oil.

This type of switch is the one almost universally used on high pressure alternating current circuits, because of the fact that the oil tends to cause the current to break when at its zero value, thus preventing the heavy arcing which would occur with an air break switch, and the consequent surges in the line which are so often the cause of breakdown of the insulation of the system.

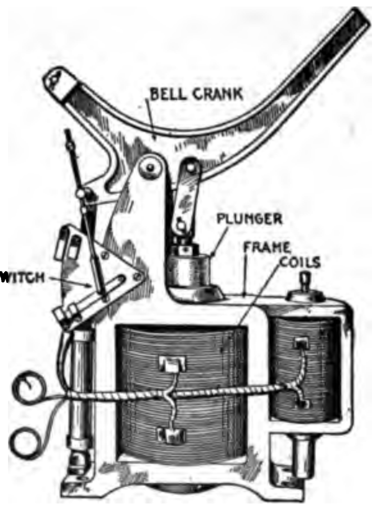


FIG. 2,227.—Kelman electric control unit for oil switch. It consists of an iron frame which contains the opening and closing coils and the bearings for the operating bell crank. A small switch on the frame automatically opens the coil circuit at the end of the stroke in either direction and operates signal lamps to indicate the open or closed position. The automatic overload release opens the switch by closing the opening coil circuit. This electrical operating unit gives satisfactory service through a wide variation of voltage. It requires a momentary expenditure of energy of from 1,500 to 4,000 watts, depending on the size.

Ques. What is the nature of an oil break?

Ans. It is not a quick break.

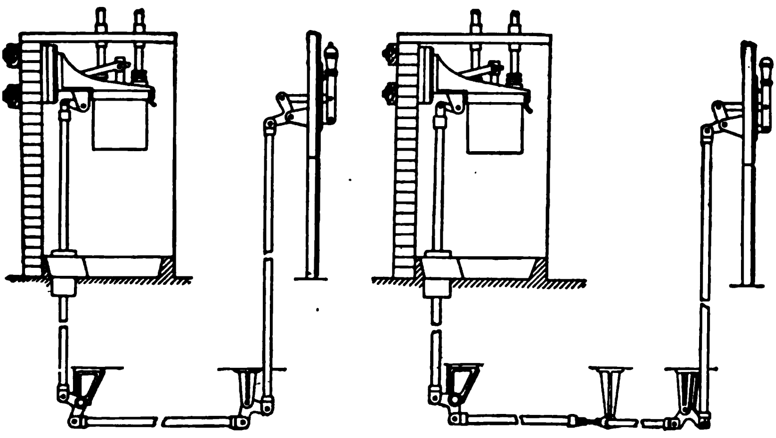
Oscillograph records show that the effect of the oil is to allow the a *to continue during* several cycles and then to break the current, usually *at the zero point* of the wave.

[redacted]

Remote Control Oil Switches.—It is desirable in the case of switches on high pressure circuits to locate the parts which carry the high pressure current at some distance from the switchboard in order that they may be operated with safety.

With respect to the manner in which the switches are operated they may be classed, as

1. Hand operated;
2. Power operated.



FIGS. 2,228 and 2,229.—Views showing mechanism of hand operated remote control switches. Fig. 2,228, straight mechanism; fig. 2,229, angular mechanism.

Ques. What kind of power is used?

Ans. Electricity is used in most cases; in some installations, switches are operated by compressed air.

Ques. For what pressures should remote control switches *be used?*

Ans. For pressures above 1,100 volts.

Ques. Describe the operating mechanism of a remote control, hand, and electrically operated switch.

Ans. For hand operation, the mechanism between the operating lever and switch proper, consists simply of a system of links and bell cranks. Various shapes of bell crank are used, to permit change in direction or position of the force applied to operate the switch.

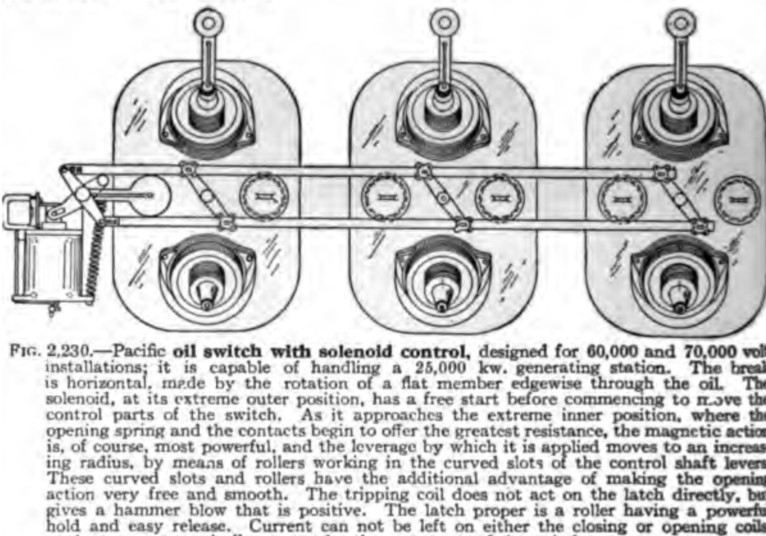


FIG. 2,230.—Pacific **oil switch with solenoid control**, designed for 60,000 and 70,000 volt installations; it is capable of handling a 25,000 kw. generating station. The break is horizontal, made by the rotation of a flat member edgewise through the oil. The solenoid, at its extreme outer position, has a free start before commencing to move the control parts of the switch. As it approaches the extreme inner position, where the opening spring and the contacts begin to offer the greatest resistance, the magnetic action is, of course, most powerful, and the leverage by which it is applied moves to an increasing radius, by means of rollers working in the curved slots of the control shaft levers. These curved slots and rollers have the additional advantage of making the opening action very free and smooth. The tripping coil does not act on the latch directly, but gives a hammer blow that is positive. The latch proper is a roller having a powerful hold and easy release. Current can not be left on either the closing or opening coils, as they are automatically cut out by the movement of the switch.

Ques. Name two classes of electrically operated remote control switch.

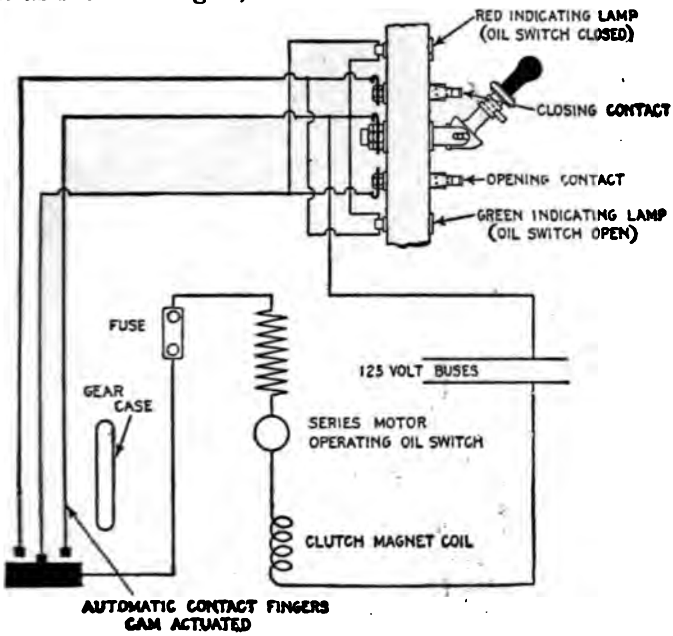
Ans. Those operated by solenoids, and those operated by motors.

The solenoid type are closed by the action of a plunger solenoid, *and opened either by* another solenoid called a "tripping coil" or by *gravity. Some* examples of remote control are shown in the accompanying illustrations.

[redacted]

Ques. What indicating devices are used with elec- lcally operated switches?

Ans. Red and green lamps; **red** for *closed* and **green** for *en* as shown in fig. 2,231.



OIL SWITCH IN CLOSED POSITION

. 2,231.—Diagram of connections of motor operated remote control switch. The motor which operates the switch is controlled by a small lever generally mounted on the panel with the instruments which are in the circuit controlled by the switch. The standard pressure for operating the motors is 125 volts.

Ques. For what service are motor operated switches ed?

Ans. For exceptionally heavy work where the kilowatt pturing capacity *is greater than* that for which the other *nes are suitable.*

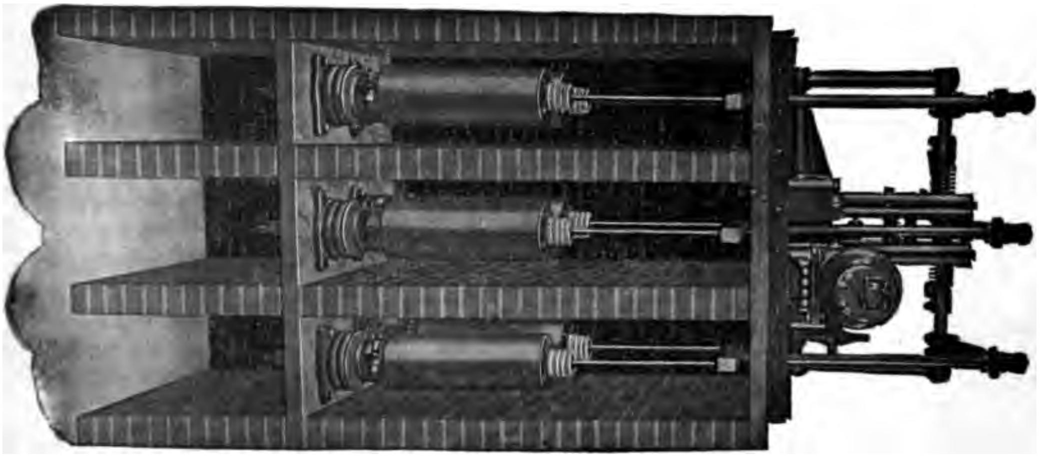
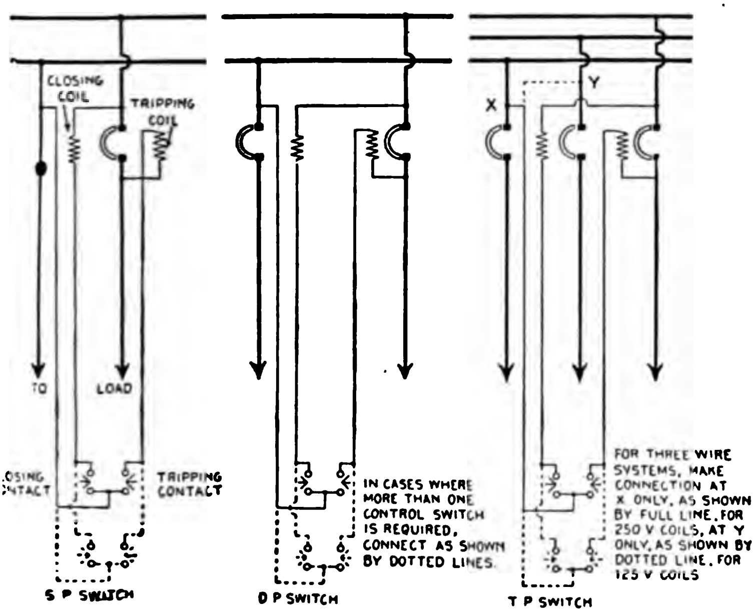


FIG. 2,232.—General Electric motor operated three phase oil switch. The operation of the oil switch is accomplished by a small hand controlling switch, generally mounted on the panel, with the instruments which are in the circuit controlled by the oil switch. The standard pressure for the operating motor is 125 volts. The switch has six breaks, each break being in a separate tank. In addition to this isolation of the breaks, each phase is enclosed in a fireproof brick compartment, making it impossible for trouble in one phase to be communicated to another. The cells are constructed of brick with top and bottom slabs of slate. The capacities of such switches, range from 2,500 to 60,000 volts, and from 100 to 1,000 amperes.

Rupturing Capacity of Oil Switches.—While an oil switch nay be designed for a given pressure and to carry a definite mount of current, it should not be understood that the switch vill necessarily rupture the amount of normal energy equivalent o its volt ampere rating.



GS. 2,233 to 2,235.—Diagrams showing connections for General Electric single, double, and triple pole, solenoid operated remote control switches. The operating coils are shown connected to main switch circuit, but may be connected to an entirely separate control circuit. Connections are the same for either alternating or direct current.

Oil switches are often used on systems with generator capacity many thousand kilowatts. It is therefore essential that the vitches shall be able to break not only their normal current, it also greatly increased current that would flow if a short *rcuit or partial short circuit occur.*

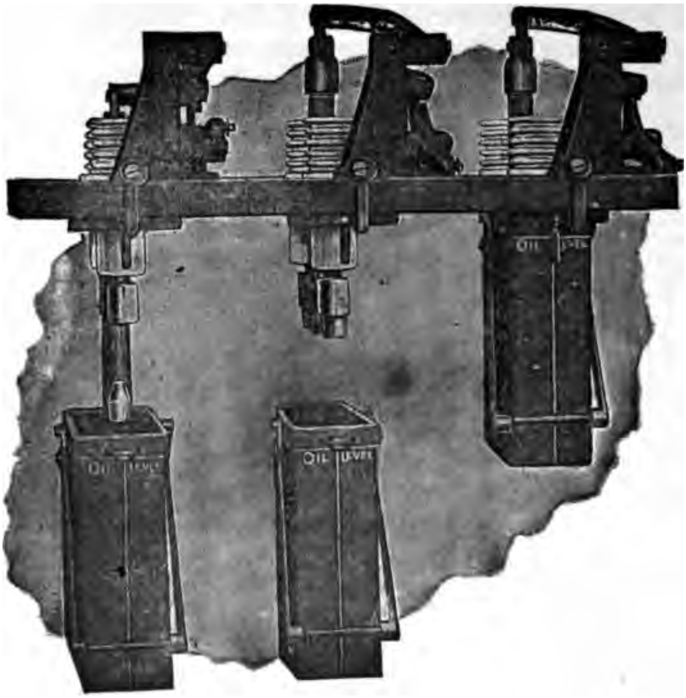


FIG. 2,236.—Westinghouse three pole hand operated remote control oil switch, adapted for the control of alternating current circuits of small and moderate capacities, the pressures of which do not exceed 25,000 volts. Each unit is installed in a separate masonry compartment. The open position of contacts is maintained by gravity. Up to and including the 600 ampere capacity, the contacts are cone shaped with an arcing tip. as shown for capacities in excess of 600 amperes, brush contacts are furnished with auxiliary arcing contacts of the butt type. Each pole has two sets of contacts, thus providing a double break in each line. With both types of contact, the final break of the arc is taken and the main contacts protected by auxiliary arcing contacts which are inexpensive and readily renewable. The upper or stationary contacts are mounted on porcelain insulators secured in the soapstone base. The lower or movable contacts are carried by a wooden rod connected to and moved vertically by the operating mechanism. The operating mechanism of the hand operated breaker consists of a simple system of levers, bell cranks, and rods. The necessary energy for making a positive contact is small owing to the use of a toggle mechanism. The leads are brought out of the top of the breaker through heavy porcelain insulators. On breakers above 3,500 volts, the connections to the line wires are made by means of a union which can be tightened with a socket wrench fitting inside the insulator. As the leads coming into the switch are necessarily insulated wire or cable, this arrangement eliminates all exposed live parts and is well adapted to making connections readily to bus bars located above or in the rear of the circuit breakers.

Under short circuit conditions alternators develop instantaneously many times their normal load current, while the sustained short circuit current is approximately two and a half to three times normal, or even higher with turbine alternators.

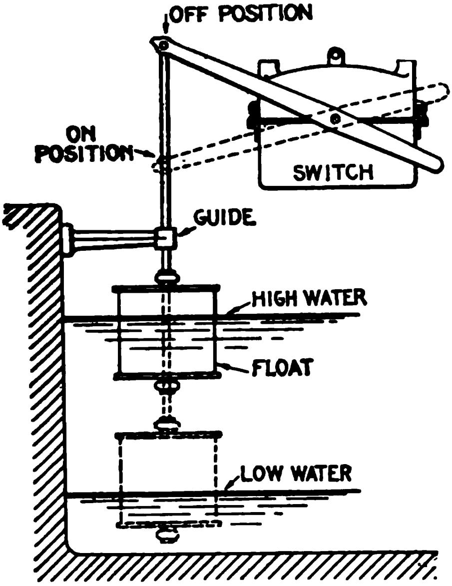


FIG. 2,237.—**Cutler Hammer enclosed float switch**, designed for the automatic control of alternating current motors operating pumps used to fill or empty tanks, sumps or other reservoirs. **The switch is operated** *by the rise and fall of a copper float which is connected to the switch lever by a brass rod or copper chain.* As the water level rises and falls, the float moves up and down. This movement is transmitted to the switch lever and the switch (if the movement be sufficient) is tripped to make or break the motor circuit. **To insure the best operation** it is necessary that the float rod be provided with a guide so that the float will move up or down in a vertical line, as shown. The minimum difference in water level at which the switch will operate is approximately 10 to 12 inches. When the float is placed in a closed tank, the minimum height inside from the bottom of the tank to the top should be at least 6 inches greater than the difference in water level to provide sufficient clearance for the float. **When this type switch is used as a tank switch,** the contacts are closed when the water level is low, putting the motor, driving the pump, in motion. When the water in the tank reaches a predetermined high level the float arm opens the switch contacts, and the motor is disconnected from the line. **For sump pump purposes,** the contacts open on low level and close on high level, the lever being reversed for this purpose. Two pole, three pole and four pole switches of this type are made, *all arranged to completely disconnect single phase, two phase and three phase motors from their circuits.* When used with small motors which may be *thrown across the line to start, the switch* may be used without a self starter if desired.

Hence, circuit breakers of the so called instantaneous type must be capable of rupturing the circuit when the current is at a maximum, whereas, non-automatic switches, or circuit breakers with time limit relays will be required to interrupt only the sustained short current circuit. The reason is evident, since the delay in opening the switch allows the current to approach the sustained short circuit conditions.

[redacted]

CHAPTER LVIII

CURRENT AND PRESSURE LIMITING DEVICES

In any electric installation there must be provided a number of automatic devices to secure proper control. The great multiplicity of devices designed for this purpose may be divided into two general classes, as

1. Current limiting;
2. Pressure limiting.

Because of the heating effect of the current which increases in proportion to the square of the strength of the current, it is necessary to protect circuits with devices which do not allow the current to exceed a predetermined value.

Accordingly fuses, circuit breakers, reactances, etc., are used, each possessing certain characteristics, which render it suitable for particular conditions of service.

For instance, just as in analogy, steam boilers must be protected against abnormal pressures by safety valves, electric circuits must be guarded against excessive voltages by pressure limiting devices, otherwise much damage would occur, such as the burning out of incandescent lamps, grounding of cables, etc.

The control of steam is simple as compared to the electric current, the latter being *the more difficult to* manage because of its peculiar *behaviour in certain respects,* especially in the case of alternating *current which necessitates* numerous devices of more or less delicate *construction for safety both to* the apparatus and the operator.

Fuses.—A fuse is "an electrical safety valve", or more specifically, *the actual wire or strip of metal in a cut out, which may be fused by an excessive current,* that is to say, by a current which exceeds a predetermined value. A fuse, thus serves to protect a circuit from any harm resulting from an undue overload.

Fuses have been treated at such length in Guide No. 2, Chapter XXV, that very little can be said here, without repetition.

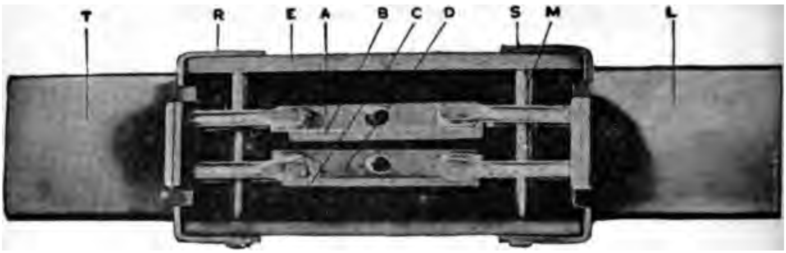


FIG. 2,238.—Sectional view of Noark 250 volt, 400 ampere **enclosed fuse.** **The fusible element** *is divided into strips* A, B, C, and D. This parallel link construction results, upon the operation of the fuse, in the formation of a number of small arcs, thus facilitating the absorption of the metal vapor formed when the fuse blows. **The fusible strips,** of which there are two or four in number, according to the ampere capacity of the fuse, are entirely surrounded by a granular material which is chemically inactive with respect to the fusible link and whose function is to absorb the metallic vapor formed upon the blowing of the fuse. **The contact blades** T and L are made of round edge copper, the round edges facilitating the insertion of the fuses in the circuit terminals. R and S are the end ferrules, attached to cover E, by the pin M.

Ques. What effect have the terminals on a fuse?

Ans. The current at which a fuse melts may be greatly changed by the size and shape of the terminals.

If near together and large, they may conduct considerable heat from the fuse thus increasing the current required to blow the fuse.

Ques. What is the objection to large fuses?

Ans. The discharge of molten metal when the fuse blows is a source of danger.

***Ques.* What should be used in place of large fuses?**

Ans. Circuit breakers.

[redacted]

Ques. What are the objections to fuses in general?

Ans. The uncertainty as to the current required to blow them; the constant expansion and contraction is liable to loosen the terminal screws when screws are used.

Ques. What is the advantage of fuses?

Ans. They form an inexpensive means of protecting small circuits.

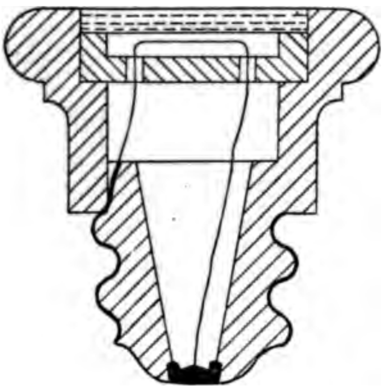


FIG. 2,239.—Cross section through plug fuse. With this type of fuse it is impossible to place any except the correct size of plug in the socket.

Ques. Describe a plug fuse.

Ans. It is constructed as shown in fig. 2,239, the fuse wire being visible and stretching between the two metal portions of the plug.

Ques. What is a cut out fuse?

Ans. One similar to a simple fuse, but provided with clip contacts as used for knife switch contacts.

The fuse wire is *usually contained in* a china or porcelain tube, which *also serves the purpose of a handle* for withdrawing the fuse.

Ques. What is an expulsion fuse?

Ans. One in which the fuse is placed in an enclosed chamber with a vent hole.

In operation, when the fuse blows, the hot air and molten metal are expelled through the vent.

Ques. What is a no arc fuse?

Ans. A cartridge type fuse, in which the space surrounding the fuse wire is filled with powdered material.

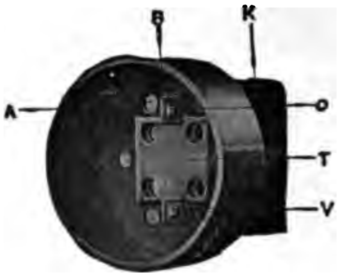


FIG. 2,240.—Inside view of end ferrule of Noark enclosed fuse. Two prongs O and V, which are a part of the knife blade K, pass through the square holes in the ends of the ferrule R, and are riveted to the anchor plate T. **The object of this plate** *is to stiffen the structure and to increase the current carrying capacity of the metal between the holes, also to permit of proper alignment of the plates.* In each ferrule is placed a **vent screen,** composed of reticulate material, such as cheese cloth. The fuzz between the threads of the cheese cloth prevents the escape of the granular material through the vent holes A, but when the fuse operates, allows free egress of the air, thereby permitting the vapor formed upon the operation of the fusible element to quickly and freely pass through the interstices of the filling material and become cooled, eliminating any possibility of flame issuing from the ends of the tube.

The object of the powdered material is to assist in extinguishing the arc formed when the fuse blows.

Ques. What is a magnetic blow out fuse?

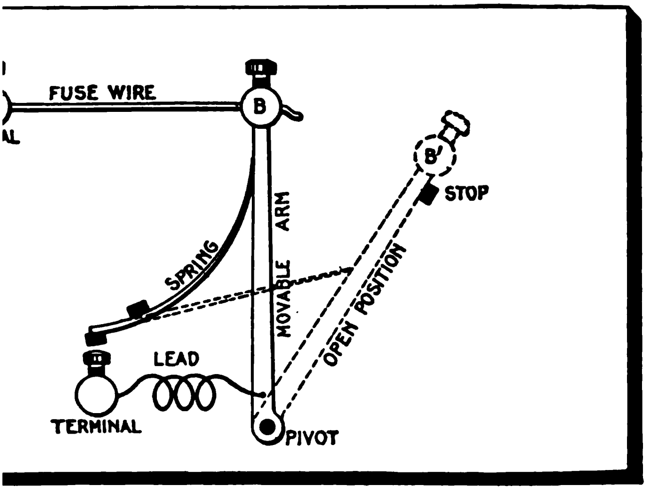
Ans. An enclosed fuse which is subject to the action of a magnetic field produced by the current, the magnetic field *tending to blow out* the arc when fusing occurs.

What is a quick break fuse?

One having a weight suspended from its center, or ttached to its ends so that the arc formed at fusing is ttenuated and extinguished.

What is the disadvantage of a fuse as compared switch circuit breaker?

When a fuse blows, the arc causes oscillations in the h cause excessive rise of pressure under certain capacity



Quick break fuse. The fuse wire is connected between the fixed terminal A novable arm B, and is held under tension by the spring which exerts pressure ovable arm in a direction tending to separate A and B. In operation, when the a, the movable arm quickly moves to the position B', thus attenuating the arc erating its extinguishment.

s, whereas this disturbance is reduced to a minimum il switch.

What metal is used for fuse wires?

Various metals. Ordinary fuse wire is made of lead or of *lead and tin.*

Ques. What is the objection to aluminum?

Ans. It becomes coated with oxide or sulphide, which acts as a tube tending to retain the metal inside and prevent rupture.

Ques. What is the objection to copper?

Ans. Its high fusing point.

Current Limiting Inductances.—The great increase in capacity of power stations, for supplying the demands of densely populated centers and large manufacturing districts, together

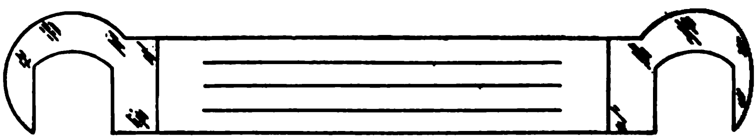


FIG. 2,242.—Notched end fuse. This is a simple form of fuse consisting of a strip of metal (*or wire*) *fixed between two end pieces to fit around the terminals.* This type is often proportioned so that it is only possible to place the correct size of fuse in the terminals. Sometimes, in place of the end pieces as shown, the fuse metal is fixed between two clamping screws.

with the decrease in the reactance of modern alternators and transformers due to improvement in design to obtain better regulation, has presented a problem in apparatus protection not contemplated in the earlier days of alternating current distribution. This problem is entirely separate and distinct from that of eliminating the tendency toward short circuit, incident to the high voltages now common in transmission lines. It accepts that all short circuits must occasionally occur and considers only the protection of the connected apparatus against *the mechanical forces* due to the magnetic stresses of such *enormous currents.*

[redacted]

Ques. What means are employed to limit the value of a short circuit current?

Ans. A current limiting inductance coil (called a *reactance*) is placed in series with the alternators or transformers.

FIG. 2,243.—General Electric current limiting reactance; view showing details of construction. The core consists of a hollow concrete cylinder, alloy anchor plates or sockets being embedded in the core near the ends to receive the radial brass bolts. An extension at each end of the core provides for clamping and bracing the reactance in installation. The supports for the winding are made of resin treated maple and are located upon the core by radial brass studs screwed into the alloy sockets, and insulated by mica tubes. The nuts by which the structure is tightened, rest upon heavy fibre washers. Wooden barriers fitted and shellaced into the supports add to the creepage surface between layers of the winding and between the winding and the core. The supports of the layer next to the core are separated from the core by strips of treated pressboard. The coil consists of bare stranded cable in several layers, usually three in number. It is wound into grooves in the treated wood supports, which are protected from contact with the cable by heat shields of asbestos shellaced into the grooves. The winding is usually in the form of two back turn sections, thereby allowing the terminals of the coil to be brought out at the ends of the outside layer. This assures accessibility and ease of connection, and the removal of the leads from proximity to the core. Two turns at each end of the winding are given extra spacing for the purpose of additional insulation. The final turn at each end of the coil is securely held in place by alloy clamps bolted to the supports. The wood is protected from contact with the clamps by shields of asbestos. The ends of the cable between the two sections are welded by the oxy-acetylene process.

Ques. What are its essential features of construction?

Ans. It consists of bare stranded cable wound around a concrete core and held in place by wooden supports as shown in *fig. 2,243.*

In order to avoid the prohibitive expense of high voltage insulation the reactance coil is designed for the low tension circuit. This requirement prohibits the use of a magnetic core which, if economically designed for normal operation, would become saturated at higher densities, or, if designed large enough to avoid saturation at short circuit conditions, would become prohibitive in cost and dimensions.

The elimination of all magnetic material from the construction of the concrete core reactance permits of no saturation, and assures a straight line voltage characteristic at all current loads.

Fig. 2,244.—Westinghouse magnetic blow out circuit breaker, designed for the protection of street railway and electric locomotive equipments; it serves the combined purpose of fuse block and canopy switch. The contact tips *are surrounded by a moulded arc chute which confines and directs the arc until the magnetic blow out extinguishes it.* The current carrying contacts consist of copper strips separated by air spaces. An auxiliary contact or "arcing tip" at the end of the switch lever takes the burning of the arc when the breaker opens, and thus confines the burning to a very small piece which can be easily removed and replaced at small cost. The hand tripping lever and the resetting lever have insulated handles, so that they can be safely handled, even in the dark.

Ques. Where is the proper location for a current limiting reactance?

Ans. As near the alternator as possible.

Ques. Why?

Ans. To lessen the possibility of a short circuit occurring etween the reactance and the alternator.

[redacted]

Ques. Beside limiting the current, what other service is performed by the reactance?

Ans. It protects the alternator from high frequency surges coming in from the outside, and limits the current from other machines on the same bus.

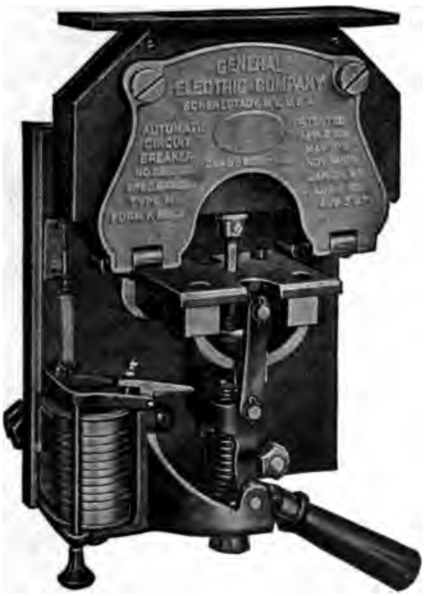


FIG. 2,245.—General Electric magnetic blow out circuit breaker. This type may be used in air or water tight boxes and is peculiarly adapted for service where the arc must be confined.

Circuit Breakers.—The importance of circuit protective devices, commonly called circuit breakers, is fully recognized. The duty of a circuit breaker is to protect the apparatus in an electrical circuit from undesirable effects arising from abnormal *conditions, by automatically* breaking the circuit. Accordingly a *circuit breaker must* comprise a switch in combination with electrical control devices designed to act under abnormal conditions in the circuit.

A circuit breaker is *a device which* **automatically** *opens the circuit in event of abnormal conditions, in the circuit.*

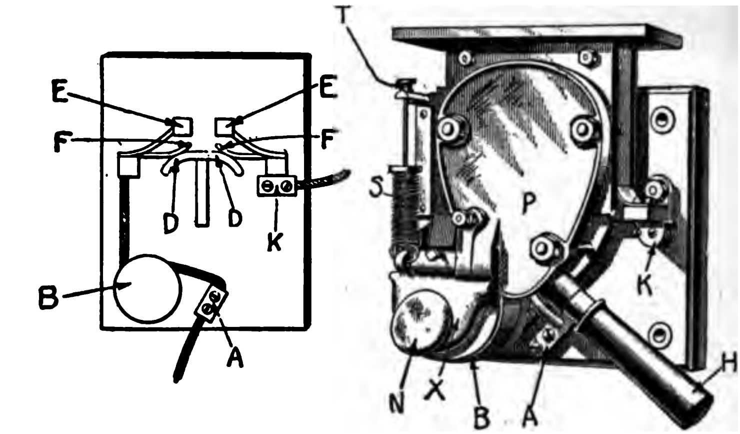


FIG. 2,246.—Magnetic blow out circuit breaker. This is a direct current breaker in which the final break occurs in a magnetic field. **It is a principle in electromagnetics** *that a conductor carrying a current in a magnetic field will tend to move in a direction at right angles to the field.* The arc set up on breaking a circuit constitutes a conductor, and in magnetic blow out circuit breakers, as generally manufactured, there is an electromagnet, energized by the current to be broken, which produces a field in the neighborhood of the arc, with the result that the arc moves outward, and so becomes attenuated and is finally extinguished. The form shown in the figure is used on cars equipped with heavy motors. When so used, it is in many cases mounted in a box with the handle H projecting at one end. A and K are the terminals of the breaker and B is the tripping coil, which also serves to set up the magnetic field necessary for blowing out the arc. X is the armature of coil B and is pulled down against the action of the spring S whenever the current exceeds that for which the breaker is set. The tripping current is adjusted by means of nut T. The iron plate P and a similar one back of it are magnetized by the current in coil B, and as the break takes place between these two poles, the arc is promptly extinguished by the field that exists there. **In operation,** A and K are the terminals, D D is a contact that is forced up against F, F when the breaker is set. The current then takes the path A-B-F-D D-F-K. **When the breaker trips,** the contact piece D D flies down and the tendency is for an arc to form between F, F; the magnetic field blows the arc upwards, and whatever burning takes place is on the contacts E, E, which are so constructed that they may be readily renewed. **To trip the breaker by hand,** the knob N is pressed.

In the design of circuit breakers, there are several methods used to effect the rupturing of the arc between contacts when *opened on heavy overload*, such as

1. Magnetic blow out; **2. Thermal break; 3. Carbon break.**

In the magnetic blow out type, the arc is extinguished between auxiliary contacts confined by a chute in which the arc is rapidly blown out due to a powerful magnetic field from one or more electromagnets. This type may be used in air or water-tight boxes and is peculiarly adapted for service where the arc must be confined.

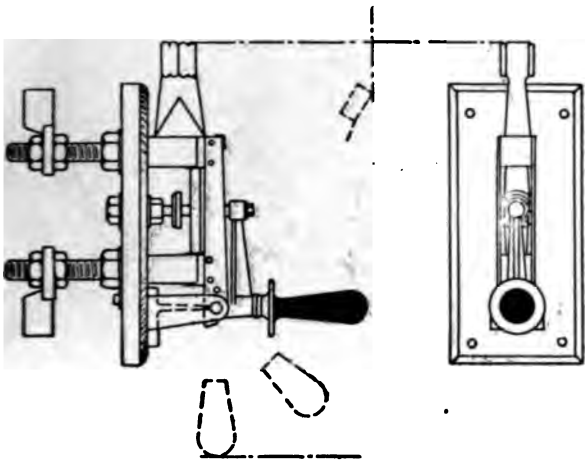


FIG. 2,247.—**Thermal overload circuit breaker.** **In construction** two contact blocks are fixed rigidly to, but insulated from, the switch arm. They are connected electrically by two parallel strips of suitable metal, each fitted with a steel catch piece. **When the switch is closed** the strips are sprung apart over a fixed catch, and the full rated current does not release the catch. Overload causes the strips to move apart, and the circuit breaker flies off under the action of a spring.

In a carbon break type, the arc is finally ruptured between carbon break contacts. The breaking of the circuit is accomplished progressively, that is to say, it is done in three stages, by several sets of contact, known respectively as

1. The main contacts;
2. The intermediate contacts;
3. The *carbon contacts.*

In operation, as the circuit breaker acts to break the circuit, first the **main** *contacts*, separate, then the **intermediate** *contacts*, and finally the **carbon** *contacts* between which the arc is ruptured.

Ques. What is the object of the intermediate contacts?

Ans. To prevent the forming of an arc on the main contacts.

FIG. 2,248.—Carbon break discs of Condit circuit breaker. The two pairs of similar discs which slide past each other are so arranged that these surfaces coincide at the instant the intermediate contact separate after which, as the contact arm opens further, they gradually disengage.

Ques. What is the object of the carbon contacts?

Ans. First to protect the intermediate contacts by providing a path for the current after the intermediate contacts separate, and 2, to "slow down" the current by means of the considerable resistance of the carbon, thus reducing to a minimum the arc which is formed when the carbon contacts separate.

[redacted]

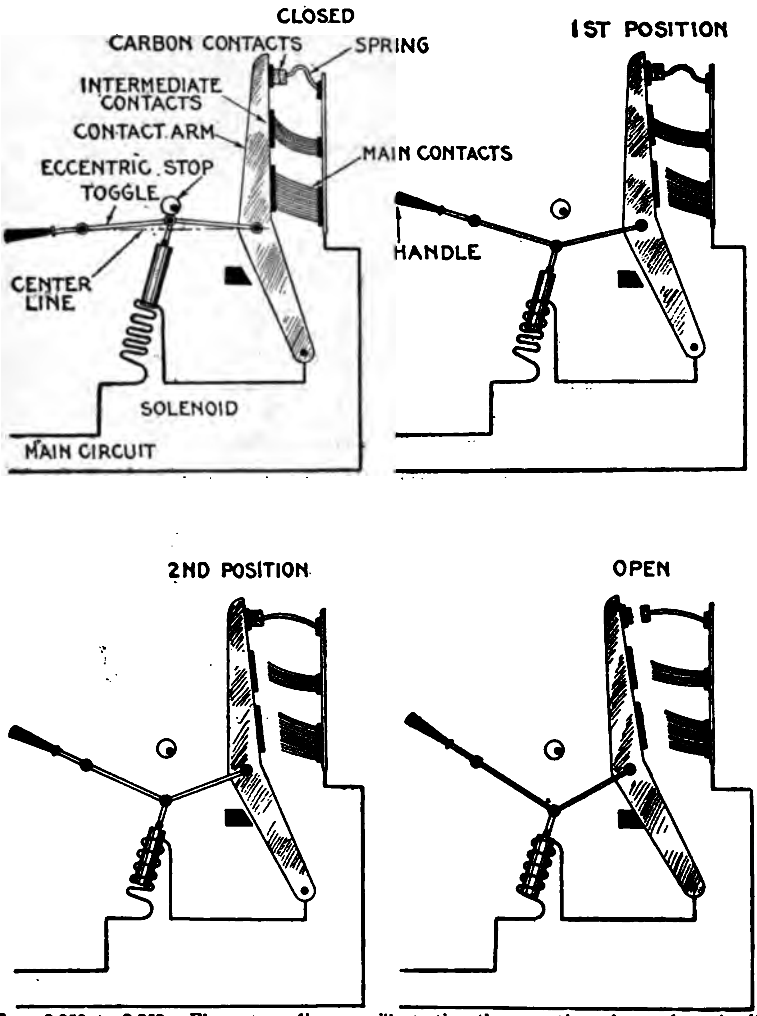
Ques. How is the automatic operation of a circuit breaker usually accomplished?

Ans. Usually through the medium of a solenoid, or electro magnet energized by current from the circuit controlled by the breaker.

IG. 2,249.—Mechanically connected insulated latches used on Condit circuit breakers to produce inter-locking tripping.

The essential features of construction and operation of a circuit breaker is shown in the elementary diagrams, figs. 2,250 to 2,253. **In construction** as shown in fig. 2,250 it consists essentially of three sets of contacts, a swinging contact arm which is set in the closed position by the handle operating through the toggle joint, the movement of which is limited in the closing direction by the stop. The latter is made adjustable by an eccentric pin or equivalent. Connected to the toggle is the plunger of the *solenoid whose winding* is energized by current from *the circuit which the circuit breaker* is to control.

[redacted]



FIGS. 2,250 to 2,253.—Elementary diagrams illustrating the operation of a carbon circuit *breaker of the overload type*, showing the progressive opening of such device. Fig. 2,250, *closed position; fig. 2,251*, main contacts open; fig. 2,252, intermediate contacts open; fig. *2,253, carbon contacts open*, circuit broken.

[redacted]

In operation, the circuit is closed by hand by turning the handle downward to the position shown in fig. 2,250, that is as far as it will go.

Since the toggle has passed the center line the arm will be held normally in this position because of the spring action of the contacts. Now, if the current rise above a pre-determined limit, the pull exerted by the solenoid will overbalance the tendency of the toggle to remain in the closed position, and pull the two toggle links downward below the center line, drawing the contact arm back and breaking the circuit.

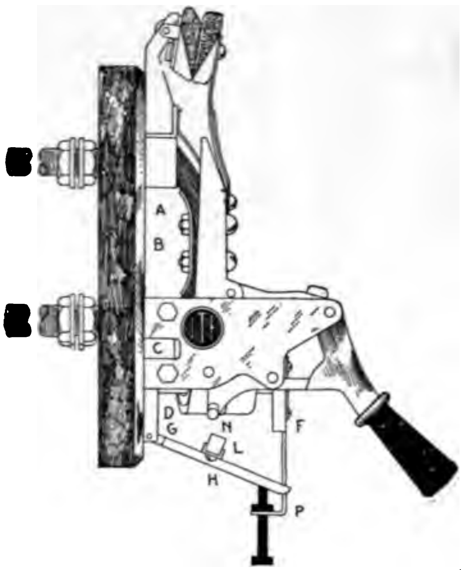


FIG. 2,254.—I-T-E overload circuit breaker. **In operation:** the current from one side of the circuit enters the circuit breaker at A, passing through the laminated bridge B to contact block C, thence through coil D and terminal E to the motor. The coil D surrounds a magnetic core, having pole pieces F and G and armature H. The effect of the current in the coil is to energize the magnet, thus tending to lift the armature against the force of gravitation. The volume of current required to trip the circuit breaker is determined by the position of the armature, which is subject to ready adjustment, and is indicated on the calibration plate P. From the opposite side of the line, the current enters at I, passing downward through the laminated bridge member J, into terminal K, whence it passes out to the motor. When the current passing through the circuit breaker attains sufficient volume, the force generated by the magnetic coil overcomes the weight of the armature H; and the latter is drawn upward toward the pole pieces with constantly increasing force, until the insulated projections L and M strike against the respective restraining latches N and O, thereby releasing the two switch members, which at once open in response to the force supplied by the spring of the contact members and auxiliary springs provided for the purpose. Positiveness in opening is further assured by the blow of the armature, which is added to the other *opening forces*; hence, the heavier the overload, the more violent the *blow and the quicker the* circuit breaker opens; or the greater the current *the more promptly it is interrupted. This is the* **I-T-E** or **Inverse Time Element principle.**

FIG. 2,255.—Condit 600 volt, 1,200 ampere, single pole, type K, circuit breaker with pull down handle.

FIG. 2,256.—Condit 600 volt, 6,000 ampere single pole, switch board mounting, circuit breaker, with pull down handle.

FIG. 2,257.—General Electric triple pole, overload, circuit breaker, with two overload coils, capacity 300 amperes, 480 volts.

[redacted]

The progressive action which takes place during this operation is shown **in figs. 2,250 to 2,253** in which the main contacts separate first, then the **intermediate,** and finally the carbon contacts as mentioned before.

Ques. What name is given to this type of circuit breaker?

Ans. It is called an overload circuit breaker.

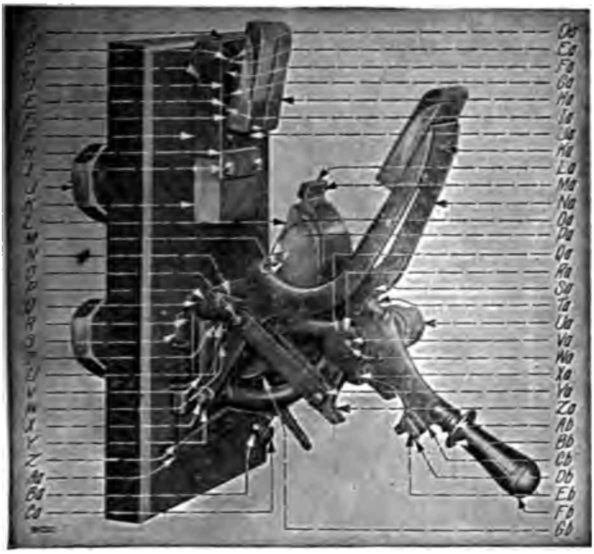
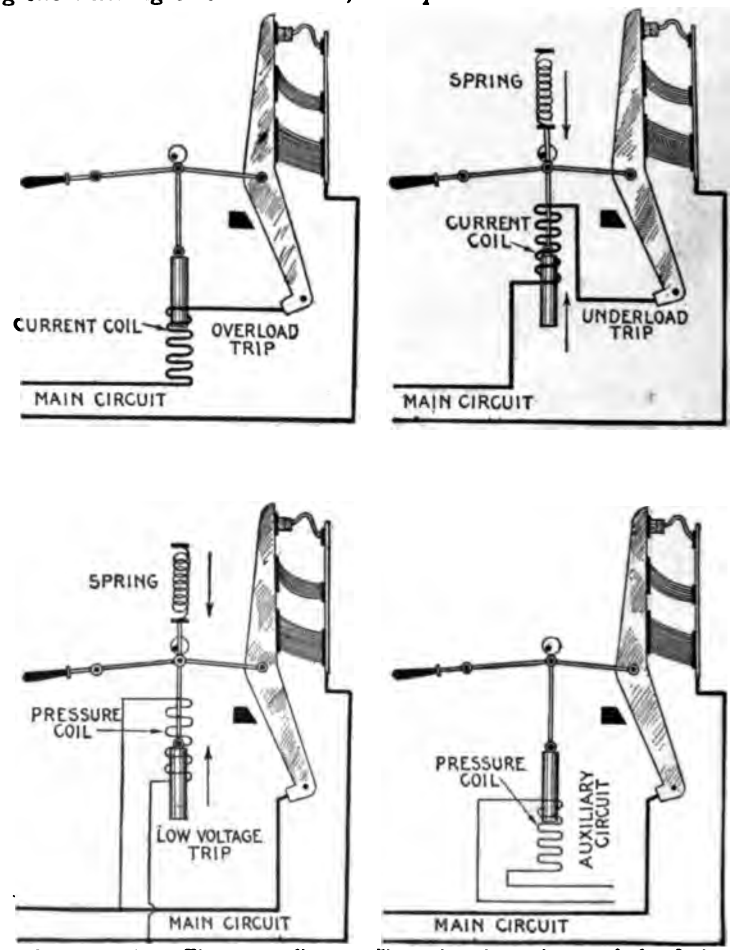


FIG. 2,255.—Parts of General Electric 2,000 ampere 650 volt circuit breaker. A, cover for secondary contact bracket; B, spring washer for Ea.; C, pin for links and G; D, spring for carbon support; E, plate for F; F, carbon support; G, secondary contact bracket; H, contact plate; I, screw for H; J, nut for K and W; K, contact stud, upper; L, laminated brush, complete with support; M, leather buffer for L; N, main link; O, pin for Na and La left hand and Cb and Na right and left hand; P, screw for N and magnet frame shaft; Q, washer for N and magnet frame shaft; R, screw for S and V; S, index plate; T, plate for Gb; U, screw for T; V, magnet frame, W, contact stud, lower; X, pin for Cb, Na and V; Y, washer for X and O; Z, calibrating screw with thumb nut; Aa, armature with contact plate; Ba, catch lever complete with catch Ca, button handle for Ba; Da, spring cotter for Ea; Ea, pin for F and Fa; Fa, operating link for G; Ga, pin for D; Ha, carbon holder with copper and carbon contacts; Ia, flexible connections for G and F; Ja, screw for G and flexible connection plate; Ka, screw for Na and Ha; La, copper secondary contact; Ma, screw for La; Na, secondary contact lever; Oa, cross bar for Na; Pa, screw for L and M; Qa, secondary toggle link (left hand); Ra, spring cotter for Wa and O; Sa, brush lever; Ta, buffer for Cb and Sa; Ua, secondary toggle link (right hand); Va, washer for Wa; Wa, pin for Cb, Qa, Ua and N; Xa, pin for Sa and Cv; Ya, spring cotter for all pins, except Wa, catch lever pin and buffer; *Za, secondary contact link; Ab,* washer for Fb; Bb, guard for Fb; Cb, *handle lever; Db, catch for Cb; Eb, screw for* Db; **Fb, handle with stud; Gb, secondary *connection.***

Automatic Features.—There are three methods of connecting the winding of the solenoid, or ***trip coil*** as it is called:



FIGS. 2,259 to 2,262.—Elementary diagrams illustrating the various methods of electromagnetic control for circuit breakers. **Fig. 2,259, overload trip; fig. 2,260, underload trip, fig. 2,261,** *low voltage trip;* **fig. 2,262, control from auxiliary circuit by means of a "relay."**

1. In series with the main circuit;
2. In shunt with the main circuit;
3. In shunt with an auxiliary circuit.

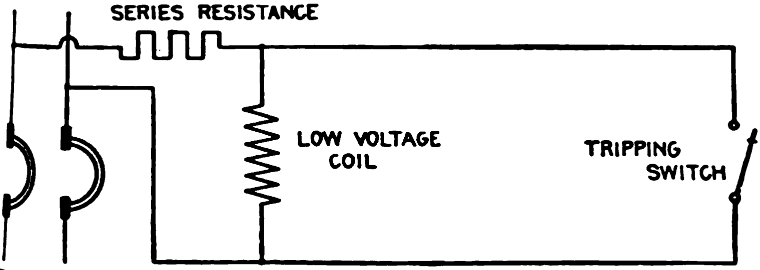


FIG. 2,263.—Diagram of General Electric low voltage trip with tripping switch *normally* open.

The automatic controls arising from these connections give various kinds of protection to the circuit and are known as

1. Overload trip;
2. Underload trip;
3. Low voltage trip;
4. Auxiliary circuit trip.

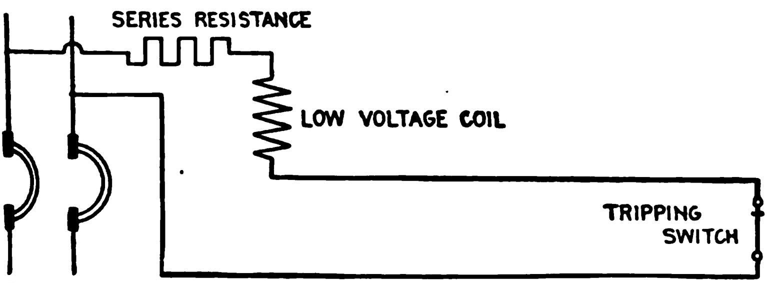


FIG. 2,264.—Diagram of General Electric low voltage trip, with tripping switch *normally* closed.

Ques. What is the object of the overload trip?

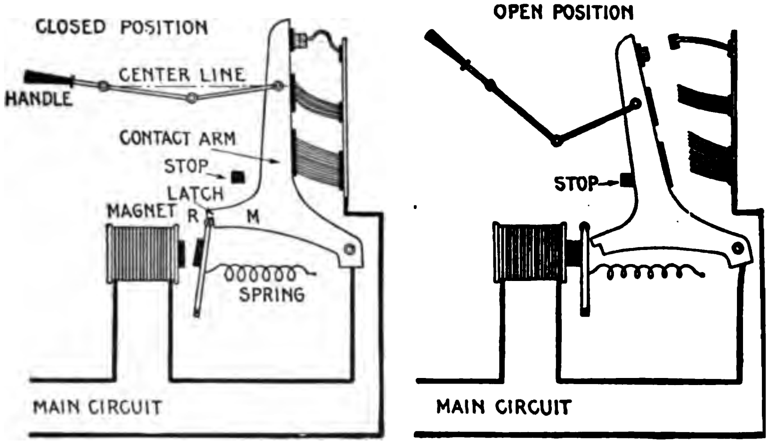
Ans. It is intended *to open the circuit when the current exceeds a predetermined value.*

Ques. What modifications are made in the mechanism shown in the elementary diagrams?

Ans. Sometimes a latch is used in place of the toggle and a magnet in place of the solenoid as in figs. 2,265 and 2,266.

Ques. Why is a magnet used in combination with a latch?

Ans. Because with this arrangement very little movement



FIGS. 2,265 and 2,266.—Circuit breaker with automatic control mechanism **consisting o magnet and latch;** views showing breaker in open and closed positions, and essenti features. The toggle is used to obtain sufficient leverage to easily close switch agains the pressure of the brush contacts but not to lock switch, this being done by the latc as shown, the latter closing by the action of a spring, there being a roller R at the en which engages the arm to reduce friction. **In operation,** when the current exceeds predetermined limit the magnet attracts the latch and releases the contact arm. Th brush contacts which are exerting pressure against the contact arm, rapidly push i away, and assisted by gravity, the arm flies open to the position shown in fig. 2,266.

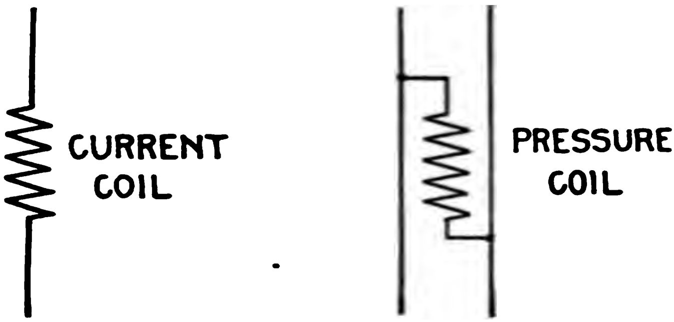
is required to trip the breaker, and for such conditions, a magnet is more efficient than a solenoid.

Ques. How does the latch arrangement work?

Ans. When the proper current is reached, the magnet pulls *open the latch* and the contact arm of the breaker moves by the *force of gravity* or other means and opens the circuit.

Ques. How does the underload trip operate?

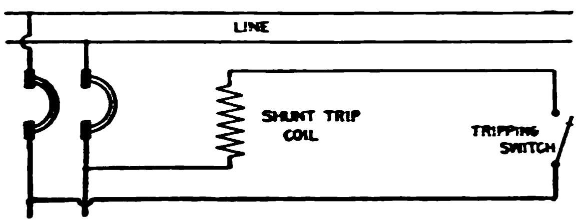
Ans. The same as the overload type except that they operate n a diminution of current instead of an excess.



ı. 2,267 and 2,268.—Positions in circuit of *current* and *pressure* coils of circuit breakers.

)ues. Describe the no voltage trip.

ıns. The energy for the trip of this breaker is derived from igh resistance or fine wire coil which is arranged to be placed



. 2,269.—Diagram of General Electric shunt trip with coil connected beyond breaker and thrown out of circuit after tripping.

rectly across the line, in operation, when the current flowing rough the circuit falls below a predetermined valve, the energy the coil is insufficient *to counteract the* force of a spring, which *en trips the breaker.*

Ques. Describe the auxiliary circuit trip.

Ans. A pressure coil is used which is energized by current from an auxiliary circuit. The coil is only *momentarily* energized,

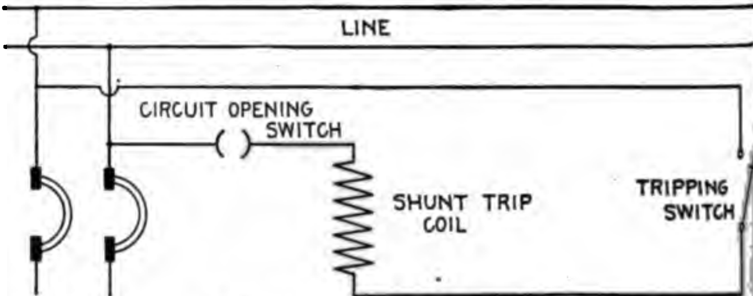


FIG. 2,270.—Diagram of General Electric shunt trip with auxiliary circuit opening, switch to throw coil out of circuit after tripping.

FIG. 2,271.—General Electric shunt trip attachment. The shunt trip attachment has been designed to provide for conditions under which the low voltage attachment cannot be successfully applied. It resembles the low voltage attachment in construction, but differs in that it trips the circuit breaker when energized. The shunt trip should be allowed to remain only momentarily in circuit; hence it should be so connected that the opening of the circuit breaker immediately disconnects it from the circuit. Whenever it is impossible to *connect the shunt trip* in this manner, the *circuit opening auxiliary* switch should be *used in connection with it.*

FIG. 2,272.—General Electric low volta attachment for circuit breakers. This lo voltage trip is designed to operate th circuit breaker when the line voltage drop to approximately 50 per cent or less of th normal voltage. It should be noted th the coil is always in circuit, as is the ca with the overload and underload coils, an that it operates with the *releasing* of it armature. It is always necessary to u a fixed amount of resistance (dependin upon the voltage of the system) in serie with the low voltage release. The lo voltage release performs the functions shunt trip coil when used in conjunc with a push button, auxiliary switc speed limiting device, and is gene preferred to the shunt trip attachm by push button, relay or other control, as distinguished from the preceding types, in which the coil is *constantly* energized.

FIG. 2,273.—**General Electric circuit opening** *auxiliary switch*. This switch opens an auxiliary circuit when the circuit breaker opens, and is intended to be used in connection with a shunt trip attachment to insure the immediate disconnection of the shunt coil from the circuit. It may also be employed to serve other purposes, such as tripping another circuit breaker having a low voltage attachment, and permitting another circuit breaker to remain closed only when the circuit breaker equipped with the auxiliary switch is open.

Ques. What other name is given to the auxiliary circuit trip?

Ans. It is sometimes called the shunt trip, though ill advisedly so.

FIG. 2,274.—**General Electric circuit closing** *auxiliary switch*. This switch closes when the circuit breaker opens, and may be used to announce the automatic opening of the circuit breaker through the means of an indicating lamp or an alarm bell. It is often necessary to arrange one circuit breaker so that, in opening, it will trip others. This may be accomplished by using a circuit closing auxiliary switch in connection with a low voltage or shunt trip attachment on the circuit breakers to be tripped. The construction of this type of switch is such that it may be opened by hand after the circuit breaker opens, but it is automatically reset when the circuit breaker is closed.

Relays.—Oil break switches and carbon break circuit breakers are commonly used to open electrical circuits at some given overload *and on short circuit*. To secure additional protection under a variety of abnormal condition or to provide for a certain pre-determined operation or sequence of operations, relays may be employed.

A relay is defined as: *A device which* **opens** *or* **closes** *an*

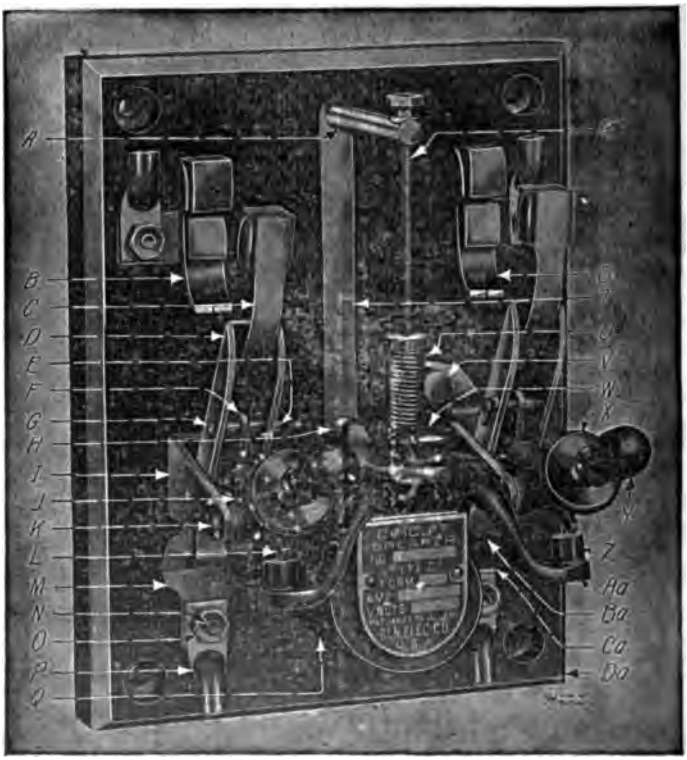


FIG. 2,275.—General Electric type C circuit breaker. Specially adapted to motor drive machine tool applications. For use in mills, machine shops, factories, foundri and office buildings. For general motor work, automobile charging outfits, storag batteries, rectifier sets, cranes, etc. List of parts: A, calibrating post; B, laminate contact; C, secondary contact spring; D, contact blade; E, cotter pin for G; F, toggle link G, pin for D and F; H, stop for Aa; I, hinge frame; J, operating lever; K, pin for I and L, toggle link; M, connection; N, screw for M, O and P; O, nut for N and P; P, termina Q, tripping coil; R, calibrating screw; S, laminated contact; T, calibrating scale; U, cal *brating spring; V, connection post*; W, knob; X, washer for Y; Y, handle; Z, buffer; A *armature; Ba, laminated* connection; Ca, connection; Da, base.

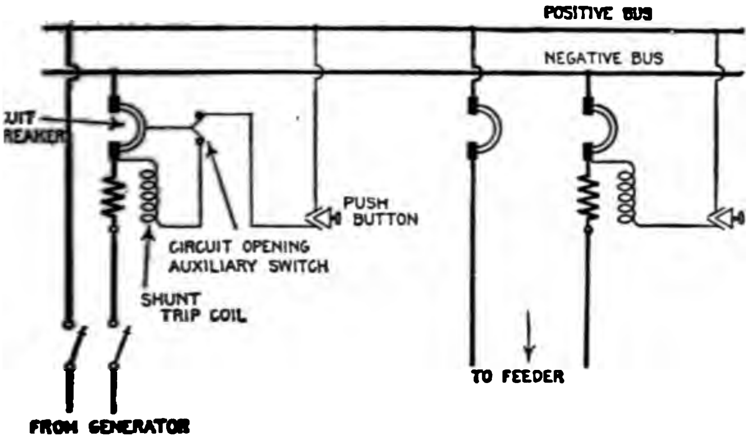
[redacted]

iliary circuit *under pre-determined electrical conditions in main circuit.*

The object of a relay is generally to act as a sort of electrical ltiplier, that is to say, *it enables a comparatively weak current ring into operation a much stronger current.*

Ques. For what service are relays largely used?

Ans. They are employed in connection with high voltage



. 2,276.—Diagram of connections of General Electric shunt trip coil with and without circuit opening auxiliary switch.

itches where the small amount of energy derived from an linary instrument transformer is insufficient for tripping.

The connections between relays and circuit opening devices are usually electrical. Combinations of this nature are extremely flexible since they permit the use of a number of devices, each having a different function, with a single circuit breaker or oil switch as well as with two or more switches, to secure the desired operation and protection.

Selection.—In all electrical installations protection of apparatus is important, but in some large central stations this is condary *to continuity of service.*

To combine maximum protection without interruptio service is not always possible, but these requirements c: approximated very closely by the use of reliable and s

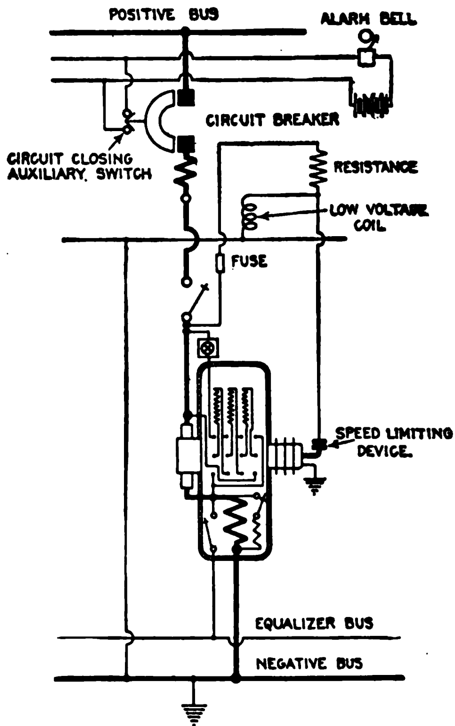


FIG. 3,073.—Diagram of connections of General Electric low voltage release coil wh with speed limiting device on rotary converter.

controlling or protecting devices if proper care be taken to the relays suited to the special conditions of the install *To do this intelligently*, a knowledge of the various tyı *relay is necessary.*

here is a multiplicity of types and a classification to be comiensive, should, as in numerous other cases, be made from ral points of view. Accordingly relays may be classified.

With respect to the nature of the service performed, as

a. Protective;
b. Regulative;
c. Communicative.

With respect to the operating current, as

a. Alternating current;
b. Direct current.

With respect to the manner of performing their function, as

a. Circuit opening;
b. Circuit closing.

With respect to the operating current circuit, as

a. Primary;
b. Secondary.

With respect to the abnormal conditions which caused ı to operate, as

a. Overload;
b. Underload;
c. Over voltage;
d. Low voltage;
e. Reverse energy;
f. Reverse phase.

With respect to the time consumed in performing their tion, as

a. Instantaneous (so called);
b. Definite time limit;
c. Inverse time limit.

7. With respect to the character of its action, as

a. Selective;
b. Differential.

8. With respect to whether it acts directly or indirectly the circuit breaker, as

a. Main;
b. Auxiliary.

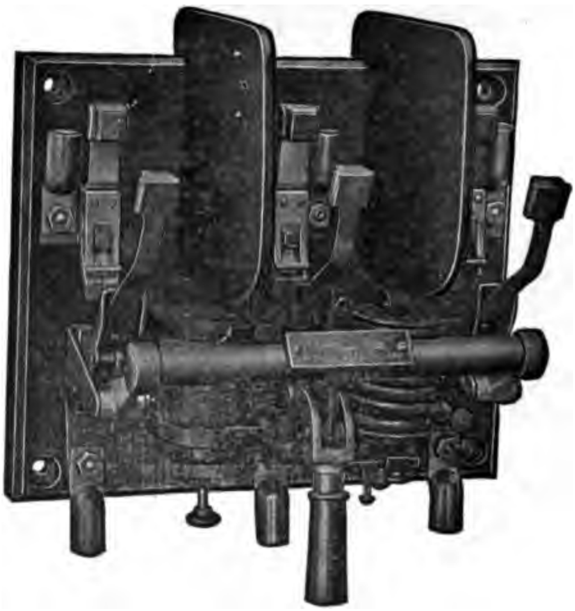


FIG. 2,278.—General Electric overload and low voltage type C circuit breaker for 600 or less. It has one overload, and one low voltage coil as shown. Screens are pro between contacts.

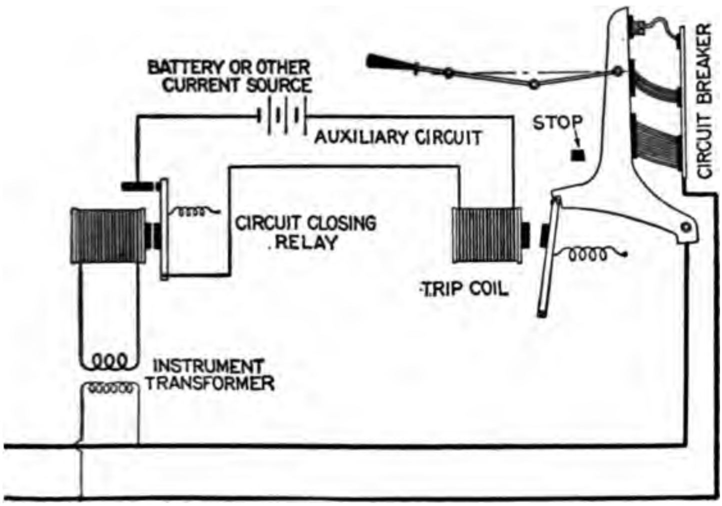
Protective Relays.—These are used to protect circuits fı abnormal conditions of voltage, or current, which would *undesirable or dangerous* to the circuit and apparatus contai *therein.*

[redacted]

Ques. How do protective relays operate?

Ans. They act in combination with automatic circuit breakers, operating when their predetermined setting has been reached, energizing the trip coil of the circuit breaker and opening the circuit.

Fig. 2,279 shows the principles of relay operation. When the current or pressure in the main circuit reaches the predetermined value at which the protective system should operate, the relay magnet attracts



2,279.—Diagram illustrating the operation ot a **circuit closing relay.** When the predetermined abnormal condition is reached in the main circuit, the relay closes the auxiliary circuit, thus energizing the trip coil and opening the breaker.

the pivoted contact arm and closes the auxiliary circuit; this permits current to flow from the current source in that circuit and energize the trip coil thus opening the main circuit.

Regulative Relays.—This class of relay is used to control the condition *of a main circuit through* control devices operated *by a secondary circuit.*

Ques. For what service are relays of this class employed?

Ans. They are used as feeder circuit or generator regulators.

Ques. How do they differ from protective relays?

Ans. They have differentially arranged contacts, that is to say, arranged for contact on either side of a central or normal position.

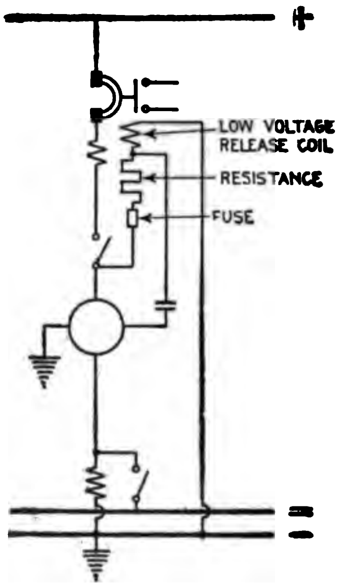
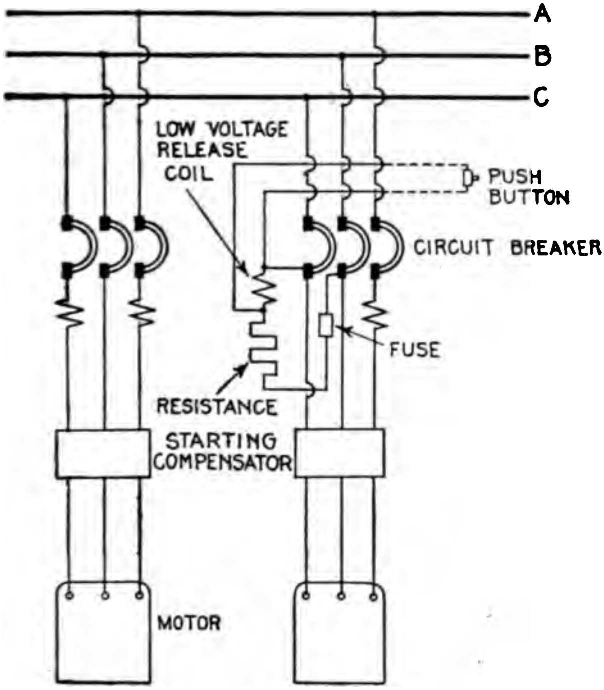


FIG. 2,280.—Diagram showing a railway synchronous converter protected by a single pole overload circuit breaker with low voltage release attachment and bell alarm switch. The low voltage attachment trips the breaker on failure of direct current voltage also when speed limit device closes. Internal troubles are taken care of by the alternating current automatic devices (not shown).

***Communicative* Relays.**—These are used for signalling in a great variety of ways for indicating the position of switching apparatus or pre-determining the condition of electric circuits.

[redacted]

A.C. and D.C. Relays.—As here used, the classification ers to the kind of current used on the auxiliary circuit. In ne cases direct current is used to energize the trip gear of the uit breaker or oil switch, and in others, alternating current.



2,281.—Diagram showing three phase motors protected by triple pole overload circuit reakers, with two overload coils, also one overload coil and low voltage release coil. The se of the low voltage release allows the breaker to be tripped from a distance by means of a short circuiting switch or push button.

.C. and D.C. relays are respectively known as *circuit ning* and *circuit closing* relays, being later fully described.

ircuit Opening Relays.—*The* duty of a circuit opening *y is to open the* **auxiliary circuit,** *usually alternating* current,

and thereby cause the oil switch or circuit breaker to be opened by the use of a trip coil in the secondary of a current transformer, or by low *voltage release coil.*

The trip coil of the breaker is generally shunted by the relay contacts and when the moving contact of the relay disengages from the sta-

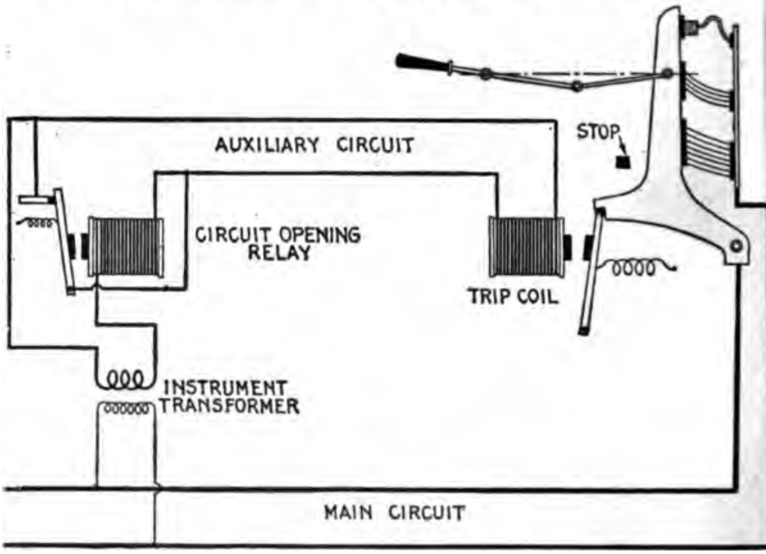


FIG. 2,282.—Diagram illustrating the operation of a **circuit opening relay.** When the relay contacts are in the normal closed position, as shown, the coil is short circuited. When the predetermined abnormal condition is reached in the main circuit, the relay contacts are opened with a quick break, sending the current through the trip coil momentarily, and opening the breaker.

tionary contact, the current from the transformer which supplies the relay, flows through the trip coil thus opening the breaker. These features of operation are shown in fig. 2,282.

Ques. Where are circuit opening relays chiefly employed?

Ans. In places where direct current is not available for *energizing the trip* coil.

[redacted]

ues. What is the objection to alternating current coils?

ns. They have relatively high impedance and impose a y volt ampere load on the transformers.

ircuit Closing Relays.—The duty of a circuit closing r is to close the auxiliary circuit at the time when the pre-rmined abnormal condition is reached in the primary iit. The closing of the auxiliary circuit energizes the trip and opens the breaker.

2,283 to **2,291.**—General Electric instantaneous overload **circuit opening** relays, covers moved. Circuit opening relays are used chiefly in those cases where direct current for e tripping circuit is not available. Alternating current trip coils have relatively high npedance and impose a heavy volt ampere load on the current transformers. To reduce is load during normal operation the circuit opening relay is frequently used and is sually necessary where instruments and meters are to be operated on the same current ansformers as the trip coils if the greatest accuracy be required. The relay contacts i the normal, closed position, short circuits the trip coil. When the relay operates on verload or other abnormal condition the contacts are opened with a quick break, sending the current through the trip coil circuit momentarily and tripping the switch. With ircuit opening relays, the trip coils of the oil switch must be set to trip somewhat lower han the setting of the relay. **In construction** the relay consists of a solenoid with iron ame forming the support for the relay; a central plunger or armature of special construction which is picked up or released by the magnetic action of the solenoid; a plunger od which actuates the relay contacts, which are mounted on an insulated base usually bove the soleniod; a tube or plate for the calibration marking and adjustment; covers f glass or metal to keep out dust; terminal boards with points corresponding to tagged ads from relay coils and external wiring diagrams. The relay contacts are of two kinds, ircuit opening, as shown above, and circuit closing, as shown in figs. 2,292 to 2,300.

ues. What kind of current is generally used for the iliary circuit of a circuit *closing* relay?

s. ***Direct current.***

Ques. At what pressure?

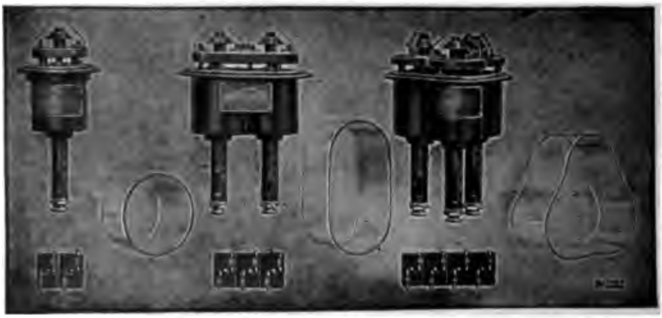
Ans. From 125 to 250 volts.

Ques. Where is this current usually obtained?

Ans. From a storage battery, or from the exciter.

Ques. For what current are the contacts ordinarily designed?

Ans. About 10 amperes.



FIGS. 2,292 to 2,300.—General Electric alternating current instantaneous overload circuit closing relays, covers removed. The function of a circuit closing relay is to close an electrical circuit, usually direct current, through a trip coil on an oil switch or circuit breaker, or it may short circuit a low voltage release coil, and thereby open the oil switch of circuit breaker on occurrence of the condition upon which the relay is designed to operate. Direct current at 125 or 250 volts taken from exciter bus bars or storage battery system is generally used for the tripping circuit. Circuit closing contacts have a cone shaped central element of carbon or metal which makes contact with flexible contact fingers symmetrically arranged above the cone. These contacts will make and break a circuit of 10 amperes at 125 volts without the use of auxiliary circuit opening switches. Relays are made with two or three contacts for connecting one side of a direct current circuit through one or two separate circuits, or trip coils respectively, to the side of opposite polarity. Usually only two contacts are required. Where two or more trip coils are used, which may not be connected permanently in parallel, the three contact relays are selected and in some cases four contacts furnished.

Primary and Secondary Relays.—Primary relays are sometimes called series, relays as they have the current coils connected directly in series with the line, both on high and low tension circuits.

Secondary relays receive their current supply from the secondary circuits of current transformers. Alternating current

[redacted]

ys connected to secondary of pressure transformers and ys with both current and pressure windings are included his class.

)ues. What is the usual winding of the coils?

ıns. The current coils are usually wound for 5 amperes and pressure coils for 110 volts.

c. 2,301.—Alternating current low voltage circuit closing low voltage relay, for 600 volts or less. The contacts are similar to those of the circuit closing overload type except that they are inverted. As long as the pressure is normal the contact cone is held above the contacts. When the pressure falls below one half normal, the cone and plunger rod drop and close the contact. This relay does not pick up its own plunger. The plunger rod is pushed up by hand after the pressure circuit is established. Low voltage relays are generally used in connection with a low voltage release or shunt trip coil on an oil switch or a circuit breaker. They are used in connection with motor booster sets to prevent a disastrous speed of the booster which might result from the loss of alternating current power. They are also sometimes used for indicating purposes.

Ques. What refinement is made in the design of relays and why?

Ans. Care is exercised to reduce to a minimum the volt ampere load imposed by the relay on the current transformer to permit the use of unstranded meters and relays upon the same transformer.

The use of circuit opening relays to cut out the trip coil of an oil switch during normal operation, has been described, and in the short time that the trip coil is in circuit, it does not affect the accuracy of the instrument readings. This practice, however, does not apply in the case of curve drawing meters, voltage compensators or other which have in themselves sufficient load for separate curren formers. In this connection it should be noted that to obtain a

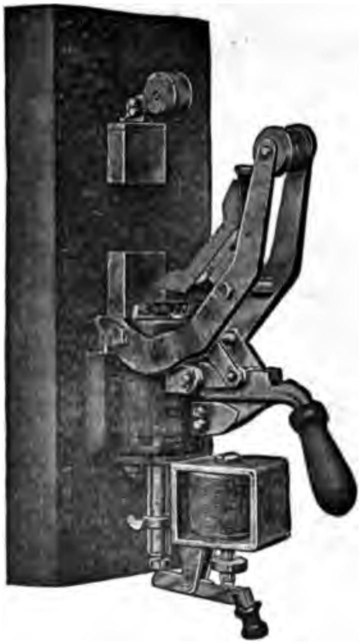


FIG. 2,302.—Condit type K circuit breaker with shunt trip and no voltage attachr **shunt trip** is usually applied as an auxiliary to other types of trip. It consists of coil which is mounted as a self-contained part of the breaker and which when trips the circuit breaker. It is used to open the breaker from some distant poi coil is arranged to be connected across the line. The coils are so arranged that breakers will operate on a voltage 25% above or 25% below normal. The shu is not intended to remain across the line and should be only momentarily energi **no voltage trip**, receives energy from a high resistance or fine wire coil which is a be placed directly across the line, but in contradistinction to the shunt trip type, in coil is *momentarily* energized to trip the breaker, the no voltage coil is *constantl* and a *decrease* or failure of pressure trips the breaker. It can be used as a rem device the same as the shunt trip. Its general use, however, is to cause the circ to open when the voltage of the line fails from any cause. Its use is recomme motor circuits, as it affords an additional protection against accidents, for if t should fail, the breaker immediately opens, and before the machine can start attendant must close the breaker. It will not work for the protection of storag or of motor generator sets charging storage batteries, as, when the voltage of th fails, the voltage of the battery still maintains its full value. The action of the *pendent of the direction* of flow of current; it simply allows the breaker to sta *long as the voltage is* on the line and opens the breaker when the voltage on the *No voltage circuit* **breakers are normally so adjusted that they will not releas** ***voltage approaches 50% of normal.***

instrument and meter readings; the current transformers should not be loaded beyond certain limits which depend upon the volt ampere load and power factor of each of the connected devices.

So great is the variety of combination used and the variations of these factors in their several combinations at different loads and settings, that special consideration of each arrangement is advisable.

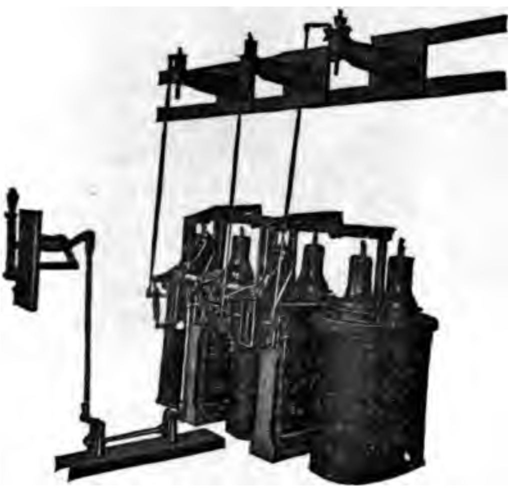


FIG. 2,303.—General Electric alternating current **high pressure** series overload relays controlling 45,000 volt oil switches. These relays are connected in series with the line. If current transformers are to be used on the same circuit for other purposes, and have sufficient capacity to supply energy for operating relay coils, then secondary relays would be more economical, otherwise the series relays are much less expensive. By means of a specially treated wooden rod, the relay operates a tripping switch, closing a separate tripping circuit, usually 125 or 250 volts direct current. Relays and switches are for mounting on flat surfaces. Series relays are essentially the same as secondary relays except in the coil winding and insulation. The corrugated horizontal arms which carry the relays, as shown, are insulated posts, insulating the relays from the ground. The wood rod from each relay is connected directly to a tripping shaft on the oil switch which buckles an auxiliary toggle, thereby opening the main toggle and tripping the oil switch.

Overload Relays.—Series relays are connected directly in series with the line and are chiefly used with high pressure oil break switches for overload protection. If current transformers are to be used on the *same circuits* for other purposes, and have *sufficient capacity to admit* of adding a relay coil, secondary

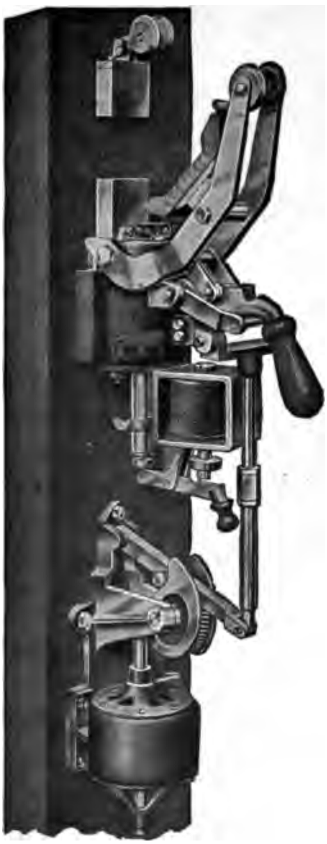


FIG. 2,304.—Condit 600 volt, 1,500 ampere single pole back connected type **motor operated.** The mechanical and electrical features of the circuit bre ent than when hand operated, the only difference being that the motor is u ing means. This motor is so arranged that even should it over travel, d to the controlling circuit, it cannot produce more than a pre-determinec cuit breaker. In other words, after the motor has closed the circuit travel of the motor will not result in putting a strain on the operatin motors are supplied for this service, the type of motor varying in ac character of the operating current supplied. The advantage of this operation is that it puts very little strain on the switch mechanism, take *ting current, allows* the use of standard parts, and makes an extremel *flexible structure.* ***Its disadvantage is that it closes slowly, and it m be used in places where quick closing is essential.***

relays would be more otherwise, the series re expensive.

By means of a spec wooden rod, the rela tripping switch, closing tripping circuit, usuall volts direct current. are essentially the sam ary relays except in tl ing and insulation.

Underload Relays. similar in construction age relays but have cu of pressure windings.

Over Voltage Rel are usually of the ci type and are similar t overload relays, but h instead of current winc

Low Voltage Rela of this class are in mos

[redacted]

protection of motors in the event of a temporary weakening e of the pressure. They are also used in connection with oltage release or shunt trip coil on an oil switch or a reaker.

se Energy Relays.—The chief object of this species of to protect the generator. When so used, the overload

.—General Electric direct current solenoid control relay. Solenoids for operating switches, etc., frequently require comparatively large operating currents in the ng" coils. This necessitates the use of relatively heavy leads between the control and the solenoid and is the cause of severe arcing at the control switch, especially olenoids of high inductance. These objectionable features can best be eliminated use of a suitable control relay located near the solenoids. The control relay con- f a solenoid plunger and switch, the latter insulated from the frame of the relay. rates satisfactorily on one-half the rated voltage and requires only a very small ing current. The terminals of the switch and the relay coils are independent. The can be wound for operation on 125, 250, or 600 volt circuits.

nent is set at the maximum value to give overload pro- only at the maximum carrying capacity of the generator sensitive reverse *protection* to prevent a return of energy *e line.*

Reverse Phase Relays.—This type of relay is used to prevent damage in case of reversal of leads in re-cor wiring to two or three phase motors.

Time Element.—It is often inconvenient that a breaker should be opened immediately on the occurr what may prove to be merely a momentary overload, time lag attachments are frequently provided, particula

FIG. 2,306.—Alternating current series reverse phase single pole, circuit closing, t relay for 600 volts or less. This type of relay is used chiefly to open motor elevators to prevent damage in case of reversal of leads in reconnecting wi or three phase motors. The relay is provided with a dust proof metal cover.

relays. These devices, which may form part of the ı may be quite distinct from it, retard its action until the c has lasted for a pre-determined time—several seconds or

Ques. What should preferably govern the tin

Ans. It should depend on the extent to which the ove *reduced as the time* elapses.

Instantaneous Relays.—The so called instantaneous relays operate almost instantly on the occurrence of the abnormal condition that they are to control.

There is of course a slight time element comparable with that of an overload circuit breaker, but for practical purposes, the operation may be considered as instantaneous.

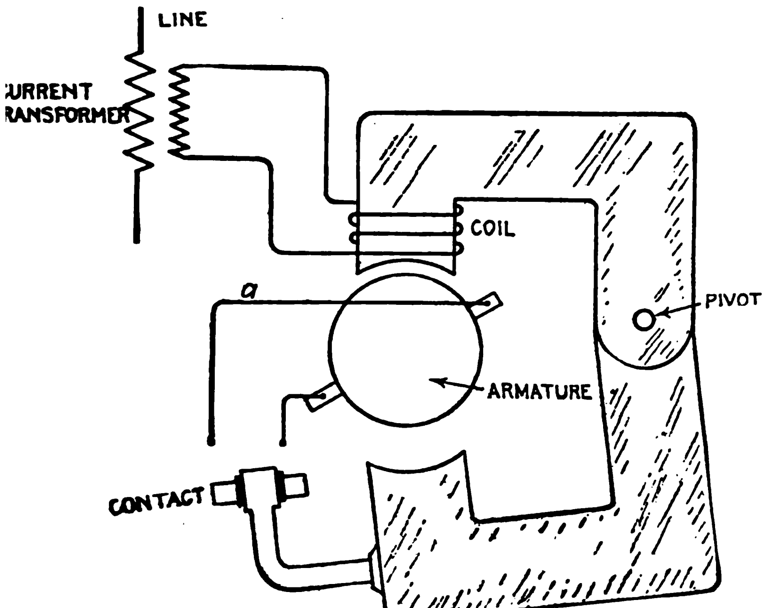


FIG. 2,307.—Electric circuits of Condit type "A" relay. The construction is described in fig. 2,309. As here shown, the relay is not in operation, but should the current passing through the coil be of sufficient value to cause the lower movable half of the magnetic circuit to approach the upper stationary half of the circuit, *the relay will be transformed from an ordinary* **electromagnet** *into a* **repulsion motor.** The contact will short circuit the brushes of the armature and thus cause it to revolve, the speed of rotation being dependent on the amount of current flowing to a predetermined point, and thereafter the speed of rotation of the motor remains constant irrespective of the current value. **Time adjustment:** This is obtained by varying the distance through which the contact travels, provision being made whereby adjustment can be made as close as .1 of a second. **Current adjustment:** This is obtained by means of a calibrated spring. Standard relays are calibrated at 6, 8, 10, and 12 amperes, the coils being designed to carry five amperes continuously, with a temperature *rise not exceeding* 86° Fahr. **Power to operate relay:** The relay *requires twenty volt amperes for its* operation at full load; the influence of this *type of relay on the ratio and phase angle* of current transformers is small.

Time Limit Relays.—Under this classification there are two sub-divisions.

1. Definite time limit;
2. Inverse time limit.

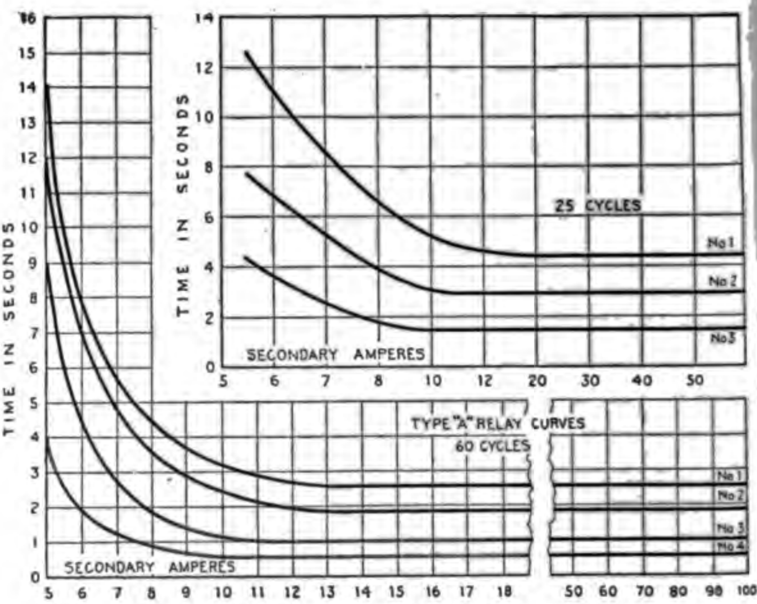


FIG. 2,308.—Characteristic curves of Condit type A selective relay. Curves 1, 2, 3, and 4 show the time variation of this relay with different settings at the various current values. The relay may be adjusted to trip the switch at any point represented between curves 1 and 4. This relay is a combination of an *inverse time limit* relay and a *definite time limit* relay. The combination of the characteristics of the two types are seen in the curve, the first part of which is **inverse,** and the latter part **definite** from a point of three or four times full load current. This combination of features being desirable as, for instance, in transmission work, particularly where it is necessary to use circuit breakers set selectively, as, due to the inverse feature of the curve, the relays can be set so that on a moderate overload, they will require the proper length of time to operate, and at the *same time will operate* quickly enough on heavy short circuits to prevent damage to *the distribution system* or its apparatus. Due to the definite feature of the latter part *of the curve, the* relays of the varying circuit breakers when once set to operate at different time values will never operate simultaneously irrespective of the value of the short circuit current, thus tending toward continuity of service.

[redacted]

Ques. Describe the time mechanism of a definite time limit relay.

Ans. It consists of an air dash pot, and an air diaphragm or equivalent retarding device connected to the contact mechanism.

Ques. How does it operate?

Ans. In some designs, when the contacts are released, they descend by gravity against the action of the retarding device

FIG. 2,309.—Condit type "A" **selective relay**, designed for use with circuit breakers where selective or discriminating action is required. The circuits and connections of this relay are illustrated in fig. 2,307, and its characteristics in fig. 2,308. **In construction**, the relay consists of *a special motor with a short circuited armature and a split field*. **Under normal conditions**, the fields are separated from each other and the motor armature does not revolve. The force tending to pull the two faces of the field together is opposed by a spring, the compression of which determines the number of amperes necessary to cause the relay to begin operation. The motor structure performs the whole work and the motor itself unmeshes and meshes the gears without the aid of any external device.

thereby making contact a definite interval after the occurrence of the abnormal condition.

Ques. How does the inverse time limit type operate?

Ans. The *actuating and contact* mechanism is attached directly to an air bellows and in operation tends to compress bellows against the action of a specially constructed esc valve in the latter.

Ques. Why is the arrangement called *inverse* time lim

Ans. Because the retardation varies inversely with

FIG. 2,310.—Condit type "B" **time limit attachment**, designed to give sufficient tim allow an induction motor to start without opening the circuit breaker, and not have circuit breaker trip on the momentary rush of current. **Its action is inverse; tha** *the greater the current the less time it takes to operate* and is so arranged that four to times full load current or a short circuit will trip the circuit breaker instantly. time limit attachment is applied directly to the armature which trips the circuit bre and is adapted for the so called primary trip. It consists of an air vacuum dash with a graphite piston, the dash pot being fastened to the stationary calibrating of the trip coil and the moving outside cylinder is fastened to the armature of the cuit breaker. When the current reaches a point where it overcomes the weight of armature and lifts the same, the magnetic force tending to raise the armature is opp by the vacuum created in the interior of the cylinder. As the magnetic force conti *the vacuum is overcome* due to the leakage of air past the plunger and the arm *gradually moves up until it* reaches the point where it trips the circuit breaker. *any point of the armature* travel, the current drop back to normal, the armature i *diately resets itself* by means of a ball valve in the top of the brass cylinder

[redacted]

ssure on the bellows, and therefore inversely with the magnide of the abnormal condition.

ues. What other device may be used to retard the ration?

ns. A damping magnet is sometimes used which acts on a or drum and which may be adjustable.

s. 2.311 and 2.312.—General Electric alternating current low pressure series overload relays. Fig. 2.311, instantaneous time limit relay; fig. 2.312, inverse time limit relay. These relays have carbon contacts and will make or break a direct current circuit of 10 amperes at 125 volts without auxiliary circuit opening switch. They are used where several circuits are controlled by one automatic oil break switch or one shunt trip, overload and shunt trip or low voltage release carbon break circuit breaker. These relays may be used for signal purposes; they are back connected, the connections can be seen in the illustrations.

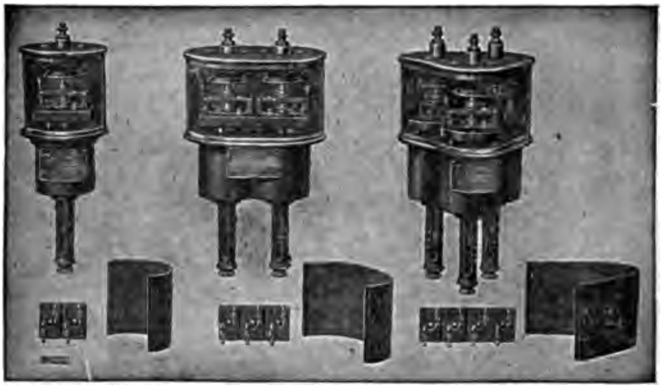
Ques. How is the inverse time element introduced this arrangement?

Ans. The retardation is due to eddy currents induced by ving the disc or drum through the magnetic field. The ction *thus induced varies inversely* with the magnitude of

the force with which the disc or drum is urged through the fi
and hence inversely with the abnormal condition.

Ques. What are the ordinary limits of adjustme for inverse time limit relays?

Ans. From one-half second to 30 seconds, depending up the time setting and magnitude of the overload current.



FIGS. 2,313 to 2,321.—General Electric time limit overload circuit opening relays with co removed. The construction of this relay is similar to that of the inverse time limit re except that it has a compression spring interposed between the plunger and diaphra The plunger compresses the spring and further motion is prevented by a stop, mal the relay practically independent of the amount of the overload, only the stored en of the spring, if the overload continue, applies power, dependent on its own mechan strength, to the diaphragm. The time limit therefore becomes practically a const for any given setting under ordinary conditions of overload or short circuit. If, h ever, the overload come on slowly so that the spring is not fully compressed at once, time limit will vary slightly. If the scheme of selective operation make it necessary take care of a creeping load of this character, two relays may be used and definite t limit positively secured. In this case, an instantaneous circuit closing, overload re would be used and a definite time limit relay, provided with a direct current coil in cuit with the closing contacts of the first relay. The time limit relay would be of circuit closing type and control a direct current trip coil on the oil switch.

A setting of from two to six seconds is ordinarily used, dependi upon the requirements. Where selective operation is desired a minimu setting of two seconds is recommended.

Differential Relays.—In this type of relay there are tw electromagnets. In normal working these oppose and neutrali *each other. Should,* however, either winding become strong

[redacted]

or weaker than the other, the balance is upset, the magnet energized, and the relay comes into operation.

A modification of such a relay for alternating current is shown in fig. 2,322, from which it will be seen that when the

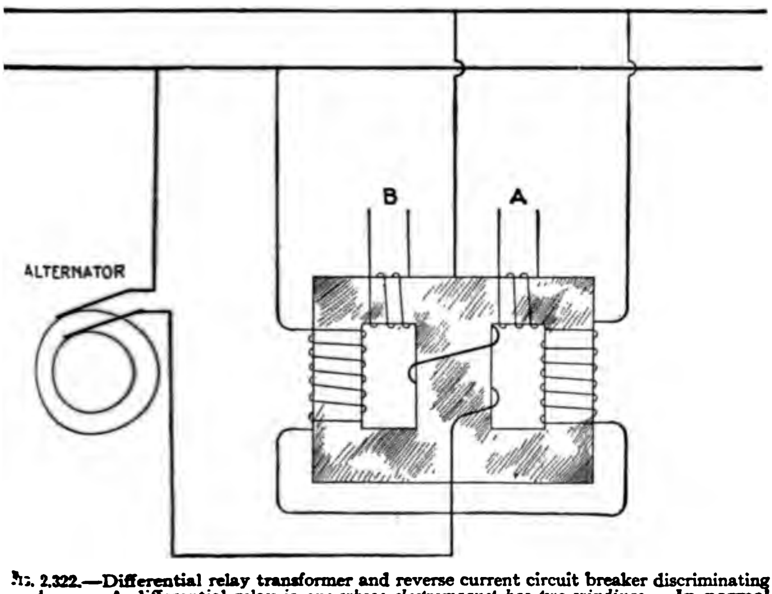


FIG. 2,322.—**Differential relay transformer and reverse current circuit breaker discriminating device.** A differential relay is *one whose electromagnet has two windings*. **In normal working** *these oppose and neutralize one another*. Should, however, either winding become stronger or weaker than the other, the balance is upset, the magnet is energized, and the relay comes into operation. A modification of such a relay for alternating current is here shown, from which it will be seen that when the currents are as indicated, the circuit A has the larger pressure induced in it, whereas, should the main current reverse with reference to the shunt current, the circuit B would have the larger induced pressure.

currents are as indicated, the circuit A has the larger pressure induced in it, whereas, should the main current reverse with reference to the shunt current, the circuit B would have the larger induced pressure.

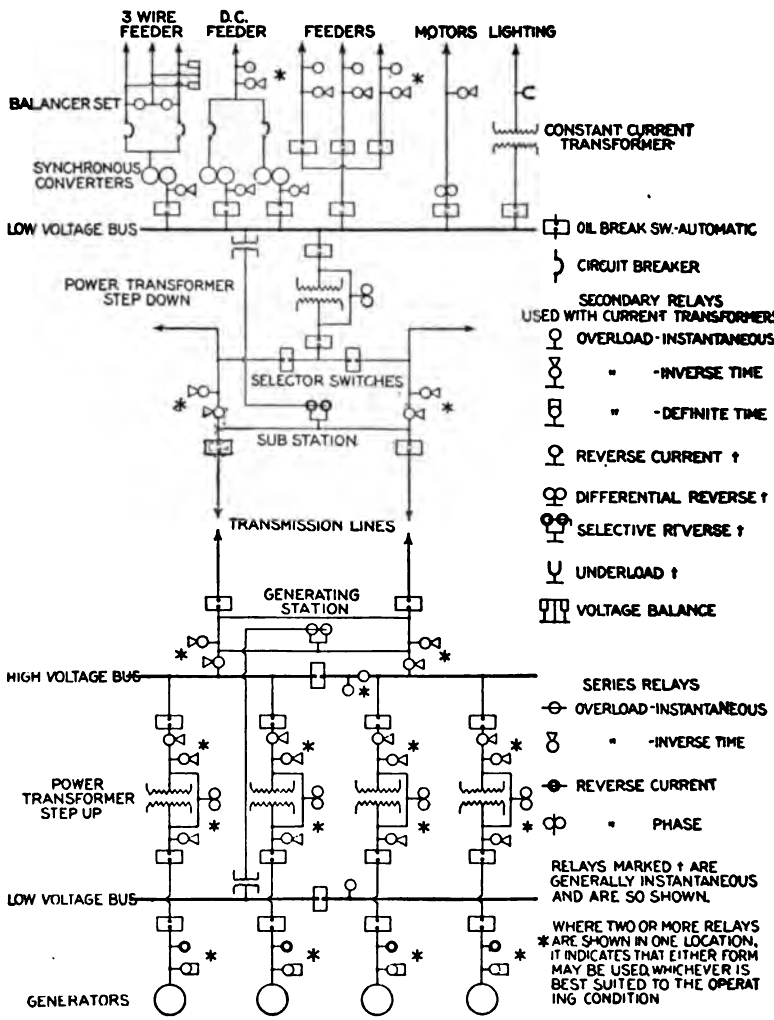


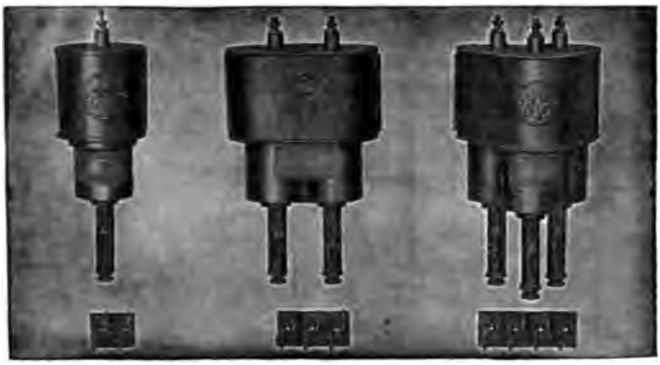
FIG. 2,323.—Diagram of modern power house wiring and busses showing location of relays.

[redacted]

How to Select Relays.—The following general information relays, together with reference to the one line diagram, 2,323, will be of interest and assistance in making a selection m the various relays previously described to meet the require-nts of modern power house and sub-station layouts.

Single pole relays are used on single phase and on balanced three phase circuits.

Double pole relays are used on ungrounded three phase and on quarter phase.



G. 2,324 to 2,329.—General Electric inverse time limit overload circuit closing relays. In this type of relay its mechanism is so designed that a delay or lapse of time in opening the circuit breaker after a pre-determined condition of the circuit has been reached, depends on the flow of current, that is, if the current be great, the time will be small, and if the current be of a moderate value, the time will be correspondingly longer.

Triple pole relays are used on three phase grounded neutral and interconnected quarterphase.

Circuit closing relays are recommended in all cases where a constant source of direct current is available for operating trip coils.

The conditions for which relays have been designed for power circuits may perhaps be best described, by considering a one line diagram from the generator end to the sub-station auxiliary machines and feeders.

Considering first alternating current circuits, the prevailing practioe is to make the circuit breakers by which the alternators are connected to the low tension bus *non-automatic*, in order to insure minimum interruption of alternator service. The chance of trouble in this part

*NOTE.—*As suggested by the General Electric Co.*

of the circuit is remote, but should it occur, the station attenc
generally open the circuit breaker before the machines would l

Reverse current relays of instantaneous or time limit often connected to the secondaries of current and of pressı formers to indicate by lamp or bell any trouble that may oc generator circuit.

These relays operate with a low current reversal at full pr conversely with a proportionally greater current at voltages normal. At zero pressure, the relay would act as an overloa for high overload. At zero current, a voltage considerably ir normal would be required to operate it.

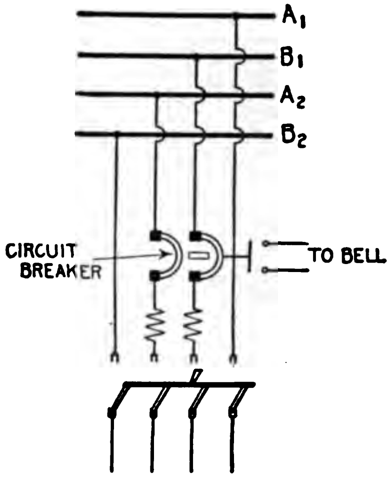


FIG. 2,330.—Diagram showing two phase motor or feeder circuit protected by double coil, overload circuit breaker (or two single pole breakers interlock alarm switch.

Specifications sometimes call for automatic generatoı breakers: in this case *definite time limit overload relays* a They are connected in the secondaries of current tran and are designed to give the same time delay for all conditions; they allow the defective circuit to be op *possible,* at a point more remote from the generator t *generator circuit* breaker.

[redacted]

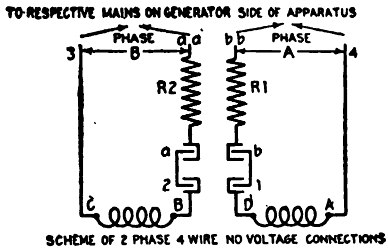
the total generator capa-
:ds the rated rupturing
of the circuit breakers, one
ectionalizing circuit break-
aced in each bus.

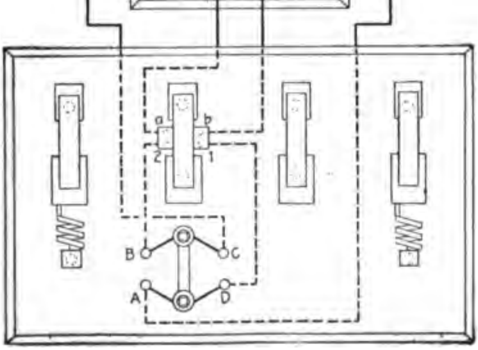
rating conditions admit, these
e made non-automatic and are
nected except in case of emer-
t if it be necessary for them to
ually in service, they may be
tomatic by *means of instan-
overload relays* connected to
ansformers in the low voltage
elays being adjusted to trip the
eaker under short circuit con-
onfining the trouble to one sec-
preventing the circuit breakers
more than their rated capacity.

tions with but *one bank
transformers*, and without
ige bus, are provided with
circuit breakers operated
erse time limit relay.

lay is connected to the second-
current transformers, which in
connected in the low voltage side
wer transformer.
s with *more than one bank of
nsformers*, a high voltage bus,
and low voltage circuit breakers,
both circuit breakers arranged
the same time or one after the
in the former case, they are
from the inverse time limit re-
cted in the low voltage side.

FIG. 2,331.—Condit 600 volt, 1,500 ampere, single pole type K circuit breaker **pneumatically operated.** It is the same as the electrically operated circuit breaker, except that a pneumatic cylinder mechanism is supplied in place of either the electromagnet or the motor. This cylinder mechanism is so arranged that the air pressure
cylinder at the instant of operation. At all other times the air pressure is shut
of a control valve. The kind of remote control to be used depends on local
n general, the hand operated remote control device is preferable where con-
ch that it *can be used, and where it is* necessary to use electrically operated,
rated type is recommended if conditions be such that slow closing is not





FIGS. 2,332 ar
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and 2,335.—Dia-
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The two no volt-
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B, C and A D on
of the base, and
nd C connections
to lower contacts
spectively of the
ting switch. Bind-
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the board. (In
nts supplied on
l bases, these con-
are made in the
let into channels
of base and cov-
h wax.) Each of
r contacts a and b
cted respectively
resistance R2 and
e of the mains at
b as shown. D is
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to the common
oth phases at 3 B
eing connected as
, thus forming a
connection for
voltage coils. Ter-
a and bb of the
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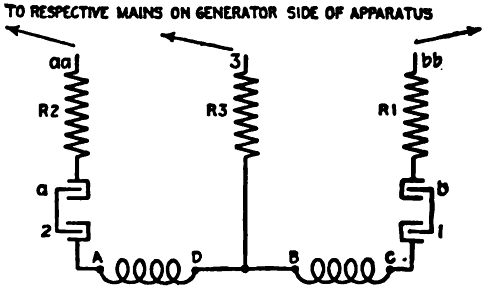
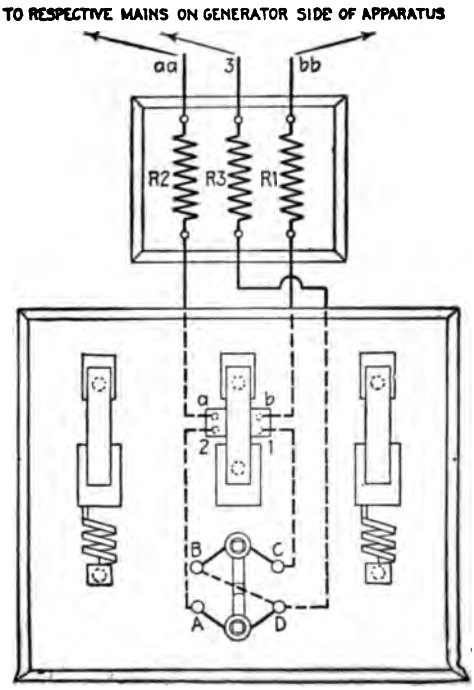
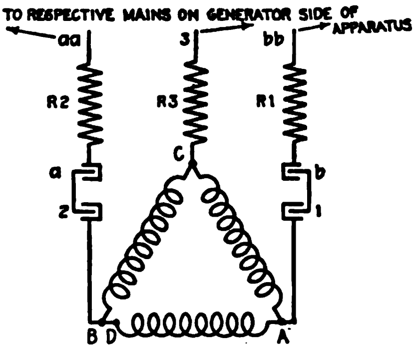


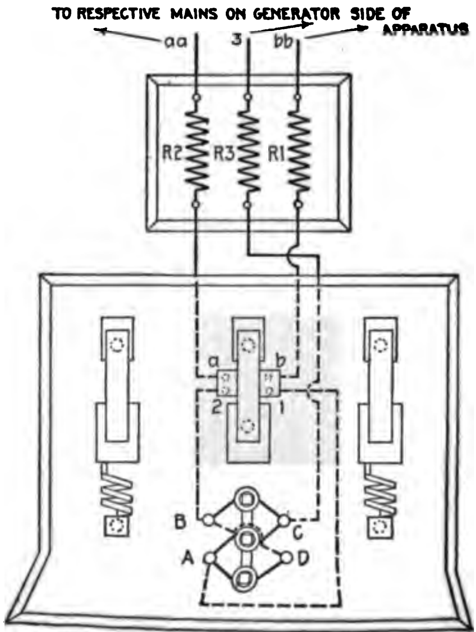
SCHEME OF 2 PHASE 3 WIRE NO VOLTAGE CONNECTIONS



2 PHASE 3 WIRE NO VOLTAGE CONNECTIONS



SCHEME OF 3 PHASE NO VOLTAGE CONNECTIONS



THREE PHASE NO VOLTAGE CONNECTIONS

FIG. 2,336 and 2,337.— Diagram showing three phase no voltage connections for I-T-E circuit breaker. The no voltage coils for three phase circuits are connected in Δ by means of binding posts A, B, C and D on the face of the base, and from the A and B of the no voltage coils, connections are made respectively to spring contacts 1 and 2 of the small disconnecting switch. Each of the contacts *a* and *b* of the disconnecting switch is connected respectively through resistance R2 and R1 to one of the mains at *aa* and *bb*. The terminal C is connected through resistance R3 on the back of the board to the middle main as shown at point 3. The terminal D is linked on the back of the board to terminal B to complete the Δ connection. The terminals *aa*, *bb* and 3 of the circuit breaker must, in all cases, be so connected that they will be *subject to full voltage of the circuit* irrespective of the position of the starting switch. Each no voltage coil is supplied with two terminal wires, one covered with green and one with black insulation. In replacing these coils particular care should be taken to see that the terminal wires connected to any one binding post are of unlike color.

[redacted]

In plants in which two or more banks of transformers are operated in parallel between high and low voltage busses, it is desirable to have for each transformer bank, an automatic circuit breaker equipment which will act selectively and disconnect only the bank in which trouble may occur. With a circuit breaker on each side of transformer bank, selective action may be secured in two ways as follows:

1. By means of an instantaneous differential relay connected in the secondaries of current transformers installed on both the high and low voltage sides of each transformer bank.

The relay operates on a low current, reversal on either side of the bank.

2. By means of one inverse time limit, secondary or series relay installed on that side of the transformer bank which is opposite the source of power, the relay being arranged to trip both the high and low voltage circuit breakers.

The first method has the disadvantage of high first cost due to the high voltage current transformers required, but is more positive than the second method and is independent of the number of transformer banks in parallel.

The second method is the less expensive of the two and protects against overloads as well as short circuits in the transformers, but it is less positive and introduces delay in the disconnection of the transformer when trouble occurs. Furthermore, it is not selective when less than three banks are operating in parallel.

The automatic circuit breakers in the outgoing line may be operated from inverse time limit relays connected in the secondaries of current transformers; or in case transformers are not necessary for use with instruments, series high voltage inverse time limit relays connected directly in the line may be used.

Whether to select current transformers with relays insulated or low voltage, or to choose series relays, is a question of first *cost and adaptability to service conditions.* Below 33,000 volts, the commercial advantages in favor of the series relay are sli and since it is somewhat difficult to design this device for large current capacities met with at the lower voltage, i generally the practice to use the relay with current transfor because of its operating advantage. This practice, howeve not entirely followed, since some service conditions (descri later) make the use of series relays very desirable and pract

FIGS. 2,338 and 2,339.—General Electric instantaneous direct current reverse current or " criminating" relays. Fig. 2,238, for 500 amperes; fig. 2,339 for 2,000 amperes. T relays are designed for mounting directly on circuit breaker studs. **These relays co** *of a horseshoe magnet with a shunt wound armature pivoted between its poles.* **The ma** is mounted on the current carrying stud of the circuit breaker between the ba the panel and the first contact or supporting nut, and is placed in a vertical position. **contacts** are insulated from the magnet permitting the use of an auxiliary circuit fo tripping device, independent of the circuit controlled by the circuit breaker. The ma is excited by the current flowing through the stud, and the armature is connected acro line in series with suitable resistance. Rotation of the armature in the normal direct prevented by a stop. **Reversal of the current** flowing through the stud *changes the tion in which the armature tends to rotate*, causing it to move away from the stop and the circuit through an auxiliary trip coil and trip the circuit breaker. **These relay used** to protect dynamos, storage batteries, or main station busses from damage c versal of current due to short circuit, or from the grounding of machines or conne Relay contacts must not be used to open the shunt trip coil circuits. An auxiliary s should be provided for this purpose in all cases where the opening of the circuit br does not disconnect the trip coil from the source of supply.

Inverse time limit relays are satisfactory for one, or m *than two outgoing* lines in parallel as they act selectively to *connect the* defective line only, but installations with only

[redacted]

tgoing lines in parallel have the same load conditions in both es and selective tripping of the circuit breakers in the defective e is obtained by means of a selective relay acting instantaously under short circuit conditions only.

The relay design and action is similar to the reverse current relay previously mentioned, and is connected to the secondaries of current

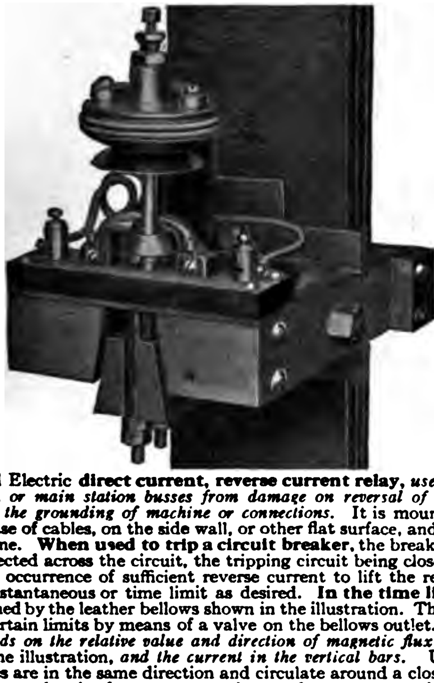


FIG. 2,340.—General Electric **direct current, reverse current relay**, *used to protect dynamos, storage batteries, or main station busses from damage on reversal of current due to short circuits or from the grounding of machine or connections.* It is mounted on vertical bus bars as in the case of cables, on the side wall, or other flat surface, and the cables threaded through the frame. **When used to trip a circuit breaker**, the breaker is provided with a shunt trip connected across the circuit, the tripping circuit being closed through the relay contacts on the occurrence of sufficient reverse current to lift the relay armature. The relay is either instantaneous or time limit as desired. **In the time limit relay**, the time interval is obtained by the leather bellows shown in the illustration. The time setting can be varied within certain limits by means of a valve on the bellows outlet. **The operation of the relay** *depends on the relative value and direction of magnetic flux set up by a pressure coil*, shown in the illustration, *and the current in the vertical bars.* Under normal conditions these fluxes are in the same direction and circulate around a closed magnetic circuit. **When the current in the bars reverse**, *the two fluxes oppose each other and force flux through the normally open leg of the magnetic circuit.* When the reversal of current is of predetermined value, the relay armature is lifted and the purpose of the relay accomplished.

transformers in each high voltage line and pressure transformers in the low voltage bus.

In the sub-station, the conditions are the reverse of those in the main *station, the incoming lines* becoming the source of power.

If there be only one incoming line **and no high voltage bus, the** circuit breaker is generally non-automatic. With one incoming line and high voltage bus, the circuits from the service side of the bus are equipped with automatic circuit breakers and relays. These relays and those used for other arrangements of two or more incoming lines in parallel, as well as high and low voltage circuit breakers, are of the same design and are applied in the same manner as for the generating station.

Regarding the relay equipments for auxiliary machines, the same practice is recommended with the generator end of alternating current motor generator sets as with the main generators, the outgoing feeder circuit breakers being tripped from inverse time limit or instantaneous relays.

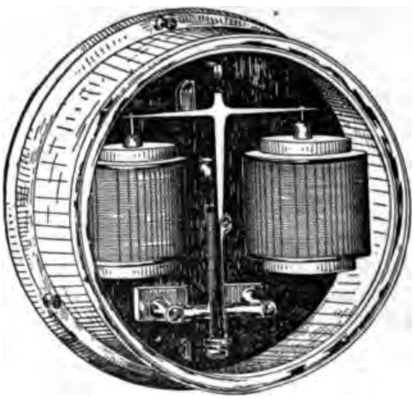


FIG. 2,341.—General Electric **direct current differential relay** for balancer set; instantaneous, 500 (or less) volt type for mounting on panel. In many power plants direct current, three wire, power service is furnished by "high voltage" two wire dynamos operating in connection with balancer sets consisting of two "low voltage" machines on a common shaft. With this combination of machine, a short circuit or heavy overload on one side of the system will shift the neutral considerably, and the lamps on the opposite side may "burn out." To protect the lamps, a differential relay operating on 15 volts unbalancing, is commonly used; it is connected to trip either the dynamo's circuit breakers (or a circuit breaker connected in the bus between the balancer set and the other dynamos).

With several synchronous machines in parallel, the relays are arranged to operate with the least time delay with which it is possible to get selective action, in order to prevent the machines being thrown out of step in event of trouble conditions causing a decrease of voltage.

The various types of *induction motor* and various conditions under which they are employed, have brought about the development of several types of relay to protect the motors and the apparatus with which they are used.

It is desirable to disconnect a *large motor* in case of voltage *failure, and with* conditions requiring either a motor operated,

[redacted]

or a solenoid operated circuit breaker, a *low voltage relay* is used to close the tripping circuit whenever the voltage decreases to, approximately, 50 per cent. below normal.

Up to 550 volts, these relays may be connected across the line, but for higher voltages they are connected to secondaries of pressure

FIG. 2,342.—**Condit time limit relay**, designed primarily for use in connection with feeder circuits, where close selection or discrimination of circuit breakers is not required. **It may be used** satisfactorily on lighting and power circuits and also where there are sudden, momentary fluctuations of current. This relay is used in connection with series transformers. The contact arrangements are provided so that the relays may be used as circuit closing or circuit opening relays. **The delayed action** is produced by an air vacuum dash pot with a graphite piston. The piston of the dash pot is connected to an arm arranged to be moved by the armature. When the current reaches a point where it overcomes the weight of the armature and lifts the same, the magnetic force tending to lift the armature is opposed by the pull of the vacuum created in the interior of the shell into which fits the graphite piston. As the magnetic pull continues the vacuum is overcome due to the leakage of air past the piston, and the armature gradually moves until it reaches a point where it causes the circuit breaker to trip, either by closing the contacts in the circuit closing type, or by opening the contacts in the circuit opening type. If, at any portion of its travel, the current drop to normal, the armature immediately resets. **The time adjustment** consists of an arrangement whereby the distance through which the armature moves before tripping the breaker, may be changed, thus altering the time of tripping. **The current adjustment is** made *by changing the effective turns of the actuating coil*, the travel of the armature and the force exerted by it being the *same for all* current adjustment. The winding is designed to carry *5 amperes continuously with a* temperature rise not exceeding 68° Fahr. standard *calibration is provided so that the relay* will start to operate at 5, 6, 8 and 12 amperes.

transformers. *Smaller motors* with which hand operated circuit brea are used, are generally provided with low voltage release attachm that perform the same function as the relay.

Induction motors are sometimes subjected to *high volt conditions* and to protect them from injury, high or exc voltage relays are employed to trip the automatic circuit break

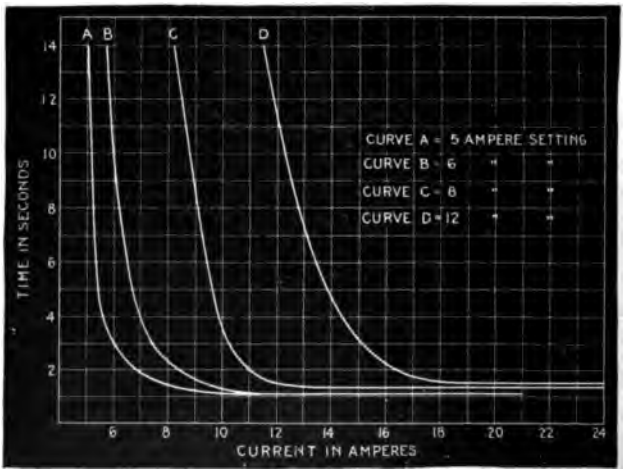


FIG. 2,343.—Characteristic curves of Condit time limit relay as illustrated in fig. 2,342. tings: curve A, 5 amperes; curve B, 6 amperes; curve C, 8 amperes; curve D, 12 amp

These relays are of similar design and wired in the same man as the low voltage relays.

Reverse phase relays have been developed for operating c ditions under which a *reversal of phase* would cause troul as for example, in the case of *elevator motors.*

These are so designed that any phase reversal that would revers induction motor, would operate the relay and disconnect the autom circuit breaker.

The design is based on the principle of the induction motor, an *the case of low voltage* motors of limited capacity, the relay may

[redacted]

connected in series in the motor leads. If the voltage or capacity of the motor make this arrangement inexpedient, the relay may be placed in the secondaries of current or pressure transformers connected in the motor leads.

Underload relays are often used to trip the automatic circuit breaker that is placed in the primaries of *arc lighting circuits* to prevent an abnormal rise of secondary voltage in case of a break in the secondary circuit.

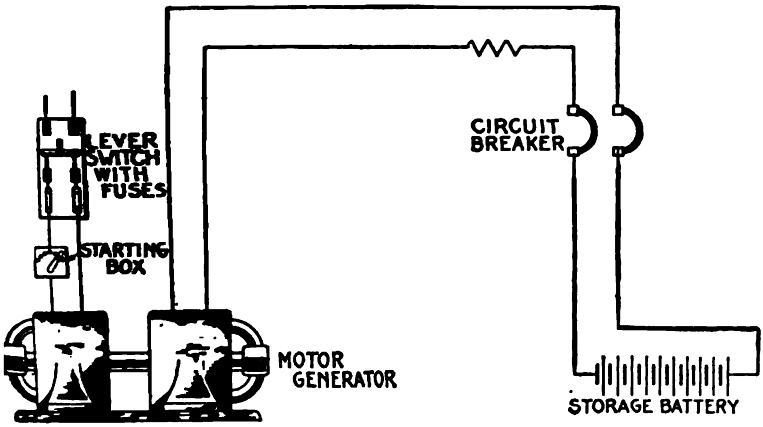
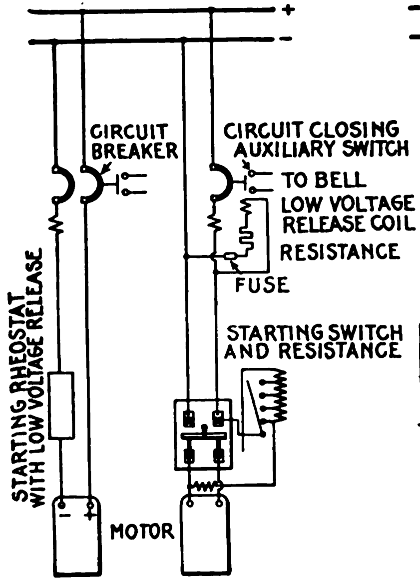
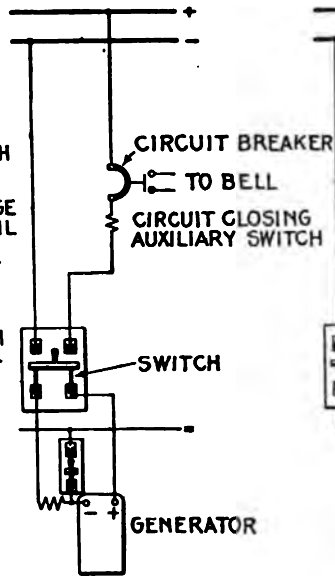


FIG. 2,344.—Diagram showing *storage battery and charging dynamo protected by* **double pole single coil underload circuit breaker. In operation**, the *circuit breaker disconnects the battery when fully charged, and protects the dynamo from reverse current.*

The underload relay is similar in design to the low voltage relay excepting that it acts on a decrease of current.

The problem of *protecting induction motors*, from injury, that may result from running on single phase, or from an overload, and at the same time permit the motor to be started with the necessarily high starting current that may be greatly in excess of the overload current, has caused the development of the *series relay*.





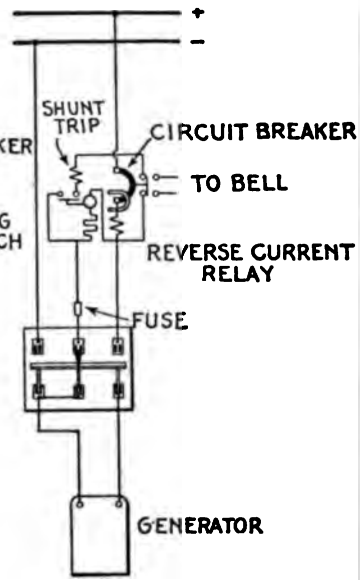


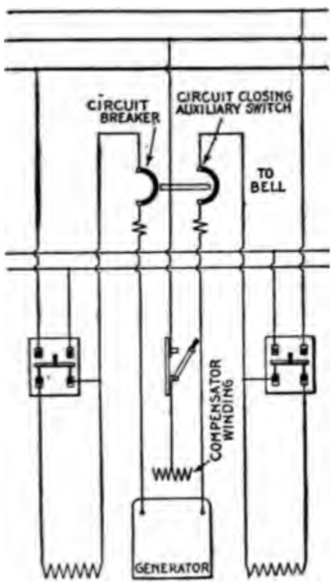
FIG. 2,345.—Diagram showing direct current motors protected by overload circuit breakers with bell alarm switches: *a*, double pole single coil breaker no switch required. Low voltage device is on the starting rheostat; *b*, single pole breaker in series with lever switch. Low voltage attachment on the breaker.

FIG. 2,346.—Diagram showing two wire dynamo, protected by a single pole overload circuit breaker with bell alarm switch. Breakers must be on opposite side from the series field.

FIG. 2,347.—Diagram showing dynamo protected by a single pole overload circuit breaker with reverse current relay and combined circuit opening and bell alarm switch.

This device may be connected in series with the motor leads for ›ltages up to 2,500; it is designed with an inverse time limit device hich may be adjusted to give the desired protection.

field for relays is more extensive for alternating current for direct current power circuits, the latter being gener- ›nfined to much smaller and simpler systems and areas tribution, and generally sufficient selective action can be



18.—Diagram showing three wire dynamo protected by double pole double coil over- l circuit breaker (or two single pole breakers with interlock) with bell alarm switches. nplete protection is secured as breaker is connected between armature and series field.

ıed by the use of fuses or circuit breakers arranged with ıtaneous trip.

›rating conditions sometimes make it advisable for the ıtor circuit breakers to open only after the auxiliary and *circuit breakers have failed to* isolate the trouble.

This is accomplished by using direct current *series inverse time limit relays* to trip the generator circuit breakers.

Instantaneous reverse current relays are used to trip the machine circuit breaker of battery charging sets, rotaries and motor generator sets to prevent their running as a motor on the charging or direct current end. These relays can act only in case of current reversal.

To prevent serious unbalancing of voltages in Edison three-wire systems causing trouble, *differential balance relays* are used to trip the circuit breakers on a small percentage of unbalancing.

[redacted]

CHAPTER LIX

LIGHTNING PROTECTION DEVICES

ightning protection devices, or lightning *arresters*, are rices for providing a path by which lightning disturbances other static discharges may pass to the earth.

Lightning arresters, designed for the protection of trans-ission lines, must perform this function with a minimum npairment of the insulation of the lines.

In general the construction of lightning arresters comprise

1. Air gaps;
2. Resistances;
3. Inductances;
4. Arc suppressing devices.

Ques. What are the causes of static charges?

Ans. They may be caused by sandstorms in dry climates, may be due to grounds on the high pressure side of a system.

Ques. What causes high frequency oscillations?

Ans. They are usually due to lightning discharges in the icinity of the line.

Ques. What are the requirements of lightning pro-ction devices?

Ans. They *must prevent* excessive pressure differences between line and ground, line and line, and between conductor turns in the electrical apparatus.

Air Gap Arresters.—A method of relieving any abnormal pressure condition is to connect a discharge air gap between some point on an electric conductor and the ground. The resistance thus interposed between the ground and the conductor is such that any voltage very much in excess of the maximum normal will cause a discharge to ground, whereas at other times the conductor is ungrounded because of the air gap. This forms the principle of air gap arresters.

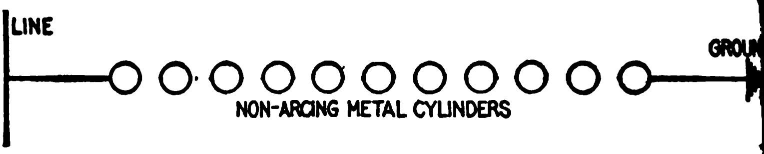


FIG. 2,349.—Non-arcing multigap arrester. Based on the principle of employing for the terminals across which the arc is formed, such metals as are least capable of maintaining an alternating arc between them. This so called non-arcing property of certain metals was discovered by Alexander Wurtz. The action is such that the "line current" which follows the lightning discharge follows as an arc, but is stopped at the end of one alternation because of the property of the non-arcing metals to carry an arc in one direction but requiring an extremely high voltage to start a reverse arc. The non-arcing metals ordinarily employed are alloys of zinc and copper. Plain multi-gap arresters as here shown operate satisfactorily with the smaller machines and on circuits of limited power, but for large machines of close regulation, and therefore of very large momentary overload capacity, especially when a number of such are operated in parallel, such arresters were found insufficient, the line current following the lightning discharge frequently was so enormous that the circuit did not open at the end of the half wave, that is the arrester held the arc and was destroyed. The introduction of synchronous motors made it necessary that the arc should be extinguished immediately, otherwise the synchronous motors and converters would drop out of step, and the system would in this way be shut down. To insure the breaking of the arc, resistance was introduced in the arrester, the modified device being known as the low equivalent arrester as shown in fig. 2,350.

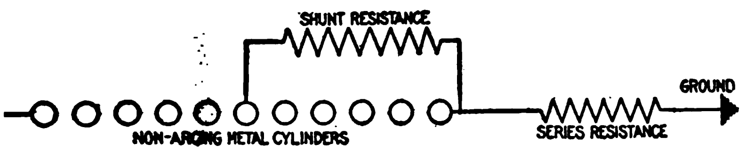
The single gap while adequate for telegraph line protection, was found insufficient for electric light and power circuits, because since the current in such circuits is considerable and usually at high pressure it would follow the lightning discharge *across the gap.* Thus the problem arose to devise means for

[redacted]

rt circuiting the line current resulting in various modifica-
ıs of gap arrester.

[ulti-gap Arresters.—The essential elements of an arrester his type are a number of cylinders spaced with a small air between them and placed between the line to be protected the ground, or between line and line.

ı *operation*, the multigap arrester discharges at a much r voltage than would a single gap having a length equal ıe sum of the small gaps. In explaining the action of multi- , there are three things to consider:



350.—Low equivalent arrester. This is a modification of the multi-gap arrester shown fig. 2,349. About half of the total number of gaps are shunted by a resistance, and other resistance inserted between the cylinders and the earth. With this arrangement e middle point is at ground pressure, and there are between line and ground only one lf of the total number of gaps. This is sufficient to prevent a bridging of the gaps der normal conditions.

The transmission of the static stress along the line of the ıders;

The sparking at the gaps;

The action and duration of the current which follows the :k, and the extinguishment of the arc.

)ues. What is a spark?

ns. The conduction of electricity by air.

)ues. What is an arc.

ns. The conduction of electricity by vapor of the electrode.

Distribution of Static Stress.—The cylinders of the arrester act like plates of condensers in series. This conde tion is the essential feature of its operation.

When a static stress is applied to a series of cylinders be and ground, the stress is immediately carried from end to er

If the top cylinder be positive it will attract a negative the face of the adjacent cylinder and repel an equal posit to the opposite face and so on down the entire row.

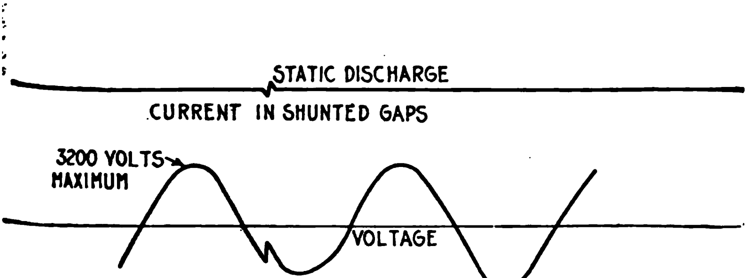
The second cylinder has a definite capacity relative to cylinder and also to the ground; consequently the charge i the third cylinder will be less than on the second cylinder, fact that only part of the positive charge on the second cylind negative electricity on the third, while the rest of the char negative electricity to the ground. Each successive cylinder from the top of the arrester, will have a slightly smaller char tricity than the preceding one.

Fig. 2,351.—General Electric 2,200 volt multi-gap arrester for station installati sists of fourteen $\frac{5}{8}$" knurled cylinders and two shunt resistance rods mount celain base. One of these rods has a low resistance, and shunts nine gaps rod has a high resistance, and shunts eleven gaps. The effect of the shunt extinguishing the line current arc is the same, therefore, as that of an equ sistance but is without the objectionable features of the latter. Series resi the discharge current to such an extent that an arrester with series resist protect against destructive rises of voltage when the conditions are severe shunt resistance responds to all frequencies and opens a discharge path f voltage when the frequencies are high as well as when they are low. Its f in withholding the line current from the gaps after the relieving discharge h is to aid the non-arcing quality of the metal cylinders in quickly suppressing follows a discharge. The arc is extinguished at the end of the half cycle of in which the discharge takes place.

Sparking at the Gaps.—The quantity of electricity indu second cylinder is greater than on any lower cylinder and its greater pressure strain across it as shown in fig. 2,357. Wher age across the first gap is sufficient to spark, the second charged to line voltage and the second gap receives the st and breaks down. The successive action is similar to ove row of ten-pins by pushing the first pin against the second. nomenon explains why a given length of air gap concentrat *gap requires more voltage to spark across it than the same t made up of a row of multi-gaps.*

[redacted]

FIG. 2,352.—General Electric 2,200 volt arrester in the act of discharging, and shunting the line current. The figure shows an actual discharge taking place. It will be seen that the heavy line current passes across only four of the gaps, and then goes through the resistance rods; while the static discharge passes straight across the entire series of thirteen gaps. When the gaps of an arrester are shunted by even a low resistance, discharges of very high frequency find it relatively difficult to pass through the resistance rods, owing to the impedance of the rods, but comparatively easy to pass across all the gaps, owing to the capacity effect in breaking down the gaps. The higher the frequency, the more pronounced is this effect, hence the discharges select different paths through gaps and resistances depending upon the frequency. By frequency is meant, not the frequency of the line current but the lightning frequency, which may run into hundreds of thousands, or into millions of cycles. The equivalent needle gap for this arrester is shown by tests to be nearly the same for all frequencies and quantities of discharge; that is, the arrester is equally responsive to all frequencies.

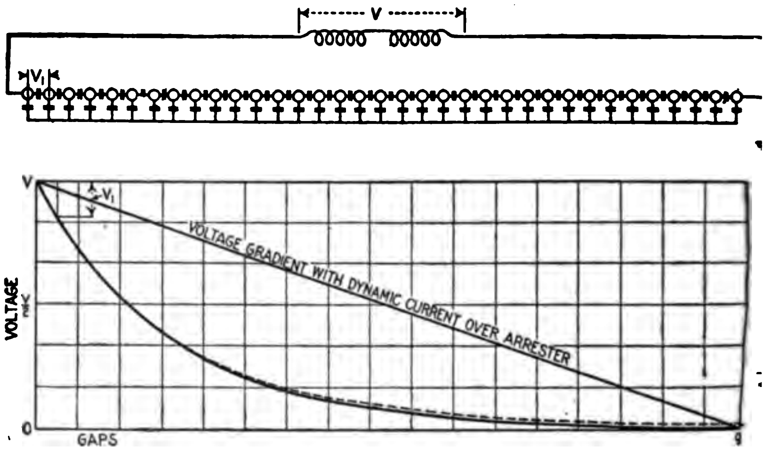


FIGS. 2,353 to 2,355.—Oscillograph *record of the phenomena* that take place in the different circuits or *selective paths of a multi-gap arrester* during a discharge such as shown in *fig. 2,352.*

As the spark crosses each successive gap, the voltage gradient alon the remainder readjusts itself.

How the Arc is Extinguished.—When the sparks extend across a the gaps the line current will follow if, at that instant, the line pressu be sufficient. On account of the relatively greater line current, th distribution of pressure along the gaps becomes equal, and has th value necessary to maintain the line current arc on a gap.

The line current continues to flow until the voltage of the generat passes through zero to the next half cycle, when the arc extinguishin quality of the metal cylinders comes into action.



FIGS. 2,356 and 2,357.—Diagram showing condenser action of cylinders and pressure gradien for static stress.

The alloy contains a metal of low boiling point which prevents th reversal of the line current. It is a rectifying effect, and before th pressure again reverses, the arc vapor in the gaps has cooled to a non conducting state.

Effect of Frequency.—The higher the frequency of the lightnin oscillation, the more readily will the multi-gap respond to the pressur

Briefly stated, the problem is to properly limit the line current so that the arc may be extinguished; to arrange a shunt circuit so tha the series resistance will be automatically cut out if safety demand i on account of a heavy lightning stroke and, while retaining these prop erties, to make the arrester sensitive to a wide range of frequency.

[redacted]

It should be noted that series resistance limits the rate of discharge of the lightning as well as of the line current. The greater the value of the line current, the greater the number of gaps required to extinguish the arcs.

Graded Shunt Resistances.—Any arc is unstable and can be extinguished by placing a properly proportioned resistance in parallel with it. All the minor discharges then pass over the resistances and the unshunted spark gaps, the resistance assisting in opening the line current after the discharge.

Very heavy discharges pass over all the spark gaps, as a path without resistance, but those spark gaps which are shunted by the resistance, open after the discharge.

The line current, after the first discharge is accordingly deflected over the resistances, and limited thereby, the circuit being finally opened by the unshunted spark gaps. The arrangement of shunted resistances is shown in fig. 2,358.

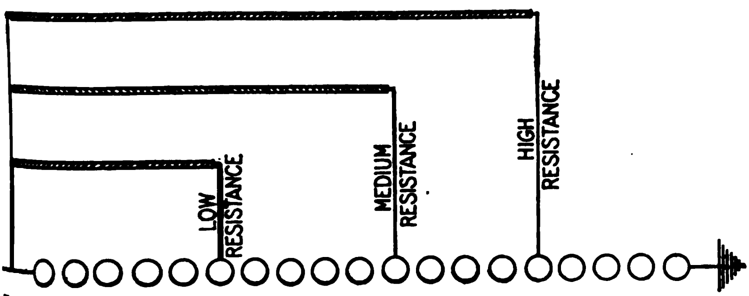


FIG. 2,358.—Arrangement of graded resistances on multigap arrester.

The Cumulative or "Breaking Back" Effect.—The graded shunt resistance gives a valuable effect, where the arrester is considered as four separate arresters. This is the "cumulative" or "breaking back" action.

When a lightning strain between line and ground takes place, the pressure is carried down the high resistance H (figs. 2,365 and 2,366), to the series gaps GS, and the series gaps spark over.

Although it may require several thousand volts to spark across an air gap, it requires relatively only a few volts to maintain the arc which follows the spark. In consequence, when the gaps GS spark over, the lower end of the high resistance is reduced practically to ground pressure.

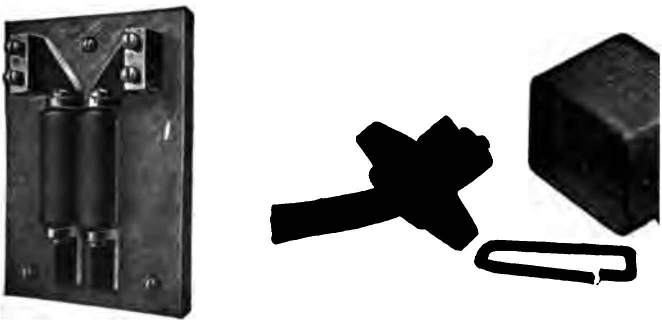
If the high resistance can carry the discharge current without giving an ohmic drop sufficient *to break* down the shunted gaps GH, nothing *further occurs—the arc goes out.*

If, on the contrary, the lightning stroke be too heavy for pressure strain is thrown across the shunted gaps, GH, equal ber to the previous set. In other words, the same voltage bre both of the groups of gaps, GS and GH, in succession. The discharge current is now limited only by the medium resistanc the pressure is concentrated across the gaps, GM.

If the medium resistance cannot discharge the lightning, GM spark, and the discharge is limited only by the low resist

The low resistance should take care of most cases but with dinarily heavy strokes and high frequencies, the discharge ca back far enough to cut out all resistance.

In the last steps, the resistance is relatively low in proporti number of shunt gaps, GL, and is designed to cut out the lin



FIGS. 2,359 to 2,364.—Westinghouse safety spark gaps. Fig. 2,359, indoor type; to 2,364, outdoor type. It is well known that with transformers, operating or age lines and having large ratios of transformation, there may occur, on the side, momentary voltages to ground greatly in excess of the normal. These increases in voltage between the low tension circuits and ground are comm **"static disturbances."** In general they are the result of a change in the sta of the high tension side and its connecting circuits. Unless certain precaution such a static disturbance on the low tension side may cause serious stresses ondary insulation of a transformer with a high ratio of transformation. Tl static voltage is independent of the ratio of transformation. The static stress serious in a high ratio transformer simply because the insulation of its secon able to withstand them. *A method of relieving this disturbance* is to connect spark gap between some point of the low tension side of the transformer to b (a middle or neutral point, if one be available) and the ground. The spark g is such that any voltage very much in excess of the maximum normal will charge to ground, and thus the low tension side is practically tied to ground disturbance, while at other times it is ungrounded. The Underwriters reco grounding of the neutral point of low tension circuits when the conditions ar the maximum normal voltage between the point connected and ground will 250 volts. The rule allows one side of a 250 volt circuit or the middle point of circuit to be grounded. **The spark gaps shown above are designed for use on** *secondary* circuits and for protecting individual series arc lamps. **These spa** *single pole, and consist* **of two cylinders of non-arcing metal with an air ga** *One of the cylinders is* **connected to the ground, the other to the line.**

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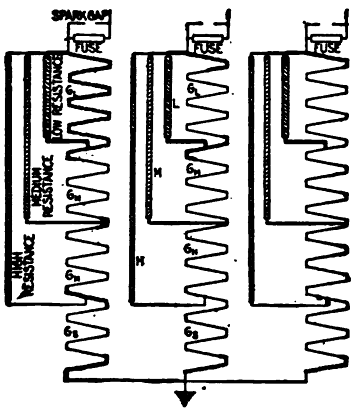
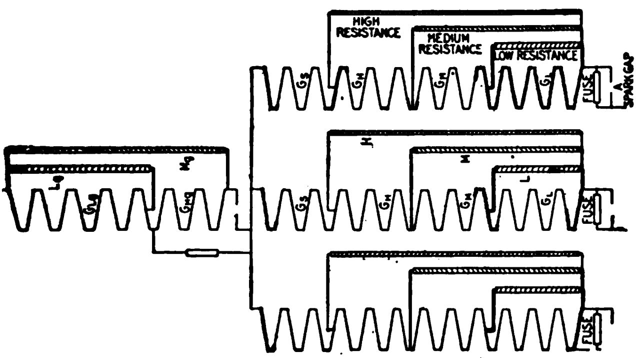




5 and 2,366.—Graded shunt resistance arrester connections. Fig. 2,365, connec-for 33,000 volt Y system with grounded neutral; fig. 2,366, connections for 33,000 lelta or ungrounded Y systems. The type of arrester shown above may be con-d **as four arresters in one. First,** for small discharges there are a few gaps in series high shunt resistance. This part of the arrester will safely discharge accumulated and also all disruptive discharges of small ampere capacity. This path is shown h H, (resistance) and GS (gaps). **Second,** there are a number of gaps in series with lium shunt resistance which will discharge disruptive strokes of medium ampere ity. This path is shown through M (resistance) and GH plus GS (gaps). **Third,** are a greater number of gaps in series with a low shunt resistance which will dis-e heavy disruptive strokes. This path is shown through L (resistance) and GM 3H plus GS (gaps). **Fourth,** the total number of gaps has no series resistance, thus ng the arrester to freely discharge the heaviest induced strokes. This path is through zero resistance and *GH plus GM* plus GH plus GS (gaps). In each of bove *circuits the number of gaps* and the resistance are so proportioned as to extin-*the line arc at the end of the half* cycle in which the lightning discharge takes place.

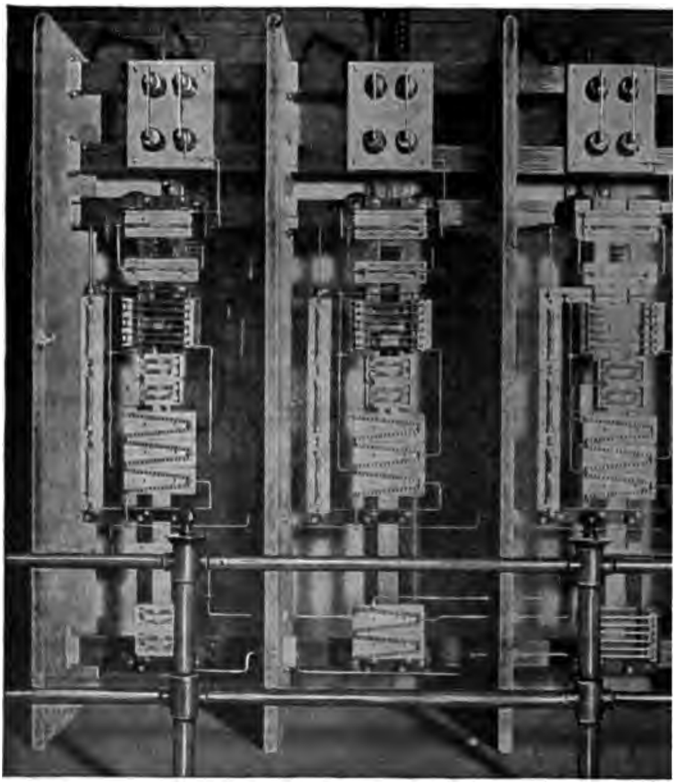


FIG. 2,367.—Installation of a General Electric 12,500 volt, three phase, multi-ɡ arrester in the Garfield Park sub-station of the West Chicago park commor unit multi-gap arrester, which is plainly seen in the illustration, is made up (consisting of gaps between knurled cylinders and connected together at t short metal strips. The base is of porcelain, which thoroughly insulates e and insures the proper functioning of the multi-gaps. The cylinders are mad that contains metal of low boiling point which gives the rectifying effect, a high boiling point which cannot vaporize in the presence of the one of low l The cylinders are heavily knurled. As the arc plays on the point of a k ually burns back and when the metal of low boiling temperature is used u increased at that point. The knurling, thus, insures longer life to the cylir ing successive arcs to shift to a new point. When worn along the entire face, should be slightly turned. The low resistance section of the graded shunt of rods of a metallic alloy. These rods have large current carrying capaci tically zero temperature coefficient up to red heat. The medium and high re are of the same standard composition previously used. The contacts arı shrunk on the ends; the resistances are permanent in value and the inductar to a minimum. The rods are glazed to prevent absorption of moisture and v

-diately from the gap, GL. This "breaking back" effect is valu- in discharging lightning of low frequency.

-ter the spark passes, the arcs are extinguished in the reversed . The low resistance, L, is propoitioned so as to draw the arcs -diately from the gaps, GL. The line current continues in the group of gaps, GM, until the end of the half cycle of the generator

8 to 2,370.—Multi-gap or low equivalent arrester. It consists of: 1, a number of in series; 2, a number of gap units in with a resistance; and 3, a series resistance. resistances are wire wound and the series is non-inductive. The shunt resistance units are mounted on marble. When a occurs, the series gaps are broken if the discharge be heavy enough, it will position in the shunt resistance and pass shunted gaps, through the series resistance The arc which tends to follow the is then withdrawn from the shunted the shunt resistance, and aided by both is suppressed by the series gaps. The of discharge is determined by the num- gaps as sufficient number is used to the normal voltage and yet give a factor of safety for the severest service.

t this instant the medium resistance, M, aids the rectifying quality he gaps, GM, by shunting out the low frequency current of the mator.

n account of this shunting effect the current dies out sooner in the , GM, than it otherwise would.

the same manner, but to a less degree, the high resistance, H, draws line current from the gaps, GH.

his current *now being limited by the* high resistance, the arc is easily *guished at the end of the first* one-half cycle of the alternator wave.

Ques. What is the difference between arrest grounded Y and non-grounded neutral systems?

Ans. The connections are shown in figs. 2,365 anc The difference in design lies in the use of a fourth arre between the multiplex connection and ground or ungı system.

Ques. Why is the fourth leg introduced?

Ans. The arrester is designed to have two legs l

FIG. 2,371.—Westinghouse three pole or four pole arrester in weather proof wooden protects the arrester units from rain and snow when they are installed in exı tions, as on poles or buildings.

line and line. If one line become accidentally grounc full line voltage would be thrown across one leg if the or ground leg were not present.

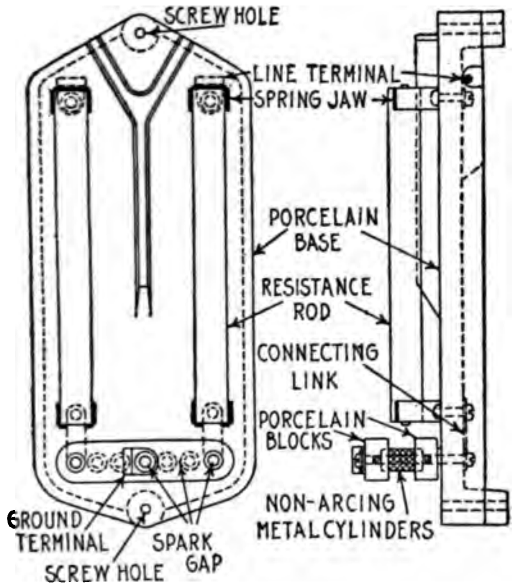
On a Y system with a grounded neutral, the accidentally ¡ phase causes a short circuit of the phase and the arrester is of the strain by the tripping of the circuit breaker. Briefl the fourth or ground leg of the arrester is used when, for an *the system could be operated, even for a short time with o grounded.*

[redacted]

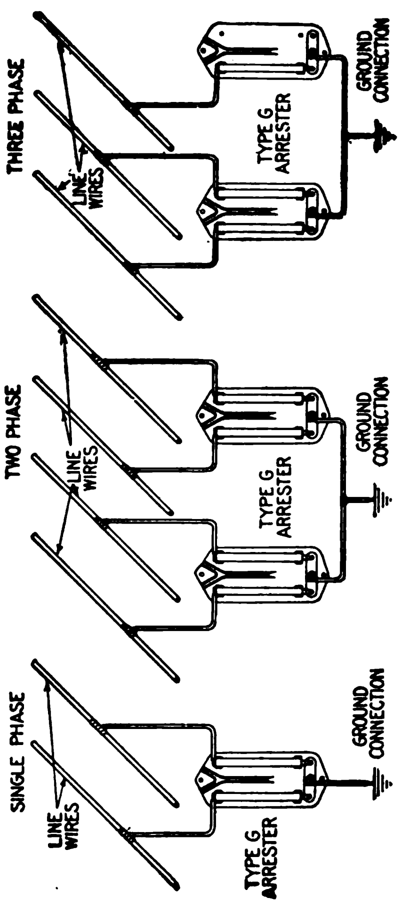
Describe the multiplex connection.

[t consists of a common connection between the phase he arrester above the earth connection and provides er better adapted to relieve high pressure surges be- es than would otherwise be possible.

use also economizes in space and material for delta and partially ıded or non-grounded Y systems.



and 2,373.—Westinghouse multi-gap lightning arrester and views showing parts. struction, a series of gaps, between non-arcing metal cylinders arranged in a row, cted between line and ground in series with a composition stick resistor having ınce of something between 80 and 120 ohms. In operation, if an excessive pres- developed on a line, electric discharge arcs form between the metal cylinders, charge of electricity flows to ground, relieving the excessive stress. The resist- the stick resistor limits the flow so that an excessive power current cannot pass the arrester. The tendency for a destructive power arc to follow the discharge us counteracted. The composition resistors and the gap cylinders are mounted on a porcelain base, and complete units are arranged within weather proof boxes as indicated. *For two pole* arresters, one unit is mounted on the back of *For three pole and four pole* arresters, two units are used; one is secured on *of the box.*



FIGS. 2,374 to 2,376.—Connections for Westinghouse multi-gap (type G) arresters. These arresters may be installed outside on poles or buildings, or indoors on station walls. The weather proof wooden case (as shown in fig. 2,371) protects the arrester units from rain and snow when installed in exposed places. Fig. 2,374 shows single phase installation, fig. 2,375, two phase installation, and fig. 2,376, three phase installation. **On a two pole circuit** one line wire is connected to the top of each of the composition resistors of each arrester unit, as shown in fig. 2,374, and the ground wire is connected to the middle point of the gap series. **On four pole circuits**, fig. 2,375, the same scheme of connections is used, but two arrester units are necessary and the connections of both are the same. **On three pole circuits**, two arrester units are used, with the same connections as for four pole circuits, except that there are but three line connections instead of four as in fig. 2,376.

Horn G resters.—A gap arreste sists essenti two horn terminals f an air gap c able lengt horn bein nected to t to be pr and the ot the ground through se sistance as in fig. 2,378

Ques. does the gap arr operate?

Ans. Tl due to th current whi lows a dis rises betwe diverging hc becoming and more a ated is fina tinguished.

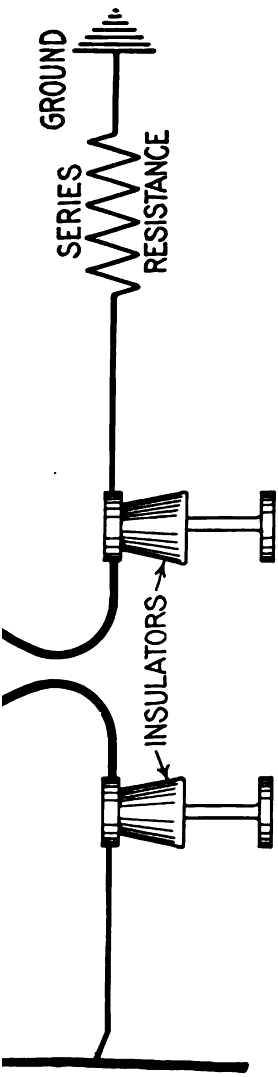


Fig. 2,377.—Horn gap arrester, diagram showing arrester and connections between line and ground. The horn type arrester was invented by Oelschlaeger for the Allgemeine Electricitaets Gesellschaft, and like the Thomson arc circuit arrester, its operation is based on the fact that *a short circuit once started at the base, the heat generated by the arc will cause it to travel upward until it becomes so attenuated that it is ruptured.* On circuits of high voltage this rupture sometimes takes a second or two, but seems to act with little disturbance of the line. **Sometimes** a *water resistance* is used, a *choke coil being* inserted in the circuit in series. **In one installation** for a 40,000 volt line, the horns were made of No. 0,000 copper wire with gap knees 2½ to 3 or 3½ inches. The capacity of the water resistance receptacle was 15 gallons. **Users differ** as to whether the water should contain salt. **The choke coil** can be made of about 18 turns of iron wire wound on a 6 inch cylinder.

Ques. What is the objection to the horn gap on alternating current circuits?

Ans. The arc lasts too long for synchronous apparatus to remain in step.

Ques. What provision was made to shorten the duration of the arc?

Ans. A series resistance was inserted in the arrester circuit as shown in fig. 2,377.

Ques. What difficulty was caused by the series resistance?

Ans. With sufficient series resistance to prevent loss of synchronism, the arrester failed to protect the system under severe conditions.

Ques. With these objections what use was found for the horn gap arrester?

Ans. It is used as an emergency arrester on some overhead lines, to operate only when a shut down is unavoidable, also for series lighting circuits.

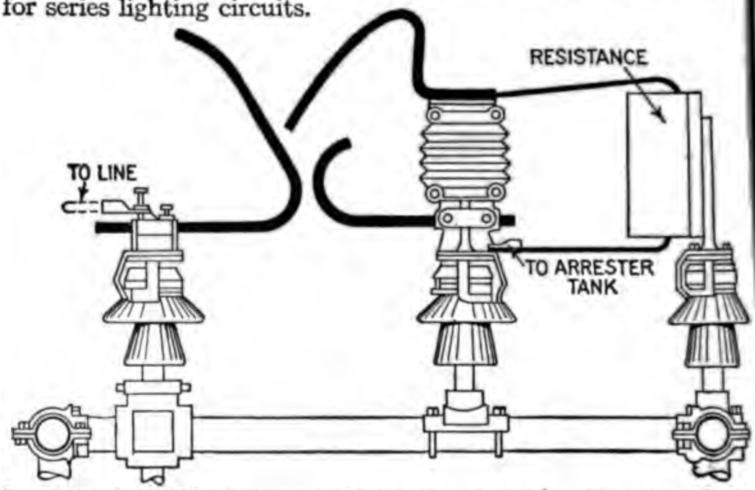
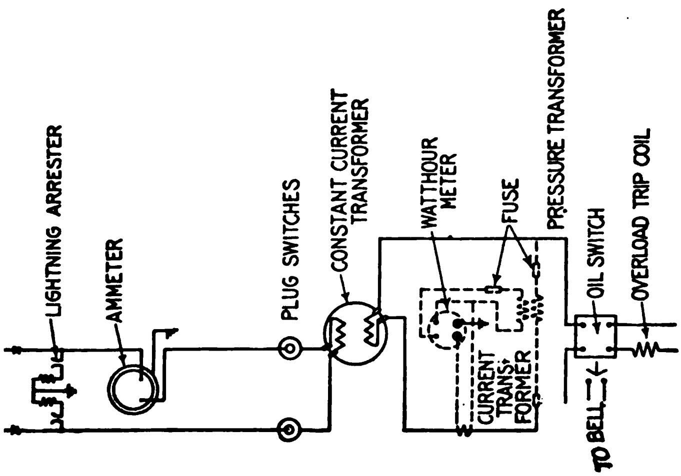
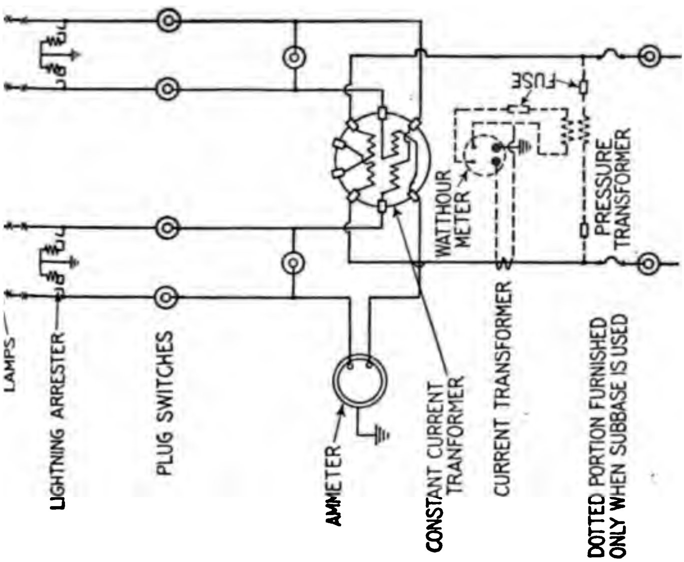


FIG. 2,378.—General Electric horn gap with charging resistance for cable system. Arresters for cable systems differ from arresters for overhead circuits only in the construction of the horn gaps. The necessity for this difference is due to the fact that a cable system has a very much higher electrostatic capacity and much less inductance than an overhead system. In consequence, the currents which flow into the arrester during charging are somewhat higher. It is desirable to avoid these heavier currents, especially during the time of breaking the arc at the horn gap. This is accomplished by using a special horn gap and resistance. This consists of an auxiliary horn mounted above and insulated from the regular horn in such a manner as to intercept the arc if it rise on the regular horns. Enough resistance is connected in series with this auxiliary horn so that the current flow and arc across this gap are always limited to a moderate value. Such a device has several advantages. Since the mechanism is so arranged that the charging is always done through the auxiliary horn the current rush is limited during the charging and thus troubles from carelessness or ignorance are avoided. It also gives a nearer uniform charging current. In the use of this auxiliary horn gap and resistance there are three successive stages, as follows: 1, light discharges will pass across the smaller gaps to the auxiliary horn and through the series resistance to the cells; 2, if the discharge be heavy, the resistance offers sufficient impedance to cause the spark to pass to the main horn. This is accomplished with only a slight increase in pressure because the gap is already ionized. If the cells be in normal condition, the spark at the gap is immediately extinguished without any flow of line current; 3, if the cells be in poor form, the line current may follow the discharge across the main gap and the arc will rise to the safety horn and be extinguished through a resistance. For mixed overhead and cable systems the choice of arrester will be a matter of judgment. If there be a comparatively short length of cable, the usual practice for overhead systems may be also. For direct connection to busbars, arresters with charging resistance should be used.





FIGS. 2,379 and 2,380.—Diagram showing connections of horn type lightning arresters on series circuits.

The necessity of service requires that series lightning systems fully equipped against damage by lightning and similar trouble. most common disturbances occurring on series circuits are the su set up by the sudden opening of the loaded circuit. These disturba are especially severe where circuits are accidentally grounded, du contact of the wires where they pass through other circuits.

Ques. How are the spark gaps adjusted?

Ans. They are set to give a low spark pressure relative the voltage of the line.

FIG. 2,381.—General Electric horn type arrester, mounted for 15 light series arc circuit. horn type arrester consists of a horn gap with series resistance between each lin ground. The resistances and horn gaps are mounted on porcelain bases and the on insulating wooden supports. The supports have asbestos barriers (except for l voltages), and backs to eliminate liability of damage from the arc which forms i horn gap at the time of the discharge. The spark gaps are adjusted to give a low pressure relative to the voltage of the circuit. The number and ohmic value resistance rods used in the various arresters depend upon the voltage and current circuit.

Ques. Why are horn arresters well suited to pro *series lighting* circuits against surges?

Ans. *Because* the surges are damped out before the *which forms* across the horn gaps is interrupted.

[redacted]

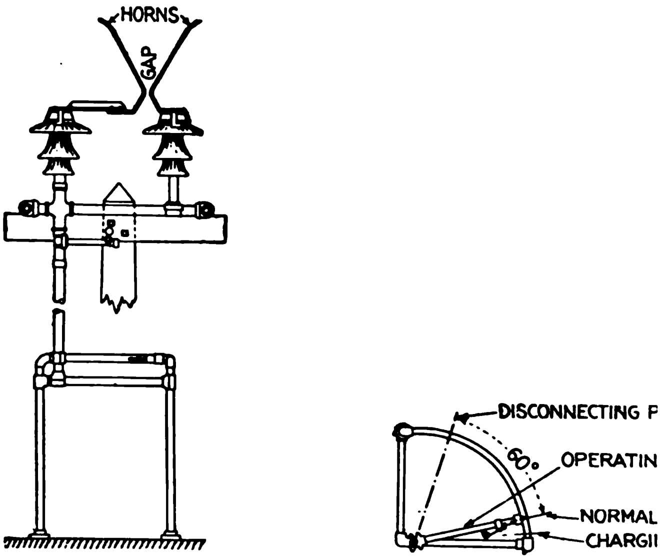
These arcs last for several cycles, since the length of the time of action of the arrester depends upon the lengthening of the arc between the horn gaps, limited by the series resistance.

Since practically all disturbances on lighting circuits are of low frequency, the series resistance can be used with good results; it aids the horn in extinguishing the arc, limits the size of the arc and prevents short circuits occurring during the period of discharge.

2,282.—General Electric horn arrester for pole installation. Quite frequently series circuits are run underground in cables for some distance from the generating station. In order to protect the cables it is advisable to place horn arresters at the points where the cable joins the overhead wires. The resistance units are mounted in the wooden box. This design is used to economize space, since if the horn gaps be placed in the box the latter would have to be made very large to accommodate the asbestos barriers and backs. In installing this type of arrester it is advisable to place it as near as possible to the top of the pole so that the arc may rise unobstructed and thus avoid the likelihood of live wires coming in contact with the horns which, during the operation of the series current, are alive.

Electrolytic Arresters.—Arresters of this class are sometimes called aluminum arresters because of the property of aluminum on which their action depends; that is, *it depends on the phenomenon that a non-conducting film is formed on the surface of aluminum when immersed in certain electrolytes.*

If however, the film be exposed to a higher pressure, punctured by many minute holes, thus so reducing ance that a large current may pass. When the p again reduced the holes become resealed and the f effective.



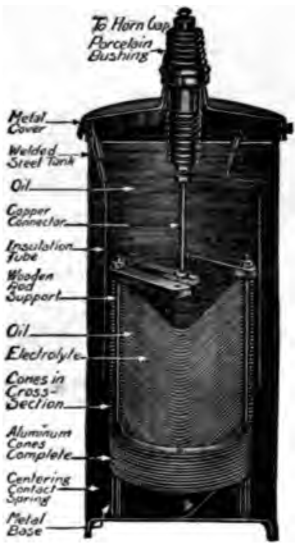
FIGS. 2,383 and 2,384.—Elevation and plan of General Electric horn gaps stand for high voltage arresters.

In construction, the aluminum arrester consists of a system of nested aluminum cup shaped trays, on porcelain and secured in frames of heated wood, ar a steel tank.

The system of trays is connected between the line an and between line and line, a horn gap being inserted *rester circuit* which prevents the arrester being subject *line voltage* except when in action.

[redacted]

rolyte is poured into the cones and partly fills the en the adjacent ones. The stack of cones with the between them is then immersed in a tank of oil. lyte between adjacent cones forms an insulation. proves this insulation and prevents the evaporation ion.



ss section of General Electric aluminum (electrolytic) lightning arrester.

er of insulating material concentric with the cone ced between the latter and the steel tank, the object nprove the circulation of the oil and increase the etween the tank and the cone stack. The arrester, ribed consists of a number of cells connected in series.

Of what does a single cell consist and what are eristics?

consists of two of the cone shaped aluminum trays or plates and an electrolyte, which forms a condenser that w stand about 350 volts before breaking down. When this volta is exceeded the cell becomes a fairly good conductor of electricit but as soon as the voltage drops its resistance again resumes very high value.

Ques. What is the critical voltage?

Ans. The voltage at which the current begins to flow free

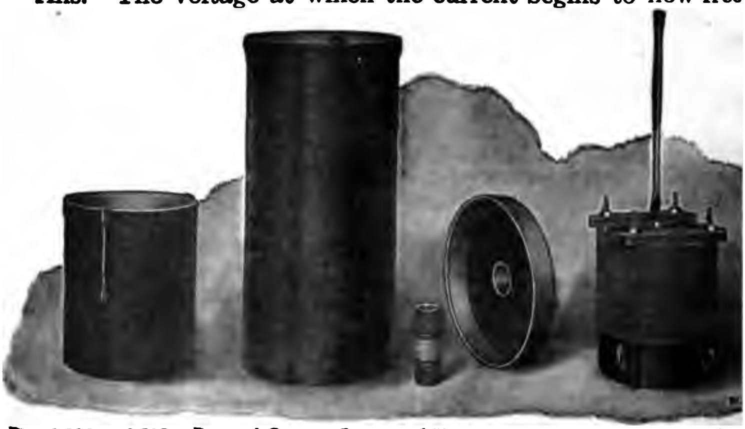


FIG. 2,386 to 2,390.—Parts of General Electric 15,000 volt aluminum lightning arrester, including horn gaps, etc.

Up to a certain voltage the cell allows an exceedingly low curren flow, but at a higher voltage the current flow is limited only by the ternal resistance of the cell, which is very low. A close analogy to action is found in the well known safety valve of the steam boiler which the steam is confined until the pressure rises above a given va when it is released. On the aluminum plates there are myriads minute safety valves, so that, if the electric pressure rise above critical voltage, the discharge takes place equally over the entire face. It is important to distinguish between the valve action of hydroxide film and the failure of any di-electric substance.

Ques. When a cell is connected permanently to t circuit what two conditions are involved?

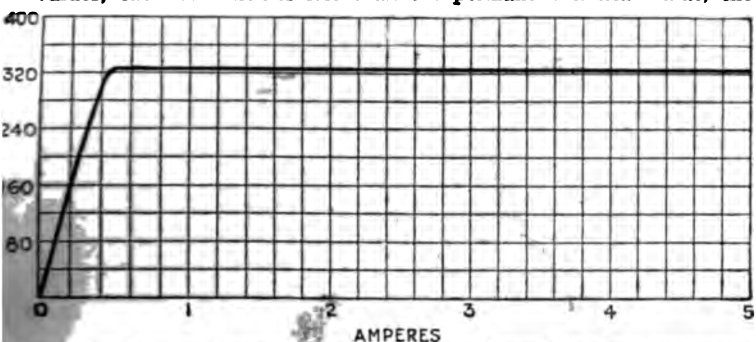
Ans. The *temporary* critical voltage and the perman *critical voltage.*

[redacted]

For instance, if the cell have 300 volts applied to it constantly, and the pressure be suddenly increased to, say 325 volts, there will be a considerable rush of current until the film thickness has been increased to withstand the extra 25 volts; this usually requires several seconds In this case 325 volts is *the* **temporary** *critical voltage of the cell.*

Similar action will occur at any pressure up to about the **permanent** critical voltage, or *the voltage at which the film cannot further thicken,* and therefore allow a free flow of current.

If the voltage be again reduced to 300 the excess thickness of film will be gradually dissolved, and if it vary periodically between two values, each of which is less than the permanent critical value, the



2,391.—Volt ampere characteristic curve of a General Electric aluminum (electrolytic) cell on alternating current. The permanent critical voltage is between 335 and 360 volts. With alternating current, the cell acts as a fairly good condenser, and there is not only the leakage through the film, but also a capacity current flowing into the cell. The phase of this current, then. is nearly 90 degrees ahead of the pressure and represents a very low energy factor.

temporary critical voltage will be the higher value. This feature is of great importance as it provides a means of discharging abnormal surges, the instant the pressure rises above the impressed value.

Ques. How is the number of cell required for a given rcuit determined?

Ans. The number required for a given operating voltage determined by allowing about 250 to 300 volts per cell.

Ques. In putting cells in commission how is the lectrolyte introduced?

Ans. *It is poured into the aluminum* trays and the overflow *awn off at the bottom of the tank.*

Ques. Describe the further operations in putting cells in commission.

Ans. After putting in the electrolyte it is allowed to stand for a few days until part has evaporated, then the oil is poured over the surface to prevent further evaporation.

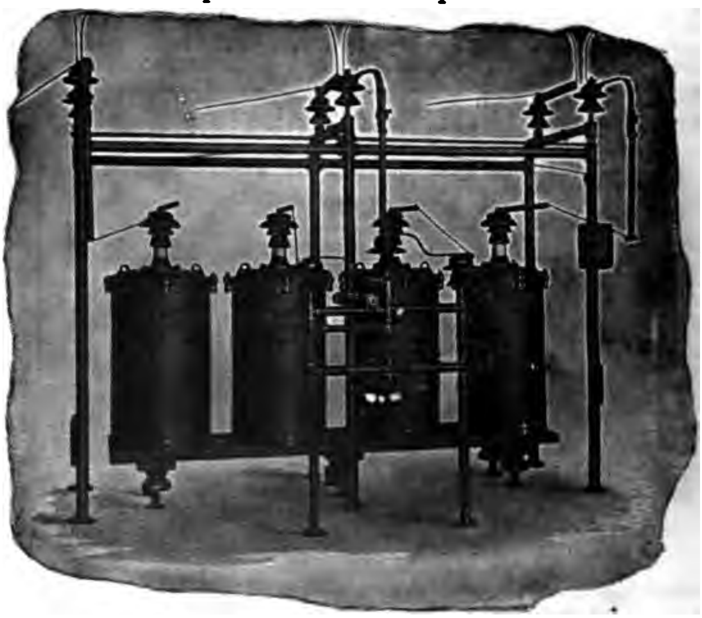


FIG. 2,392.—Westinghouse electrolytic lightning arrester, for three phase ungrounded neutral service, 25,000 maximum voltage. These arresters are designed for the protection of alternating current circuits from all kinds of static disturbances. They have been standardized for installation on three phase circuits of voltages of 2,200 to 110,000. They cannot be used for voltages of less than 13,500. For voltages below this the horn gaps cannot, with safety, be set close enough together, out of doors, to take advantage of the freedom of discharge of the electrolytic element. If the horn gaps be set too close together they may be short circuited by rain. A shelter should be built for arresters of 13,500 volts and below for their protection when installed outside.

Ques. What action takes place when the trays stand in the electrolyte and cell is disconnected from the circuit?

Ans. Part of the film deteriorates.

Ques. What is the nature of the film?

Ans. The film is composed of two parts, one of which is hard and insoluble, and apparently acts as a skeleton to hold the more soluble part. The action of the cell seems to indicate that the soluble part of the film is composed of gases in a liquid form.

Ques. What action takes place when a cell which has stood for some time disconnected, is reconnected to the circuit?

FIGS. 2,393 and 2,394.—Aluminum trays for Westinghouse electrolytic lightning arresters.

Ans. There is a momentary rush of current which reforms the part of the film which has dissolved.

This current rush will have increasing values as the intervals of rest of the cell are made greater.

Many electrolytes have been studied, but none has been found which does not show this dissolution effect to a greater or lesser extent.

If the cell has stood disconnected from the circuit for some time, especially in a warm climate, there is a possibility that the initial current rush will be sufficient to open the circuit breakers or oil switches. This current rush also raises the temperature of the cell, and if the temperature rise be great, it is objectionable.

When the cells *do not stand for more than a day*, however, the film *dissolution and initial current rush* are negligible.

Ques. What is the object of using horn gaps on ele trolytic arresters?

Ans. The use is threefold: 1, it prevents the arrester bei subjected continually to the line voltage: 2, acts as a disco necting switch to disconnect the arrester from the line f repairs, etc., and 3, acts as a connecting switch for charging.

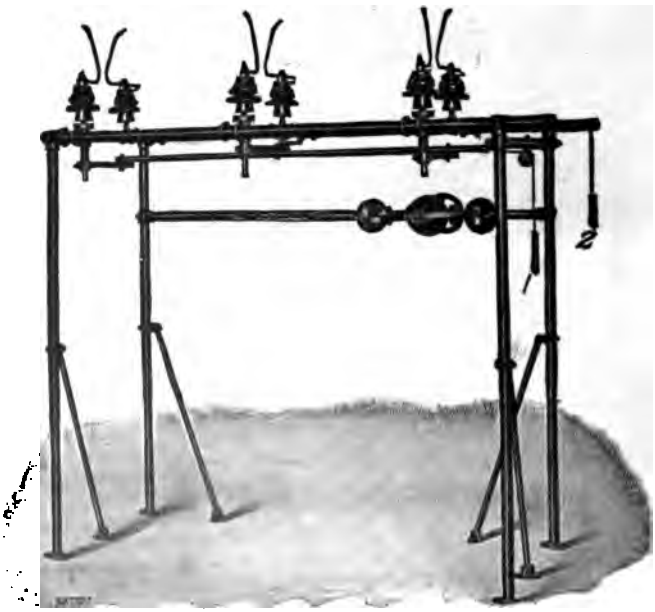


FIG. 2,395.— Horn gaps and transfer device of General Electric aluminum lightning arres for 12,500 volt non-grounded neutral circuit. The object of the transfer device is provide a means for interchanging the ground stacks with one of the line stacks of co during the charging operation so that the films of all the cells will be formed to the sa value. The transfer device consists of a rotating switch which may be turned 180 grees, thus interchanging the connections of the ground stack and one of the line stac For arresters up to 27,000 volts the device is mounted with three insulators on the p frame work, and is operated by a hand wheel; for arresters of higher voltage, the tra fer device is mounted directly over the tanks and is operated by bevel gears and hand wh

***Charging of* Electrolytic Arresters.**—In electrolytic a rresters *all electrolytes* dissolve the film when the arrester is

[redacted]

open circuit, the extent of the dissolution depending upon the length of time the film is in the electrolyte, and upon its temperature. It is therefore necessary to *charge* the cells from time to time and thus prevent the dissolution and consequent rush of current which would otherwise occur when the arrester discharges.

Ques. Describe the charging operation for arresters with grounded circuits.

Ans. It consists in simply closing simultaneously the three horn gaps so that the full pressure across the cells causes a

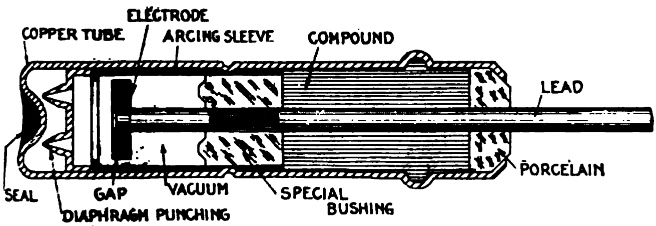


FIG. 2,396.—Sectional view of General Electric **vacuum tube arrester** for railway signal circuits. **The arrester** *is essentially a gap in a vacuum*. **In construction,** the gap is formed between the inner wall of a drawn metal shell and a disc electrode mounted concentric with it. **The electrode** is supported on a brass rod which serves as the lead in connection, and has ample current carrying capacity. The electrode system is insulated from the tube and rigidly supported in position by a bushing made of vitreous material. The bushing does not form the vacuum seal, that being made by a special compound. **The open end of the tube** is finally closed by a porcelain bushing. The tube is exhausted in a special machine which solders a small hole in the end after the vacuum has been established. The possibility of solder entering the active part of the vacuum space is prevented by a diaphragm punching, and both the electrode and the lining of the tube are of non-arcing metal. **The arrester has a spark pressure of** from 350 to 600 volts direct current, and an equivalent needle gap of about .005 inch. The arrester will not stand a continuous flow of current due to excessive heating, hence if there be a possibility of this due to high pressure crosses, fuses should be used. R. R. S. A. standard terminals are used.

small charging current to flow and form the films to their normal condition.

Ques. Describe the charging operation for arresters for non-grounded circuits.

Ans. First, the horn gaps are closed for five seconds and *opened again to normal position,* thus charging the cells of the three line stacks. Second, with the horn gaps still in n position, the position of the transfer device is reversed an horn gaps are again closed for five seconds and returned t normal position.

The complete charging operation takes but a few moment should be performed daily. The operation is valuable, not o keeping the films in good condition, but also in giving the op some idea of the condition of the arrester by enabling him to o the size and color of the charging spark.

FIG. 2,397.—Highland Park sub-station, Charlotte, N. C., showing old lightning arrest on the left and General Electric aluminum (electrolytic) cell lightning arrester a gaps in foreground.

Grounded and Non-grounded Neutral Circuit is important to avoid the mistake of choosing an arrester thoroughly grounded neutral when the neutral is only pa grounded, that is, grounded through an appreciable resis Careful consideration of this condition will make the statement clear.

In an arrester for a grounded neutral circuit, each stack of cones normally receives the neutral pressure when the arrester discharges, but if a phase become accidently grounded, the line voltage is thrown across each of the other stacks of cones until the circuit breaker opens the circuit. The line voltage is 173 per cent. of the neutral or normal operating voltage of the cells and therefore about 150 per cent. of the permanent critical voltage of each cell. This means that when a grounded phase occurs,

FIG. 2,398.—Westinghouse electrolytic station lightning arrester for direct current up to 1,500 volts consists of a tank of oil in which are placed, on properly insulated supports, a nest of cup shaped aluminum trays. The spaces between the trays are filled with electrolyte, a sufficient quantity for one charge being furnished with each arrester. The top tray is connected with the line through a 60 ampere fuse, and the bottom tray is connected to the tank which is thoroughly grounded by means of a lug. The fuse is of the enclosed type and mounted on the cover of the arrester. A **small charging current** flows through the trays continuously and keeps the films on the trays built up, so that no charging is required. This charging current is not, however, of sufficient value to raise the temperature appreciably. The immersed area of each tray is 100 square inches. The shape and the arrangement of the trays is such that any gases generated by the discharge can pass out readily without disturbing the electrolyte between the trays.

this 50 per cent. excess pressure is short circuited through the cells until the circuit breaker opens.

The amount of energy to be dissipated in the arrester depends upon *the kilowatt capacity of the* generator, the internal resistance of the cells, and the time required to operate the circuit breakers. It is evident that the greater the amount of resistance in the neutral, the longer will be the time required for the circuit breakers to operate. Therefore, in cases where the earthing resistance in the neutral is great enough to prevent the automatic circuit breakers opening practically instantaneously, an arrester for a non-grounded neutral system should be installed.

FIGS. 2,399 to 2,401.—Westinghouse ground fittings. Fig. 2,399, ground plate; fig. 2,400, ground point; fig. 2,401, cap. The ground plate consists of a circular piece of cast iron, 12 inches in diameter, 1⅜ inches thick with a ¾ inch pipe tap in center to connection to arrester. The surface is increased by means of corrugations, as shown in the accompanying illustrations, to 461 square inches, affording ample contact with the earth and enabling it to take care of all discharges through the arrester. The plate should preferably be buried at the foot of the pole so that the ground wire runs to it in a straight line from the arrester. Care should, of course, be taken to see that the earth in which the plate is buried is damp. If the ground wire be placed within the pipe leading to the ground plate it should be soldered to a cap at the top of the pipe to eliminate the inductive effect due to the wire being surrounded by iron. A simple and effective method of securing a good ground is by means of an iron pipe with a malleable iron point having a dipped galvanized finish, and a brass cap with a lug for soldering the ground wire. The pipe may be driven into the earth, or if it be too hard to permit driving, a hole may be dug and the pipe placed therein. It should extend from eight to ten feet above and below the earth to secure, respectively, a good ground and prevent any tampering with the ground wire. Should it be desired to make use of a longer pipe which would be inconvenient to drive into the earth, two pieces can be used and connected together by a coupling. The brass cap and malleable iron point are tapped for use with ¾ inch pipe.

Ground Connections.—In all lightning arrester installations it is of the utmost importance to make proper ground connections, as many lightning arrester troubles can be traced to bad grounds. It has been customary to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal at a depth of six or eight feet in the earth.

A more satisfactory method of making a ground is to drive a number of one inch iron pipes six or eight feet into the earth surrounding the station, connecting all these pipes together by means of a copper wire or, preferably, by a thin copper strip. A quantity of salt should be placed around each pipe at the surface

FIGS. 2,402 to 2,404.—General Electric **magnetic blow out arrester** for use on railways. It consists of *an adjustable spark gap in series with a resistance.* Part of the resistance is in shunt with a blow out coil, between the poles of which is the spark gap. The parts are mounted in a strong, porcelain box, which, for car and pole use, is in turn mounted in a substantial asbestos lined, wooden box. **In operation**, when the lighting pressure comes on the line, it causes the spark gap to break down and a discharge occurs through the gap and the resistance rod to ground. Part of the current shunts through the blow out coil producing a strong magnetic field across the spark gap. The magnetic field blows out the discharge arc and restores normal conditions. The resistance is only 60 ohms (for 500 volt rating work), and the spark gap only one-fortieth of an inch (.025 in.).

of the ground and the ground should be thoroughly moistened with water. It is advisable to connect these pipes to the iron framework of the station, and also to any water mains, metal flumes, or trolley rails which are available.

The following suggestions are made for the usual size station.

1. Place three pipes equally spaced near each outside wall, making twelve altogether, and place three extra pipes spaced about six feet apart at a point nearest the arrester.

2. Where plates are placed in streams of running water, they should be buried in the mud along the bank in preference to being laid in the stream. Streams with rocky bottoms are to be avoided.

3. Whenever plates are placed at any distance from the arrester, it is necessary also to drive a pipe into the earth directly beneath the arrester, thus making the ground connection as short as possible. Earth plates at a distance cannot be depended upon. Long ground wires in a station cannot be depended upon unless a lead is carried to the parallel grounding pipes installed as described above.

4. As it is advisable occasionally to examine the underground connections to see that they are in proper condition, it is well to keep on file exact plans of the location of ground plates, ground wires and pipes with a brief description, so that the data can be readily referred to.

FIG. 2,405.—General Electric magnetic blow out arrester for line use. It consists essentiall of *a small spark gap which is in series with a resistance, and between the poles of a magne* The operation is similar to that of the arrester shown in figs. 2,402 to 2,404, but the magne is a permanent magnet instead of an electromagnet. The spark gap and the magnet ar mounted within porcelain blocks in such a way that the discharge arc is blown by the mag net through an arc chute and a cooling grid which is also held by the porcelain. Th cooling grid in the arc chute materially assists the magnet in extinguishing the discharg arc, giving the arrester a high arc rupturing quality. The series rod is carborundum and i connected externally to the other portion of the arrester. The arrester is self-contained

5. From time to time the resistance of these ground connections should be measured to determine their condition. The resistance of a single pipe ground in good condition has an average value of about 15 ohms. A simple and satisfactory method of keeping account of the condition of the earth connections is to divide the grounding pipes into two groups and connect each group to the 110 volt lighting circuit with an ammeter in series.

Choke Coils.—A lightning discharge is of an oscillatory character and possesses the property of self-induction, accordingly it passes with difficulty through coils of wire. Moreover *the frequency* of oscillation of a lightning discharge being much *greater than that* of commercial alternating currents, a coil can

[redacted]

readily be constructed which will offer a relatively high resistance to the passage of lightning and at the same time allow free passage to all ordinary electric currents.

Opinions on the design of choke coils for use with lightning arresters vary considerably. Some engineers recommend the use of very large choke coils, but while large choke coils of high inductance do choke back the high frequency currents better than smaller coils of less inductance, they cost more, and under many conditions they are a menace to the insulation unless the lightning arresters be installed on both sides of them.

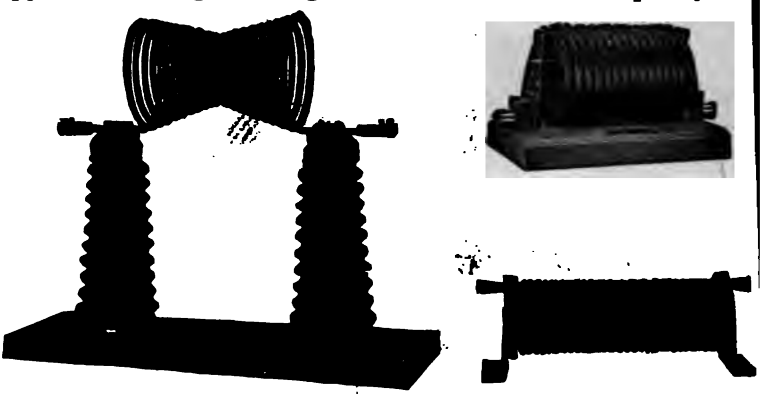
FIG. 2,406.—Westinghouse line suspension choke coil. It is so designed that it can be inserted directly in the transmission line wire or in the station wiring and held in position therein by the tension of the line or station wires. Because of the fact that no insulators are required, solely to support this choke coil, and that it can be installed in either a vertical or a horizontal position it can often be utilized effectively in power and substation layouts. Terminals, each having a ½ inch round hole, to accommodate the conductors are provided at each end of the coil. Three square headed binding screws are supplied which clamp the conductors in position. The coil is provided with a strain insulator, so arranged within the coil at its axis, that it assumes any mechanical tension transmitted from the conductors. No mechanical tension reaches the turns of the choke coil proper. In construction, the choke coil is made in but one size having a current carrying capacity of 200 amperes and is suitable for a voltage of 2,000 to 22,000. For higher voltages than 22,000, several choke coils are connected in series. One coil is used for each 22,000 volts or fraction thereof, of the pressure between the wires of the circuit. **Application:** *This type of choke coil may* be used for alternating current service for the *entire range from 22,000 to 110,000* volts. It may be used on transformers, but *is not recommended for the protection of generators.*

Part of the functions of the choke coil are performed by the end turns of a transformer and extra insulation is invariably installed in all power transformers built in recent years.

The choice of choke coils must be influenced by the condition of insulation in the transformers as well as by the cost, pressure regulation, and nature of the lightning protection required.

Ques. What are the primary objects of a choke coil?

Ans. To hold back the lighting disturbance from the circuit apparatus during discharge, and to lower the frequency of



FIGS. 2,407 to 2,409.—General Electric choke coils. Fig. 2,407, hour glass choke coil, 45,000 volts; fig. 2,408, low voltage choke coil, 6,600 volts; fig. 2,409, low voltage choke coil, 4,600 volts.

the oscillation so that whatever charge gets through the choke coil will be of a frequency too low to cause serious pressure drop around the first turns of the end coil in either alternator or transformer.

If there be no arrester, the choke coil cannot perform the first function, accordingly a choke coil is best considered as an auxiliary to an arrester.

Ques. What is the principal electrical condition to be avoided with a choke coil?

Ans. Resonance. The coil should be so arranged that

[redacted]

continual surges be set up in the circuit, a resonant voltage due to the presence of the choke coil cannot build up at the transformer or generator terminals. This factor is a menace to the insulation. Another way of stating the condition is as follows: So arrange the choke coil as not to prevent surges, originating in a transformer, passing to the arrester.

Ques. What is another electrical condition to be avoided and why?

Ans. Internal static capacity between adjacent turns

FIG. 2,410.—Westinghouse choke coil for high pressure transmission circuits, 2,200 to 25,000 volts. Choke coils of this type are wound without iron cores on circular or elliptical center blocks. They have a large number of layers and few turns per layer (except those made for small currents, they usually have one turn per layer), which give the best condition for insulating and cooling. They are air cooled, heavily insulated and have a line lead at the top, as shown. Choke coils are designed to prevent the short circuits sometimes caused by the local concentration of pressure such as may be produced by a lightning discharge. They limit, to some extent, an abnormal rise of pressure on the apparatus by delaying the advance of a static wave from the line and thus give the arrester more time to act. The disturbance caused by a lightning flash passes along the line in the form of a surge or "tidal wave." If this wave pass a choke coil, it is flattened out, and if the coil be of sufficient power, becomes practically harmless. It is evident, however, that the choke coil receives the full force of the wave, and that, consequently, it must be heavily *insulated; moreover, the choke coil must not overheat under load, nor introduce into the circuit excessive inductive resistance.*

of the choke coil, because this lowers the effectiveness of t

Ques. What is the object of making choke c the form of an hour glass?

Ans. To prevent sagging between the supports.

FIG. 2,411.—Westinghouse **air cooled choke coil** particularly suitable for outdoor **method of mounting** is such that insulation for any desired voltage is readil with the same type of porcelain, and mounting in any position is possible. Tl helix of aluminum rod, about 15 inches in diameter and containing about 30 tu ing clamps are provided to give mechanical strength to the helix, and the rod sufficient diameter to carry 200 amperes. The coil is supported on two insu umns made up of porcelain insulators, which, except for the end pieces, are in able. The number of insulators used in the columns depends on the voltage cuit in which the coil is to be used. The apparatus can be mounted in any po venient for the wiring, on floor, wall, or ceiling. **It is intended principally** *tection of transformers*. Where greater reactance than is afforded by a sin desired on the higher voltage circuits, it is recommended that two or more co nected in series, one coil being used for each 22,000 line voltage. This coil be used for generators. The insulating columns are supported on substantia blocks on wooden bases.

Ques. How are choke coils cooled?

Ans. By air, or by oil.

Ques. For what service are oil cooled choke coils

Ans. On circuits of pressures above 25,000 volts, coils immersed in oil, as are transformer coils, have adv *in that the coil is* amply insulated not only from the nt against side flash, and that copper of comparatively small tion may be used without undue heating.

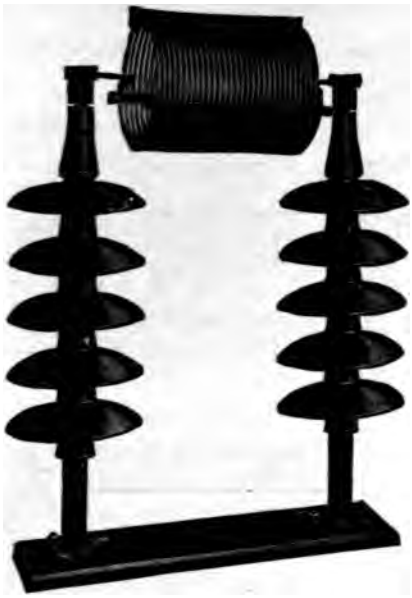


FIG. 2,412.—**Westinghouse air cooled choke coil**, for voltages of from 2,200 to 110,000. In construction, the coils are made of aluminum rod wound into a helix of about 15 inches in diameter and having 20 turns. The helix is supported on two insulators. For mechanical reasons it is necessary to have the aluminum rod of sufficient size to secure rigidity, consequently every coil has a capacity of 200 amperes and may be used on any circuit up to that capacity. The coils are insulated according to the standard practice for disconnecting switches, the insulators being mounted on wooden pins supported by a wooden base. This apparatus can be mounted in any position. The wiring of a station or sub-station is facilitated because the protection may be placed so as to simply form part of the wiring. The coils are symmetrical so that it is immaterial which end is connected to the line or to the apparatus.

"Static" Interrupters.—A static interrupter is a *combination of a choke coil and a condenser*, the two being mounted together and placed in a tank and oil insulated.

It is used on high pressure circuits and its function is to so delay the erroneously called "static" wave in its entry into the transformer coil, that a *considerable portion* of the latter will become charged before the *terminal will have reached full pressure.*

A choke coil alone sufficiently powerful to accomplish thi would be too large and costly on very high pressure and woul interfere with the operation of the system.

Ques. How is the condenser and choke coil connected?

Ans. The condenser is connected between the line and groun behind the choke coil near the apparatus to be protected a shown in fig. 2,413.

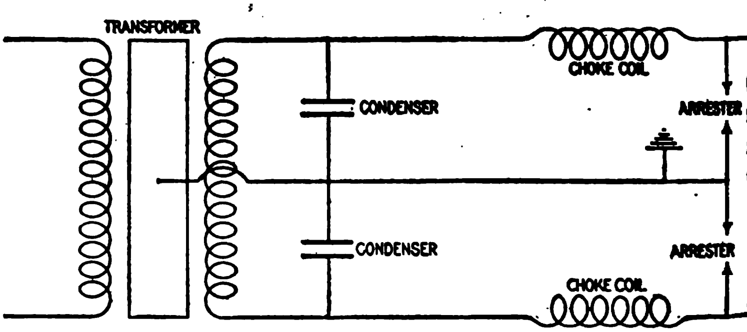


FIG. 2,413.—Diagram showing connections of static interrupter for protecting a transform

Ques. What is the effect of the condenser?

Ans. The condenser, which has a very small electro-stati capacity, has no appreciable effect upon the normal operation but a very powerful effect upon the static wave on account o its extremely high frequency.

[redacted]

CHAPTER LX

REGULATING DEVICES

Regulation of Alternators.—Practically all the methods employed for regulating the voltage of direct current dynamos and circuits, are applicable to alternators and alternating current circuits. For example: in order that they shall automatically maintain a constant or rising voltage with increase of load, alternators are provided with composite winding similar to the compound winding of direct current dynamos, but since the alternating current cannot be used directly for exciting the field magnets, an accessory apparatus is required to rectify or change it into direct current before it is used for that purpose.

It is a fact, however, that composite wound alternators do not regulate properly for inductive as well as non-inductive loads.

In order to overcome this defect compensated field alternators have been designed which automatically adjust the voltage for all variations of load and lag. These machines have already been described.

Alternating Current Feeder Regulation.—With slight modification, the various methods of feeder regulation employed with direct current, may be applied to alternating current distribution circuits. For instance, if a non-inductive resistance be introduced *in any electric circuit,* the consequent drop in voltage will be equal to the current multiplied by the resistance. fore, feeder regulation by means of rheostats is practi same in the case of alternating current as in that current. In the case of the former, however, the effect induction may also be utilized to produce a drop in In practice, this is accomplished by the use of self-i coils which are commonly known as reactance coils.

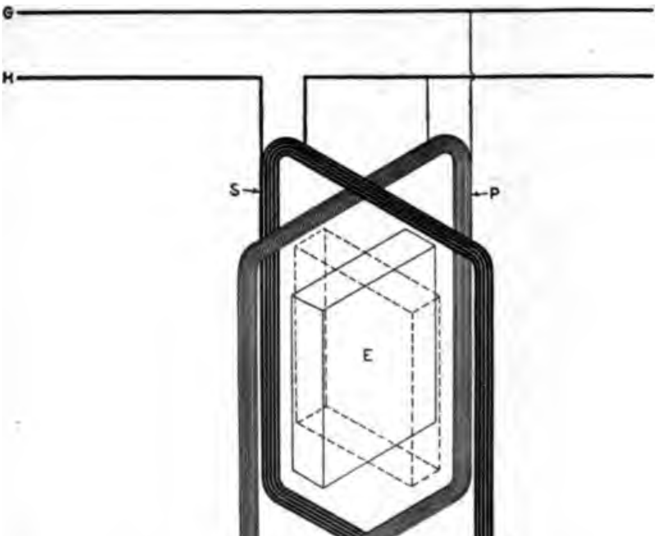


FIG. 2,414.—Diagram *illustrating the principle of* **induction voltage regulators.** T coil P, *consisting of many turns of fine wire*, is connected across the main cond D, coming from the alternator. **The secondary coil** S, *consisting of a few t wire*, is connected in series with the conductor D. The laminated iron core within the coils, is capable of being turned into the position shown by the When the core is vertical, the magnetic lines of force produced in it by the induces a pressure in the secondary coil which aids the voltage; when t position indicated by the dotted lines, the direction of the magnetic lines reversed with respect to the secondary coil and an opposing pressure will therein. Thus, by turning the core, the pressure difference between the and H, can be varied so as to be higher or lower than that of the main c *and D.* Regulators operating on this principle may be used for *theatre dim trollers for series* lighting, and also to adjust the voltage or the branches of *three wire single phase* and polyphase systems.

Application of Induction Type Regulators.—In supplying lighting systems, where the load and consequently the pressure drop in the line increases or decreases, it becomes necessary to raise or lower the voltage of an alternating current, in order

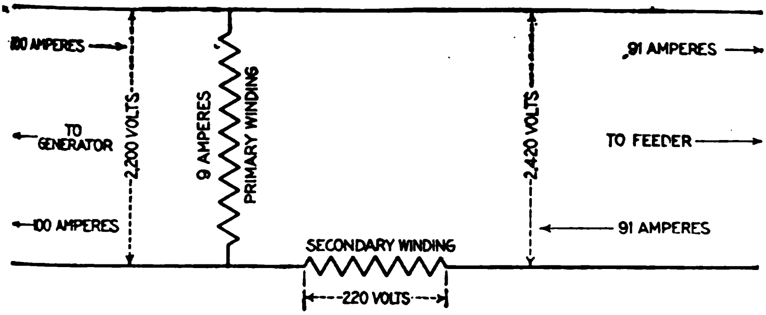


FIG. 2,415.—Diagram of induction regulator **raising the voltage** 10%. In the diagram an alternator is supplying 100 amperes at 2,200 volts. The regulator raises the feeder pressure to 2,420 volts, the current being correspondingly reduced to 91 amperes, the other 9 amperes flowing from the alternator through the primary of the regulator, back to the alternator.

to regulate the voltage delivered at the distant ends of the system. This is usually accomplished by means of *alternating current regulators or induction regulators.* A devise of this kind is essentially a transformer, the primary of which is excited

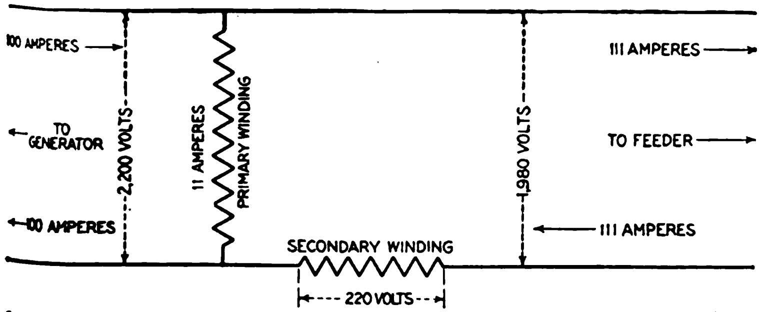


FIG. 2,416.—Diagram of induction regulator **lowering the voltage** 10%. The diagram shows the regulator lowering the feeder pressure to 1,980 volts with an increase of the secondary current to 111 *amperes, the additional* 11 amperes flowing from the feeder, through the *primary back to the feeder.*

by being connected directly across the circuit, while the secondai is in series with the circuit as shown in fig. 2,414. By th method the circuit receives the voltage generated in the se ondary.

Ques. Name two types of pressure regulator.

Ans. The induction regulator, and the variable ratio trans former regulator.

Ques. Of what does an induction regulator consist?

Ans. It consists of a primary winding or exciting coil, secondary winding which carries the entire load current.

FIG. 2,417.—Moving element or **primary** of Westinghouse motor operated single phase duction regulator. It consists of a core of punchings built up directly on the prim shaft and carrying the primary winding, which is divided into four coils. The prim coils are machine wound and the layers of the winding are separated from each other heavy insulating material in addition to the cotton covering of the inductors. The co plete coils are insulated and impregnated with insulating compound before being pla in the slots. The coils are held in position by fibre wedges.

The primary is wound for the full transmission voltage, and is co nected across the line, while the secondary is connected in series wi the line.

Ques. What is its principle of operation?

Ans. When the primary coil is turned to various positio the magnetic flux sent through the secondary coil varies in valu thereby causing corresponding variation in the secondary vol *age, the character* of which depends upon the value and direc *tion of the flux.*

[redacted]

Ques. What is the effect of turning the secondary coil to a position at right angles with the primary coil?

Ans. The primary will not induce any voltage in the secondary, and accordingly it has no effect on the feeder voltage.

Ques. What is this position called?

Ans. The neutral position.

Ques. What are the effects of revolving the primary coil from the neutral position first in one direction then in the other?

FIG. 2,418.—Moving element or primary of Westinghouse motor operated polyphase induction regulator.

Ans. Turning the primary in one direction increases the voltage induced in the secondary, thus increasing the feeder voltage like the action of a booster on a direct current circuit while turning the primary in the opposite direction from the neutral position, correspondingly decreases the feeder voltage.

Ques. It was stated that for neutral position the primary had no effect on the secondary; does the secondary have any effect on the feeder voltage?

Ans. The secondary tends to create a magnetic field of its own *self-induction, and has* the effect of a choke coil.

Ques. How is this tendency overcome?

Ans. The primary is provided with a short circuited winding, placed at right angles to the exciting winding. In the neutral position of the regulator, this short circuited winding acts like the short circuited secondary of a series transformer, thus preventing a choking effect in the secondary of the regulator.

Ques. What would be the effect if the short circuited winding were not exployed?

FIG. 2,419.—Top end of stationary element or secondary of Westinghouse polyphase induction regulator; view showing leads. The secondary is built up in a short skeleton frame with brackets for the rotor bearings bolted to the frame and the top cover bolted to the top brackets. In assembling the secondary, the punchings are stacked loosely in the skeleton frame and an expanding building mandrel placed inside the punchings and expanded, thereby truing up the latter before they are finally compressed and the end plates keyed in position. Then, prior to removing the mandrel a finishing cut is taken on the surface of the frame to which the bearing brackets are attached, and as the top cover and brackets are also accurately machined the alignment of the primary with the secondary is almost perfect, thus reducing to a minimum the tendency to develop vibration and noise.

Ans. The voltage required to face the full load current *through the* secondary would increase as the primary is turned *away from* either the position of maximum or minimum regulation, *reaching* its highest value at the neutral position.

[redacted]

The short circuited winding so cuts down this voltage of self-induction that the voltage necessary to force the full load current through the secondary when the regulator is in the neutral position is very little more than that necessary to overcome the ohmic resistance of the secondary.

Ques. What effect is noticeable in the operation of a single phase induction regulator?

Ans. It has a tendency to vibrate similar to that of a single phase magnet or transformer.

FIG. 2,420.—Bottom end of stationary element or secondary of Westinghouse polyphase induction regulator.

Ques. Why?

Ans. It is due to the action of the magnetizing field varying in strength from zero to maximum value with each alteration of the exciting current, thus causing a pulsating force to act across the air gap, which tends to cause vibration when the moving part is not in perfect alignment.

Ques. Explain the effect produced by bad alignment?

Ans. If the bearings of the primary be not in perfect alignment with the *bore of the secondary*, thereby making the air gap on one side smaller than that on the other, the crowdi over of the flux to the smaller air gap will cause an intermitte pull in that direction, which will develop vibration unless th primary bearings are tight and the shaft sufficiently stiff t withstand the pull.

Ques. Upon what does the regulator capacity for an given service depend?

FIG. 2,421.—Westinghouse two kw., hand operated, air cooled induction regulator for test purposes.

Ans. It depends upon the range of regulation required a the total load on the feeder.

Ques. How is the capacity stated?

Ans. In percentage of the full load of the feeder.

For instance, on a 100 kilowatt circuit, a 10 kw. regulator will g 10 per cent. regulation, and a 5 kw. regulator, 5 per cent. regulation.

Polyphase Induction Regulators.—The *polyphase induc tion regulator* is similar to the single phase regulator exce

[redacted]

that both the primary and secondary elements are wound with as many sets of coil as there are phases in the circuit.

In construction these windings are distributed throughout the complete circumference of the stationary and moving

Fig. 2,422.—Westinghouse polyphase motor operated induction regulator showing operating mechanism. The primary shaft is turned by means of a bronze worm wheel engaging a forged steel worm, provided with a ball bearing end thrust. This worm gear is housed in a separate casting bolted to the cover. The casting is made separate in order to permit close adjustment between the worm wheel and the worm to aid in counteracting the tendency to vibration. Finished surfaces on the worm gear casting are provided for mounting the motor and the brake. On the automatic regulator, the worm shaft is connected to the motor through a spur gear and pinion, which constitutes a compact driving device having very little friction. Provision is made for either alternating current or direct current motor drive. When a motor driven regulator is operated by hand, the brake must be held in the release position, otherwise it will be impossible to operate the regulator. In the hand operated regulator the spur gear is replaced by a hand wheel and the regulator is driven directly from the worm shaft.

elements and closely resemble the windings of an induction motor.

Polyphase regulators have but little tendency to vibrate because *the field across the air* gap is the resultant of two or more single phase fields and is of a constant value at all times. This field rotates at a rate depending upon the number of pole and the frequency of the circuit. This produces a mechanical pull of constant value which rotates with the magnetic field varying its position from instant to instant.

It is evident that this pull is of an entirely different character from that produced by the single phase field and that there is no tendency to set up the vibration that the mechanical pull of the single phase regulator tends to establish.

FIG. 2,423.—General Electric **adjustable compensation shunt. It is used as the compensating** shunt for direct current voltage regulators. **In operation, the shunt may be adjusted** so as to compensate for any desired line drop up to 15 per cent. **It is preferably placed** in the principal lighting feeder but may be connected to the bus **bars so that it will take** the total current. The latter method is sometimes undesirable, **as large fluctuating power** loads on separate feeders might disturb the regulation of the lighting feeders. **Adjustment is made** *by sliding the movable contact* shown at the center of the shunt. **This contact** may be clamped at any desired point and it determines the **pressure across the compensating** winding of the regulator's control magnet. **Where pressure wires are run back** to the central station from the center of distribution, **they may be connected directly to** the pressure winding of the main control magnet, and it **is unnecessary to use the compensating shunt.**

There is, however, considerable torque developed, and the device for revolving the moving element must be liberally designed so as to withstand the excess torque caused by temporary overloads or short circuits.

Ques. In what respects do polyphase induction regulators differ in principle from single phase regulators?

Ans. The induced voltage in the secondary has a constant

:, and the regulation is effected by varying the phase rela- between the line voltage and the regulator voltage.

ies. How is the primary wound?

s. It is wound with as many separate windings as there hases in the circuit, and these primary or shunt windings nnected to the corresponding phases of the feeder.

4.—General Electric **direct current** (form S) **voltage regulator. It consists of** *is control magnet, relay, condenser and reversing switch*, as shown in the diagram :,428. This regulator cannot be used for compensation of line drop as the current coil iitted; it is not a switchboard instrument, but is designed for inexpensive installa- such as for regulating the voltage of motor generator sets when the current is taken a trolley line or some other fluctuating source. **The regulating outfit comprises,** ies the regulator, one or more condenser sections according to field discharge, set of brackets when regulator cannot be mounted on front of switchboard, one compen- g shunt, when it is desired to compensate for line drop. Field rheostats having ient resistance to reduce the voltage the proper amount must be used with voltage lator installations. To prevent undue decay at the relay contacts, allow one section ach 15 kw. capacity of dynamo with laminated poles, and one for each 22 kw. capacity solid steel poles.

:s. What kind of magnetizing flux is produced by rimary windings?

. A practically constant flux which varies in direction

:s. How is the secondary wound?

. There is a separate winding for each phase.

es. Why is the voltage induced in the secondary ant?

. *Because of the constant* magnetizing flux.

Ques. How is the line voltage varied by a polypha regulator?

Ans. When the regulator is in the position of maxim boost, the line AB, fig. 2,425 represents the normal bus voltage, BC the regulator voltage, and AC the result feeder voltage. When the regulator voltage is displaced 1 degrees from this position, the regulator is in the position deliver minimum voltage to the feeder, the regulator volt being then represented by BD, and the resultant feeder volt

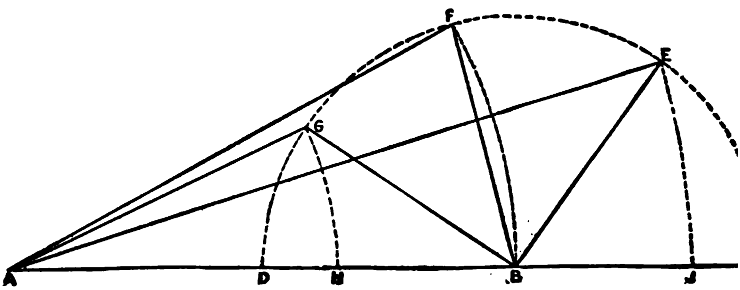


FIG. 2,425.—Diagram illustrating operation of polyphase induction regulator.

by AD. When the regulator voltage is displaced angularly the direction BF, so that the resultant feeder voltage AF comes equal to the normal busbar voltage AB, the regulator in the neutral position. Intermediate resultant voltages compensating the voltage variations in the feeders may obtained by rotating the moving element or primary in eit direction from the neutral position. For example, by rotati the primary through the angle FBE, the resultant voltage m be made equal to AE or AJ, thereby increasing the feeder volta by an amount BJ; or by rotating it in the opposite directi *through the* angle FBG, the feeder voltage may be reduced *an amount BH.*

Ques. How are induction regulators operated?

Ans. By hand or automatically.

Ques. How is automatic operation secured?

Ans. By means of a small motor, controlled by voltage regulating relays.

Ques. How is the control apparatus arranged?

Ans. Two relays are employed with each regulator, a primary relay connected to the feeder circuit and operating under changes of voltage therein, and a secondary relay connected between the primary relay and the motor, and operated by the contacts

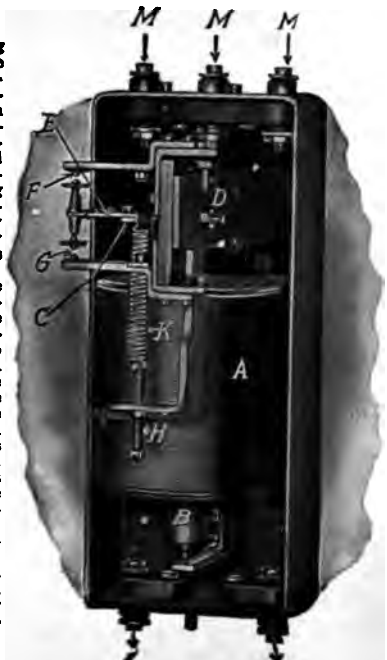


Fig. 2,426.—Westinghouse voltage regulating primary relay; view of mechanism with case removed. This relay is practically a voltmeter arranged for making and breaking contacts with fluctuations of voltage. As shown in the figure, it consists essentially of a solenoid and a balance beam carrying two movable contact points on one end and attached to the solenoid core at the other. The oscillation of the core causes the contact carrying end of the beam to move between two stationary contact points connected to the auxiliary or secondary relay circuit. The stationary contact points are fitted with adjusting screws for either increasing or decreasing the distance between them, to the amount of change in the voltage required for making or breaking contact; in other words, for varying the sensitiveness of the relay. Means for varying the normal voltage which it is desired to maintain are provided in the spring attached to the balance beam and controlled by the micrometer adjusting screw. Increasing the tension of the spring results in lowering the normal voltage position. The relay is wound for a normal voltage of 110 volts, and has a range of adjustment from 90 to 130 volts. The total energy required for its operation is about 50 watts at normal voltage. Voltage transformers having at least 50 watts capacity are, therefore, required. The parts are: A, solenoid; B, solenoid core; C, end of balance beam; D, pivots, bearings; E, movable contact arm; F, upper stationary contact point; G, lower stationary contact point; H, adjusting screw; K, adjusting spring; L, feeder binding posts; M, auxiliary circuit and secondary relay binding posts.

of the former, for starting, stopping and reversing the mot accordance with changes in the feeder voltage, thereby ca the regulator to maintain that voltage at its predeterm normal value.

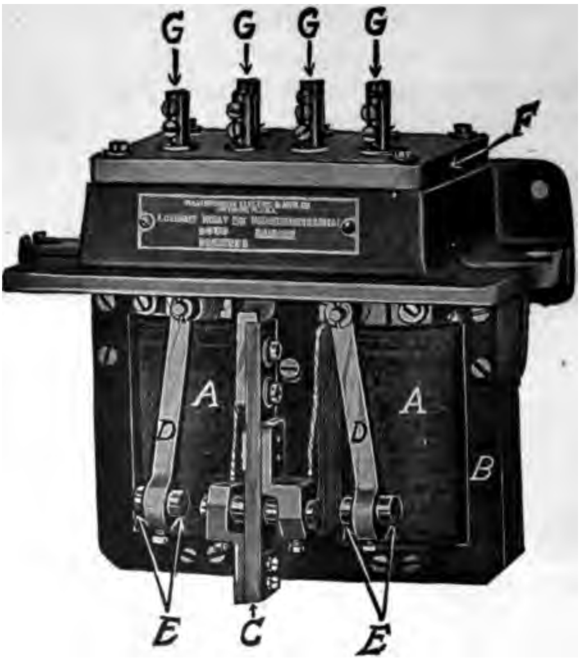


FIG. 2,427.—Westinghouse voltage regulating secondary relay; view showing relay re from oil tank. The secondary relay is practically a motor starting switch of the pole double throw type, electrically operated through the contacts of the primary It is provided with contact points of one-half inch rod. The relay is suitably con for starting, stopping and reversing the motor and for properly operating the brake. The parts are: A, solenoid; B, laminated field; C, movable contact an stationary contact arms; E, removable brass contact points; F, terminal block; minals.

Ques. **Why are two relays used?**

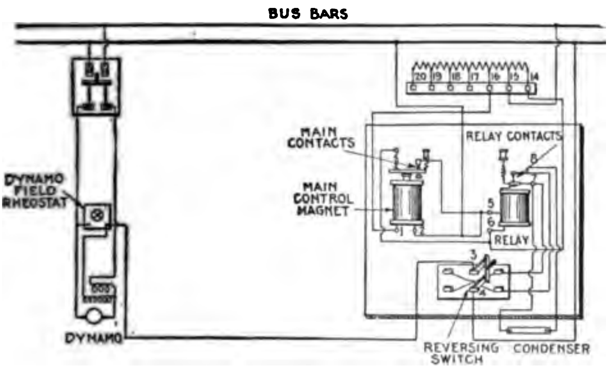
Ans. For the reason that a primary relay, of suffi *accuracy* and freedom from errors due to temperatur ıency variations, could not be made sufficiently powerful ɜrry the relatively large current required for operating the ɔr.

ues. What names are given to the relays?

ıs. Primary and secondary.

ues. What difficulties were encountered in the ration of relays?

ns. Vibration or chattering at the contacts of both relays



2,428.—Diagram of connections of General Electric **direct current** (form S) **voltage egulator, for 125, 250, and 550** volts. **The range of voltage** is given in the following table:

Regulator	Range of voltage				
	16	17	18	19	20
125.......	105	110	115	120	125
250.......	210	220	230	240	250
550.......	550				

tendency of the movable contact arm of the primary relay ıug closer to one of the stationary contact points than to the ɛr, thereby operating too often.

ues. What causes vibration or chattering at the tacts?

s. This is due to the voltage frequently approximatin the value required for closing a contact, thereby causin[contact points to barely touch and make several poor con in succession.

Ques. What objectionable action is produced vibration at the contacts?

Ans. Arcing, burning and pitting of the contacts, even alloys of the rarer metals are used, such as those of the plat group, having extreme hardness and high melting points.

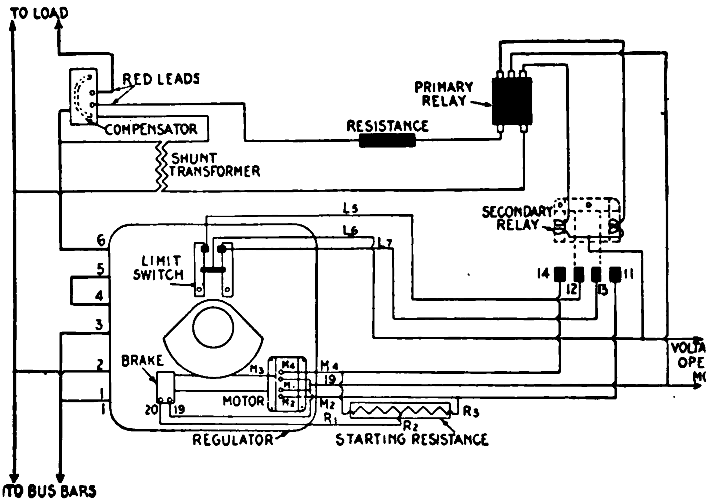


FIG. 2,429.—Diagram of connections of automatic induction regulator and auxiliary ap on single phase circuit.

Ques. What effect is produced by poor contact of primary relay?

Ans. It causes chattering in the secondary relay; burns out and wears away its contact points, increasing *heating of the motor*, creating objectionable noise and ent *wear and tear on the whole outfit.*

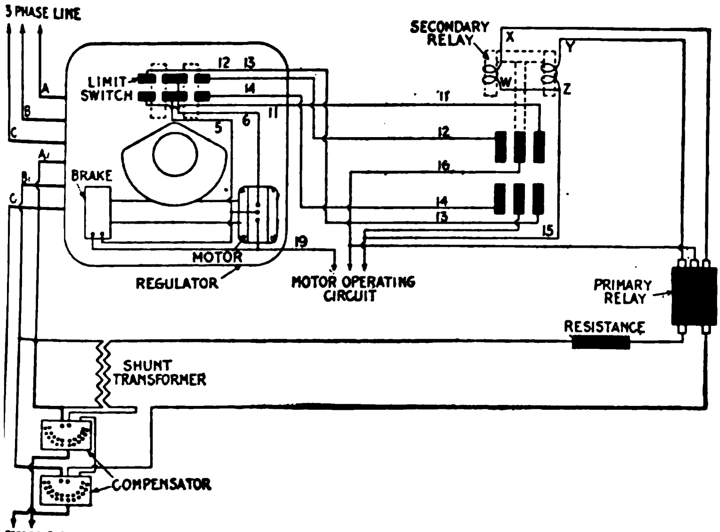
[redacted]

Ques. Why does the movable contact arm of the imary relay tend to remain nearer one of the stationary ntact points than the other?

Ans. This is due to the tendency of the relay to open the conct whenever the voltage equals that at which the contact closes.

Ques. What provision is made in the primary relay prevent vibration or chattering?

Ans. Two auxiliary windings are provided: one in series



. 2,430.—Diagram of connections of automatic induction regulator and accessory apparatus on three phase feeder circuit.

h each of the stationary contact points and so arranged as assist in making the contact by increasing the pressure on contact points at the instant of closure.

The best effect of the compounding action of the auxiliary coils is *obtainable when arranged for ½ per* cent. of the torque of the main coil.

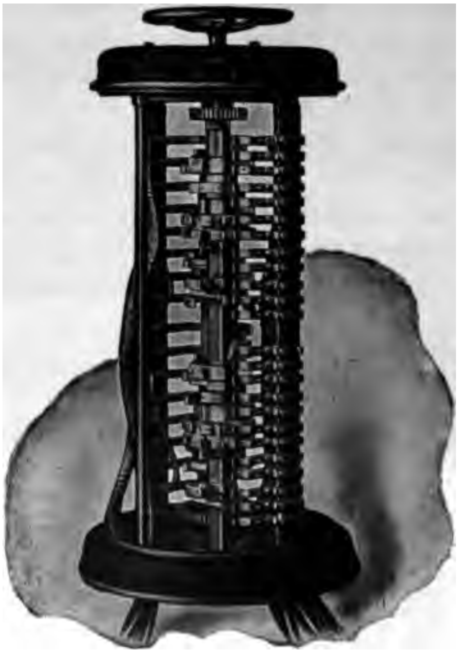
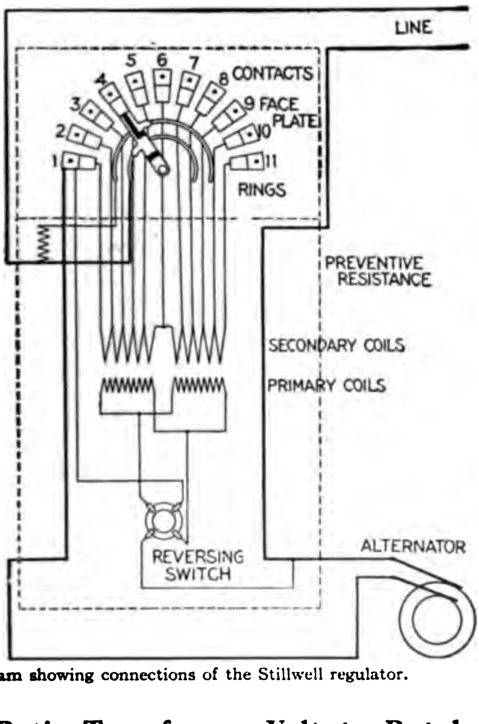


FIG. 2,431.—Westinghouse drum type variable transformer voltage regulator. It con a drum and finger type switch. A preventive resistance is used between the c contacts, making it unnecessary to open the circuit when moving from one tap regulating transformer to the next tap. A spring actuated, quick moving, centr ping mechanism is used to prevent burning the resistances. The regulator is a to give 40 points of regulation. In many cases this large number of points is no lutely necessary, but it is desirable to use them because the voltage per step is duced to a small value, and a corresponding increase in the life of the contacts because of the reduced sparking at the lower voltage. **Two drums** are employe **first drum** has ten contacts and a corresponding number of fingers, the latte mounted upon an insulated bar. These fingers are connected to the floating the regulating transformer, and as the drum is rotated, the finger connected to is brought into contact successively with each of the ten taps. The **second dr** similar construction and consists of a changing and reversing switch. It conne two floating coils to the various taps on the main secondary coil of the regulatin former at the proper time, and also reverses the transformer so that the total can be used for either raising or lowering the voltage. All the points of regula obtained by a continuous motion of the handle, the various connections produce manner are shown in the diagram, fig. 2,433. The top and base of the regulator ar of cast iron and the top is supported by steel bars, two of which are insulated, a to support the metallic bases finger to which the cable leads are attached. The consist of metal castings mounted upon insulated shafts. The first drum, whic only one upon which arcing can take place, is provided with removable copper tips. The main castings are made of aluminum to secure low inertia of the dr sheet iron cover is used to enclose the regulator, and the leads are brought out the bottom of the controller.

[redacted]

A non-inductive resistance placed in parallel with each coil of the ɔondary relay, takes current approximately in phase with the current the main coil of the primary relay, and of proper strength to make the mber of ampere turns in the auxiliary coil three-fourths per cent. of ɘ number in the main coil. The resistances have the additional effect absorbing the "discharge" from the main coils of the secondary relay ıen the contacts are broken, thereby obviating sparking at the primary ıtact points.



2.—Diagram showing connections of the Stillwell regulator.

iable Ratio Transformer Voltage Regulators.—The ɔle of operation of this class of regulator is virtually the as that of the induction type regulator; that is to say, *ɔonsist of regulating transformers,* but **in the variable** *ıethod the primary or series coil is divided* **into a numbe**

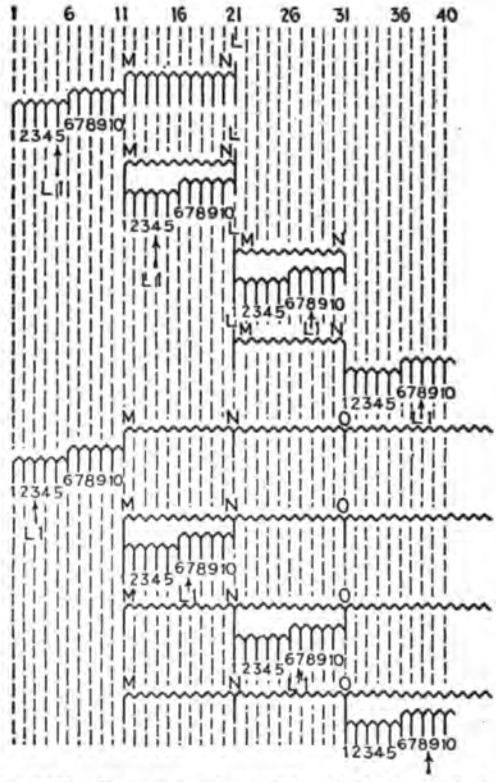


FIG. 2,433.—Diagram showing **position of the floating coil** on different steps of Westinghouse **drum type variable ratio transformer regulator.** *The upper half of the diagram* shows the connections of the various coils for each position of the regulator handle. This arrangement applies to a regulator used in connection with an independent regulating transformer. When regulators are used in connection with large power transformers, the regulating transformer can be omitted and auxiliary coils can be placed on the main transformer to provide the necessary taps for regulating purposes. *The lower half of the diagram* shows the connections used when auxiliary coils are added to a large transformer. **The diagram shows** connections for a **single phase regulator.** *Where polyphase* regulators are required, the connections *consist essentially of* two sets of single phase connection, and *the controller is* extended in length so as to contain double sets of drum and contact.

of sections which may be successively cut in or out of the circuit to be regulated, instead of varying the flux through the entire coil, as in the induction type. There are two distinct mechanical forms of variable ratio regulator:

1. Drum type;
2. Dial type.

Drum Type Regulators.—This form of variable ratio transformer consists essentially of a drum and finger type switch, similar to a railway controller.

There are many contacts, giving a large number of points of regulation, obtained by the use of changing switches and floating coils.

[redacted]

The floating coil is a part of the secondary winding of the regulating transformer which is insulated from the main portion of the winding, and is sub-divided by taps into a number of equal sections.

The sub-divisions of the main secondary winding are much larger, each one being equivalent to the whole of the floating coil.

Ques. Describe the operation of a drum regulator.

Ans. The floating coil and main windings are first connected

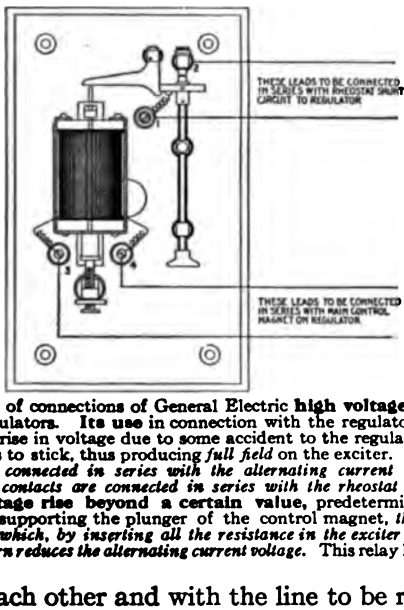


FIG. 2,434.—Diagram of connections of General Electric **high voltage cut out relay** (form A) for voltage regulators. **Its use** in connection with the regulator protects the system from any sudden rise in voltage due to some accident to the regulator which might cause the relay contacts to stick, thus producing *full field* on the exciter. **In construction,** *the control magnet is connected in series with the alternating current control magnet on the regulator and the contacts are connected in series with the rheostat shunt circuit.* Then, **should the voltage rise beyond a certain value,** predetermined by the setting of the thumb screw supporting the plunger of the control magnet, *the contacts of the relay are tripped open which, by inserting all the resistance in the exciter field, reduces the exciter voltage which in turn reduces the alternating current voltage.* This relay has to be reset by hand.

in series with each other and with the line to be regulated. The floating coil is then cut out of the circuit step by step. When entirely cut out it is transferred to the next lower tap on the main winding, after which it is again cut out step by step and then transferred again. By continuing this process a large number *of steps are provided with* but comparatively few *actual taps on the transformer.*

Ques. How many floating coils are used and why?

Ans. Two floating coils are included in each regulator so that one can be transferred while the other is supplying the current to the line.

Dial Type Regulators.—This form of variable ratio transformer regulator consists of a regulating transformer and a dial

FIG. 2,435.—Dial of Westinghouse dial type variable ratio voltage regulator. The dial consists of a marble slab, upon which the contacts are mounted in a circle as shown. The contact arm is arranged to move from contact to contact. The alternate small contacts are dummies, serving to prevent the contact arm springing down between contacts when moving from one to another. The panel contains a changing switch which makes it possible to double the range of a regulator, since the transformer connections can be changed to both raise and lower to an extent equal to the full range of the transformer. The total range in voltage from a certain per cent. below to a certain per cent. above the line voltage can be obtained in a number of steps equal to twice the number of divisions into which the secondary winding of the transformer is divided.

type switch as shown in the accompanying illustrations. The regulating transformer is similar to a standard transformer, *except that* the secondary winding is provided with a number *of taps leading* to the contact of the dial switch as shown in *the diagram fig.* 2,437.

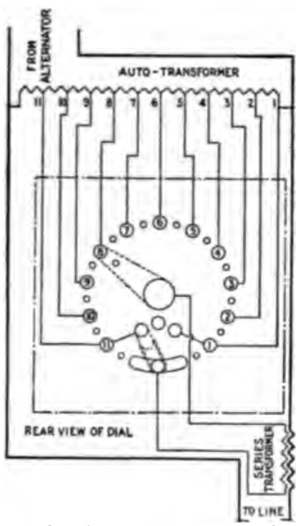
[redacted]

. What modification is made to adapt dial regu- for heavy current?

A dial with a series transformer, and a shunt or auto- rmer are employed as shown in fig. 2,436.

s. Why is such modification desirable?

. Because, the additional cost of a series transformer is



. 2,436.—Diagram of connections for Westinghouse 11 point dial, series transformer auto-transformer. The auto-transformer has a number of taps connected acros line, the series transformer is placed in series with one side of the line, and connect a dial, as shown.

nall in comparison with the cost of building a dial with a urrent carrying capacity, and the cost of bringing out a nu heavy leads from a small transformer.

Ques. How are dial regulators modified for ltage?

Ans. Standard dials may be used with series and shunt rmers *similar to the method* used for heavy current cir

Ques. Describe the connections.

Ans. The primary of the shunt transformer is across the line and the secondary has a number of t are connected to contacts on the dial. The primary o transformer is connected in series with the line and from the secondary winding are connected to the dial

The connections are similar to those shown in fig. 2,437 shunt transformers are used instead of auto-transformers.

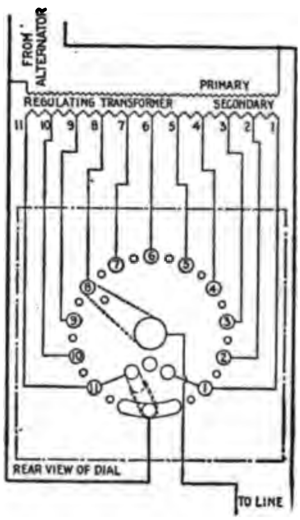


FIG. 2,437.—Diagram of connections for Westinghouse **dial type variable ratio former. In construction** the secondary winding of the transformer is 14, or 20 parts giving 11, 15, or 21 taps which are brought out from the s ing and connected to the various points of the dial. The diagram sho for an 11 point dial and regulating transformer. **Since there is a differ** between adjacent contacts, *the contact arm must not touch the contac it is moving until after it has left the contact upon which it was resting* is undesirable to open the circuit each time in moving from one conta These conflicting requirements are met by the use of arcing tips which the contact arm so that a very close adjustment can be obtained, and s the contacts are not short circuited but always have a gap of from one-e eighth inch in the circuit during the time of changing from one contact to air gaps form a "preventive resistance." **A quick moving mechanism** erate the movement from one contact to the next, a very quick moveme *sary to avoid undue arcing.* **The capacity of the regulator is 200 ampere** *being arranged to give* a maximum increase in voltage of 400 volts. The *sure between* **contacts is 25 volts.**

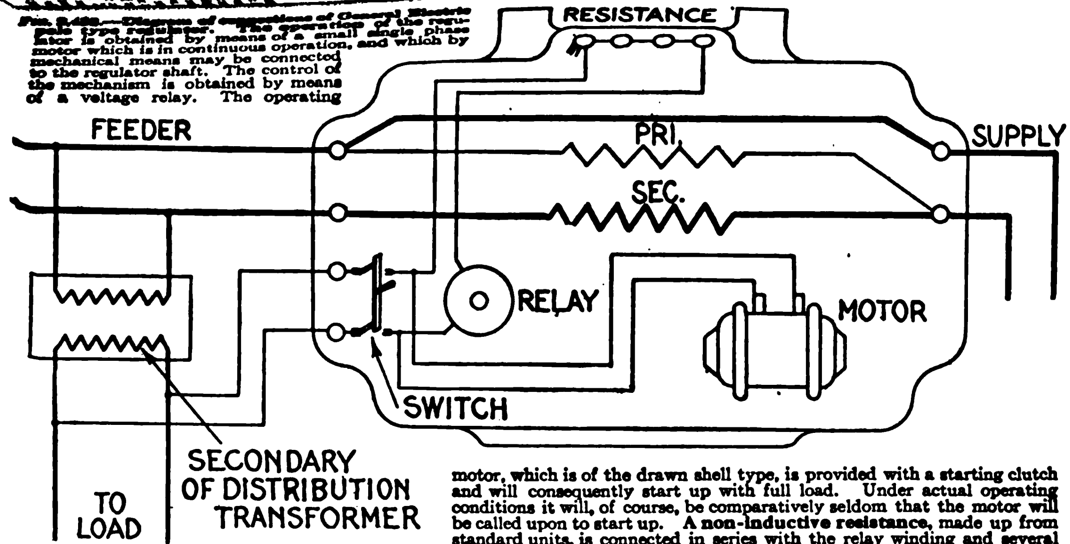
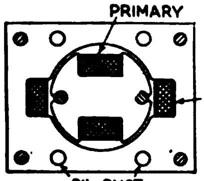


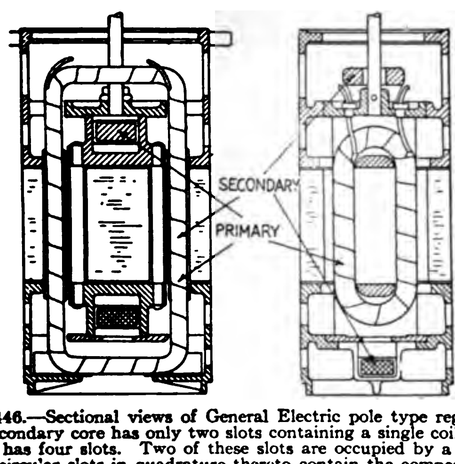
FIG. [illegible].—Diagram of connections of General Electric pole type regulator. The operation of the regulator is obtained by means of a small single phase motor which is in continuous operation, and which by mechanical means may be connected to the regulator shaft. The control of the mechanism is obtained by means of a voltage relay. The operating motor, which is of the drawn shell type, is provided with a starting clutch and will consequently start up with full load. Under actual operating conditions it will, of course, be comparatively seldom that the motor will be called upon to start up. A **non-inductive resistance**, made up from standard units, is connected in series with the relay winding and several taps are provided, so that the relay can be adjusted for any voltage from 10 per cent. below normal. In order to readily dissipate the heat developed in the resistance, it has been mounted in a pocket on the back of the tank, openings being provided for natural air ventilation. **The relay plunger** is hinged to one end of a balance arm, which arm is provided with two trip pins to control the mechanism. **An adjustable helical spring** is attached to the other end of the arm to assist the magnetic pull of the coil in balancing the plunger and also for adjustment. The relay is not provided with series winding for line drop compensation, but it may be used with a standard line drop compensator, which then has to be installed outside of the regulator. The voltage relay must be connected to the feeder side of the regulator, the necessary low voltage to be obtained from a distributing transformer, or if this should not be available in the immediate vicinity, a 200 watt step down transformer will be satisfactory. **The motor is designed to operate** in parallel with the relay, the normal connections being as shown. The speed of the motor and the ratio of the gearing is such that it requires about 90 seconds to operate the regulator from limit to limit, but, as this regulator is not intended to take care of sudden voltage fluctuations, the comparatively long time of operation will not be objectionable.

FIGS. 2,439 to 2,443.—General Electric **pole type regulator** removed from tank. **It consists essentially** *of a primary and secondary coil, operating motor, and voltage relay mechanism.* The regulator and mechanism is suspended in a cast iron tank, the lower part, containing the regulator core and coils, being filled with oil. The leads for the regulator are brought out at the upper part of the tank. The outgoing leads are compressed into bushings and connected to the leads of the regulator by means of terminals, the arrangements being such that the regulator with mechanism can be removed from the tank without difficulty. Besides the cover, the tank is also provided with a hinged door on the front side so as to give access to the mechanism. The door is provided with a gasket and the construction is practically rain and dust proof. However as there is always danger of the door not being clamped down perfectly, thus making it possible for water to enter the tank, a pocket has been provided inside the tank and underneath the door to collect the water. Capacity up to 2.3 kw., to control 2,300 volts, 60 cycle, 10 ampere feeders, and for a voltage range of 10 per cent. above or below normal, the operating motor and relay being designed for 110 or 220 volts. No provision is made for line drop compensation, although this can be obtained by installing a current transformer and a line drop compensator externally to the regulator.

[redacted]

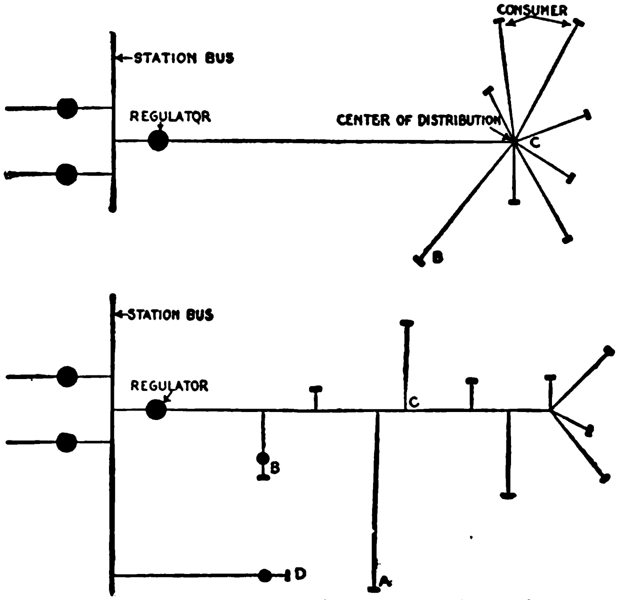
will be seen that the circuit comprising the dial, the secondary he shunt, transformer and the secondary of the series transformer ı a circuit which is not electrically connected to the main circuit. an therefore be grounded without disturbing the main circuit as a guard to render it impossible for the pressure of the dial to be higher re the ground than the secondary voltage of the shunt transformer.





to 2,446.—Sectional views of General Electric pole type regulator winding and The secondary core has only two slots containing a single coil, while the rotor or y core has four slots. Two of these slots are occupied by a single primary coil, e two circular slots in quadrature thereto contain the compensating or short cirinding. This winding also serves to hold the primary punchings together, and it s of two copper rods riveted to the two cast brass flanges. The secondary coil is round, while the primary coil is wound directly on the core. The rotor flanges, op and bottom, are provided with discs which are turned in alignment with the ngs, and these discs bear against the top and bottom flanges between which the ary punchings are clamped. These secondary flanges are also turned in alignment e secondary punchings, so that an even air gap between the primary and the secondassured. The secondary coil is wound with an opening in the upper horizontal hich affords passage for the operating shaft of the rotor. A bearing for this shaft rided in the table which supports the mechanism and from which the regulator is ded. Flexible leads are brought out from the rotor and twisted around the shaft standard regulator practice. The regulator being two pole, the rotor is turned an angle of 180 deg. to obtain the full range of the regulator.

Small Feeder Voltage Regulators.—In some gener stations the voltage is maintained constant at the busbars the line drop compensated by automatically operated lators connected in the main feeders. It is possible in this to obtain constant voltage at all loads at the various distrib centers, that is, at those points on the feeders where the lir the majority of consumers are connected as shown in fig. 2



FIGS. 2,447 and 2,448.—Systems of distribution illustrating use of **small feeder** or po voltage regulators.

It is evident, however, that, while the voltage at the c of distribution can be maintained constant, no account be taken of the drop in the lines between this center and consumers. This drop is generally negligible, except in *particularly long lines*, as, for example, consumer B in fig. 2

In order to obtain perfect regulation at B, it would be necessary to install a separate regulator in that line, this regulator to be installed either at the center C or preferably at B.

In a great many cases the power distribution is not as ideal as indicated in fig. 2,447, but rather as shown in fig. 2,448, that is, the consumers are connected all along the feeder. In this case there is no definite center of distribution, and the automatic regulator installed in the station can be adjusted to give only approximately constant voltage at an imaginary center of distribution C; that is, the voltage cannot be held constant at any definite point during changes of load distribution.

FIG. 2,449.—General Electric pole type regulator in service; its construction is shown in fig. 2,450.

The majority of the consumers may, however, obtain sufficiently good voltage while a few may have reason for criticism. To overcome this difficulty it is necessary either to increase the copper in the feeder or else to install small automatic regulators.

There are also cases where a small amount of power is transmitted a long distance through a feeder direct from the station.

The amount of copper required to reduce the line drop is usually too great to be considered and the cost of the ordinary automatic regulator is also comparatively high. *In such cases small pole type regulators as shown in fig. 2,449 are desirable.*

Ques. Describe the operation of the regulator mec ism shown in fig. 2,450.

Ans. Assuming the voltage to be normal, the balance of the relay will be held horizontal, the trips F will not e

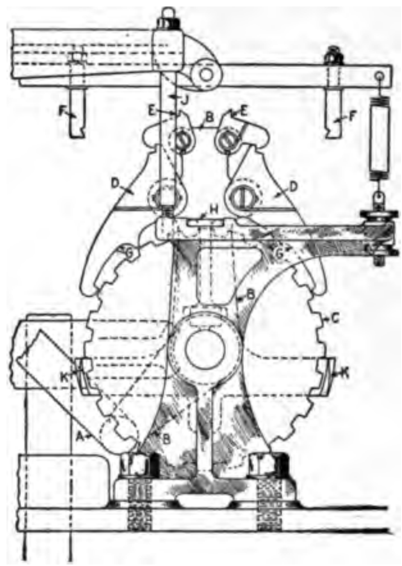
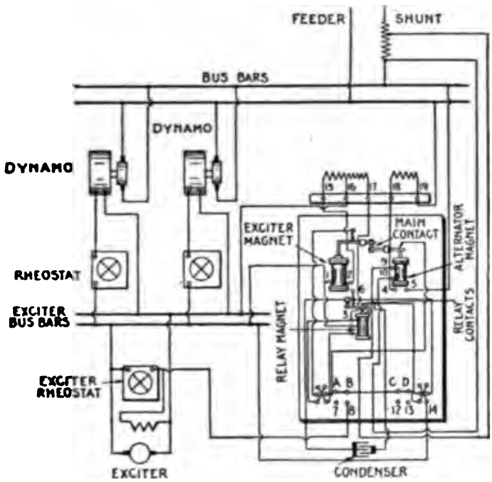


FIG. 2,450.—Mechanism of General Electric pole type regulator. The operating mo scribed in fig. 2,438) is direct connected to a worm and gear, the shaft of which vided with a bell crank. A rod A, connects the crank with the rocker arm B, wh may be caused to oscillate over a ratchet wheel C. The rocker arm is provid two pawls D, which can engage with the teeth of the ratchet wheel, so that th can be rotated one way or the other. The ratchet wheel is mounted on the san as a worm, which engages with the gear segment carried by the regulator shaft, the movement of the ratchet wheel is directly transmitted to the regulator. Bes two large pawls D, the rocker arm also carries two smaller ones E, called the t These triggers usually hold the pawls locked in such positions as not to engage ratchet wheel, but the pawls will be released when the triggers strike the trips relay arm. A limiting device for the movement of the ratchet wheel and the r segment is provided, as shown. This device consists of two cams K, mounted on mon arm, which can turn on the shaft of the ratchet wheel. Normally these c not within reach of the pawls, but through a lever arrangement, controlled by t lator segment, the arm holding the cams may be rotated so that, if the trigger h raised, so as to release the pawl, the tip of the pawl will bear on the cam of the device, and before the pawl can engage with the ratchet wheel it has already bee by its trigger. A further movement of the ratchet wheel in that particular dir therefore impossible, while it is free to be moved the other way. A positive stop gear segment is also provided. The motor is provided with oil ring bearings, gear for the motor worm runs in oil, the supporting casting forming a well there

[redacted]

he triggers E, and no movement is therefore transmitted ratchet wheel C. If the voltage drop below normal, the nd trip will descend until it finally gets in the way of the nd trigger just before it reaches the limit of its counter-ise travel. This trigger will therefore release the left), which will engage with the ratchet wheel and will



.—Diagram of connections of General Electric direct current voltage regulator T) with two dynamos and one exciter. In cases where several shunt or compound d direct current machines are operating in parallel, either on two wire or three wire ns, a good arrangement for voltage regulation and line drop compensation is ned by using this regulator and a separate exciter. The compensating shunt as well ssure wires can be used to maintain a constant pressure at the center of distribution.

uently turn it clockwise until the rocker arm reaches its ıand limit. Before the rocker arm reaches the left hand the released pawl must be locked by its trigger, so that voltage has reached its normal value, further movement ratchet wheel will not take place, whereas if the voltage . too low, the trigger will *again* release the pawl by striking *p of the relay.*

Ques. How is this automatic locking of the obtained?

Ans. By having a lip G on the under side of the paw a finger H fastened to the bearings in front of the ratchet

The pawl is thus raised just before it reaches the limit of its c travel sufficient to be locked by its trigger.

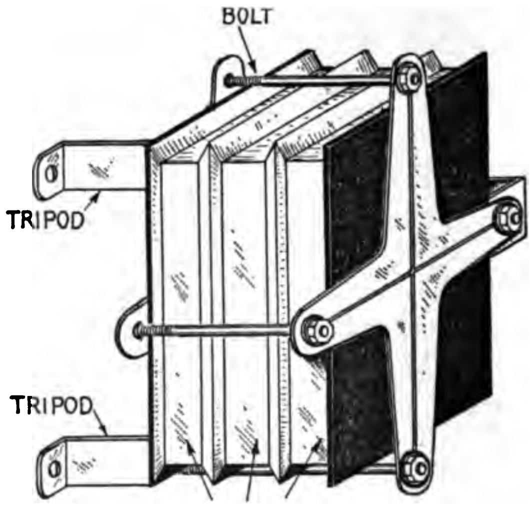


FIG. 2,452.—**Condenser sections** and method of assembling same with tripod. Tl bolts are made of extra length to accommodate the addition of extra condens if necessary. The illustration shows three sections in position.

Ques. How does the mechanism operate whe voltage rises above normal?

Ans. As described above, with the exception that th hand trip causes a rotation of the regulator in the o direction.

***Ques.* How is adjustment made for various vol**

Ans. *Taps* are provided on the resistance in series w

[redacted]

relay, and finer adjustment can be obtained by means of the helical spring on the right hand end of the balance arm.

In order to adjust the sensitiveness of regulation, the bearing for the balance arm can be raised or lowered by means of a stud J, fig. 2,450, connecting this bearing with the bearing of the operating shaft, and the regulator can be made to maintain the voltage within 1 per cent. above or below normal.

FIG. 2,453.—Westinghouse unit switch type pressure regulator, designed for handling heavy currents where a variable ratio transformer type of regulator is desired. The regulator consists of a number of electrically operated switches controlled from a master switch. These switches are arranged to perform practically the same cycle of operation as previously described for the drum type regulators. The transformer windings are divided into sections, and two floating coils are provided which are connected to various taps on the main auto-transformer. These floating coils have intermediate steps, and the successive operation of the switches connects the floating coils in proper sequence to the main auto-transformer, and transfers the line connection from one point of the floating coil to the next. In this way a 23 point regulator with sixteen switches, and a 71 point regulator with 21 switches may be supplied. The master switches are arranged with an automatic lock to prevent their being operated too rapidly. The magnet switches themselves are so interlocked that the proper sequence of operation is insured. The electrically operated switches may be of the open type, mounted on a slate or marble switchboard, when the whole control outfit is placed in a room which is comparatively free from dust or dirt of any kind, and where there is no danger of employees coming in contact with the switches. The other type of switch is entirely enclosed, the main contacts being oil immersed. The frames of these switches are grounded and the whole design is arranged to operate under ordinary dirty conditions. All of these switches, however, should receive the necessary inspection and attention. The contacts have a long life and are easily renewed. Regulators of this type are adapted for metallurgical purposes where the regulation is effected in the primary circuit and the secondary circuit is of very low voltage but large current capacity and is used for supplying power to the furnaces. These regulators have been built in capacities up to 800 amperes at 3,300 volts.

Ques. What provision is made for convenient inspection?

Ans. A snap switch is provided by means of which the power to the motor and relay can be disconnected.

Automatic Voltage Regulators for Alternators.—The accurate regulation of voltage on any alternating current system

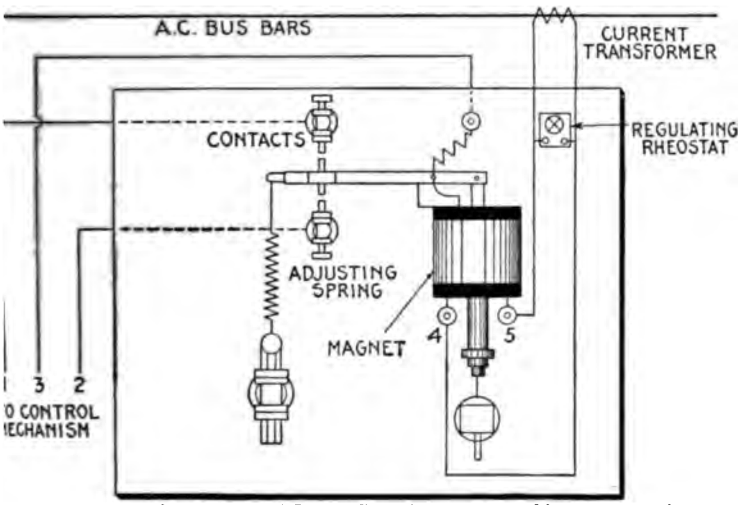
FIGS. 2,454 and 2,455.—Front and rear views of General Electric automatic voltage regulator. The regulator has *a* **direct current** *control magnet, an* **alternating current** *control magnet, and a relay.* The **direct current control magnet** is connected to the exciter bus bars. This magnet has a fixed stop core in the bottom and a movable core in the top which is attached to a pivoted lever having at the opposite end a flexible contact pulled downward by four spiral springs. For clearness, however, only one spring is shown in the figure. Opposite the direct current control magnet is **the alternating current control magnet** which has a pressure winding connected by means of a pressure transformer to the alternator or bus bars. **There is an adjustable compensating winding** on the alternating current magnet connected through a current transformer to the principal lighting feeder. The object of this winding is to raise the voltage of the alternating current bus bars as the load increases. The alternating current control magnet has a movable core and a lever and contacts similar to those of the direct current control magnet, and the two combined produce what is known as the "floating main contacts." **The relay** *consists of a* U *shaped magnet core having a differential winding and a pivoted armature controlling the contacts which open and close the shunt circuit across the exciter field rheostat.* **One of the differential windings** of the relay is permanently connected across the exciter bus bars and tends to keep the contacts open; the other winding is connected *to the exciter* bus bars through the floating main contacts and when the latter are closed, *neutralizes the* effect of the first winding and allows the relay contacts to short circuit *the exciter* field *rheostat.* **Condensers** are connected across the relay contacts to prevent *severe arcing* and possible injury.

[redacted]

; of importance. The desired voltage may be maintained ›nstant at the alternator terminals by rapidly opening and ›sing a shunt circuit across the exciter field rheostat.

Ques. Describe in more detail this method of regu-:ion.

Ans. The rheostat is first turned in until the exciter voltage ;reatly reduced and the regulator circuit is then closed. This



2,456.—Diagram of connections of General Electric ***contact making*** **ammeter** for operating on alternating current circuits. ***The instrument is designed to indicate*** with the aid of a current transformer, ***certain values of current in an alternating current system.*** This value depends upon the setting of the regulating rheostat in parallel with the pressure coil of the ammeter. It is also possible with this instrument, together with the necessary control apparatus, to *hold* certain values of current. **By using a different magnet coil** this meter may be connected to a shunt instead of a current transformer and used on a direct current system.

›rt circuits the rheostat through contacts in the regulator and : voltage of the exciter and alternator immediately rise. At a :determined *point, the regulator* contacts are automatically opened and the field current of the exciter must again pass through the rheostat. The resulting reduction in voltage is arrested at once by the closing of the regulator contacts which continue to vibrate in this manner and keep the generator voltage within the desired limits. The connections are shown in fig. 2,457.

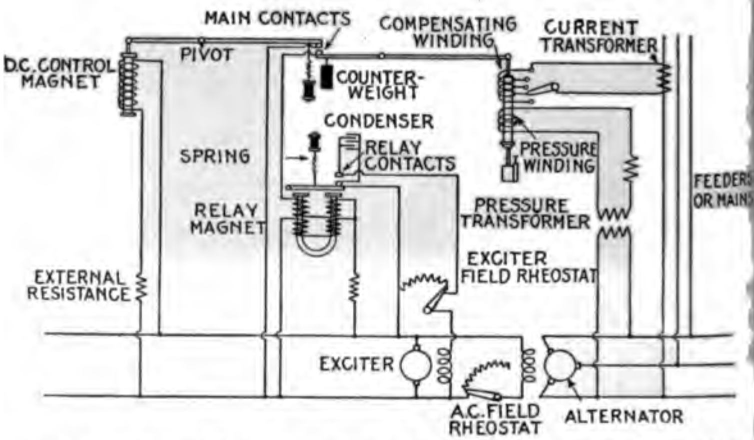


FIG. 2,457.—Diagram of General Electric automatic voltage regulator connections with alternator and exciter. **In operation,** the circuit shunting the exciter field rheostat through the relay contacts is opened by means of a single pole switch at the bottom of the regulator panel and the rheostat turned in until the alternating current voltage is reduced 65 per cent. below normal. This weakens both of the control magnets and the floating main contacts are closed. This closes the relay circuit and demagnetizes the relay magnet, releasing the relay armature, and the spring closes the relay contacts. The single pole switch is then closed and as the exciter field rheostat is short circuited, the exciter voltage will at once rise and bring up the voltage of the alternator. This will strengthen the alternating current and direct current control magnets, and at the voltage for which the counterweight has been previously adjusted, the main contacts will open. The relay magnet will then attract its armature and by opening the shunt circuit at the relay contacts will throw the full resistance into the exciter field circuit tending to lower the exciter and alternator voltage. The main contacts will then be again closed, the exciter field rheostat short circuited through the relay contacts and the cycle repeated. This operation is continued at a high rate of vibration due to the sensitiveness of the control magnets and maintains a steady exciter voltage.

***Line* Drop Compensators.**—In order that the actual voltage at a distant point on a distribution system may be read at the station some provision must be made to compensate for the line

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agram, fig. 2,458.

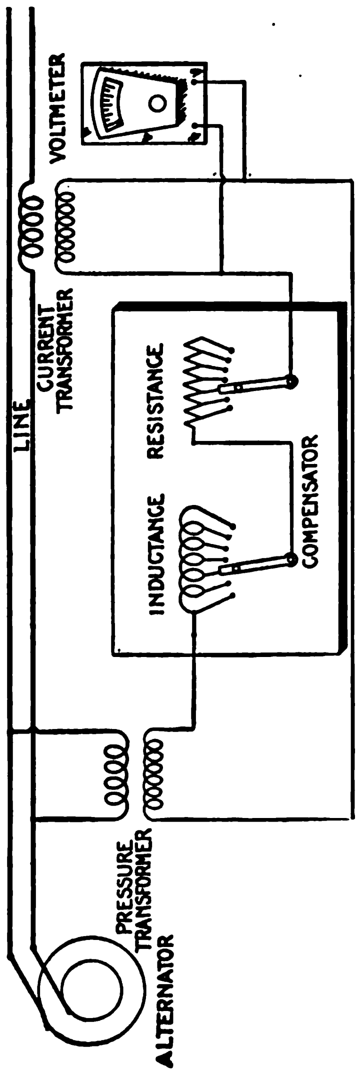


FIG. 2,458.—Diagram showing essential parts and connections for a line drop compensator. *The compensator corrects the voltmeter indication at the supply end of a feeder for the ohmic and inductive drop in pressure between that point and the point of consumption*, so that the reading of the station voltmeter corresponds with the actual voltage at the point of consumption, independent of the power factor and current. **It is especially useful for adjusting pressure regulators.**

[redacted]

Ques. How are the inductance and resistance wou

Ans. They are wound so that any proportion of the win of either can be put in or out of the voltmeter circuit.

FIG. 2,459.—General Electric line drop compensator. It has two dial switches with taps to the resistance and reactance in the box so that it can be adjusted to co sate accurately for line losses with loads of varying power factor. Dial R chan sistance, and dial X, reactance.

FIG. 2,460.—General Electric line drop compensator. This compensator contains resistance and inductance, a current transformer, the secondary of the transform connected in series with the resistance and inductance; the primary of the co current transformer is connected to an external current transformer. The reacta resistance are both so wound that any proportion of the winding can be cut in the voltmeter circuit. Both elements have 12 points of adjustment of one giving a total combined drop at maximum setting of about 17 volts.

[redacted]

Ques. How can the voltmeter indicate the pressure at the center of distribution?

Ans. If the amount of inductance and resistance be properly adjusted, there will be produced a local circuit corresponding exactly in all its characteristics to the main circuit. Hence, any change in the main circuit produces a corresponding change in the local circuit, and causes the voltmeter to always indicate

FIG. 2,461.—Westinghouse line drop compensator. For single phase circuits, one compensator and one series transformer, that is the instrument as listed with transformers, will give correct indications for a single phase circuit. The same voltage transformer serves for both voltmeter and compensator. For balanced two phase circuits one compensator and one transformer connected in one of the phases is sufficient. Two single phase compensators should be used for unbalanced two phase circuits. For three phase circuits the compensator should be connected by means of two series transformers.

the pressure at the end of the line or center of distribution or at any point for which the adjustment is made.

Ques. How should the adjustment be made?

Ans. It is advisable *to calculate* the ohmic drop for full load and *set the resistance arm* at the point which will give the

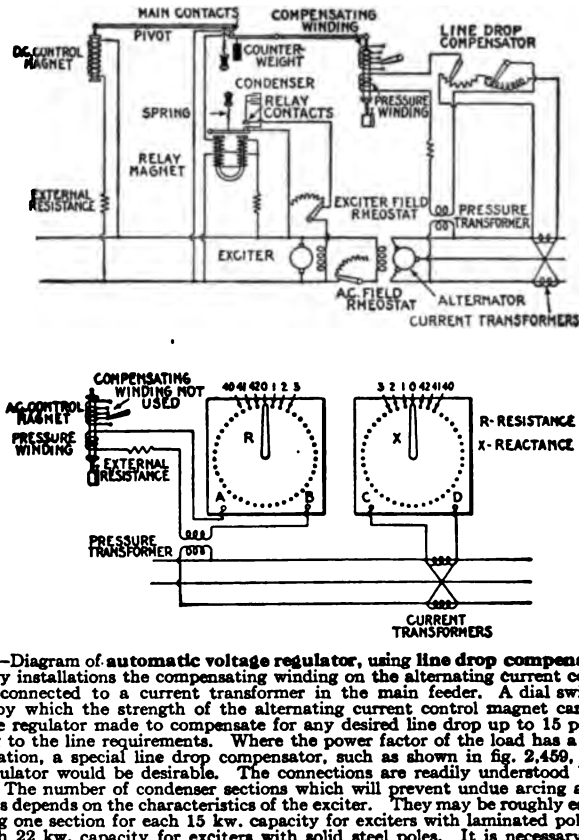


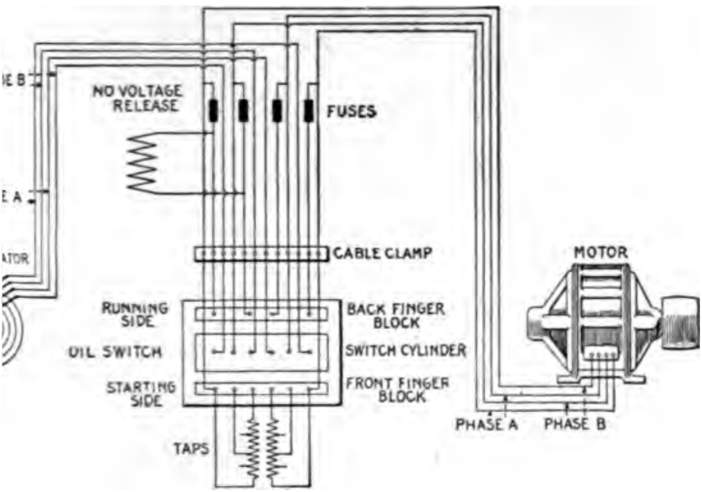
FIG. 2,462.—Diagram of **automatic voltage regulator, using line drop compensator.** ordinary installations the compensating winding on the alternating current control n net is connected to a current transformer in the main feeder. A dial switch is vided by which the strength of the alternating current control magnet can be va and the regulator made to compensate for any desired line drop up to 15 per cent, cording to the line requirements. Where the power factor of the load has a wide ra of variation, a special line drop compensator, such as shown in fig. 2,459, adapte the regulator would be desirable. The connections are readily understood by the gram. The number of condenser sections which will prevent undue arcing at the r contacts depends on the characteristics of the exciter. They may be roughly estimate allowing one section for each 15 kw. capacity for exciters with laminated poles, and for each 22 kw. capacity for exciters with solid steel poles. It is necessary thoug have one condenser section for each pair of relay contacts, and at times it becomes ne sary to apply a double section for each pair of contacts. In the lower part of the fi the line drop compensation and connections is reproduced in more detail on a larger s

NOTE.—It is desirable, in any system of distribution, to read the active voltage at point of distribution, by means of the voltmeters in the station. A compensator pr consists of a variable resistance and a variable inductance, and sometimes a current tr former. In wiring, the voltmeter, instead of being connected directly across the second *of a pressure transformer*, has inserted in series with it, portions of the resistance and *ductance of the compensator.* These are so connected that the drop in pressure across t *will be combined* with that of the pressure transformer, so that the voltmeter reading i *cates the pressure* at the center of distribution or end of the line.

[redacted]

red compensation and then adjust the inductance arm the voltmeter reading corresponds to the voltage at the on the line selected for normal voltage.

irting Compensators.—These are used for starting tion motors and consist of inductive windings (one for phase) with a number of taps connecting with switch



63.—Diagram of connections of General Electric two phase starting compen- r with no voltage release and fuses.

cts as shown in fig. 2,463. A starting compensator is r to a rheostat except that inductive windings are used in of the resistance grids.

es. Describe the inductive windings.

:. The compensator winding consists of an inductive i each phase with each coil placed on a separate leg of a ated iron core. Each coil is provided with several taps *ited that a number of* sub-voltages may be obtained.

Ques. Are starting compensators necessary for sma motors? Why?

Ans. No, because the full voltage starting current take although equal to several times the load current, is neve theless so small, compared with the capacity of the stati

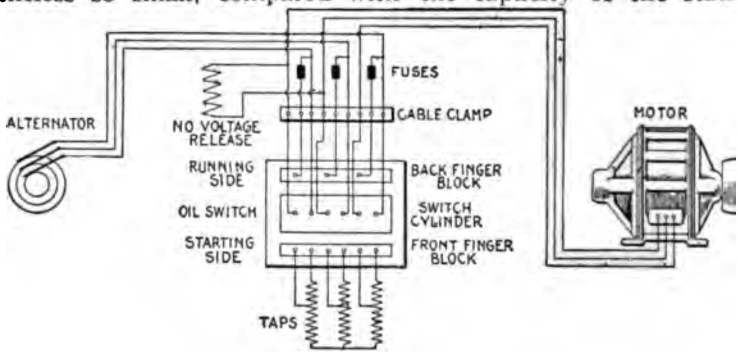


FIG. 2,464.—Diagram of connections of General Electric three phase starting compensator w low voltage release and fuses.

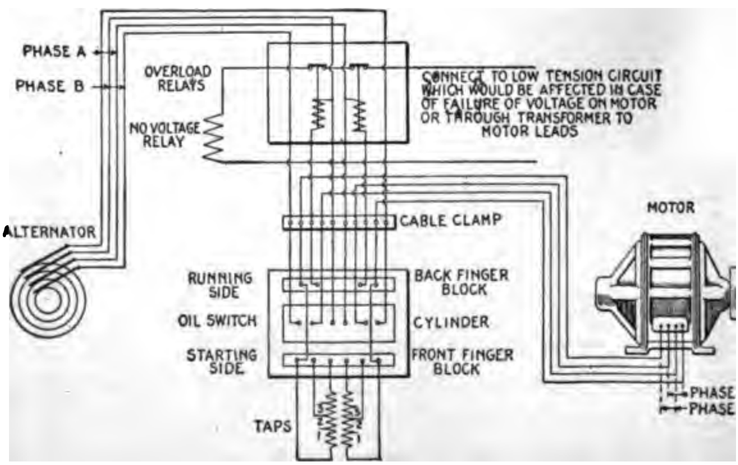


FIG. 2,465.—Diagram of connections of General Electric two phase starting comp *sator with no voltage* release and overload relays for 1,040 to 2,500 volt circuits.

[redacted]

ternators or feeders, that it does not materially affect the gulation of the circuit.

Motors larger than about 7 horse power cause an objectionably heavy rush of current if thrown directly on the line. Starting compensators obviate such sudden variations of line load and are accordingly recommended for motors above 7 horse power except in cases where voltage variations and excessive starting currents are not objectionable.

FIGS. 2,466 and 2,467.—General Electric **three phase hand operated starting compensator** Fig. 2,466, compensator in case; fig. 2,467, compensator with case removed. **The compensator consists of** *a core and windings, a cable clamp, and a switch, assembled in a substantial metal case with external operating handle and release lever.* **The windings** consist of coils wound on separate legs of a laminated core, and tapped at several points, the connections terminating at the switch contacts. The shaft of the switch extends through the sides of the compensator case, and is operated by a lever at the right, being held in the running position by a lever at the left. It is provided with wiping contacts. The switch is immersed in oil, and is intended to be used as a line switch as well as for starting the motor. **The lever has three positions:** "off," "starting," and "running." **In the off position,** *both compensator and motor windings are disconnected from the line.* **In the starting position,** *the switch connects the line to the ends and the motor to the taps of the compensator winding* without overload relays or fuses in circuit. **In the running position,** *the compensation winding is cut out and the motor is connected to the line through suitable fuses or overload relays* mounted directly above the compensator. To prevent the attendant throwing the motor directly on the line, and thereby causing a rush of current which it is the object of the compensator to avoid, an automatic latch is provided and so arranged that the lever at *off* position can be thrown only into the *starting position* (backward); and can be thrown thence into the running position (forward) *only by a quick throw of the lever,* whereby any appreciable drop in speed and consequent increase in current in passing from the starting into the running position is avoided.

Ques. What should be noted with respect to the compensator winding taps?

Ans. The choice of a tap giving so low a voltage as to require over one minute for starting should be avoided so as to prevent the overheating to which starting compensators, in common with other motor starting devices, are liable if left in circuit unnecessarily long, or if the motor be started several times in rapid succession.

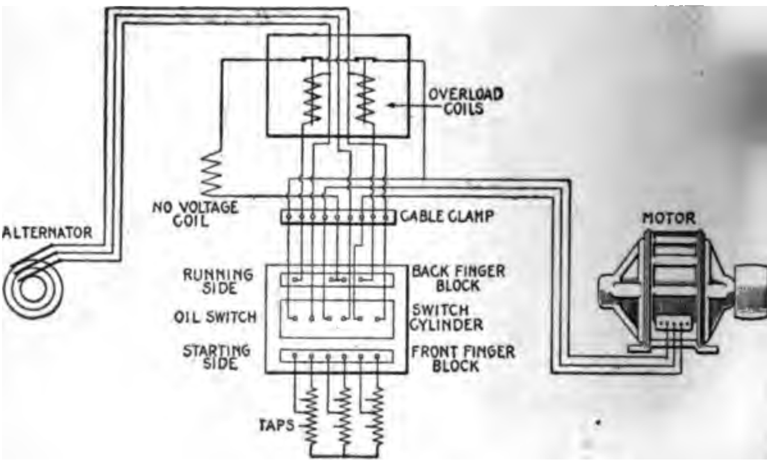


FIG. 2,468.—Diagram of connections of General Electric three phase starting compensator with no voltage release and overload relays.

It should also be noted that the starting current diminishes rapidly as full speed is approached. It is, therefore, important that the switch be kept in the starting position until the motor has finished accelerating to prevent any unnecessary rush of current when the switch is thrown to the running position.

Ques. What is the usual arrangement of starting compensators for large motors?

Ans. Starting compensators may be wound for any voltage

[redacted]

FIG. 2,469.—General Electric starting compensator with low voltage release and overload relays. On the switch shaft there are mounted two levers, held together with a strong spring which operates in either direction and prevents the switch being left on the starting position. On the running side it is held by the external low voltage release lever until released either by hand or by the action of a low voltage relay. The low voltage release consists of a cast iron frame open at the bottom and totally enclosing the coil. A laminated plunger is used to hold the tripping lever, the latter engaging with the lever mounted on the switch shaft. The compensator cannot be thrown into the running position without first going to the starting position and it *cannot be left on the starting position.*

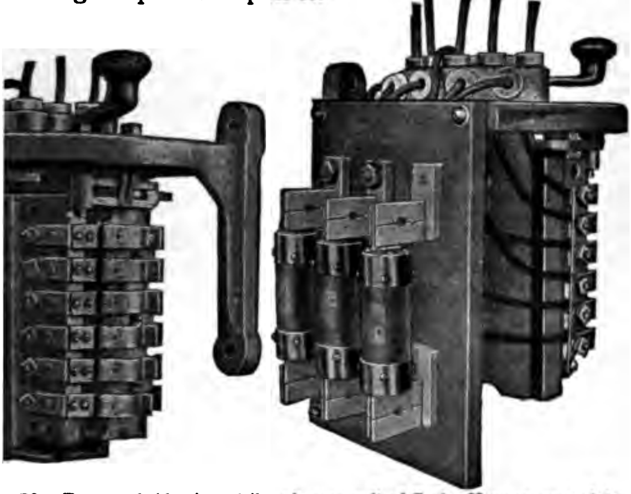
or current for which it is practicable to build motors. For very large motors the switching device is generally separate from the compensator itself and consists of triple and four pole switches for three phase and two phase motors respectively. One double throw switch or two interlocked single throw switches are required for the motor and a single throw switch for energizing the compensator, the running side of the motor circuit being provided with fuses or automatic circuit breakers, or the switches provided with low voltage and overload release attachments.

Star Delta Switches.—These are starting switches, designed for use with small three phase squirrel cage motors having their windings so arranged that they may be connected in star for starting and in delta for running.

Ques. Describe the operation of a star delta switch.

Ans. In starting the motor, *the drum lever is thrown in the* starting direction which connects the field windings o **in star.** When the motor has accelerated and has coı up to speed the starting lever is quickly thrown to · position in which position the field windings are cc

FIGS. 2,470 to 2,474.—Gene **limit overload relay** *for sator.* In case of over armature is raised and a travel, opens the small s which in turn opens th low voltage release coil c pensator switch to retu position. **The oil dash** certain time element a justed to operate immedi load or at any interval utes. Each relay has points, the lowest being load current of the m 300 per cent. full load cu on the calibration tube shows various values of the relay may be set **change overload setti** screw; 2, turn relay plur until white mark corr quired value of current screw. **Time elemen** Removing oil dash pot b left will expose the cu inside of which are two (B and C) held together nut, A. There is a h through must plunger raised. may be ing the s between is, to ha ate in a time, in the op versa. **time se** the oil the disc piston lock nu the op and C, opening of op smaller er time nut A; in pist oil dash e effect of connecting the field winding in star at o reduce the voltage applied to each phase winding, e running position each phase of the field winding voltage impressed upon it.



:,476.—Front and side views (oil tank removed) of Cutler-Hammer **star delta** *tarting small three phase squirrel cage motors.* **In construction,** the switch ne set of stationary fingers and a rotating wooden cylinder, carrying two sets These parts are supported from the switch frame casting and are enclosed ık which contains an insulating oil. Flexible oil proof cable leads are brought insulated bushings in the top of the switch and tagged for convenience in o the lines and motor. To prevent seepage of oil, the leads are sealed into ıe cover with an oil proof sealing wax. The lever of the star delta switch is th an interlock which prevents its being thrown directly into the running n the off position. It is necessary to throw the lever first into the starting then with an uninterrupted movement to the running position. The circuit · is broken only for an instant in changing from star to delta and no heavy ıt occurs. **No voltage release** protection is provided by a latching solenoid the spring centered drum cylinder in the running position. The no voltage s mounted in the lower part of the starting switch, immersed in the oil tank, :ted against mechanical injury and grounding. The coil is in circuit during period only and requires not more than 8 to 15 watts to hold the switch in position. The operation of this protective device is such that on failure of ;tar delta switch will immediately be returned to the off position. **Overload** ection consists of two relays on a small slate panel, which is mounted directly f the star delta switch. The switch contacts of the overload release are con- ies with the connections to the no voltage release coil so that when an over- :he overload relay operates to open the circuit to the no voltage release coil, ing the switch lever to return to the off position. The overload relays do not ad protection during the starting period, and when such protection is desired s should be installed. *These fuses, if used, should have a capacity of 250 to . of the normal full load current of the motor.*

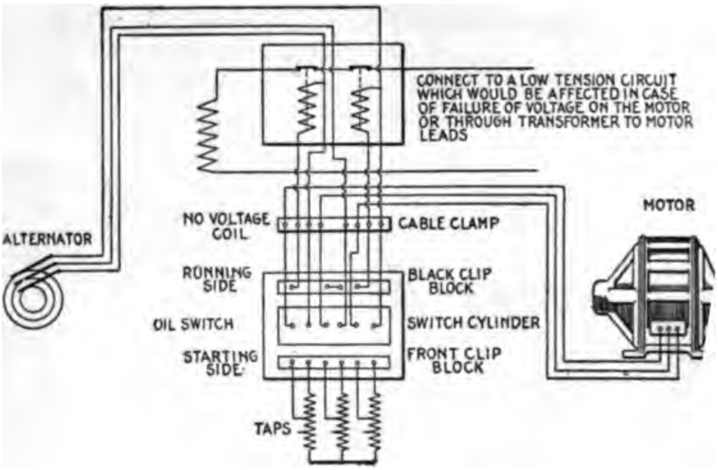


Fig. 2,477.—Diagram of connections of General Electric three phase starting co with low voltage release and overload relays for 1,040–2,500 volt circuits.

CHAPTER LXI

SYNCHRONOUS CONDENSERS

Synchronous Condensers.—A synchronous motor when sufficiently excited will produce a leading current, that is, when over excited it acts like a great condenser, and when thus operated on circuits containing induction motors and similar apparatus for the purpose of improving the power factor it is called a *synchronous condenser*.

Although the motor performs the duty of a condenser it possesses almost none of the properties of a stationary condenser other than producing a leading current, and is free from many of the inherent defects of a stationary condenser.

The relation of power factor to the size and efficiency of prime movers, generators, conductors, etc., and the value of synchronous condensers for improving the power factor is generally recognized.

Induction motors and other inductive apparatus take a component of current which lags behind the line pressure, and thereby lowers the power factor of the system, while a non-inductive load, such as incandescent lamps, takes only current in phase with the voltage and operates at unity power factor.

Since transformers require the magnetizing current, they may seriously affect the power factor when unloaded or partially loaded, but when operating at full load their effect is practically negligible.

The relative effect of fully loaded and lightly loaded induction motors on the power factor is indicated by the diagram, fig. 2,478. The magnetizing current is nearly constant at all loads and is wattless, lagging 90 degrees behind the impressed pressure, or at right angles to the current which is utilized for power.

In the figure, AB is the magnetizing component, which is always wattless, and CB the power component. The angle ACB gives the phase relation between voltage and current; the cosine of this angle CB ÷ AC is the power factor.

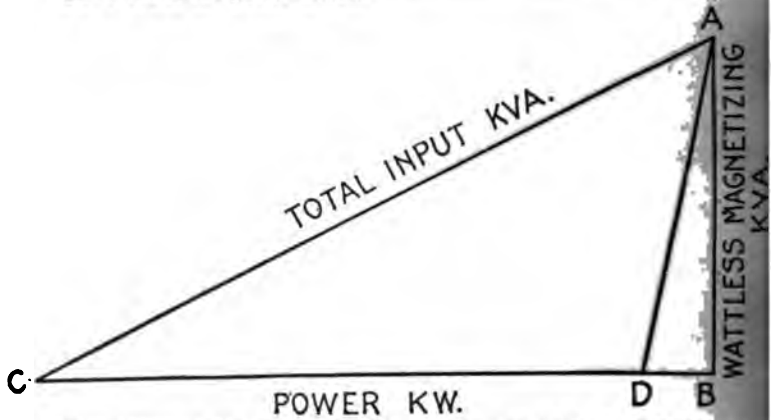


FIG. 2,478.—Diagram showing relative effect of fully loaded and lightly loaded induction motors on power factor.

It is evident from the diagram that if the load be reduced, the side CB is shortened, and as AB is practically constant, the angle of lag ACB is increased. It therefore follows that the cosine of this angle, or the power factor is reduced.

The figure clearly shows the reason for the low power factor of induction motors on fractional loads and also shows that since the magnetizing current is practically constant in value, the induction motor can never operate at unity power factor.

With no load, the side CB (real power) is just sufficient to supply the friction and windage. If this be represented by DB, since AB remains constant, the power factor is reduced to 10 or 15 per cent. and the motor takes from the line about 30 per cent. of full load current. It therefore follows that a group of lightly loaded induction motors can take from the system a large current at exceedingly low power factor.

The synchronous motor when used as a condenser, as before stated, has the property of altering the phase relation between pressure and current, the direction and extent of the displacement being dependent on the field excitation of the condenser.

It can be run at unity power factor and minimum current input, or it can be over excited and thereby deliver leading current

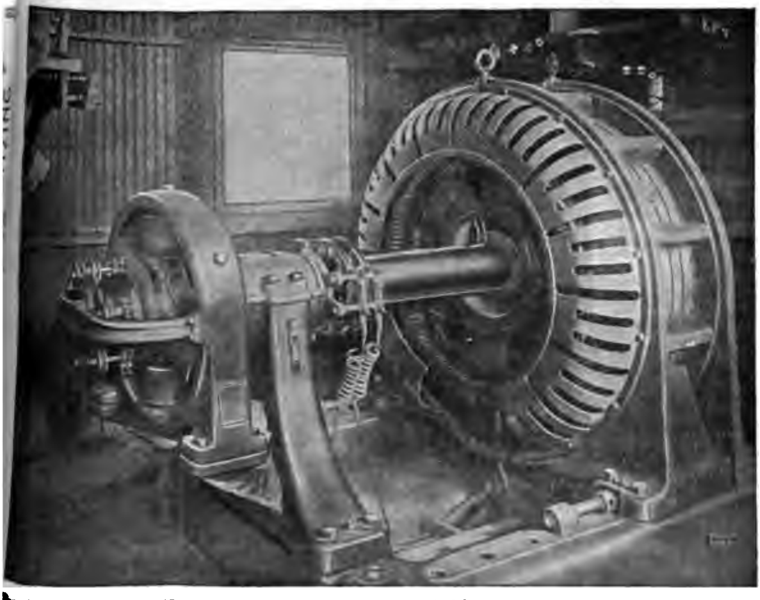


Fig. 2479.—General Electric 400 kw., 550 volt, 600 R.P.M., **synchronous condenser** with direct connected exciter installed in sub-station No. 1 of the Colorado Light & Power Co., Cripple Creek, Colo. The machine is designed for alternating current starting by means of a compensator. The field is provided with a standard synchronous motor winding, and, in addition, an amortisseur winding which assists in starting and serves as a damping device to minimize hunting.

hich compensates for the inductive load on other parts of the stem. The synchronous condenser, therefore, can supply agnetizing current *to the load on* a system while the power *mponent is supplied by the generators.*

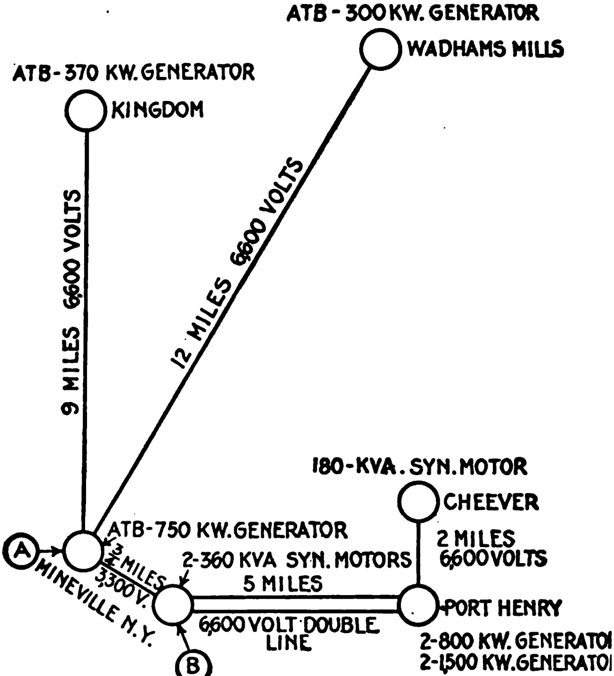


FIG. 2,480.—Diagram showing relative location of alternators and synchronous : plant of Witherbee Sherman & Co., Mineville N. Y. The distribution system of pany is provided with three synchronous motors, as shown. The system inc hydro-electric, one turbine driven, and one engine driven generator plants; fro these, current is transmitted to the fourth, which is located in Mineville, at the p the current being distributed to the motor circuits from the points "A" and " transmission to the central station at Mineville is over three phase circuits at 6, For operating the mine at Cheever, current is transmitted direct from the g station at Port Henry. The distribution from "A" and "B" is all at 3,300 v stepped down to 440 volts for the operation of the motors, which have a total ra ity of 4,762 horse power. Excepting three synchronous motors, the load is prac inductive, there being less than 10 kw. required for lighting. The actual powe ranges from 60 to 65 per cent. of the rated motor capacity, and prior to the i of the synchronous motors, the power factor was approximately 68 per cent., denser effect of these motors making it possible to maintain an average of ab cent. power factor in spite of the fact that a considerable portion of the induct load is very widely distributed. The three synchronous motors are partially lo motor driving an air compressor through belting. The 180 kva. motor at Che about 150 kw. for the operation of a 1,250 cubic foot compressor, while the two *machines* take about 300 kw. each, for the operation of two 2,500 cu. ft. s *operation of these* compressors affords a method of utilizing a portion of the mo *ity mechanically,* inasmuch as the load on the motors is practically constant d *time the mines are in* operation, and thereby permit the motors to be run at appr *80 per cent.* power factor.

[redacted]

Effects of Low Lagging Power Factors.—Transformers are rated in kva. output; that is, a 100 kva. transformer is supposed to deliver 100 kw. at unity power factor at normal voltage and at normal temperatures; but, if the power factor should be, say .6 lagging, the rated energy output of the transformer would be only 60 kw. and yet the current and, consequently, the heating would be approximately the same as when delivering 100 kw. at unity power factor.

FIG. 2,481.—Field of a synchronous condenser Note the **amortisseur winding,** *erroneously* called ***squirrel cage*** **winding,** consisting of two end rings which serve to short circuit spokes passing through the pole tips as shown. **The amortisseur winding** *assists in* **starting** *and serves also as a damping device to minimize* **hunting.**

The regulation of transformers is inherently good, being for small lighting transformers about 1½ to 2 per cent. for a load of unity power factor, and about 4 to 5 per cent. at .7 power factor. Larger transformers with a regulation of 1 per cent. or better at a unity power factor load, would have about 3 per cent. regulation at .7 power factor.

Alternators also are rated in kva. output, usually at any value of power factor between unity and .8.

The deleterious effects of low power factor loads on alternators are even more marked than on transformers. These are, decreased kw. capacity, the *necessity* for increased exciter capacity, *decreased efficiency, and impaired* regulation.

Assume the case of a 100 kva. .6 power factor, 60 kw. output. It is probable that normal voltage could be obtained only with difficulty, unless the alternator was especially designed for low power factor service. The lagging power factor current in the armature sets up a flux which opposes the flux set up by the fields, and in consequence tends to demagnetize them, resulting in low armature voltage.

It is often impracticable, without the installation of new exciters, to raise the alternator voltage by a further increase of the exciting voltage and current. The field losses, and therefore the field heating of

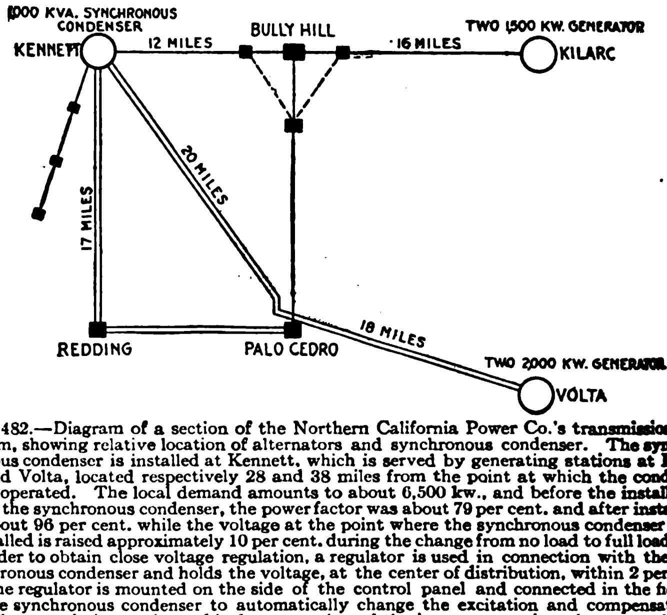
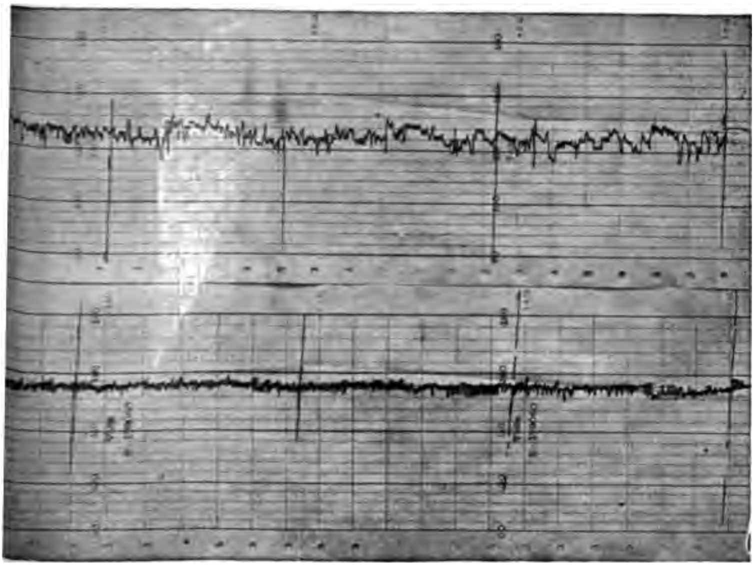


FIG. 2,482.—Diagram of a section of the Northern California Power Co.'s transmission system, showing relative location of alternators and synchronous condenser. The synchronous condenser is installed at Kennett, which is served by generating stations at Kilarc and Volta, located respectively 28 and 38 miles from the point at which the condenser is operated. The local demand amounts to about 6,500 kw., and before the installation of the synchronous condenser, the power factor was about 79 per cent. and after installing about 96 per cent. while the voltage at the point where the synchronous condenser is installed is raised approximately 10 per cent. during the change from no load to full load. In order to obtain close voltage regulation, a regulator is used in connection with the synchronous condenser and holds the voltage, at the center of distribution, within 2 per cent. The regulator is mounted on the side of the control panel and connected in the field of the synchronous condenser to automatically change the excitation and compensate for voltage variations. A graphic demonstration of the improvement in voltage regulation, which has been secured in this case, is given by the curve drawing voltmeter records reproduced in fig. 2,483.

the alternator, when it is delivering rated voltage and current, are greater at lagging power factor than at unity. Increased energy input and decreased energy output both cause a reduction in efficiency.

The regulation at unity power factor of modern alternators *capable of carrying* 25 per cent. overload, is usually about 8 per it. Their regulation at .7 power factor lagging is about 25 cent. The effect of low power factor on the lines can best be own by the following example:

EXAMPLE.—Assuming a distance of five miles and a load of 1,000 kw. and desiring to deliver this load at a pressure of about 6,000 volts, three phase, with an energy loss of 10 per cent., each conductor at unity power factor would have to be 79,200 c.m., at .9 power factor, 97,533 c.m.,



G. 2,483.—Curve drawing voltmeter records at Kennett, Cal. The upper curve shows voltage regulation with synchronous condenser out of service, and the lower curve, with synchronous condenser in operation.

and at .6 power factor, 218,000 c.m. In other words, at the lower power factor of .6, the investment in copper alone would be 2.8 times as much.

If the same size of wire were used at both unity and .6 power factor lagging, the energy loss would be about 2.8 times the loss at unity power factor, or about 28 per cent. Low lagging power factor on a system, therefore, will generally mean limited output of prime movers; greatly reduced kilowatt capacity of generator, transformer and line; and increased energy losses. *The regulation of the entire system will also be poor.*

Cost of Synchronous Condenser vs. Cost of Cop]
—Referring to the example given in the preceding paragr: and calculating the necessary extra investment in co] with the .6 power factor load, and copper at 17 cents pound, the result is that 29,292 pounds more copper is requ than with the power factor of .9 which means a total extra inv ment in copper alone of $5,000 (29,292 x $.17). A synchroı

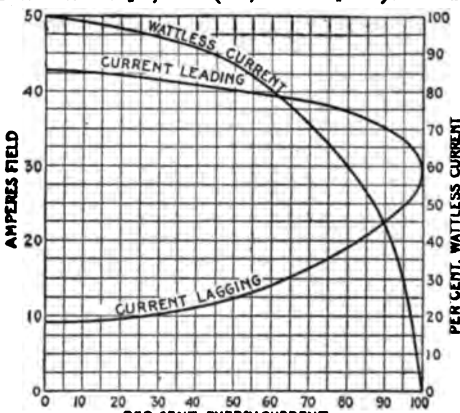


FIG. 2,484.—Diagram showing the **field current taken by a synchronous motor** of n design when operating at normal kva. input at various power factors. **It will be** ı that a **slight departure from unity power factor necessitates a considerable ch in field current.** As the field curves increase with the square of the current, the rapid increase in temperature with leading current. *This action of leading or laggin rent serves automatically to keep the flux constant in the armature with changes in field ation.* **When the motor is running at unity power factor,** an increase in field ation causes a leading current to flow, and at the same time this leading current dem izes the field until the density of the armature is restored to its normal value. **If the be decreased** a lagging current flows which in turn magnetizes the field bringin density back to its original value. Therefore, with a constant line voltage, the iron in a synchronous motor are approximately constant irrespective of the field exciti with the exception that the internal voltage will vary slightly due to the armatur drop, the density being a trifle lower at full load than at no load.

condenser of sufficient capacity to accomplish the sı result would cost about the same amount. It would there cost less to install the condenser because at the same tir *considerably* increased capacity would be obtained from *alternators*, transformers, etc.

Synchronous Condenser Calculations.—In figuring on the installation of a condenser for correcting power factor troubles, a careful survey of the conditions should be made with a view of determining just what these troubles are and to what extent they can be remedied by the presence of a leading current in the system.

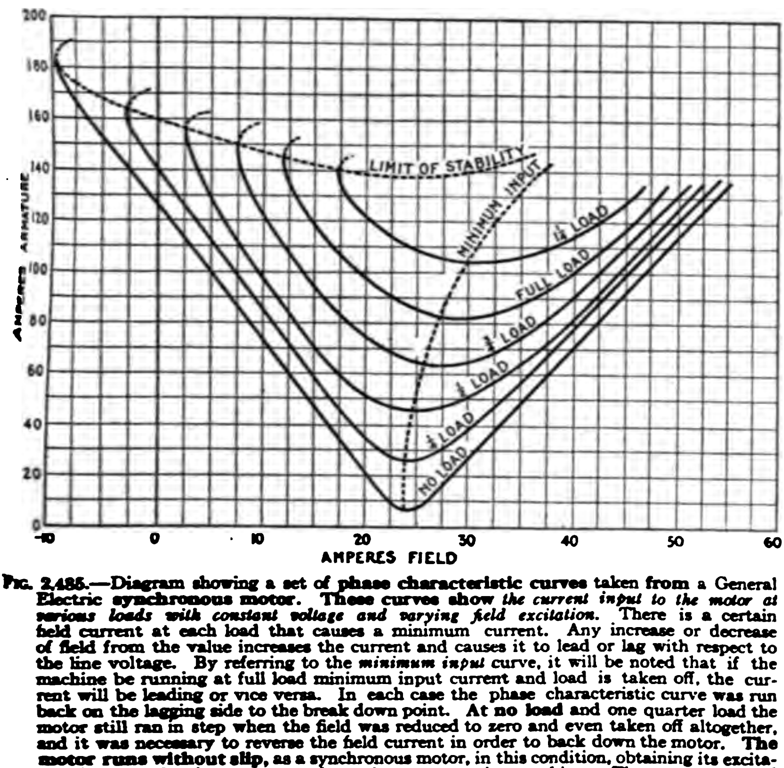


FIG. 2,485.—Diagram showing a set of phase characteristic curves taken from a General Electric synchronous motor. These curves show *the current input to the motor at various loads with constant voltage and varying field excitation*. There is a certain field current at each load that causes a minimum current. Any increase or decrease of field from the value increases the current and causes it to lead or lag with respect to the line voltage. By referring to the *minimum input* curve, it will be noted that if the machine be running at full load minimum input current and load is taken off, the current will be leading or vice versa. In each case the phase characteristic curve was run back on the lagging side to the break down point. At no load and one quarter load the motor still ran in step when the field was reduced to zero and even taken off altogether, and it was necessary to reverse the field current in order to back down the motor. The motor runs without slip, as a synchronous motor, in this condition, obtaining its excitation from the lagging current and running as a reaction machine. The amount of load a machine will carry without field varies with the design, the average being about 40% of full load. It will be noted from the *limit of stability* curve that the lighter the load on the machine when it breaks down from lack of sufficient excitation, the greater the current input at this point. *The no load characteristic* rises sharply on each side with *slight change in field current, while it flattens* out with increase in load until at *overload the current input is practically* the same throughout a large range of field current.

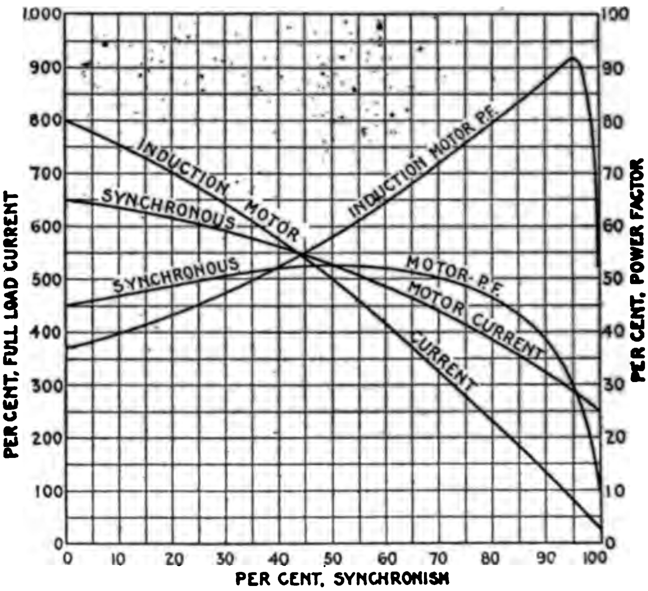
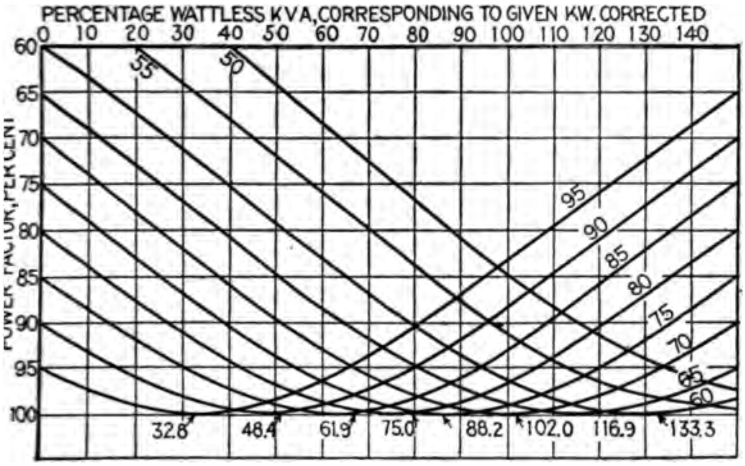


FIG. 2,486.—Comparison of the speed current curves and speed power factor curves of a typical synchronous, and induction motor. It will be noted that the power factor of the synchronous motor at start is higher than that of the induction motor owing to the higher resistance of the squirrel cage winding. As the machine approaches synchronism, however, the magnetizing current of the induction motor drops to a very much lower value than in the synchronous motor and the power factor is consequently much higher. The magnetizing current of the induction motor at full speed is usually 25 per cent. of full load current while that of the synchronous motor is from 200 to 250 per cent. of full current, or even higher when running full speed and normal voltage. This of course is due to the large air gap on the synchronous machine. The current at start with full voltage applied is usually higher in an induction motor owing to the fact that the total impedance of the stator and rotor are less due to the greater distribution of the windings and the lower resistance of the squirrel cage. The high magnetizing current of a synchronous motor should not be lost sight of as it is a very important consideration in starting the machine. Even though the motor can be brought practically to synchronous speed while still on the compensator, if line voltage be thrown on, there will be a very heavy rush of current. The obvious thing to do is to get the field on the motor while still on the compensator, whenever possible, to avoid the high magnetizing current. This magnetizing current is obviously equal to the circuit current of the machine at no load field. In some cases additional torque near synchronism can be obtained by short circuiting the field winding through the field rheostat. This has the effect of reducing the resistance of the rotor winding to some extent and causing the motor to have less slip with a given load. The gain from this source is small, however, in most cases, as the self-inductance of the field winding is so high as to allow very little current to flow even if the field be short circuited so that the total effective resistance of the rotor winding is not materially reduced. In some cases where the torque is nearly sufficient, however, enough gain may be obtained to take care of the conditions. If the field be short circuited before the motor is started there will be a reduction in starting torque and an increase in current from the line, hence if this method be resorted to, arrangements must be made to short circuit the field after the motor has come to constant speed.

[redacted]

It is necessary to possess a thorough knowledge of the system, vering the generating capacity in energy and kva., average and aximum load, and power factor on the alternators, average and aximum load, and power factor on the feeders, system of dis- bution, etc.

The desirable location of a condenser is, of course, nearest the ductive load in order to avoid the transmission of the wattless



2,487.—**Curves showing amount of wattless component required to raise the power factor of a given kw. load to required higher value. The wattless components are expressed as percentages of the original kw. load. The numbers at the right which indicate the points of tangency of the power factor curves to the 100 per cent. line, show the amount of wattless component required to raise a given kw. load of given lagging power factor to unity power factor. Obviously the addition of further wattless component in a given case would result in a leading power factor less than unity.**

irrent, but it often happens that a system is so interconnected iat one large condenser cannot economically meet the conditions, which case it may be better to install two or more smaller ones.

The question of suitable attendance should also be considered id. for this reason, *it may be necessary to compromise on the ation. When the location of the condenser has been deci* upon and the load and power factor within its zone determin the proper size of condenser to raise the power factor to a gi value can be found as follows:

The method of procedure can best be explained by reference t concrete case. Assume a load of 450 kw. at .65 power factor. I desired to raise the power factor to .9. What will be the rating of condenser?

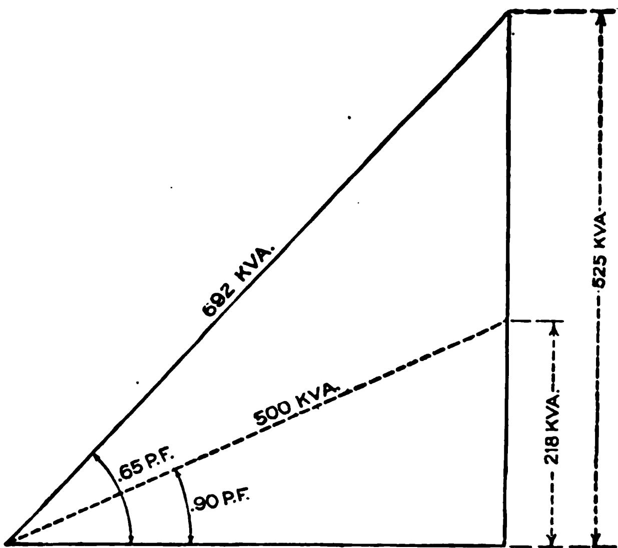


FIG. 2,488.—Diagram for synchronous condenser calculations.

Referring to the diagram, fig. 2,488, it is necessary to start with 4 kw. At .65 power factor, or 692 kva., this has a wattless lagging co ponent of $\sqrt{692^2-450^2}=525$ kva. With the load unchanged and power factor raised to .9, there will be 500 apparent kva., which will h a wattless component of $\sqrt{500^2+450^2}=218$ kva.

It is obvious that the condenser must supply the difference betw 525 kva. and 218 kva., or 307 kva. A 300 kva. condenser wo *therefore,* meet the requirements.

If it be desired to drive some energy load with the condenser still bring the total power factor to .9, proceed as indicated in fig. 2

[redacted]

e a total load of 150 kw. on the motor. As before, 450 kw. at wer factor, or 692 kva., with a wattless component of 525 kva.

energy load will be increased from 450 to 600 kw. as indicated, th the power factor raised to .9 there will be a kva. of 667 with a ss component of $\sqrt{667^2+600^2}=291$.

re must be supplied 525 − 291 = 234 in leading kva.

synchronous motor then must supply 150 kw. energy and 234 vattless, which would give it a rating of $\sqrt{150^2+234^2}=278$ kva. power factor.

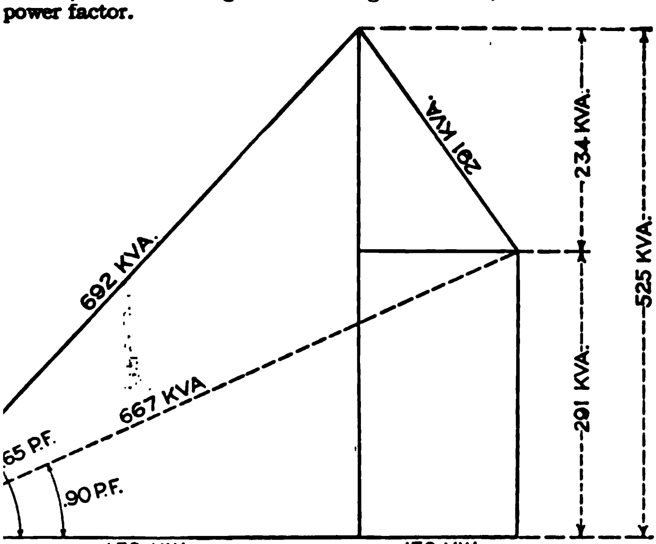


Diagram for synchronous condenser calculation for cases where it is desired to e energy load with the condenser and still bring the total power factor to .9.

standard 300 kva. condenser would evidently raise the power slightly above .9 power factor leading.

reference to the chart, fig. 2,490, the size of the required condenser e obtained direct without the use of the above calculation. The d of using this curve is as follows: Assume a load of say 3,000 kw. ower factor and that it be desired to raise the power factor to .9. p the vertical line at 3,000 kw. to the .7 power factor line, and from along the horizontal line to the margin and find a wattless comt at this power factor of 3,000 kva., approximately. Again run 3,000 kw. *vertical line to the* .9 power factor line and from there *the horizontal line to the* margin and find a wattless component of 1,500 kva. The rating of the condenser will then be 3,000 kva. − 1,500 kva. = 1,500 kva. This table of course can be used for hundreds of kilowatts as well.

For determining the rating of a synchronous motor to drive an energy load this curve is not so valuable, although it can be used in determining the wattless component direct in all cases where the energy component

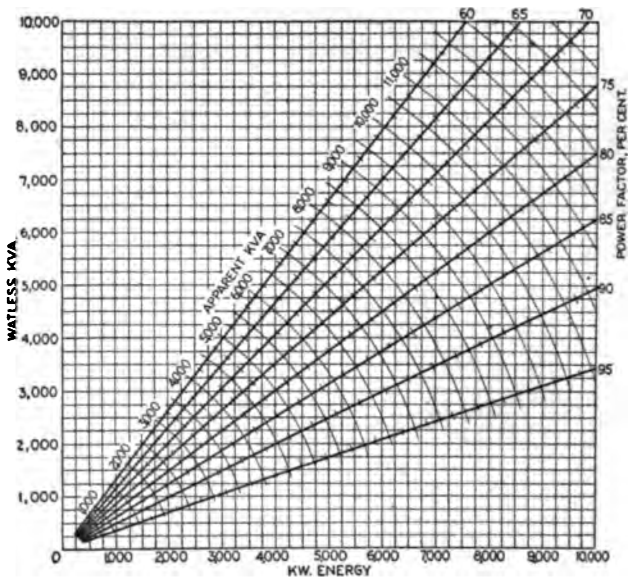


FIG. 2,490.—Curve showing the relation of energy load to apparent load and wattless components at different power factors.

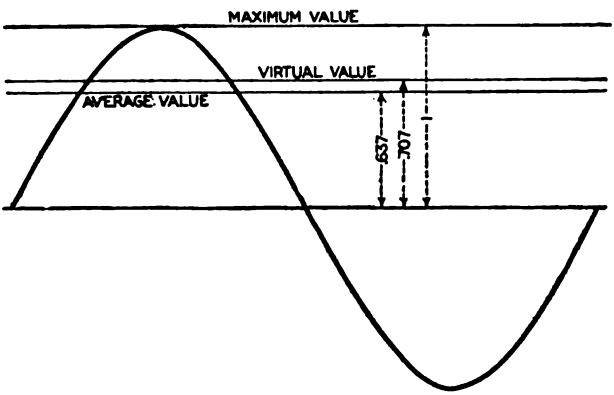
and power factor are known. Knowing this energy component and power factor or wattless component, the energy load can obviously be found by referring to the curved lines on the diagrams, the curve that crosses the junction of the vertical energy line and the power factor or wattless component line giving the total apparent kva.

[redacted]

CHAPTER LXII

INDICATING DEVICES

:ernating current ammeters or voltmeters indicate the *il* values of the current or pressure respectively, that is to they indicate, *the square root of the mean square of a variable ity.*



491.—Line curve of alternating current, illustrating various current or pressure values. he virtual value, or .707 × maximum value, is the value indicated by an ammeter or voltleter. Thus, if the maximum value of the current be 100 volts, the virtual value as indiated by an ammeter is 100 × .707 = 70.7 amperes.

he virtual value of an alternating current or pressure *is valent to that of a direct current or pressure which would produce ame effect.*

For instance *an alternating current of 10* virtual amperes will produce *the same heating effect as 10* amperes direct current.

The relation of the virtual value of an alternating c the other values is shown in fig. 2,491. When the curre the sine law, the square root of the mean square, val sine functions is obtained by multiplying their maxim by $1 \div \sqrt{2}$, or .707.

The word **effective** is commonly used *erroneously* fo even among the best writers and the practice cannc strongly condemned*.† The difference between th

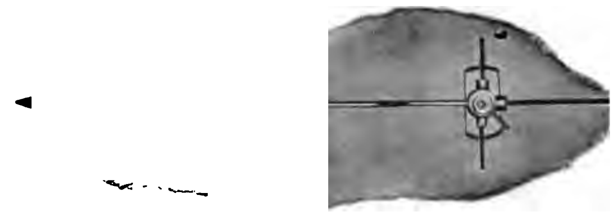


FIG. 2,492.—Wagner tubular aluminum pointer.

illustrated in Guide No. 5, page 1,013, fig. 1,237, the m analogy here given may make the distinction more ma

In the operation of a steam engine, there are two pressure the piston:

1. The *forward* pressure;
2. The *back* pressure.

The forward pressure on one side of the piston is that due steam from the boiler, and the back pressure, on the other sic to the resistance or opposition encountered by the steam as from the cylinder.

In order that the engine may run and do external work, i that the forward pressure must be greater than the back pı

*NOTE.—I adhere to the term virtual, as it was in use before the term was recommended in 1889 by the Paris Congress to denote the *square root of mea* The corresponding English adjective is *efficacious*, but some engineers mistra the word *effective*. I adhere to the term virtual mainly because effective is r usual meaning in kinematics to represent the resolved part of a force which act the line of motion, the effective force being the whole force multiplied by the angle at which it acts with respect to the direction of motion.—*S. P. Thompson.*

†NOTE.—The author adheres to the term *virtual* because in mechanics *effective* is used to denote the difference of two opposing forces; for instance, *in the operation of a steam engine, effective pressure = forward pressure—back p* *to be consistent* in nomenclature, the term effective cannot be used for the forw *pressure, that is, the pressure* impressed on an electric circuit.

[redacted]

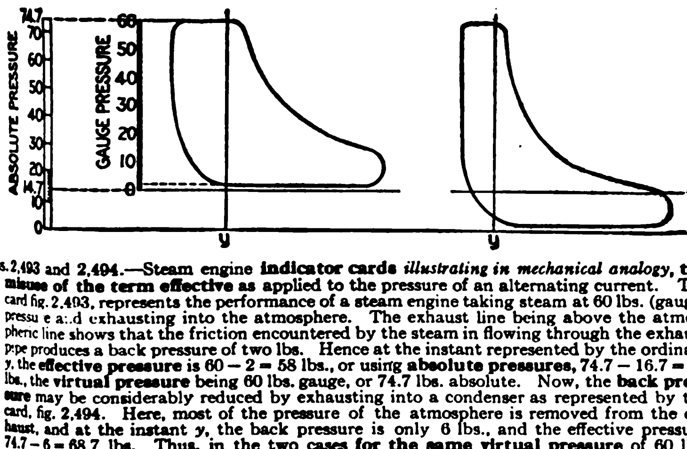
it follows that the pressure available to run the engine is the difference between these two pressures, *this pressure difference being known as the* **effective pressure,** that is to say

effective pressure = forward pressure − back pressure

Thus, electrically speaking, the effective voltage is that voltage which is available for driving electricity around the circuit, that is,

effective volts = virtual volts − back volts
= virtual pressure − (virtual pressure − drop)

In the case of the steam engine, the forward pressure absolute, that is, measured from a perfect vacuum is the virtual pressure (not considering the source). The back pressure may vary widely for different conditions of operation as illustrated in figs. 2,493 and 2,494.



FIGS. 2,493 and 2,494.—Steam engine **indicator cards** *illustrating in mechanical analogy,* **the misuse of the term effective** as applied to the pressure of an alternating current. The card fig. 2,493, represents the performance of a steam engine taking steam at 60 lbs. (gauge) pressure and exhausting into the atmosphere. The exhaust line being above the atmospheric line shows that the friction encountered by the steam in flowing through the exhaust pipe produces a back pressure of two lbs. Hence at the instant represented by the ordinate y, the **effective pressure** is 60 − 2 = 58 lbs., or using **absolute pressures,** 74.7 − 16.7 = 58 lbs., the **virtual pressure** being 60 lbs. gauge, or 74.7 lbs. absolute. Now, the **back pressure** may be considerably reduced by exhausting into a condenser as represented by the card, fig. 2,494. Here, most of the pressure of the atmosphere is removed from the exhaust, and at the instant y, the back pressure is only 6 lbs., and the effective pressure 74.7 − 6 = 68.7 lbs. **Thus, in the two cases for the same virtual pressure** of 60 lbs. gauge or 74.7 lbs. absolute, **the effective pressures are** 58 lbs. and 68.7 lbs. respectively.

In the measurement of alternating current, it is not the average, or maximum value of the current wave that defines the current commercially, but the *square root of the mean square* value, because this gives the equivalent heating effect referred to direct current. There are several types of instrument for measuring *alternating current,* and they may be classified as

[redacted]

1. Electromagnetic (moving iron);
2. Hot wire;
3. Induction;
4. Dynamometer.

Electromagnetic or Moving Iron Instruments.—' type of instrument depends for its action upon the pull of

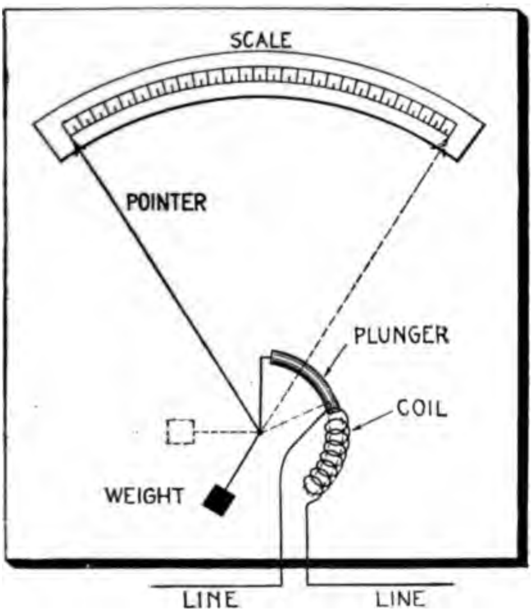
FIG. 2,495.—A **calibrated** scale. This means that printed scales are not employed, bu instrument has its scale divisions plotted by actual comparison with standards, after the division lines are inked in by a draughtsman. There are makes of direct c instruments employing printed scales in which the scale deflections are fairly acc even though the scales are printed, but printed scales should not be used on alter current instruments.

in endeavoring to reduce the reluctance of its path. This is proportional to the product of the flux and the current, so long as no part of the magnetic circuit becomes satura *the* flux is proportional to the current, hence the pull is *portional to* the square of the current to be measured.

[redacted]

. What are some objections to moving iron nents?

Instruments of this type are not independent of the fre-, wave form, or temperature and external magnetic fields fect the readings temporarily.



r.—**Plunger** form of electromagnetic or moving iron type of ammeter.

re are several forms of moving iron ammeters, which may sified as

lunger;
nclined coil;
Iagnetic vane.

Ques. Describe the plunger type.

Ans. This type of ammeter consists of a series coil an soft iron plunger forming a solenoid, the plunger is so suspen that the magnetic pull due to the current flowing through coil is balanced by gravity, as shown in fig. 2,497.

Ques. How should the plunger be constructed adapt it to alternating current, and why?

Ans. It should be laminated to avoid eddy currents.

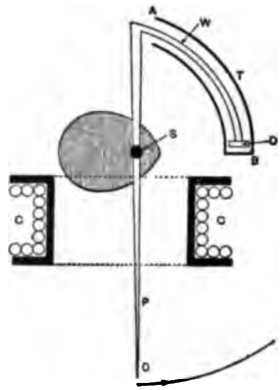


FIG. 2,497.—One form of **plunger instrument** as made by Siemens. *It has gravity co is dead beat. and is shielded from external magnetic influence.* **The moving system sists of** a thin soft iron pear shaped plate I pivoted on a horizontal spindle S runni jewelled centers. To this spindle S is also attached a light pointer P and a light W, bent as shown, and carrying a light piston D, which works in a curved air tu This tube T is closed at the end B but fully open at the other A, and constitute air damping device for making the instrument dead beat.

Ques. What is the character of the scale and h should it be constructed?

Ans. The scale is not uniform and should be hand m and calibrated under the conditions which it is to be used.

Ques. What is the objection to moving iron ammete

Ans. Since the coil carries the entire current they are l *and expensive.*

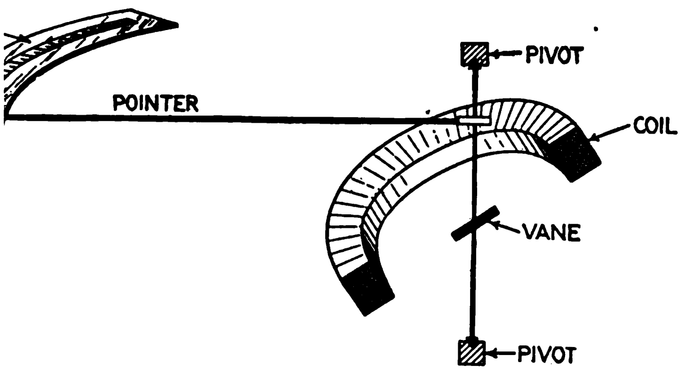
[redacted]

. What precaution should be taken in installing ; iron ammeters?

Since gravity is the controlling force, the instrument ›e carefully levelled.

. Describe an inclined coil instrument.

It consists of a coil mounted at an angle to a shaft ; the vane and pointer, as shown in fig. 2,498. A spring ıe controlling force and holds the pointer at zero when :nt is flowing.



–Inclined coil form of electromagnetic or moving iron instrument.

. What is the principle of operation of the inclined trument?

When a current is passed through the coil, the iron ı take up a position with its longest sides parallel to the force, which results in the shaft being rotated and the moved on the dial, the amount of movement depending ɜ strength of the current in the coil.

, Describe a magnetic vane instrument.

It consists of a small piece of soft iron or vane mounted

[redacted]

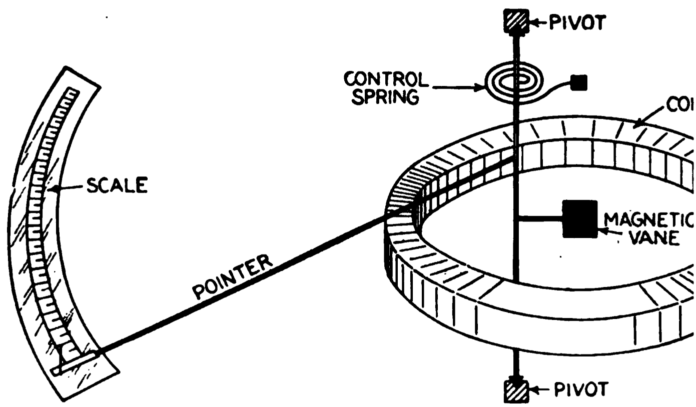


FIG. 2,499.—Magnetic vane form of electromagnetic or moving iron instrument.

FIG. 2,500.—Magnetic vane movement of a Wagner instrument; it is used both for v and ammeters. This type differs from the dynamometer movement in that a va *soft iron replaces* the moving coil. The magnetic vane movement makes use (*trolling spring* only for the purpose of resisting the pull on the vane and the return *needle to zero.* The spring does not carry any current.

[redacted]

on a shaft that is pivoted a little off the center of a coil as shown in fig. 2,499, and carrying a pointer which moves over a scale.

Ques. How does it work?

Ans. Its principle of operation is that *a piece of soft iron placed in a magnetic field and free to move, will move into such position as to conduct the maximum number of lines of force.* The current to be measured is passed around the coil, producing a magnetic field through the center of the coil. The magnetic field inside the coil is strongest near the inner edge, hence, the vane will move against the restraining force of a spring so that the distance between it and the inner edge of the coil will be as small as possible.

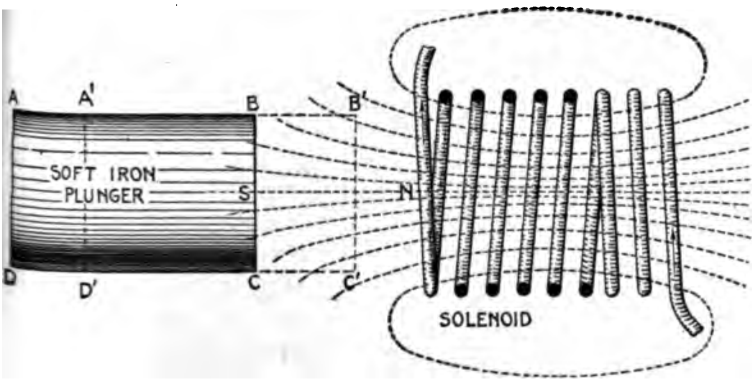


FIG. 2,501.—**Solenoid and plunger illustrating the operation** *of moving iron instruments.* When a current flows through the coil, a field is set up as indicated by the dotted lines of force. The current flowing in the direction indicated by the arrow induces a north pole at N, which in turn induces a south pole in the plunger at S, thus attracting the plunger. **The effect of the field upon the plunger** may also be stated by saying that *it tends to cause the plunger to move in a direction so as to conduct the maximum number of lines of force,* that is, *toward the solenoid.* Thus if ABCD be the initial position of the plunger only five lines of force pass through it; should it move to the position A' B' C' D', the number of lines passing through it will then be 9, assuming the field to remain unchanged.

The operation of moving iron instruments of the plunger type may be explained by saying that the current flowing in the coil produces a pole at its end *and induces an unlike pole* at the end of the plunger nearest *the coil, thus attracting the plunger,* as illustrated in fig, 2,501 above.

FIGS. 2,502 and 2,503.—Wagner series transformers. Fig. 2,502, wound primary series transformer; fig. 2,503, open primary transformer. Wagner series transformers are made in three general types: One for switchboard mounting with wound primary; one for switchboard mounting with open primary, and one with open primary suitable for slipping over bus bars or switch stud. These transformers have 5 ampere secondary winding, and are intended for use in connection with instrument of scale capacity 0–5, although the scale should be calibrated to indicate the primary current. The capacities are from 2 watts to 50 watts, being suitable for operation on circuits of 750 to 66,000 volts.

Hot Wire Instru
—Instruments of t
depend for their c
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traction of a fine w
rying either the cu
be measured or a
proportion of that c

The expansion or
tion of the wire is
by temperature
which in turn are du
heating effect of the
flowing through the

Since the variatio
length of the wire
tremely small, con
magnification is n
Pulleys or levers a
times used to mult
motion, and somet
double sag arra
shown in fig. 2,504.

As here shown
active wire carryin
rent to be meas
stretched between
nals T and T'. I
taut at its middl
another wire C,
ries no current,
in its turn, k
by a thread pass
the pulley D a

[redacted]

the pointer spindle, the whole system being kept in tension by the spring E.

Hot wire instruments are equally accurate with alternating or direct current, but have cramped scales (since the deflection is proportional to the square of the current), and are liable to creep owing to unequal expansion of the parts. There is also the danger that they may be burnt out with even comparatively small overloads. They are not affected by magnetic fields but consume more current than the other types, these readings are inaccurate near either end of the scale.

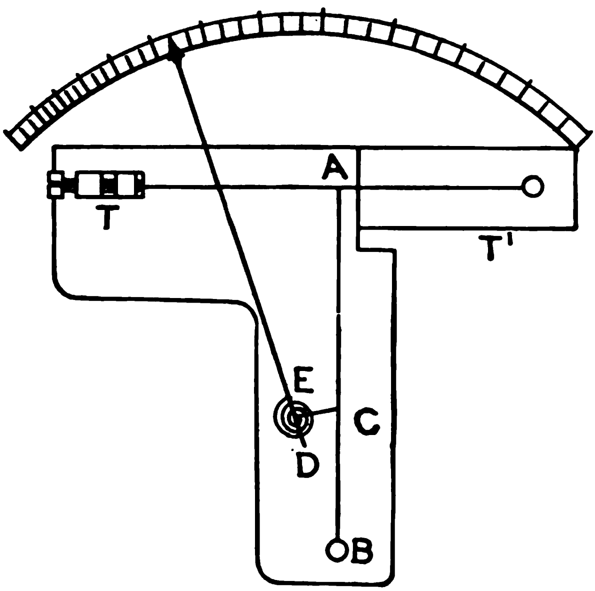


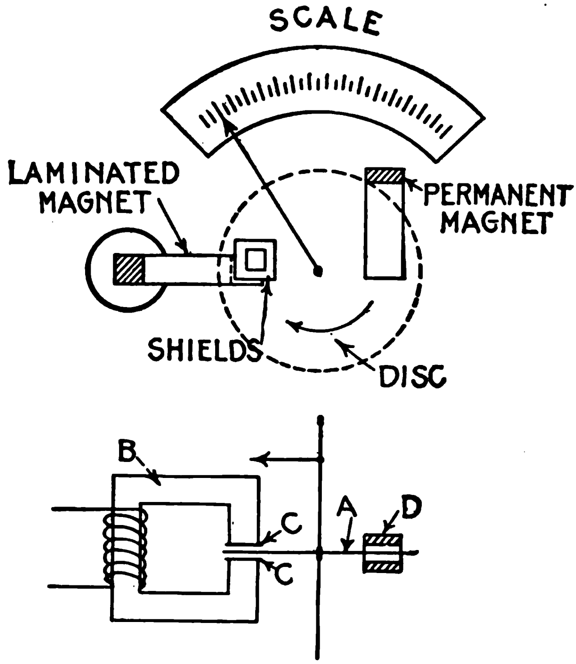
FIG. 2,504.—Diagram illustrating the principle of hot wire instruments. The essential parts are the active wire A, stretched between terminals T and T', tension wire C, thread E, and pulley D to which is attached the pointer.

Induction Instruments.—These were invented by Ferris, and are sometimes called after him. They are for alternating current only, and there are two forms:

1. Shielded pole type;
2. *Rotary field type.*

Ques. Describe the shielded pole type of indu instrument.

Ans. As shown in figs. 2,505, and 2,503 it consists, tially of a disc A, or sometimes a drum and a laminated n B. Covering some two-thirds of the pole faces are two (plates or shields C, and a permanent magnet D.



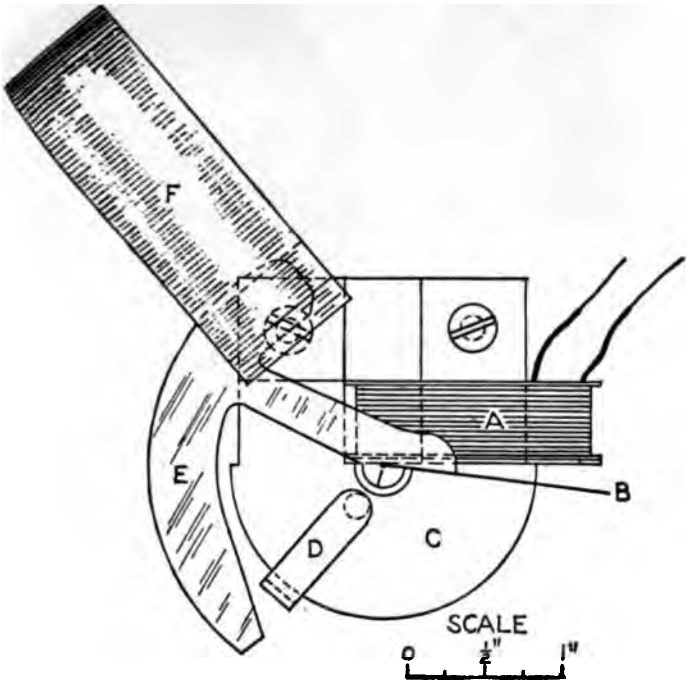
FIGS. 2,505 and 2,506.—Plan and elevation of shielded pole type of induction instrum

Ques. How does it work?

Ans. Eddy currents are induced in the two copper pla *shields C, which* attract those in the disc, producing in *quence a torque* in the direction shown by the arrow, a

[redacted]

the opposing action of a spring. Magnet D damps the oscillations.



2,507.—Diagram showing construction and operation of Hoskins instrument. It is of the modified induction type in which the torque is produced from the direct repulsion between a primary and a secondary, or induced current. As shown in the diagram, the instrument embodies the principle of a short circuited transformer, consisting of a primary or exciting coil A, a secondary or closed coil B, linked in inductive relation to the primary by a laminated iron core C, constructed to give a completely closed magnetic circuit, that is, without air gap. The secondary is so mounted with respect to the primary as to have a movement under the influence of their mutual repulsion when the primary is traversed by an alternating current. This movement of the secondary B is opposed by a spiral spring, so that the extent of movement will be dependent upon and will indicate the strength of the primary current. To increase the sensitiveness of the instrument and also to adjust the contour of the scale, an adjustable secondary D, which has an attraction effect upon the coil B, is provided upon the core. The effect of this coil is inversely proportional to its distance from the end of the swing of the coil B. The vane, E, which is a part of the stamping B, is adjusted to swing freely and with a large amount of clearance, between the poles of a permanent magnet F, which acts as a damper on the oscillation of the moving element, but does not cause any friction or affect the accuracy of the calibration. The primary, like that of a transformer, is an independent electrical circuit and may be highly insulated. This meter will withstand several hundred per cent. overload for some time because of the very high value of the self-induction and the fact that the controlling spring is not in the circuit and therefore cannot burn off.

FIGS. 2,508 to 2,511.—Hoskins instruments. Fig. 2,508, voltmeter, small pattern; fig. 2,509, ammeter, large pattern; fig. 2,510, voltmeter, horizontal edgewise pattern; fig. 2,511, illuminated dial voltmeter.

[redacted]

es. Describe the rotary field type of induction ument.

s. The parts are arranged similar to those of wattmeters, **cessary** split phase being produced by dividing the current **wo circuits**, one inductive and the other non-inductive.

12.—Hoskins instrument with case removed. It has a very short magnetic circuit ich is composed of silicon steel, permitting low magnetic densities to be used.

namometers.—This type of instrument is used to measure , amperes, or watts, and its operation depends on the ion between two coils when the current to be measured ssed through them. One of the coils is fixed and the other ible.

ies. Describe the construction of a dynamometer.

is. It consists, as shown in fig. 2,513, of a fixed coil, composed number of turns of wire, and fastened to a vertical support. *fixed coil is surrounded* by a movable coil composed of

[redacted]

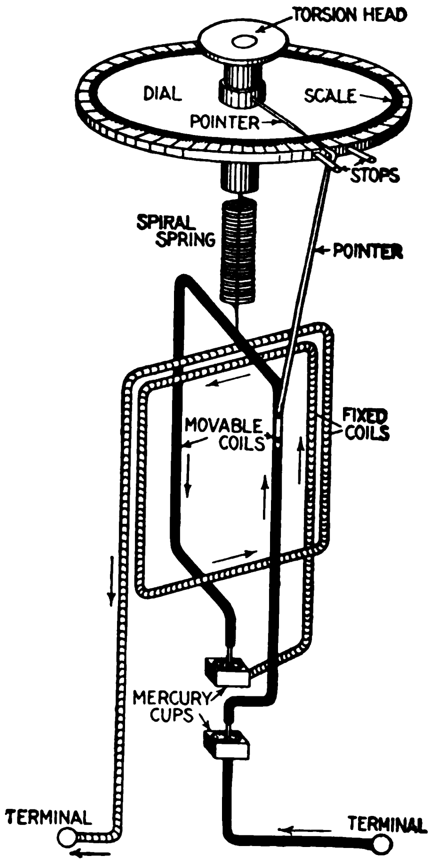


FIG. 2,513.—Diagram of Siemens' dynamometer. It consists of two coils on a commo but set in planes at right angles to each other in such a way that a torque is pro between the two coils which measures the product of their currents. This torque is ured by twisting a spiral spring through a measured angle of such degree that the coi resume their original relative positions. *When constructed as a* **voltmeter**, botl are wound with a large number of turns of fine wire, making the instrument sensi small currents. Then by connecting a high resistance in series with the instrument be connected across the terminals of a circuit whose voltage is to be measured. *constructed as a* **wattmeter**, one coil is wound so as to carry the main current a other made with many turns of fine wire of high resistance suitable for connecting the circuit.

[redacted]

nberof turns or often of only one turn of wire. The movable suspended by a thread and a spiral spring attached to a head which passes through the center of a dial. The f the movable coil dip into mercury cups, which act as and electrical contacts, making connection with one end fixed coil and one terminal of the instrument as shown. rtion head can be turned so as to place the planes of the

ı.—Wagner dynamometer movement. In this type of instrument the deflection is rtional to the square of the current, producing a constantly decreasing sensitiveness : pressure applied is decreased. The dynamometer movement is, for any indication, accurate than the magnetic vane, but cannot readily be employed for the indication rent, as required in ammeters.

t right angles to each other and to apply tortion to the to oppose the deflection of the movable coil for this n when a current is passed through the coils. A pointer ed to the movable coil indicates its position on the grad- dial between the two stops. Another pointer attached to tion head performs a similar function.

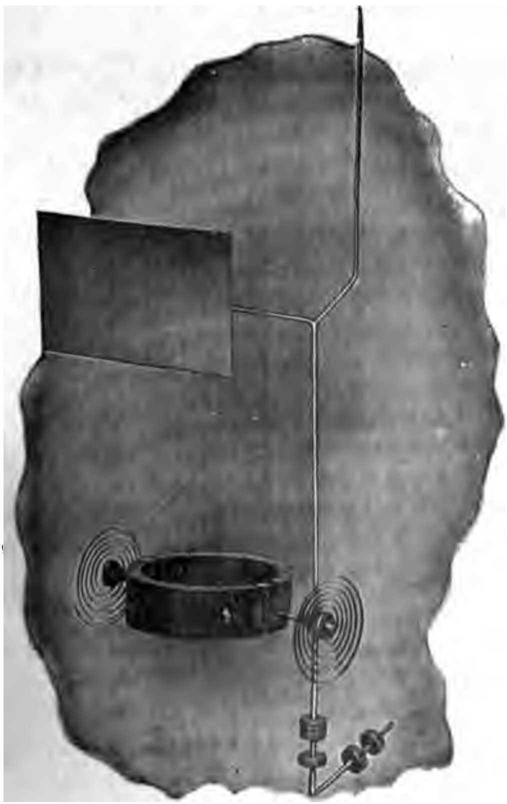
FIG. 2,515.—**Armature of dynanometer movement. accuracy is claimed for thi ment than the magnetic va it cannot readily be emplc the indication of current required in ammeters. Th netic vane movement on the A. C. ammeter, and used also in the A. C. volt it makes use of its con spring only for the purpo sisting the pull on the va the returning of the poi zero. The dynanometer ment is recommended fo meters.**

FIG. 2,516.—**Wagner 25 watt pressure transformer for use with various alternating current instruments, such as voltmeters, wattmeters, etc. They are made in capacities 25, 50, 100, and 200 watts, and are built for pressures of 750 to 60,000 volts.**

[redacted]

s. How does the dynamometer operate?

When current is passed through both coils, the movable deflected against one of the stop pins, then the tortion ; turned to oppose the movement until the deflection has vercome and the coil brought back to its original position.



7.—*Moving element of Keystone* dynamometer instrument. The illustration shows novable coil, pointer, aluminum air vane for damping the oscillations, controlling s, and counter weights.

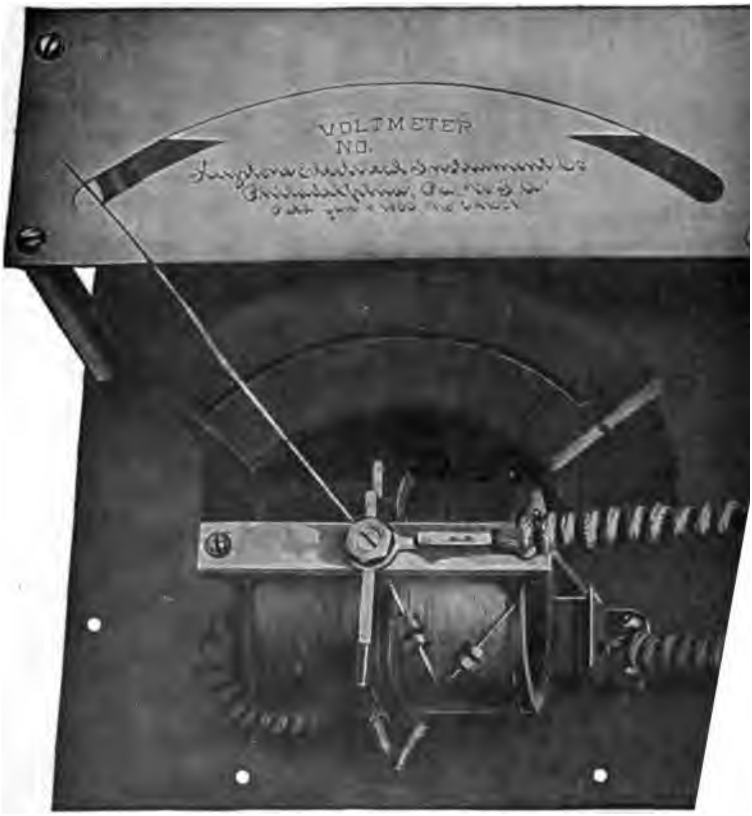


FIG. 2,518.—Keystone dynamometer movement. Since the **law** governing this t
ment is the law of current squares, it follows that in the case of voltmeters, ec
scales cannot be obtained. In the case of **wattmeters,** the scale is approxin
divided, due to the fact that the movement of the moving coil is proportion
uct of the current in the fixed and moving coils. **The moving parts** have
light in weight as is consistent with mechanical strength, and the entire mo
supported on jeweled bearings. The motion of the pointer is rendered ap
use of an aluminum air vane moving in a partially enclosed air chamber
of damping the oscillations of the moving parts renders unnecessary the us
brakes or other frictional devices, which tend to impair the accuracy of
The illustration shows a **voltmeter,** which, however, differs but little fr
In the case of a wattmeter the fixed coils are connected in series with the lir
-h a current transformer, while the moving coil is connected in

gle through which rtion head was being proportional square root of the f tortion, the cur-ength in amperes is the square root of le of tortion *multi-y a calculated con-* urnished by the of the instrument.

. How is the dy-neter arranged to re watts?

When measuring **the** instrument **be so arranged that l carries** the main **, and** the other a **urrent** which is pro-**al** to the pressure.

. In the con-tion of a dyna-eter what material d not be used and

FIG. 2,519.—Leeds and Northrup **electro-dynamometer.** *It is a reliable instrument for the measurement of alternating currents of commercial frequencies.* **When wound with fine wire** and used in connection with properly wound resistances, it is equally useful for measuring alternating pressures, and may thus be employed to calibrate alternating current voltmeters as well as ammeters. **To give accurate results** the instruments must be carefully constructed and designed with a view to avoiding the eddy currents always set up by alternating currents in masses of metal near, or in the circuits. **The constant of a dynamometer** may be obtained with a potentiometer, but this is usually done with precision by the manufacturer and a certificate giving the value of the constant is furnished with the instrument. **The size and cost** of dynamometers rapidly increase with the maximum currents which they are designed to carry, and when more than 500 amperes are to be measured, the use of other instruments and methods is recommended.

. No iron or other etic material should iployed because of the hysteresis losses occasioned thereby. rame should be of non-conducting material so as to avoid currents.

FIGS. 2,520 to 2,526.—Various types of Wagner instruments. Fig. 2,520, small round type; fig. 2,521, horizontal edgewise type; fig. 2,522, smallest switchboard type; fig. 2,523, portable type; fig. 2,524, combination voltmeter and ammeter in one case; fig. 2,525, vertical type; fig. 2,526, polyphase type.

[redacted]

Watt Hour Meters.—A watt hour meter is a watt meter hat will register the watt hours expended during an interval of time. *Watt hour meters are often erroneously called* **recording** or **integrating** *watt meters.*

There are several types of the electromotor form of watt hour meter, which may be classified as

FIG. 2,527—**Interior Weston** single phase wattmeter. The general appearance of the dynamometer movement and the relative positions of the various parts are clearly shown. The parts are assembled on one base, the whole movement being removable by unfastening two bolts. **The fixed winding** is made up of two coils, which together produce the field of the wattmeter. ***The movable coil is*** wound to gauge with silk covered wire and treated with cement. *While winding, the coil is spread at diametrical points to allow the insertion of the staff, which is centered by means of two curved plates cemented to the inside surface of the coil and forming a part thereof.* The coil is held in a definite position by two tiny pins which pass through the staff and engage with ears on the curved plate

[redacted]

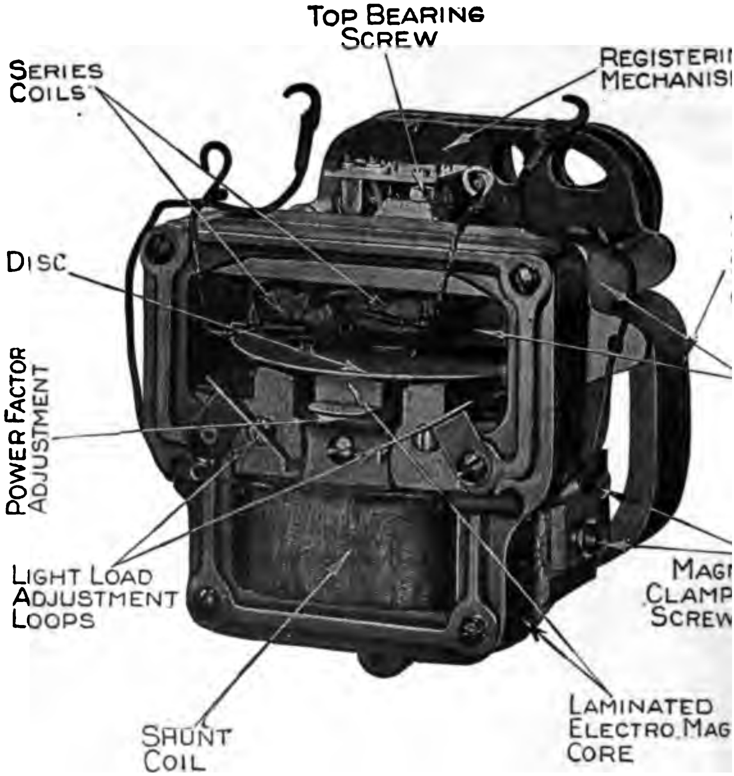


FIG. 2,528.—Westinghouse **single phase induction type watt hour meter removed from** **The friction compensation**, or light load adjustment, is accomplished by sli unbalancing the two legs of the shunt magnetic circuit. To do this a short circuited is placed in each air gap, and means are provided for adjusting the position of the so that one loop will enclose and choke back more of the flux than the other loop thus produce a slight torque. It will be noted that this torque depends on vc alone, which is practically constant, and is entirely independent of the load. Adjust is accomplished by means of either of two screws which makes micrometer adjust possible. It is clamped when adjusted by means of a set screw, which prevents ch This method makes possible an accuracy of adjustment which effectively prevents cree **The power factor adjustment** consists of an adjustable compensating coil placed ar the shunt pole tip. This is adjusted at the factory by twisting together the leads c compensating coil, thus altering its resistance until the desired lagging effect is had. ***quency adjustment.*** 133 cycle meters are first calibrated on 60 cycles and the *then untwisted to* make them correct on 133 cycles. To change such a meter for u *60 cycles it is* necessary only to retwist these leads to the point shown by the cond *of the wire.*

1. Commutator type;
2. Induction type;
3. Faraday disc type.

Ques. What are the essential parts of a watt hour meter?

Ans. A motor, generator, and counting mechanism.

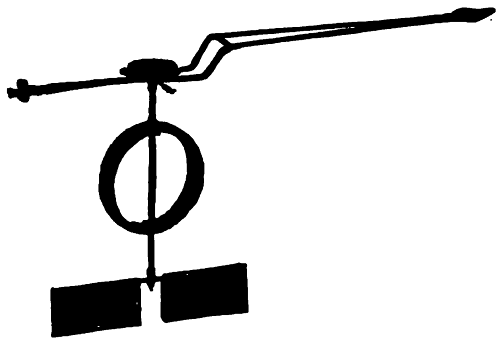


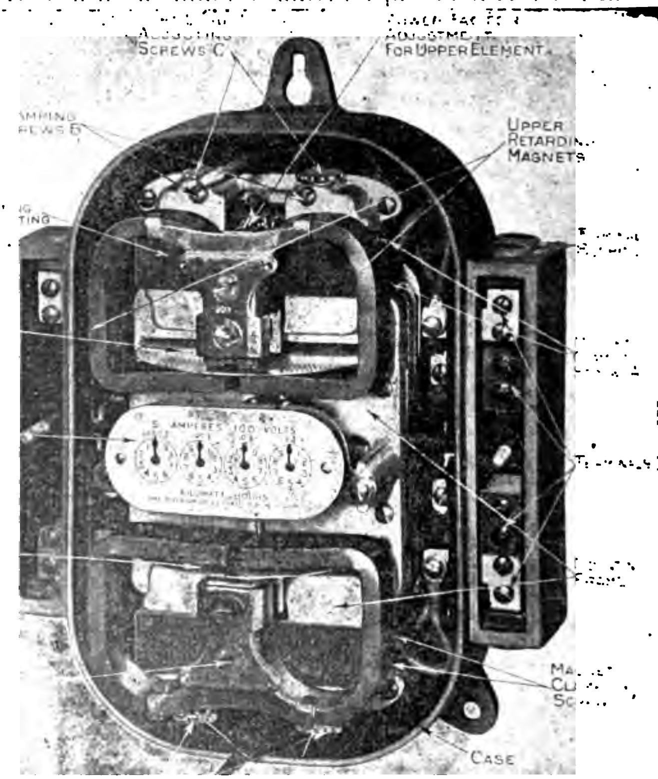
FIG. 2,529.—Pointer and movable system of Weston wattmeter. The coil is described in fig. 2,527. The pointer consists of a triangular truss with tubular members, an index tip of very thin metal being mounted at its extremity. The index tip is reinforced by a rib stamped into the metal. The pointer is permanently joined to a balance cross, consisting of a flat center web, provided with two short arms and one long arm, each arm carrying a nut by means of which the balance of the system may be adjusted. The longest arm, which is opposite the pointer, carries a balance nut, consisting of a thin walled sleeve provided with a relatively large flange at its outer end. The sleeve is tapped with 272 threads to the inch, the internal diameter of the sleeve being made slightly smaller than the outside diameter of the screw, and the sleeve is split lengthwise; therefore when sprung into place and properly adjusted it will remain permanently in position. A sleeve which is forced over the end of the staff carries the pointer firmly clamped between a flanged shoulder and a nut. By perforating the webb plate of the balance cross with a hole having two flat sides that fit snugly over a similarly shaped portion of the sleeve, the pointer is given a definite and permanently fixed angular position. The air damper consists of two very light symmetrically disposed vanes, which are enclosed in chambers made as nearly air tight as possible. These vanes are formed of very thin metal stiffened by ribs, stamped into them and by the edges, which are bent over to conform to the surface of the side walls of the chambers. They are attached by metal eyelets to a cross bar carried on a sleeve similar in construction to the one at the upper end of the staff. This cross bar is held in place by a nut, and is provided at the center with a hole having two flat sides, being similar in shape to the one in the balance cross. This hole likewise fits over a sleeve and definitely locates the vanes with reference to the other parts of the system. The damper box is cast in one piece to form the base that carries the field coils and the movable system.

Ques. What is the function of the motor?

Ans. Since the motor runs at a speed proportional to the energy passing through the circuit, it drives the counting mechanism at the proper speed to indicate the amount of energy consumed.

Ques. What is the object of the generator?

Ans. It provides a suitable counter torque or load for the motor ;



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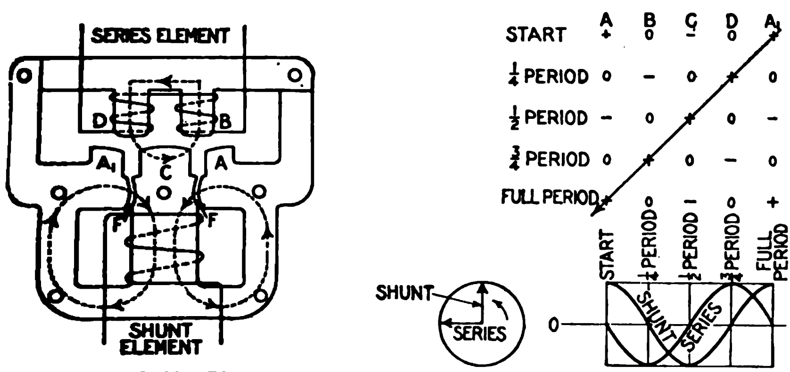
Ques. Is there any other resistance to be overcome by the motor?

Ans. It must overcome the friction of all the moving parts.

Ques. Is the friction constant?

Ans. No.



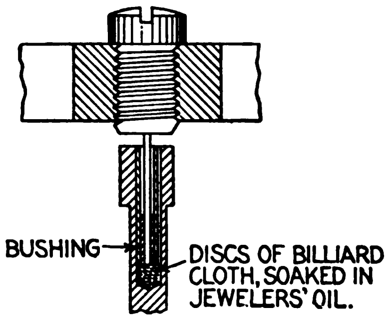
FIGS. 2,531 to 2,533.—Diagram of electro-magnetic circuit of Westinghouse induction type watt hour meter, and diagram showing rotation of field. The dotted lines show the main paths of the magnetic flux produced by the two windings, the directions, however, are constantly reversing owing to the alternations of the current in the coils. Denoting the shunt and series pole tips by the letters as shown, a clear statement of the relation of the fields for each quarter period may be given. The signs + and − represent the instantaneous values of the poles indicated. Thus, at one instant the shunt pole tips A, C, and A_1 are maximum +, −, and +, respectively because the instantaneous value of the current is maximum, while the value of the series flux is zero. At ¼ period later the shunt current is zero, giving zero magnetic pressure at the pole tips, while the series current has reached a maximum value, giving maximum − and + at the pole tips B and D. At the next ¼ period the shunt current is again maximum, but in a direction opposite to what it was at the beginning, making the pole tips A, C, and A_1 +, −, and +, respectively, while the series current again is zero, etc., the values for the complete cycle being given in fig. 2,533. It will be observed from the table that both the + and − signs move constantly in the direction from A_1 to A, indicating a shifting of the field in this direction, the process being repeated during each cycle.

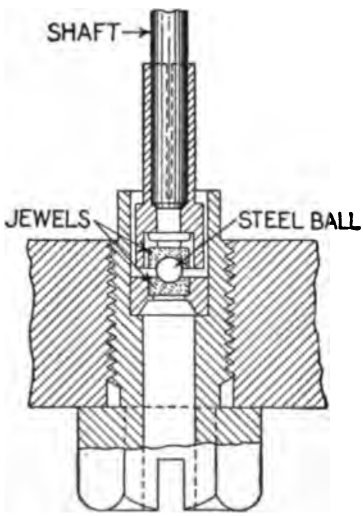
Ques. What provision is made to correct the error due to friction?

Ans. The meter is compensated by exciting an adjustable auxiliary field from the shunt or pressure circuit.

Ques. What is the construction of the generator?

Ans. In nearly all meters it consists of a copper or aluminum





disc carried on the same shaft with the motor and rotated in a magnetic field of constant value.

Ques. How is the counter torque produced?

Ans. When the disc is rotated in the magnetic field, eddy currents are induced in the disc in a direction to oppose the motion which produces them.

Ques. For what services is the commutator type meter used?

Ans. It is used on both direct and alternating current circuits.

FIGS. 2,534 and 2,535.—Cross section of bearings of Westinghouse induction type watt hour meter. The lower bearing consists of a very highly polished and hardened steel ball resting between two sapphire cup jewels, one fixed in the end of the bearing screw and the other mounted in a removable sleeve on the end of the shaft. Owing to the minute gyrations of the shaft the ball has a rolling action, which not only makes a lower friction coefficient than the usual rubbing action, but presents constantly new bearing surfaces and thus produces long life. The upper bearing is only a guide bearing to keep the shaft in *a vertical position*, and is subject to virtually no pressure, and consequently little friction. *It consists of a steel* pin fastened to a removable screw and projecting down into a bushing *in a recess drilled* in the shaft. The bottom of this recess is filled with billiard cloth *saturated with* watch oil. A film of oil is maintained around the pin by capillary action

[redacted]

Ques. What is the objection to the commutator meter?

Ans. The complication of commutator and brushes, and the fact that the friction of the brushes is likely to affect the accuracy of the meter.

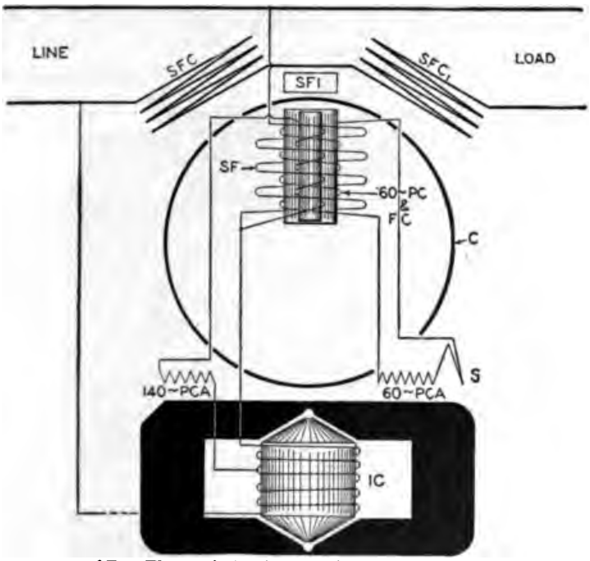


FIG. 2,536.—Diagram of Fort Wayne, induction watt hour meter. **It is designed** to register the energy of alternating current circuits regardless of the power factor, **and embodies** *the usual induction motor, eddy current generator and registering mechanism.* The electrical arrangement of the meter consists of ***a current circuit*** composed of two coils connected in series with each other and in series with the line to be measured, and ***a pressure circuit*** consisting of a reactance coil and a pressure coil connected in series with each other and across the line to be measured. In addition, the pressure circuit contains a light load coil wound over a laminated sheet steel member, adjustably arranged in the core of the pressure coil and connected across a small number of turns of the reactance coil so as to give a field substantially in phase with the impressed pressure. The light load winding is further provided with a series adjustable resistance furnished for the purpose of regulating the current flowing in the light load winding, thereby providing a means of lagging the meter on high frequencies, such as 125 or 140 cycle circuits. The pressure circuit also comprises a lag coil wound over the upper limb of the core of the pressure circuit and provided with an adjustable resistance for obtaining a field component in quadrature with the shunt field.

Ques. What are *its characteristics*?

Ans. It is independent of power factor, wave form, and *frequency when no iron is* used in the motor.

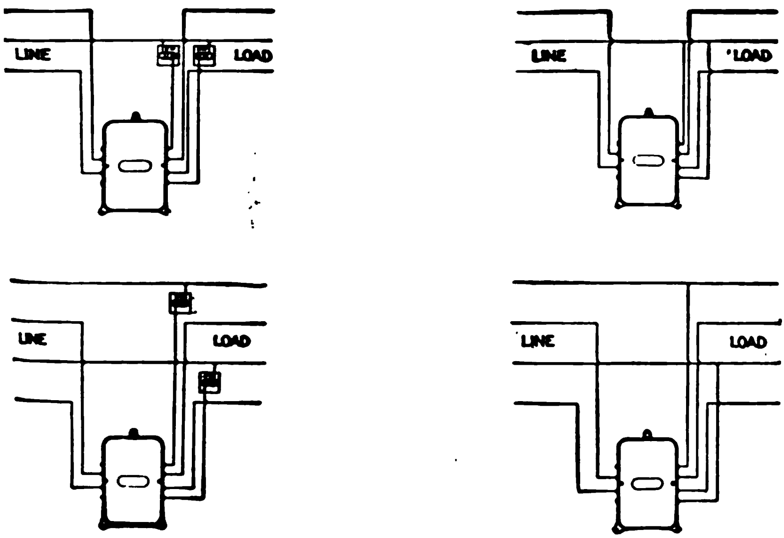
Ques. What meter is chiefly used on A. C. circuits?

Ans. The induction meter.

Principles of Induction Watt Hour Meters.—Every commercial meter of this type is made up of a number of elements,

FIG. 2,537.—Fort Wayne multiphase induction watt hour meter. **The construction of the mechanism** *is essentially two single phase motor elements*, one at the bottom of the meter in a suitable position, the other inverted and placed at the top of the meter. **Each element** acts on a separate cup, but both cups are mounted on a single shaft so that the registration is due to the resultant torque of the two elements. The meter is provided with three supporting lugs, the one at the top being keyholed and one of the bottom two, slotted to facilitate leveling. **The registering mechanism** is mounted on a cast iron bracket at the middle *of the meter* between the two motor elements. The supporting bracket is attached to the *meter base by* two screws and aligned by two dowel pins. The register is of the four dial *type, reading in* kilowatt hours. Each division of the right hand circle, or that passed *over by* the most rapidly moving pointer, equals one kilowatt hour in meters without a *dial constant.* In meters of larger capacities, dial constants of 10, 100 and 1,000 are used, in which case it is only necessary to add one, two or three ciphers to the observed reading scribed below. Each of these elements and parts has certain nctions, and each is therefore necessary to the successful operion of the meter; moreover, each element, unless correctly degned, may introduce a source of inaccuracy. These elements are:

1. The field producing element;
2. The moving element;
3. The retarding element;



Figs. 2,538 to 2,541.—Connections of Fort Wayne multi-phase watt hour meters (type k_3—forms MAB and MAK), for 100–625 volt circuits, 5–150 amperes. Fig. 2,538 two and three phase, three wire circuit, 25–36 cycles; fig. 2,539 two and three phase, 3 wire circuit, 36 cycles and above; fig. 2,540, two phase 4 wire circuit, 25–36 cycles; fig. 2,541 two phase, 4 wire circuit 36 cycles and above.

4. The registering element;
5. The mounting frame and bearings;
6. The friction compensator;
7. The power factor adjustment;
8. Frequency adjustment;
9. *The case and cover.*

1. The Field Producing Element.—This consists of the electro-magnetic circuit and the measuring coils. One of these coils, connected in series with the circuit to be metered, is wound of few turns and is therefore of low inductance. The current through it is in phase with the current in the metered circuit. The other coil, connected across the circuit, is highly inductive, and therefore the current in it is nearly 90 degrees out of phase with, and proportional to the voltage of the metered circuit

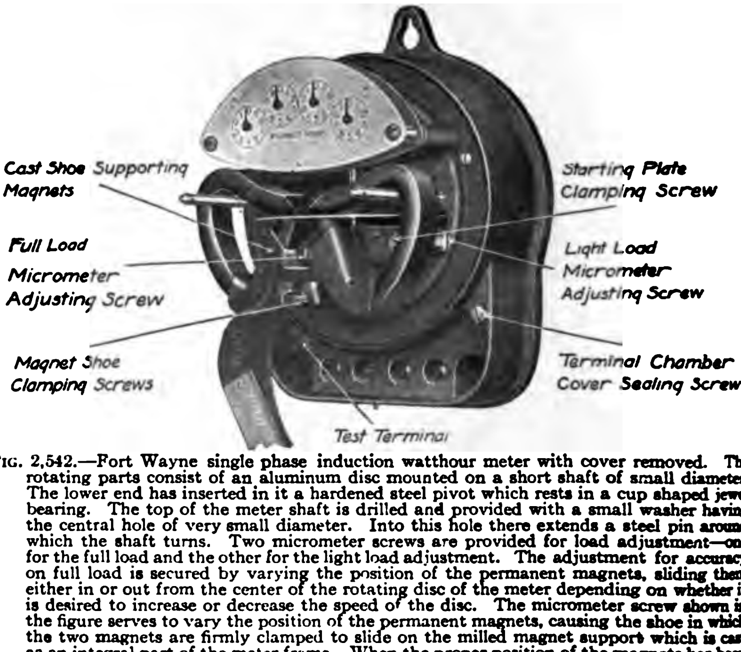


FIG. 2,542.—Fort Wayne single phase induction watthour meter with cover removed. The rotating parts consist of an aluminum disc mounted on a short shaft of small diameter. The lower end has inserted in it a hardened steel pivot which rests in a cup shaped jewel bearing. The top of the meter shaft is drilled and provided with a small washer having the central hole of very small diameter. Into this hole there extends a steel pin around which the shaft turns. Two micrometer screws are provided for load adjustment—one for the full load and the other for the light load adjustment. The adjustment for accuracy on full load is secured by varying the position of the permanent magnets, sliding them either in or out from the center of the rotating disc of the meter depending on whether it is desired to increase or decrease the speed of the disc. The micrometer screw shown in the figure serves to vary the position of the permanent magnets, causing the shoe in which the two magnets are firmly clamped to slide on the milled magnet support which is cast as an integral part of the meter frame. When the proper position of the magnets has been accurately determined by adjustment and test, the shoe which holds the two magnets is clamped firmly to the milled magnet support by two screws, one of which is shown in the figure. The adjustment for accuracy on light load is secured by varying the position of a metal punching, known as the starting plate, laterally under the pressure pole in the path of the pressure flux. This lateral movement is accomplished by means of the micrometer screw. When the proper position of this punching has been accurately determined by adjustment and test, it is secured in place by tightening the two brass screws which serve to clamp it to the meter frame.

[redacted]

across its terminals. Therefore, when the current in the circuit is in phase with the voltage (100 per cent. power factor) the currents in the meter coils are displaced almost 90 degrees with respect to each other.

Ques. How is this angle made exactly 90 degrees?

Ans. By means of the power factor adjustment.

Ques. How are the coils mounted?

Ans. They are so mounted on the core that the currents in

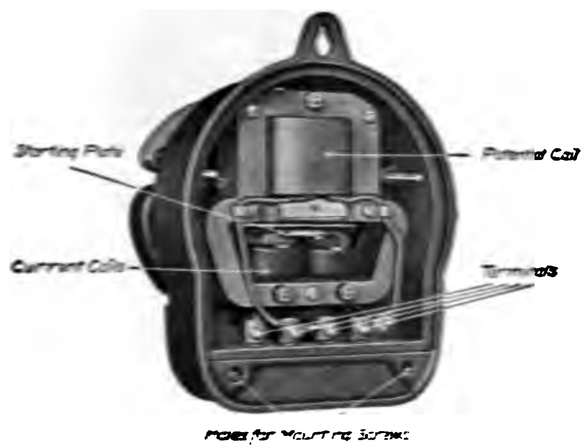


Fig. 2,542.—Rear view of Fort Wayne single phase induction watthour meter with back cover plate removed. The pressure and current coils and their respective cores lie behind the main frame of the meter. This complete electromagnetic unit can be removed as a whole from its mounting in the case. The pressure coil is wound from enameled wire, the number of turns being very high. The current coils have but few turns each and are wound from cotton covered wire. All coils are treated with insulating compound before assembling in the meters. The laminated iron cores placed within these coils are built up from magnetic steel. The magnetic circuits formed by the cores of the pressure and current coils are so arranged that they exert a high torque upon the disc of the rotating element in order that minute variations in the friction of the moving parts which are likely to occur will not cause any appreciable error in the registration of the meter. The iron case surrounding the electrical elements protect that part of the meter from the effects of external stray fields, while the astatic arrangement of the permanent magnet tends to prevent any influence on the damping system. The fact that the iron frame of the meter lies between the permanent magnets and the current coils protects the magnets from the effects of short circuits which create a strong magnetic field within the meter [illegible] them produce a rotating or shifting field in the air gap, in somewhat the same manner that the currents in the primary windings of an induction motor produce a rotating field.

Ques. What is the strength of the rotating field with 90 degrees phase difference between the currents?

Ans. It is proportional to the product of the currents in the

FIG. 2,544.—Fort Wayne single phase induction watthour meter with cover register and permanent magnets removed to show solid meter frame. A heavy steel back plate held in place by two screws inserted from the front of the central casting encloses the back part of the completely assembled meter. A felt gasket lying on a suitable ledge seals the joint against the entrance of dust or moisture when the back plate is drawn down firmly by the screws. The cover which encloses the back part of the meter is a non-magnetic metallic stamping. It is held in place by wing nuts on the two light brass studs extending forward from the meter frame. This joint between the main frame and the cover is also sealed against the entrance of dust and moisture by the use of a suitable felt gasket. Two glass windows are provided in this cover, one to permit the reading of the register dial, the other to permit observation of the disc's rotation. The cover is sealed in place in the usual way by passing a sealing wire through a hole drilled in the cover sealing stud and thence through a hole provided in the wing of the seal nut. The terminal chamber is an extension of the casting which supports all the inner parts of the meter. The heavy brass terminals used for connecting the meter in circuit are held permanently by a non-combustible insulating compound which is moulded in place around them. This construction gives excellent insulation and is a safeguard against accidental short circuits across terminals. A punched terminal cover which fits over the terminal chamber is hinged at the upper left hand corner so that it will of its own accord swing out of the way when the terminal cover sealing screw is removed. This hinged style of cover will be found convenient when installing and connecting the meter in circuit. When this cover is swung back into closed position it is fastened in place by passing a seal right through the screw and through a lug provided on the cover.

ro coils and therefore proportional to the product of current ıd voltage in the metered circuit.

At any other power factor the field is proportional to this product multiplied by the sine of the angle of phase difference between the two meter currents. If the current in the voltage coil be in quadrature with the voltage of the metered circuit, at any power factor the sine of the angle of phase difference between the currents in the meter circuits will be equal to the cosine of the angular displacement between the current and voltage in the metered circuit. Under these conditions therefore the strength of the shifting field is proportional also to the power factor of the circuit. In other words, the strength of the rotating field is proportional to the product of the volts, amperes and power factor and is therefore a measure of the actual power.

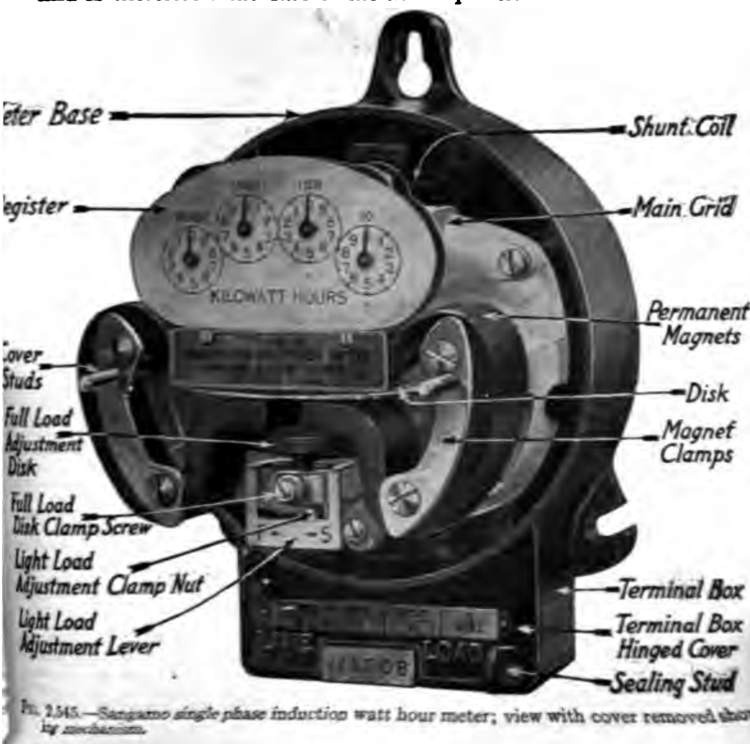


Fig. 2,345.—Sangamo single phase induction watt hour meter; view with cover removed show- ing mechanism.

Ques. In what part of the meter is energy consumed

Ans. In the field producing element.

It is upon the design of this element that the losses in the meter depend. Current is flowing through the shunt coil continuously, even when no energy is being taken, and the higher the inductance of this

FIG. 2,546.—Main grid or supporting frame of Sangamo single phase induction watt hour meter. The grid is of cast iron and its design is such that the weight of the permanent magnets, series laminated element and return plate are carried on the main portion, the smaller projecting brackets carrying no weight except that of the moving system. The supporting grid is removed by taking out the three screws locating and holding it in position, to the iron base, also removing at the same time the screws connecting the leads of the series coils to the binding posts at the bottom. The meters are all built with four binding posts so that they may be connected either with two series leads and a tap for the pressure connection or with both sides of the circuit carried through the meter. The wire meters employ a 220 volt shunt coil, connected across the binding posts within the meter, one series coil being in each of the outer lines of the three wire system. This renders unnecessary the use of a pressure tap.

coil, the smaller will be the energy component of the constant flow. The series coil causes a loss of energy proportional to the square of the current flowing. It also causes a drop in voltage, both inductive and resistive, hence, the resistance and inductance of the series coil of the meter should be as low as possible.

Ques. How should the magnetic circuit be designed?

Ans. The design should be such that the increase of magnetic x with high voltage or high current will not have a retarding tion but will act only to increase the torque.

If the retarding effect be not prevented, the meter will, of course, run slow at overloads. A comparative test of meters at varying load and at varying voltage will reveal the characteristics of the magnetic circuit.

2. The Moving Element.—This usually consists of a light etal disc revolving through the air gap in which the rotating eld is produced.

FIG. 2,547.—Moving element of Sangamo single phase induction watt hour meter. It consists of a light aluminum disc mounted on a hard brass shaft, the entire system weighing 15.6 grams. The disc is swaged under heavy pressure, to render it stiff. The arrangement of the disc, shaft, and bearings is shown in fig. 2,548. By unscrewing the upper and lower bearings the disc and shaft can be removed without disturbing the magnets or adjustments.

Ques. What is the action of the disc?

Ans. It acts like the squirrel cage armature of an induction motor, developing the motive torque for the meter.

Ques. How is this torque counter balanced?

Ans. By the retarding element so that the speed is proportional to the torque.

Ques. How should the disc be made and why?

Ans. As light as possible to reduce wear on the bearings to a minimum.

[redacted]

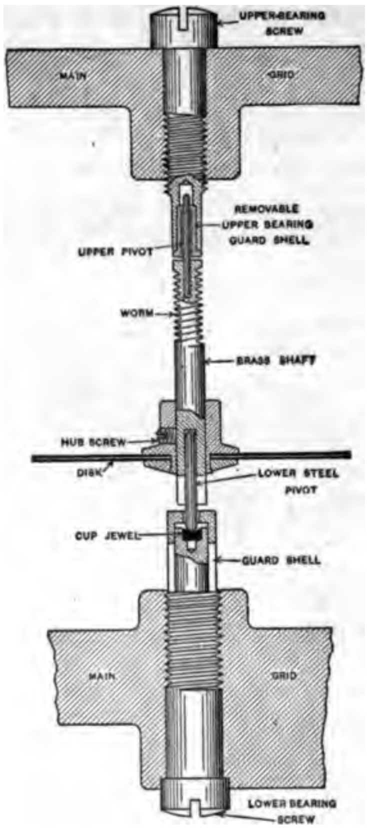


FIG. 2,548.—Bearing system of Sangamo **single phase** ***induction*** **watthour m** **upper pivot, or bearing** is made of tempered steel wire and of sufficiently small be quite flexible in the length between the top of the brass shaft and the guide ring rotates. The guide ring, made of phosphor bronze, has the heavy hole lined and The upper bearing screw, in which the bronze bushing is carried, is so constructed brass sleeve closely surrounds the upper pivot of the spindle. Any blow against system, caused by accident or short circuit, will slightly deflect the shaft unt pivot touches against the side of the shell, thus preventing danger of breaking off the upper pivot. At the same time a cushioning or flexible action between th the bearing shell is secured, thus eliminating the effect of vibration in the mov which would tend to produce rattling. **The lower bearing** consists of a cup sap supported in a threaded pillar, the upper end of which is provided with a sleev that it prevents the moving element dropping out during shipment. This prote is held friction tight on the shaft and can be removed if it be desired to insp

[redacted]

Ihe Retarding Element.—This part acts as a load on duction motor and enables the adjustment of its speed to d limits. In order that the speed shall be proportional to riving torque, which varies with the watts in the circuit, ecessary that the torque of the retarding device be propor- to the speed. For this reason a short circuited constant generator, consisting of a metal disc rotating between per- nt magnet poles, has been generally adopted.

es. How is the retarding torque produced?

s. Eddy currents are induced in the disc in rotating through agnetic field which, according to Lenz law, oppose the that produces them, thus developing a retarding torque.

es. How is the constant field for the retarding disc iced?

. By permanent magnets.

The retarding disc may be the same disc used for the moving element, which case the meter field acts on one edge while the permanent agnet field acts on the edge diametrically opposite. This arrangement mplifies the number of parts and saves space and weight of moving ement.

es. What error is likely to be introduced by the ling element?

s. If the strength of the permanent magnets change any cause, the retarding torque will be changed and the ation of the meter rendered inaccurate.

es. How may the strength of the permanent mag- be changed?

s. They may become weak with age, or affected by the nity of other magnetic fields. The series coil of the meter under short circuit so affect the strength of the permanent ets as *to render the meter* inaccurate.

Ques. What precautions are taken to keep the strength of the permanent magnets constant?

Ans. Weakening with age is prevented by the process of "Aging." The effect of neighboring fields is overcome by iron shields; this prevents the electro-magnets affecting, through overloads, the strength of the permanent magnets.

4. The Registering Element.—This mechanism comprises the dials, pointers, and gear train necessary to secure the

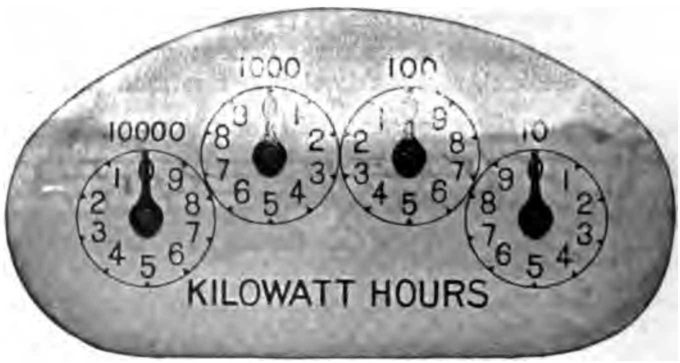


FIG. 2,549.—Register dial of Sangamo single phase induction watt hour meter (full size). The dial circles read 10, 100, 1,000, and 10,000 kilowatt hours from right to left.

required reduction in speed. This gear train is driven directly by the rotor and therefore its friction should be low and constant. The dials should be easily read and should register directly in kilowatt hours. If a constant be used to reduce the reading to kilowatt hours, it should be some multiple of 10, to avoid errors in multiplication. By means of suitable gears in the meters this is easily accomplished.

***5. The* Mounting Frame and Bearings.**—These parts *have an important* influence on the accuracy of the meter, as it

[redacted]

is in the bearings that most of the friction in the meter occurs. The frame should be rigid and free from vibration, so that the bearings will be at all times in perfect alignment.

Initial friction is unavoidable in any meter construction and can be easily compensated for. A *change* in the initial friction, however, due to wear of bearings, makes readjustment necessary.

In selecting a meter the special attention should therefore be given, to the construction of the bearings, particularly the lower, or "step" bearing which supports the weight of the moving element.

FIG. 2,550.—Canadian dial of Sangamo single phase induction watt hour meter. It has a small test circle indicating one kilowatt hour per revolution in all sizes where the first regular circle indicates 10. This is provided to conform with the requirements of the Canadian government and it is intended that the hand on the test circle shall make not less than ½ revolution in one hour with full load on a meter. In the case of a 10 ampere meter, it will make one complete revolution in one hour and for a 20 ampere, two revolutions, and so on. The train or indicating mechanism is carried on a rigidly formed and swaged brass bracket, accurately located by two dowel pins set in the top face of the main grid, and is held to the grid with two screws easily accessible when it is desired to remove the train for any purpose. All indicating trains used on type "H" meters are marked with symbols on the back of the train and on the compound attachment to indicate the gear ratio of each combination; this ratio being different for meters of different capacities in order to obtain a direct reading in kilowatt hours on the dial.

Ques. Describe a good construction for the step bearing.

Ans. A desirable construction would consist of a very highly polished *and hardened ball with jewel seats.*

6. The Friction Compensator.—The object of this device is to overcome the initial friction of the moving parts. It is evident that if this initial friction were not compensated some of the driving torque of the meter would be used in overcoming it, and the meter would therefore not rotate at very light load, and not fast enough at other loads, thus rendering the registration inaccurate, especially at light loads.

Fig. 2,651.—Base and shunt coil of Sangamo single phase induction watt hour meter. Should the shunt or pressure coil sometimes breaks down or burns out, due to abnormal line conditions or accident, provision is made for easy replacement. The shunt magnet with its coil is held to the base by two dowel pins and four screws, enabling it to be removed as a unit as shown. A new core and coil may then be substituted without the necessity of removing and replacing laminations. The shunt coil in 25 cycle meters is wider and contains more steel than the 60 and 133 cycle coils, the winding also being correspondingly increased. The return plate and series coil laminations are also changed in proportion to correspond to the increased width of the shunt magnet. The laminations forming the core are laced into the shunt coil, and subjected to enormous hydraulic pressure, the rivets being set at the same time, to form a compact unit and eliminate humming. The laminated core of the shunt element has but a single air gap in which these discs rotate.

Since meters are usually run at light loads it is important that an efficient light load adjustment or friction compensator should be provided.

Ques. What important point should be considered in the design of the friction compensator?

Ans. The compensating torque must not cause the moving element to rotate or "creep" without current in the series coil.

[redacted]

The rotation of a meter is caused by two distinct torques, the varying meter torque, dependent on the power in the circuit, and the constant torque adjusted to compensate the initial friction.

The friction at all speeds is not exactly the same as the initial friction, and therefore the friction compensating torque may be in error a few per cent. at high speeds.

FIGS. 2,552 and 2,553.—Arrangement of magnetic circuit of Sangamo single phase induction meter. Fig. 2,552, front view; fig. 2,553, rear and side view. As shown, the gap of the shunt field in which the disc rotates, projects in between the poles of the series magnet, the return plate bending around so as to clear the upper leg of the shunt magnet. This gives the desired proximity of shunt and series fields with a maximum radius of action for both sets of field. In all capacities up to and including 60 amperes, 2 wire and 3 wire, round wire and taped series coils are used, and in capacities of 80 and 100 amperes, strap windings. Meters exceeding 100 ampere capacity have five ampere coils and are operated from external current transformers having 5 ampere secondaries. The series windings or coils are mounted on a laminated iron U shaped magnet having a laminated return path above the disc of the meter, thus forming air gaps in which the disc rotates. The series coils in all capacities not having strap windings are held firmly in position on the yoke so that they cannot slip up from the lowest position. This is accomplished by means of a pair of spring brass clips slipped through the coils on the rear face of the yoke, the clips being held by the two screws which fasten the series magnet to the main grid. As an additional precaution, spring steel lock washers are put beneath the heads of the holding screws, thus eliminating any chance of the series magnet loosening and changing position.

If the compensating torque be small compared with the driving torque, this small error *percentage is negligible* in its effect on accuracy. The *smaller it is, the greater will be the* accuracy at all loads, and therefore, *as the compensating torque is* adjusted to balance the initial friction, *the initial friction should be small* compared with the driving torque.

In the wattmeter type, the phase relation between the pressure and the current fluxes is such that on a non-inductive load the torque is zero.

For instance, in a dynamometer wattmeter, the pressure circuit is made highly inductive and the instrument then indicates *volts* × *amperes* × *sin* ϕ instead of *volts* × *amperes* × *cos* ϕ, that is to say, it will indicate the wattless component of the power. A dynamometer of this type is sometimes called an idle current wattmeter.

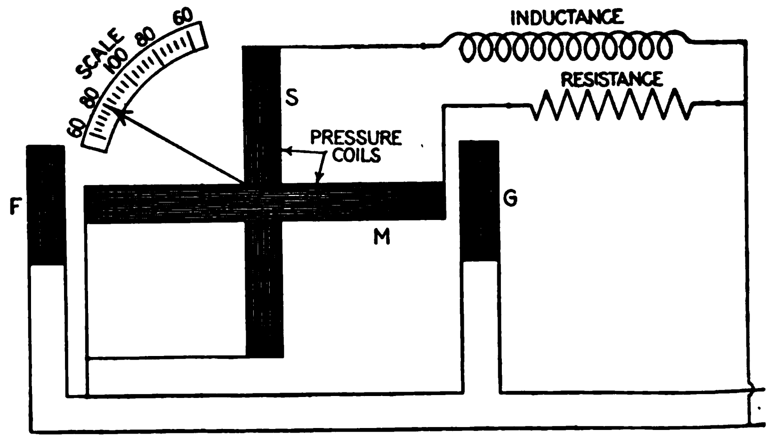


FIG. 2,579.—Single phase power factor meter of the rotating field or disc type.

Ques. Describe a single phase power factor meter of the disc or rotating field type.

Ans. It consists of two pressure coils, as shown in fig. 2[illegible] placed at right angles to each other, one being connected thr[illegible] a resistance, and the other through an inductance so as to "[illegible] the phase and get the equivalent of a rotating magnetic [illegible]

The coils are placed about a common axis, along which is pivo[illegible] iron disc or vane. The magnetizing coils F6 are in series with the [illegible] If the load be very inductive, the coil M experiences very little torq[illegible] the system will set itself as shown in the figure. As the load becom[illegible] inductive, the torque on S decreases and on M increases so that the system takes up a particular position for every angle of lag or lead.

Ground Detectors.—Instruments of this name are used for *detecting* (and sometimes measuring) the leakage to earth or

[redacted]

the insulation of a line or network and are sometimes called *ground* or *earth indicators*, or *leakage detectors*.

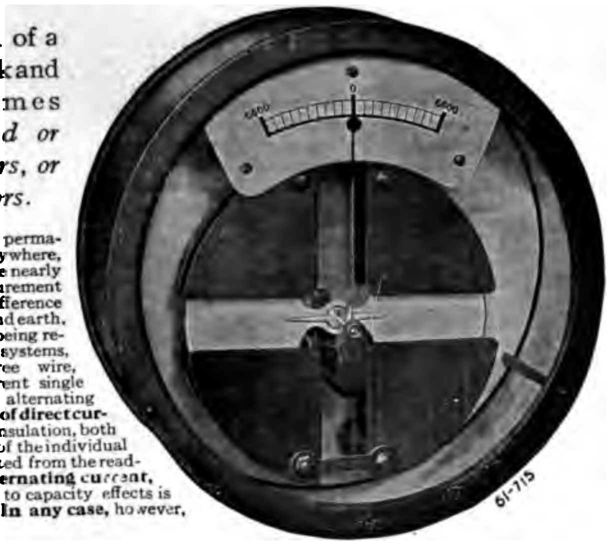


FIG. 2,580.—Westinghouse single phase electrostatic ground detector.

For systems not permanently earthed anywhere, these instruments are nearly all based on a measurement of the pressure difference between each pole and earth, two measurements being required for two wire systems, and three for three wire, whether direct current single phase, or polyphase alternating current. In the case of direct current systems, the insulation, both of the network and of the individual lines, can be calculated from the readings, **but with alternating current,** the disturbance due to capacity effects is usually too great. **In any case,** however, the main showing the smallest pressure difference to earth must be taken as being the worst insulated.

For low tension systems **moving coil** (*for alternating current*) or **moving iron** instruments (*for direct current*) are the most used, while for high tension systems electrostatic voltmeters are to be preferred. **On systems having some point permanently earthed** at the station, as for instance the *neutral wire* of direct current system, or the neutral point of a three phase system, an ammeter connected in the *earth wire* will serve as a rough guide. It should indicate no current so long as the insulation is in a satisfactory state, but on the occurrence of an earth it will at once show a deflection. The indications are, however, often misleading, an serve more as a warning th anything else.

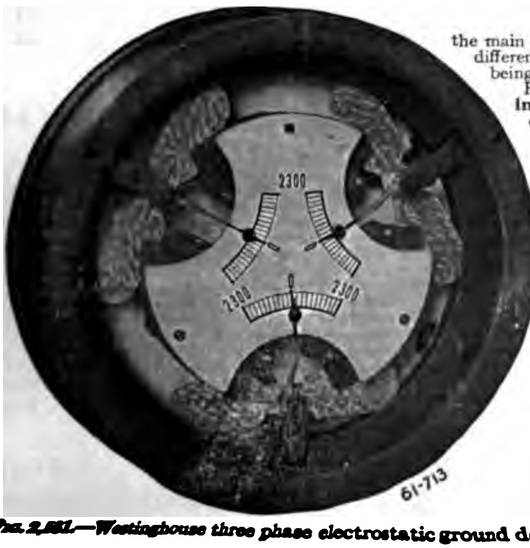


FIG. 2,581.—Westinghouse three phase electrostatic ground detector.

feature, particularly in meters that require no adjustment at installation, as they prevent entrance of dust into the main meter chamber.

A window through which the rotation of the disc can be observed in checking, should be provided for the same reason.

The Faraday Disc, or Mercury Motor Ampere Hour Meter.—On this type of meter the mercury motor consists

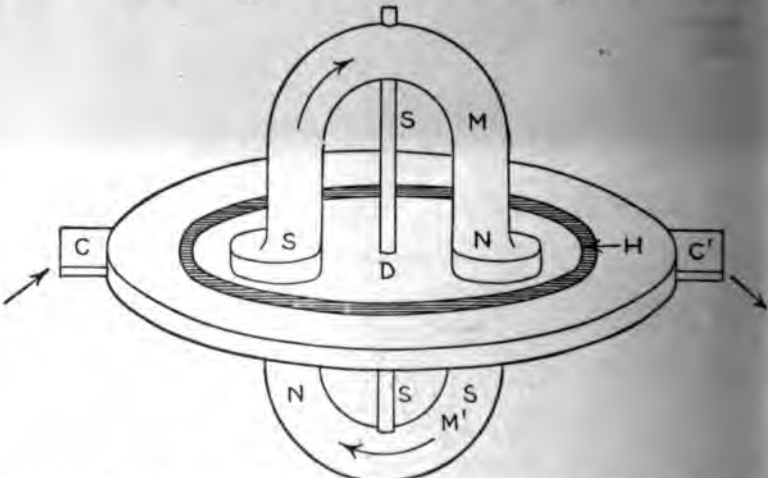


FIG. 2,558.—Faraday disc, or mercury motor ampere hour meter; view showing electric and magnetic circuits.

essentially of a copper disc floated in mercury between the poles of a magnet and provided with leads to and from the mercury at diametrically opposite points. **The th** relations of the various parts are shown in fig. **2,558.**

***Ques.* Explain its operation.**

Ans. The electric current, as shown in fig. **2,558, en**

FIG. 2,559.—Diagram showing relative direction of current, magnetic flux, and motion of disc in Faraday disc, or mercury motor ampere hour meter.

contact C, passes through the comparatively high resistance mercury H to the edge of the low resistance copper disc D across the disc to the mercury H and out of contact C′. The magnetic flux cuts across the disc on each side from N to S, making a complete circuit through M and M′. The relative directions of the magnetic flux and the current of electricity as well as the resulting motion are shown in fig. 2,559. According to the laws of electromagnetic induction, if a current carrying conductor cut a magnetic field of flux at right angles, a force is exerted upon the conductor, tending to push it at right angles to both the current and the flux. When connected to an eddy current damper or generator which requires a driving force directly proportional to the speed of rotation, the mercury

Ques. How is a synchronous motor employed frequency indicator?

Ans. A small synchronous motor is connected in th cuit of the current whose frequency is to be measured.

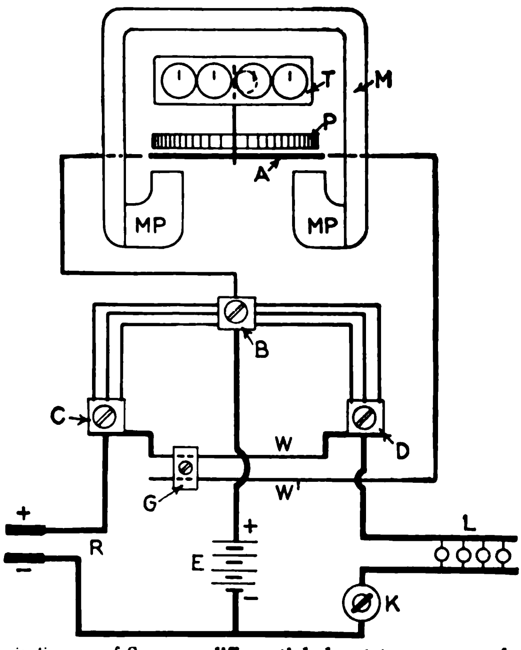
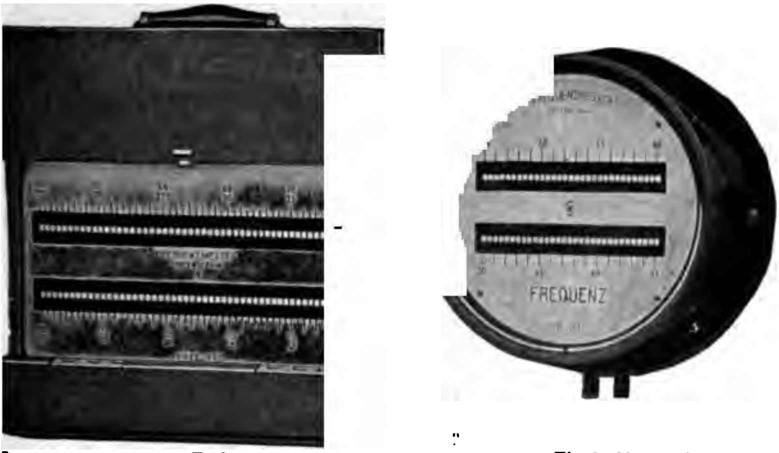


FIG. 2,562.—Circuit diagram of Sangamo **differential shunt type ampere hour n** *use in battery charging.* Since a battery absorbs more energy on charge than it out on discharge, at its working voltage, it is usually given a certain amount charge. This makes desirable a meter that automatically allows for the proper of overcharge. Such a meter indicates at all times the amount of electricity for useful work without resetting the pointer every time the battery is charged. words, the battery and the meter would keep in step for considerable periods without readjustment. The Sangamo differential shunt meter is designed to m requirements, and it consists essentially of a Sangamo meter with two shunts c as shown. The relative value of shunt resistance is adjustable by means of slid that the meter can be made to run slow on charge or fast on discharge, whichever desired. The usual method is to allow the meter to register less than the true on charge and the exact amount on discharge, the difference representing the lo battery, or the overcharge. If the meter be provided with a charge stopping de *battery can be* given an amount of overcharge predetermined by the setting of t G. *Therefore* the amount of overcharge can be fixed in advance by a skilled ma *actual charging* done by any unskilled person, since all there is to do is to make the co

letermining the revolutions per minute by using a revolution ounter, the frequency is easily calculated as follows:

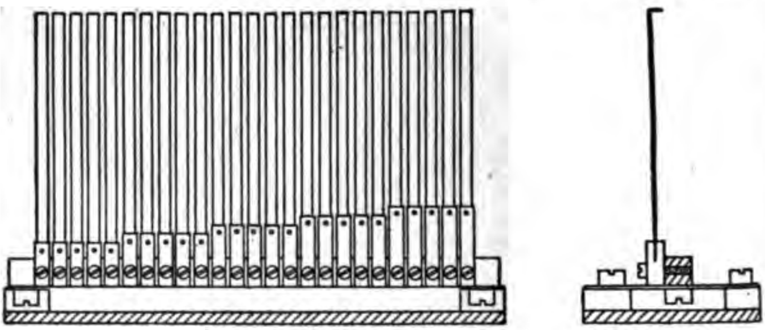
frequency = (*revolutions* **per second** × *number of pole*) ÷ *2*.



FIGS. 2,563 and 2,564.—Frahm **resonance ... frequency meter.** Fig. 2,563, portable meter; fig. 2,564, switchboard meter. The readings are correct in either the vertical or horizontal position. **The energy consumption** at 100 volts is about 1 to 2 volt amperes, and is approximately proportional for other pressures. The regular portable meters are arranged for pressures of from 50 to 300 volts, and for this purpose they are fitted with terminals for 65, 100, 130, 180, and 250 volts. In order to obtain full amplitude at intermediate pressures, a milled headed screw is provided for adjusting the base piece mechanically, and thereby permitting of regulating the pressure range within ± 20 per cent; this insures indications of maximum clearness. Should it be desired to extend the standard pressure range of 50 to 300 volts, up to 600 volts, two further terminals for 350 and 500 volts are necessary, so that these instruments are provided with eight fixed terminals in addition to the mechanical regulating device. Instruments which are intended for connecting to one specific supply or to the secondary of a pressure transformer, require only a single pressure range, say 100 volts, with the aforementioned regulating device. **The frequency range** is from 7.5 to 600 cycles per second. In order to obtain easily readable indications, one reed is provided for every quarter period for frequencies below 30, for every half period for frequencies between 30 and 80, and for every whole period for frequencies between 80 and 140. The use of a smaller number of reed, that is to say, of larger intervals between the periods of vibration of adjoining reeds, is only recommended for circuits having very variable frequencies, as otherwise no reed might respond to the vibrations caused by intermediate frequencies. The arrangement of the separate reeds on a common base piece, permits supplying any combination of interval that may be required. It is often desirable to secure two ranges with one set of reed. To do this a second electromagnet is supplied. It is polarized, and operates on the same base plate. In the case of alternating current when the unpolarized magnet is used the reeds receive two impulses during each cycle, while with the polarized magnet they receive but one impulse per cycle. A commutator is provided to easily make the change from one range to the other. If there be two sets of reed, the one commutator may be connected to change both. This device is only applicable when alternating current is measured. *Instruments with unpolarized magnets are made with frequencies of 15 to 300 cycles per second.*

Ques. Describe the resonance method of obtaining the frequency.

Ans. In construction, the apparatus consists of a pendulum, or reed, of given length, which responds to periodic forces having the same natural period as itself. The instrument comprises a number of reeds of different lengths, mounted in a row, and all simultaneously subjected to the oscillatory attraction of an electromagnet excited by the supply current that is being



Figs. 2,565 and 2,566.—Side and end views of Frahm resonance type frequency meter reeds. Owing to the principle employed in the meter it is evident that the indications are independent of the voltage, change of wave form, and external magnetic fields.

measured. The reed, which has the same natural time period as the current will vibrate, while the others will remain practically at rest.

The construction and operation of the instrument may be better understood from figs. 2,565 and 2,566, which illustrates the indicating part of the Frahm meter. This consists of one or more rows of tuned reeds rigidly mounted side by side on a common and slightly flexible base.

The reeds are made of spring steel, 3 or 7 mm. wide, with a sma portion of their free ends bent over at right angles as shown in fig. 2,56 and enameled white so that when viewed end on they will be easi visible. The reeds are of adjustable length, and are weighted at the en

A piece of soft iron, rigidly fastened on the base plate which suppor *the reeds,* forms the armature of a magnet.

When the magnet is excited by alternating current, or interrupted direct current, the armature is set in vibration, and that gives a slight movement to the base plate at right angles to its axis, thereby affecting all the reeds, especially those which are almost in tune with its vibrations.

The reed which is in tune will vibrate through an arc of considerable amplitude, and so indicate the frequency of the exciting current.

Ques. For what use is the resonance type of frequency eter most desirable?

Ans. For laboratory use.

G. 2,567.—Westinghouse induction type frequency meter. The normal frequency is usually at the top of the scale to facilitate reading. The damping disc moves in a magnetic field, thus damping by the method of eddy currents. The standard meters are designed for circuits of 100 volts nominal and can be used for voltages up to 125 volts. For higher voltages, transformers with nominal 100 volt secondary should be used.

Ques. Describe the induction type of frequency meter.

Ans. It consists of two voltmeter electro-magnets acting in pposition on a disc attached to the pointer shaft. One of the agnets is in series with an inductance, and the other with a esistance, so that any change in the frequency will unbalance he forces acting on the shaft and cause the pointer to assume a ew position, when the forces are again balanced. The aluminum isc *is so arranged that* when the shaft turns in one direction the torque of the magnet tending to rotate it decreases, while the torque of the other magnet increases. The pointer therefore comes to rest where the torques of the two magnets are equal, the pointer indicating the frequency on the scale.

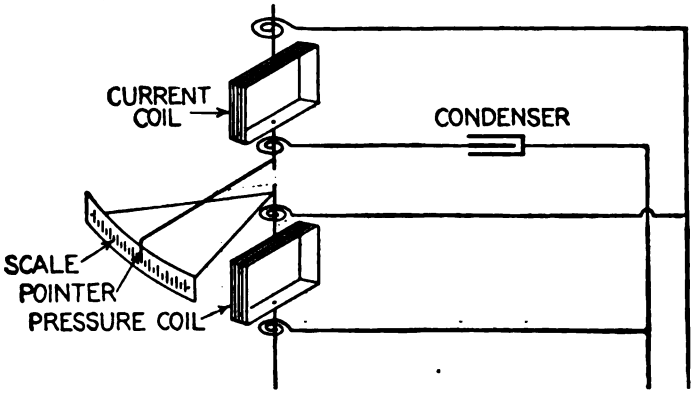


FIG. 2,568.—Langsdorf and Begole frequency meter. The operation of this meter is based on the fact that if an alternating pressure of E Volts be impressed on a condenser of capacity C, in farads, the current in amperes will be equal to 2π ~ EC, provided the pressure be constant. **In construction**, the scale is mounted on the same axis as the pressure coil, across the mains so as to render the instrument independent of variation of voltage. **For a discussion of this meter, see Electrical Review, vol. LVIII, page 114.**

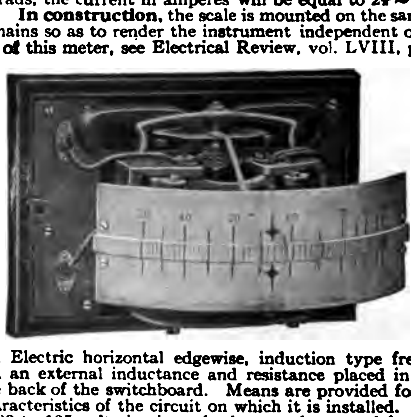


FIG. 2,569.—General Electric horizontal edgewise, induction type frequency indicator. It is provided with an external inductance and resistance placed in a ventilated cage for mounting on the back of the switchboard. Means are provided for adjusting the instrument for the characteristics of the circuit on which it is installed. Standard instruments are wound for 100 to 125 volt circuits only, but can be wound for circuits up to and including 650 volts. Instruments for use on circuits in excess of 650 volts are also provided with pressure transformers. The normal operating point is marked at approximately the center of the scale, thus giving the advantage of very open divisions. **The standard frequencies are 25, 40, 60, 125 and 133.**

[redacted]

Ques. What is the object of the aluminum disc?

Ans. Its function is to damp the oscillations of the pointer.

Synchronism Indicators.—These devices, sometimes called nchroscopes, or synchronizers *indicate the exact difference in ase angle at every instant,* and the difference in frequency,

FIG. 2,570.—Westinghouse rotary type of synchroscope or synchronism indicator. The indication is by means of a pointer which assumes at every instant a position corresponding to the phase angle between the pressures of the busbars and the incoming machine, and therefore rotates when the incoming machine is not in synchronism. The direction of rotation indicates whether the machine be fast or slow, and the speed of rotation depends on the difference in frequency. The pointer is continuously visible, during both the dark and light periods of the synchronizing lamps.

between an incoming machine and the system to which it is to be connected, so that the coupling switch can be closed at the proper instant. There are several types of synchronizer, such as

1. Lamp or voltmeter;
2. Resonance or vibrating reed;
3. *Rotating field.*

The simplest arrangement consists of a lamp or preferably a voltmeter connected across one pole of a two pole switch connecting the incoming machine to the busbars, the other pole of the switch being already closed.

If the machines be out of step, the lamps will fluctuate in brightness, or the voltmeter pointer will oscillate, the pulsation

FIG. 2,571.—General Electric synchronism indicator. **The synchronism indicator** is *a motor whose field is supplied with single phase current from one of the machines to be synchronized, and its armature from the other.* The armature carries two inductance coils placed at a large angle, one supplied through a resistance, the other through an inductance. This arrangement generates a rotating field in the armature, while the stationary field is alternating. The armature tends to assume a position where the two fields coincide when the alternating field passes through its maximum; hence, the armature and pointer move forward or backward at a rate corresponding to the difference of frequency, and the position when stationary depends on the phase relation. When the machines are running at the same frequency and in phase the pointer is stationary at the marked point. **In construction,** it is like a small, two phase, bipolar synchronous motor, the field being supplied with alternating instead of direct current. *The armature* is mounted in ball bearings in order to make it sufficiently sensitive and smooth in operating. The armature coils are not exactly 90 degrees apart, since it is not possible to get the current in the two coils exactly in quadrature without introducing condensers or other complicated construction. *Standard ratings* are for 110 and 220 volt circuits. *Synchronism indicators should be ordered for the frequency of the circuit on which they are to be operated,* although the instruments may be used on circuits varying 10 per cent to 15 per cent from the normal. The words **"Fast"** and **"Slow"** on the dial indicate that the frequency on binding posts E and F is respectively higher or lower than that on A and B; or, in other words, clockwise rotation of the pointer means that the incoming machine is running at too high speed, counter clockwise rotation indicating too low speed.

becoming less and less as the incoming machine approaches *synchronous* speed. Synchronism is shown by the lamp remaining *out,* or the voltmeter at zero.

[redacted]

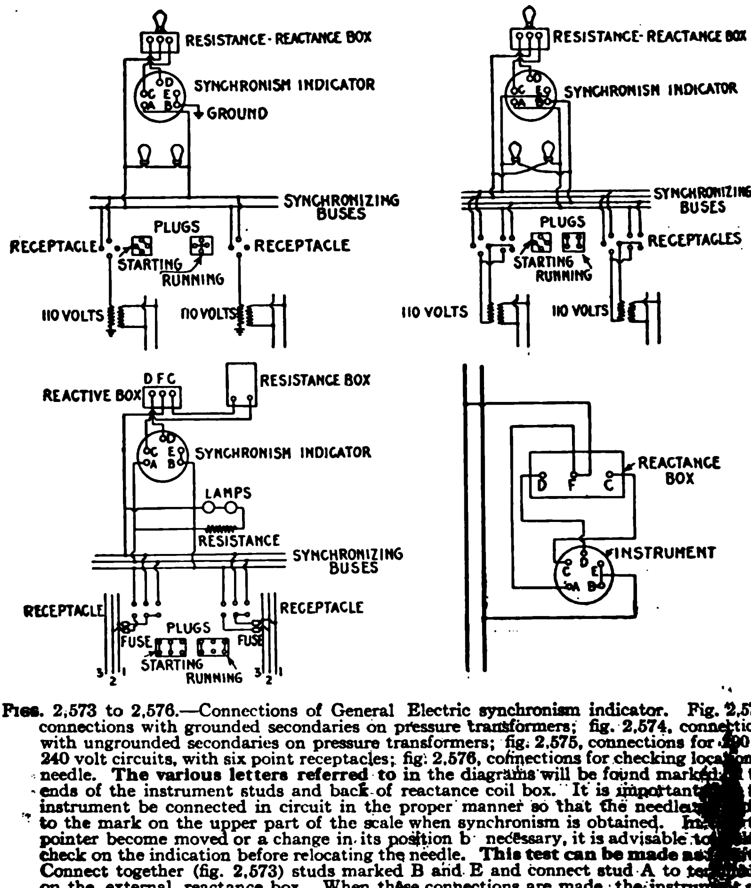
…s. How does the resonance type of synchronism …itor operate?

. On the same principle as the resonance type of fre… indicator, already described.

…s. What is the principle of the rotating field type …chronism indicator?

. Its operation depends on the production of a rotating field by the currents of the metered circuits in angularly placed coils, one for each phase in the case of a polyphase indicator. In this field is provided a movable iron vane or armature, magnetized by a stationary coil whose current is in phase with the voltage of one phase of the circuit. As the iron vane is attracted or repelled by the rotating field, it takes up a position where the zero of the rotating field occurs at the same instant as the zero of its own field. In the single phase meter the positions of voltage and current coils are interchanged and the rotating field is produced by means of a split phase winding, connected to the voltage circuit.

—General Electric external resistance …ductance for 110 volt synchronism …tor. Both the resistance and inductance are *intended to be placed behind* …itchboard.



FIGS. 2,573 to 2,576.—Connections of General Electric synchronism indicator. Fig. 2,573, connections with grounded secondaries on pressure transformers; fig. 2,574, connections with ungrounded secondaries on pressure transformers; fig. 2,575, connections for 400 to 240 volt circuits, with six point receptacles; fig. 2,576, connections for checking location of needle. **The various letters referred to in the diagrams will be found marked** [illegible] the ends of the instrument studs and back of reactance coil box. It is important [illegible] the instrument be connected in circuit in the proper manner so that the needle [illegible] to the mark on the upper part of the scale when synchronism is obtained. In [illegible] the pointer become moved or a change in its position b necessary, it is advisable to [illegible] a check on the indication before relocating the needle. **This test can be made as follows:** Connect together (fig. 2,573) studs marked B and E and connect stud A to terminal F on the external reactance box. When these connections are made, the instrument can be connected to a single phase circuit of normal voltage and if the instrument be correct, the pointer will stand vertically at the point of synchronism. If it do not, the needle can be moved and should be fastened in the correct position. The synchronizing lamps when connected as illustrated in the diagrams, show dark when synchronism is reached. **This** is the only connection possible when grounded secondaries are used, as in fig. 2,573, *and for the high* voltage indicators when used as in fig. 2,575, but with ungrounded *secondaries (fig. 2,574)* the lamps may be connected as indicated, when they will show bright *at the moment of synchronism.* The connections to the synchronism indicator remain the *same as before.*

[redacted]

Power Factor Indicators.—Meters of this class indicate the phase relationship between pressure and current, and are therefore sometimes called *phase indicators*. There are two types:

1. Wattmeter type;
2. Disc, or rotating field type.

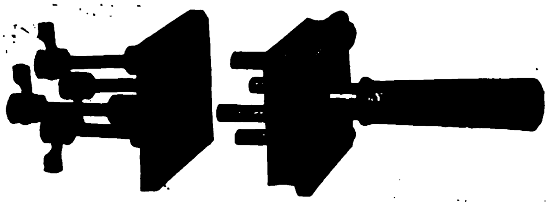


Fig. 2,577.—General Electric synchronizing receptacle and plug for use with synchronism indicator.

Fig. 2,578.—Westinghouse rotating field type power factor meter. The rotating field is produced by the currents of the metered circuits in angularly placed coils, one for each phase of the system, in the case of polyphase meters. In the three phase meter the rotating field is produced by three coils spaced 60° apart; in the two phase meter by two coils spaced 90°; in the single phase meter the positions of voltage and current coils are interchanged and the rotating field is produced by means of a split phase winding, connected to the voltage circuit. There are no movable coils or flexible connections. Single phase meters indicate the power factor of a single phase circuit, or of one branch of any polyphase circuit. Special calibration is necessary in order to use a single phase instrument on a three *phase circuit unless* the voltage coil be connected from one line to the *neutral. Polyphase meters indicate* the average angle between the currents and *voltages and are superior for polyphase* service to meters having only one current coil.

In the wattmeter type, the phase relation between the pressure and the current fluxes is such that on a non-inductive load the torque is zero.

For instance, in a dynamometer wattmeter, the pressure circuit is made highly inductive and the instrument then indicates *volts* × *amperes* × *sin* ϕ instead of *volts* × *amperes* × *cos* ϕ, that is to say, it will indicate the wattless component of the power. A dynamometer of this type is sometimes called an idle current wattmeter.

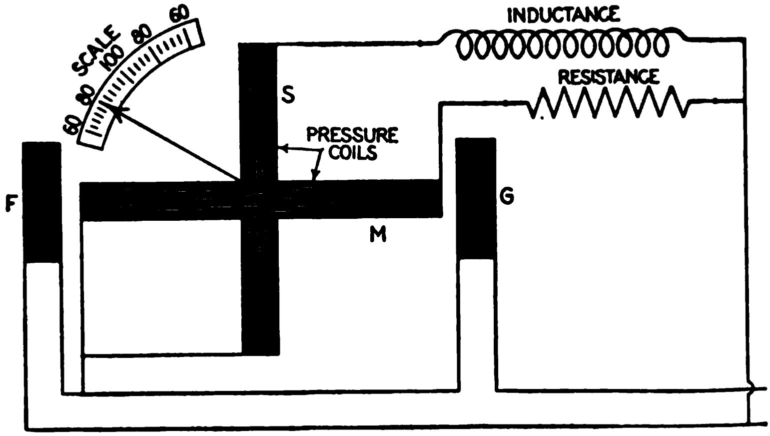


FIG. 2,579.—Single phase power factor meter of the rotating field or disc type.

Ques. Describe a single phase power factor meter of the disc or rotating field type.

Ans. It consists of two pressure coils, as shown in fig. 2,579, placed at right angles to each other, one being connected through a resistance, and the other through an inductance so as to "split" the phase and get the equivalent of a rotating magnetic field.

The coils are placed about a common axis, along which is pivoted an iron disc or vane. The magnetizing coils F6 are in series with the load. If the load be very inductive, the coil M experiences very little torque and the system will set itself as shown in the figure. As the load becomes less inductive, the torque on S decreases and on M increases so that the system takes up a particular position for every angle of lag or lead.

Ground Detectors.—Instruments of this name are used for *detecting* (and sometimes measuring) the leakage to earth or

ulation of a
network and
ometimes
ground or
ndicators, or
detectors.

items not permanently earthed anywhere, instruments are nearly on a measurement pressure difference each pole and earth, urements being re- two wire systems, for three wire, direct current single polyphase alternating **n the case of direct cur**- ems, the insulation, both work and of the individual be calculated from the read- **with alternating current**, bance due to capacity effects is o great. **In any case**, however,

Fig. 2,580.—Westinghouse single phase electrostatic ground detector.

the main showing the smallest pressure difference to earth must be taken as being the worst insulated.

For low tension systems **moving coil** *(for alternating current)* or **moving iron** instruments *(for direct current)* are the most used, while for high tension systems electrostatic voltmeters are to be preferred. **On systems having some point permanently earthed** at the station, as for instance the *neutral wire* of direct current system, or the neutral point of a three phase system, an ammeter connected in the *earth wire* will serve as a rough guide. It should indicate no current so long as the insulation is in a satisfactory state, but on the occurrence of an earth it will at once show a deflection. The indications are, however, often misleading, and serve more as a warning than anything else.

—Westinghouse three phase electrostatic ground detector.

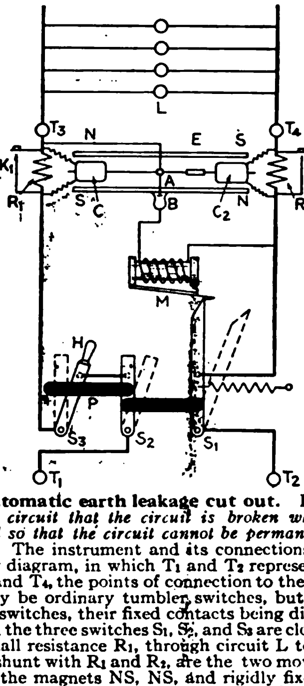


FIG. 2,582.—Wallis-Jones **automatic earth leakage cut out.** It is *an instrum protects a direct current circuit that the circuit is broken whenever a leak either main to earth, and so that the circuit cannot be permanently re-establish leak has been removed.* The instrument and its connections may be explai aid of the accompanying diagram, in which T_1 and T_2 represent the points of from the mains, and T_3 and T_4, the points of connection to the circuit to be pr S_2, and S_3 will preferably be ordinary tumbler switches, but they are diagra represented as plain bar switches, their fixed contacts being diagrammatically by dotted circles. When the three switches S_1, S_2, and S_3 are closed, the current T_1 to T_3 through the small resistance R_1, through circuit L to T_4, and back resistance R_2 to T_2. In shunt with R_1 and R_2, are the two moving coils C and in the magnetic field of the magnets NS, NS, and rigidly fixed on one spind broken electrically by an ebonite block E. The points of connection to the adjusted so that when the same current passes out through one and back throug the effect on the two coils is equal and opposite, and there is thus no movemen however, any minute portion of the current through R_1 leak to earth instead via R_2, the balance is disturbed, C becomes stronger than C_2, the system is de a contact is made by the arm A at B, no matter in which direction the coils de system is similarly deflected for a leak on the other lead. In the diagram th are shown at right angles to their normal plane. As soon as the contact is made, magnet M is energized, the arm of S_1 is released and the spring at once pulls it tact, at the same time breaking S_2. The positions of the blades when the s open are shown dotted. The only means the user has of closing the circuit is on S_3 by the handle H, which is outside the locked box. The first effect of p is to break its circuit; it then by means of the slotted bar P begins to pull on S_2 a can thus be closed again, and held closed by the trigger as before. The circuit, still broken till S_3 is pushed back. Then if the leak be still on, the slot in and S_2 to open at once as before. It is therefore impossible to keep the ci while the leak exists. The working condition of the instrument can be tested by switching a lamp on in the circuit and depressing one of the keys K_1, K_2. circuits R_1 or R_2, throws the coils out of balance, and the switch opens. The *is closed* in an inner dust tight case, and it will be noted that it *makes* conta *break* occurs at the switches, thus avoiding any sparking. Since the two coils *two gaps* of one and the same field, changes in the strength of the magnets ha *the apparatus is enclosed* in a locked metallic box, and the only part to wh **has access is the handle H, and, if desired, the testing keys K_1 K_2.**

[redacted]

THE THOUGHT IS IN THE QUESTION THE INFORMATION IS IN THE ANSWER

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TABLE OF CONTENTS
GUIDE No. 8

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ANAGEMENT—*Continued*

MANAGEMENT—*Continued*

CHAPTER LXIII

WAVE FORM MEASUREMENT

The great importance of the wave form in alternating ırrent work is never denied, though it has sometimes been verlooked. The application of large gas engines to the :iving of alternators operated in parallel requires an ccurate knowledge of the wave form, and a close confor- ation to a sine wave if parallel operation is to be satis- ctory. It is also important that the fluctuations in mag- etism of the field poles should be known, especially if solid eel pole faces be used.

If an alternator armature winding be connected in delta, the presence of a third harmonic becomes objectionable, as it gives rise to circulating currents in the winding itself, which increase the heating and lowers the efficiency of the machine.

That the importance of having a good wave form is being realized, is proved by the increasing prevalence in alternator specifications of a clause specifying the maximum divergence allowable from a true sine wave. It is however perhaps not always realized that an alternator which gives a good pressure wave on no load may give a very bad one under certain loads, and the ability of the machine to maintain a good wave form under severe conditions of load is a better criterion of its good design than is the shape of its wave at no load.

The question of wave form is of special interest to the power station engineer. Upon it depends the answer to the questions: whether he may ground his neutral wires without getting large circulating currents; whether he may safely run any combination of his alternators in parallel; whether the constants of his distributing circuit are of an order liable to cause dangerous voltage surges due to resonance with the harmonics of his pressure wave; what stresses he is getting in his insulation due to voltage surges when switching on or off, etc. It has been shown by

[redacted]

Rossler and Welding that the luminous efficiency of the alternating c rent arc may be 44 per cent. higher with a flat topped than wit peaked pressure wave, while on the other hand it is well known t transformers are more efficient on a peaked wave. Also the accur of many alternating current instruments depends upon the wave sha

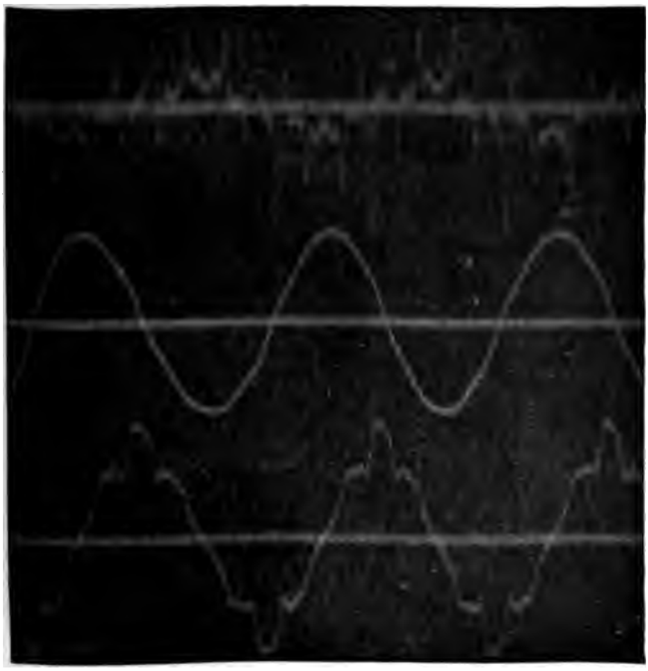
In making insulation breakdown tests on cables, insulators, machinery, large errors may be introduced unless the wave form at time of the test be known. It is not sufficient even to know that testing alternator gives a close approximation to a sine wave at no lo since if the capacity current of the apparatus under test be moderat large compared with the full load current of the testing alternator, t

Fig. 2,583.—General Electric oscillograph record of three waves with common zero.

charging current taken may be sufficient to distort the wave for considerably, thus giving wrong results to the disadvantage of either the manufacturer or purchaser.

The desirability of a complete knowledge of the manner in *which the* pressure and current varies during the cycle, has *resulted in* various methods and apparatus being devised taining this knowledge. The apparatus in use for such purse may be divided into two general classes,

1. Wave indicators;
2. Oscillographs.



c. 2,584.—General Electric simultaneous record of three waves with separate zeros.

ıd the methods employed with these two species of apparatus ay be described respectively as,

1. Step by step;
2. Constantly recording.

ıt *is to say, in the first* instance, a number of instantaneous values are obtained at various points of the cycle, which are plotted and a curve traced through the several points thus obtained. A constantly recording method is one in which an infinite number of values are determined and recorded by the

FIGS. 2,585 and 2,586.—Oscillograms (from paper by Morris and Catterson-Smith, Proc. I. E. E., Vol. XXXIII, page 1,023), showing *how the current varies* **in one of the armature coils of a direct current motor.** Fig. 2,585 was obtained with the brushes in the neutral position, and fig. 2,586 with the brushes shifted forward.

machine, thus giving a complete record of the cycle, leaving no portion of the wave to be filled in.

The various methods of determining the wave form may be *further* classified as:

1. Step by step:
   - Joubert's method;
   - Four part commutator method;
   - Modified four part commutator method;
   - Ballistic galvanometer method;
   - Zero method;
   - By Hospitalier ondograph.

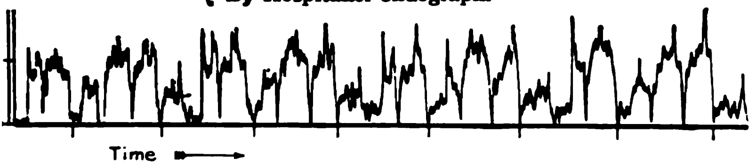


FIG. 2,587.—**Oscillogram** by Bailey and Cleghorne (Proc. I. E. E., Vol. XXXVIII), **showing** ***the sparking pressure or pressure between the brush and the commutator segment at the moment of separation.*** **The waves fall into groups of three owing to the fact that there were three armature coils in each slot.**

2. Constantly recording: by use of various types of **oscillograph,** such as
   - cathode ray;
   - glow light;
   - moving iron;
   - moving coil;
   - hot wire.

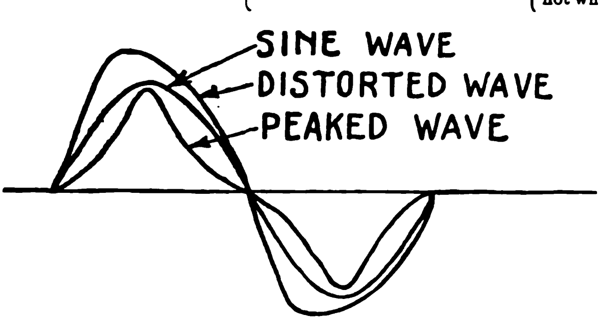


FIG. 2,588.—**Various wave forms.** The sine wave represents a current or pressure which **varies according to the sine law.** A distorted wave is due to the properties of the circuit, for **instance, the effect of** hysteresis in an iron core introduced into a coil is to distort the **current wave** by adding harmonics so that the ascending and descending portions may not be symmetrical. A peaked wave has a large maximum as compared with its virtual value. A peaked wave is produced by a machine with concentrated winding.

Joubert's Method.—The apparatus required for determining the wave form by this step by step method, consists of a galvanometer, condenser, two, two way switches, resistance and *adjustable contact maker,* as shown in fig. 2,589.

The contact maker is attached to the alternator shaft so that it will rotate synchronously with the latter. By means of the adjustable contact, the instant of "making" that is, of "closing" the testing circuit may be varied, and the angular position of the armature, at which the testing circuit is closed, determined from the scale, which is divided into degrees.

A resistance is placed in series with one of the alternator leads, such that the drop across it, gives sufficient pressure for testing.

Ques. Describe the method of making the test.

Ans. For current wave measurement switch No. 1 is placed on contact F, and for pressure wave measurement, on contact G,

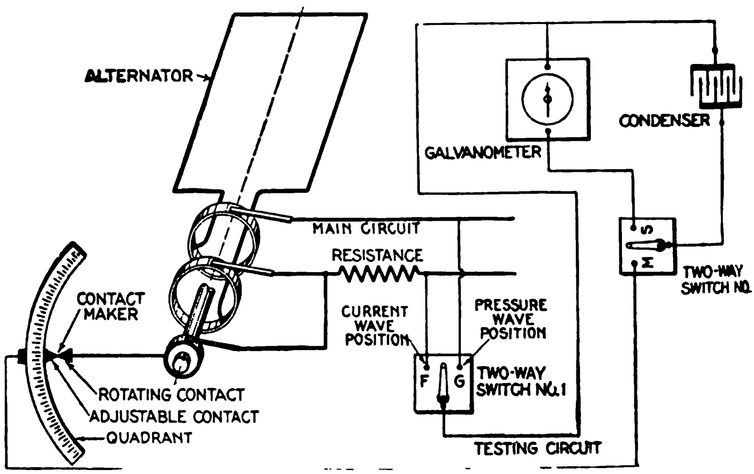


FIG. 2,589.—Diagram illustrating Joubert's step by step method of wave form measurement

switch No. 2 is now turned to M and the drop across the resistance (assuming switch No. 1 to be turned to contact F) measured by charging the condenser, and then discharging it through the galvanometer by turning the switch to S. This is repeated for a number of positions of the contact maker, noting each time the galvanometer reading and position of the contact maker. By plotting the positions of contact maker as abscissæ, and th

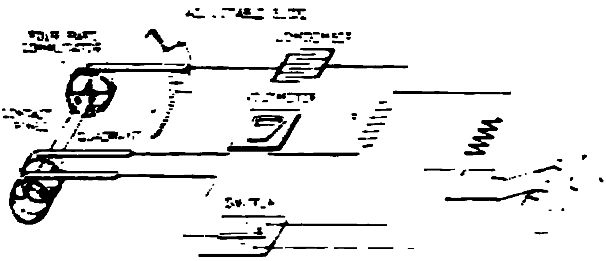


FIG. 2,590.—**Four part commutator method** [illegible] device consists of two slip rings and a four part [illegible] to the terminal of the source, the other [illegible] condenser. By adjusting [illegible] the terminals, the voltmeter can be [illegible] reading.

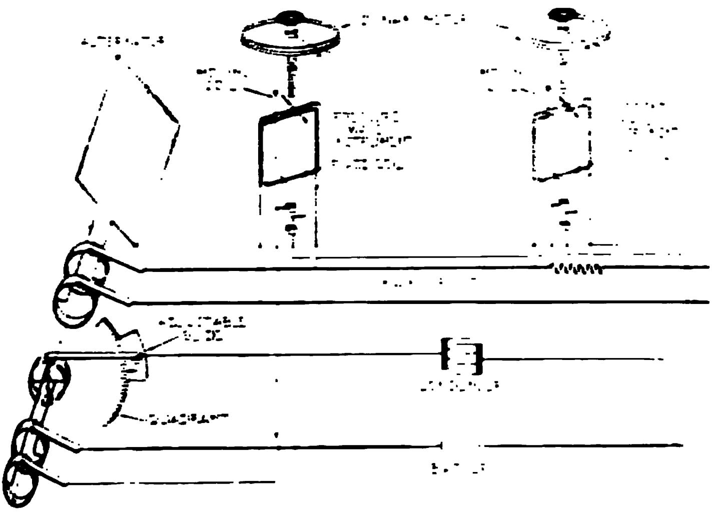


FIG. 2,591.—**Modified four part commutator method** of [illegible] measurement (Duncan's modification). [illegible] of waves having the same frequency [illegible] nections are made as here shown. [illegible] make, and the fixed rings are connected [illegible] then the deflection will be steady and [illegible] directly in watts.

galvanometer readings as ordinates, the curve drawn tl
them will represent the wave form.

The apparatus is calibrated by passing a known constant
through the resistance.

Ballistic Galvanometer Method.—This method, wl
due to Kubber, employs a *contact breaker* instead of a

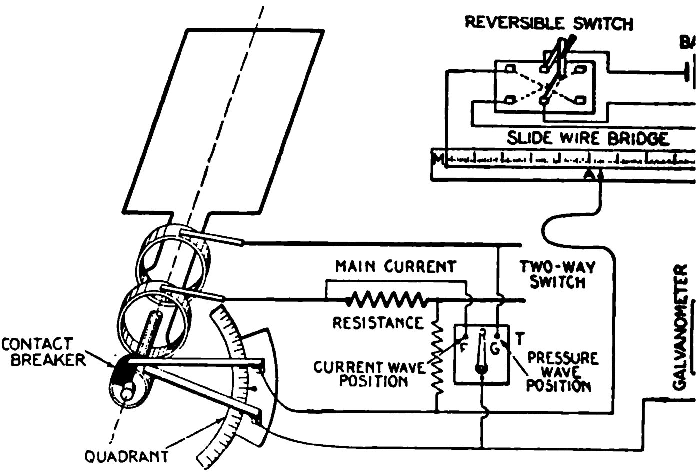


Fig. 2,592.—Diagram illustrating the **ballistic galvanometer method of wave form** ment. **The test may be made** as described in the accompanying text, or in case tact breaker is belted instead of attached rigidly to the shaft, it could be arrang slightly out of synchronism, then by taking readings at regular intervals, point obtained along the curve without moving the contact breaker. If this method a non-adjustable contact breaker suffices. **In arranging the belt drive** so slightly out of synchronism, if the pulleys be of the same size, the desired result is by pasting a thin strip of paper around the face of one of the pulleys thus alt velocity ratio of the drive slightly from unity.

maker. The distinction between these two devices sho
noted: A contact maker keeps the circuit *closed* during
revolution for a short interval only, whereas, a contact b
keeps the circuit *open* for a short interval only.

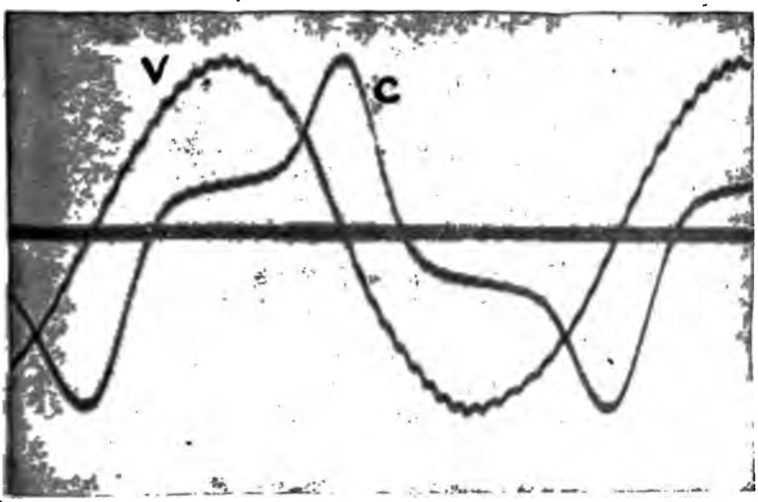
Fig. 2,592, shows the necessary apparatus and connections for a
the ballistic galvanometer method. The contact breaker consi
commutator having an ebonite or insulating segment and two

In operation the contact breaker keeps the circuit closed during all of each revolution, except the brief interval in which the brushes pass over the ebonite segment.

The contact breaker is adjustable and has a scale enabling its various positions of adjustment to be noted.

Ques. Describe the test.

Ans. The contact breaker is placed in successive positions



FIGS. 2,593 and 2,594.—**Two curves** *representing pressure and current respectively of a rotary converter*. **Fig. 2,593, pressure wave V, fig. 2,594** current wave C. These waves were **obtained from a converter which was being** driven by an alternator by means of an independent motor. The rotary converter was supplied with current [illegible] transformers and the ripples clearly visible in the pressure wave V, correspond to the number of teeth in the armature of the rotary converter.

and galvanometer readings taken, the switch being turned to F, fig. 2,592, in measuring the current wave, and to G in measuring the pressure wave. The results thus obtained are plotted giving respectively current and pressure waves.

Ques. How is the apparatus calibrated?

Ans. *By sending a constant current of known value through the resistance R.*

Zero Method.—In electrical measurements, a zer is one *in which the arrangement of the testing devices is the value of the quantity being measured is shown whe vanometer needle points to* **zero.**

In the zero method either a contact maker or conta may be used in connection with a galvanometer and bridge, as shown in figs. 2,595 and 2,596.

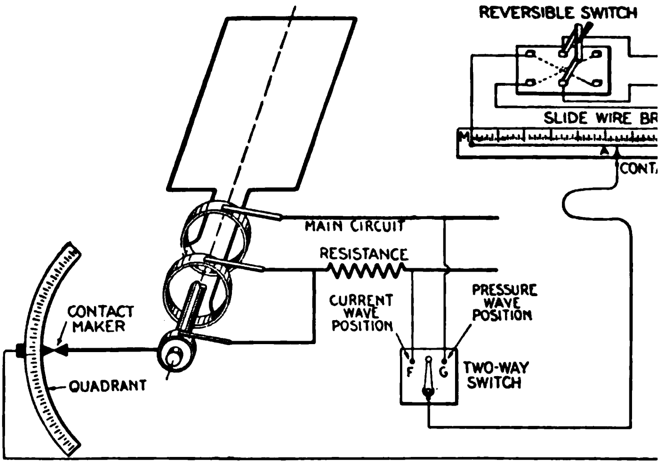


FIG. 2,595.—Diagram illustrating zero method of wave measurement with cc The voltage of the battery must be at least as great as the maximum measured and must be kept constant.

Ques. What capacity of battery should be use

Ans. Its voltage should be as great as the maxim sure to be measured.

Ques. What necessary condition must be ma in the battery?

Ans. Its pressure must be kept constant.

Ques. **How are instantaneous values measure**

Ans. The bridge contact A is adjusted till the galv

[redacted]

shows no deflection, then the length AS is a measure of the pressure.

The drop between these points can be directly measured with a voltmeter if desired.

Ques. How did Mershon modify the test?

Ans. He used a telephone instead of the galvanometer to determine the correct placement of the bridge contact A.

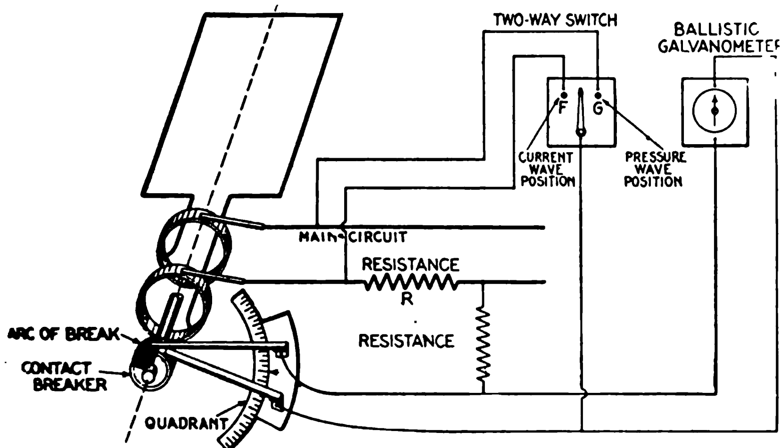


FIG. 2,596.—Diagram illustrating zero method of wave measurement with contact breaker. The voltage of the battery must be at least as great as the maximum pressure to be measured and must be kept constant.

Ques. How can the instantaneous values be recorded?

Ans. By attaching to the contact A, a pencil controlled by an electromagnet arranged to strike a revolving paper card at the instant of no deflection, the paper being carried on a drum.

Hospitalier Ondograph.—The device known by this name is a *development of the Joubert step by step method of wave form measurement, that is to say*, the principle on which it

action is based, consists in *automatically charging a condenser from each 100th wave, and discharging it through a recording galvanometer, each successive charge of the condenser being automatically taken from a point a little farther along the wave.*

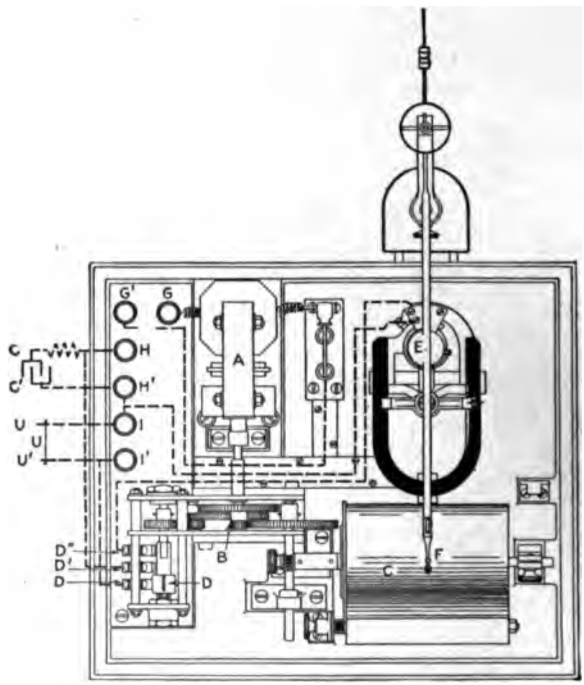


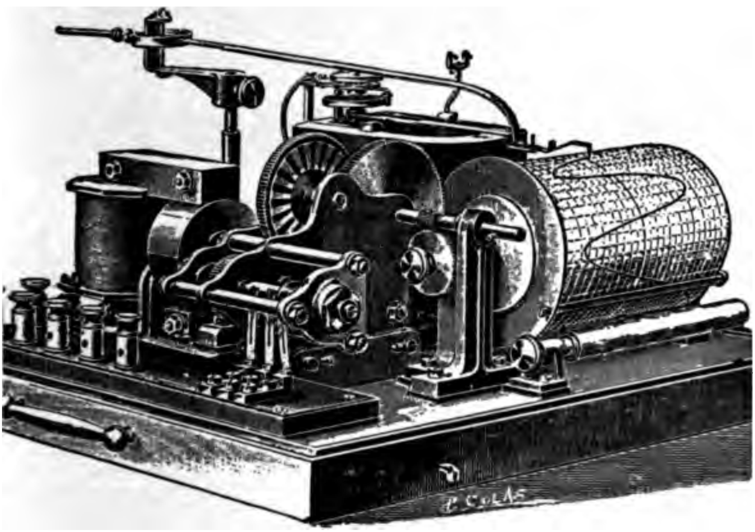
FIG. 2,597.—Diagram of Hospitalier ondograph showing mechanism and connections. It represents a development of Joubert's step by step method of wave form measurement.

As shown in the diagram, fig. 2,597, the ondograph consists of a synchronous motor A, operated from the source of the wave form to be measured, connected by gears B to a commutator D, in such a manner that while the motor makes a certain number of revolutions, the *commutator* makes a like number diminished by unity; that is to say, if *the speed of the motor be 900 revolutions per minute, the commutator will have a speed of 899.*

The commutator has three contacts, arranged to automatically charge the condenser *cc'* from the line, and discharge it through the galvanometer E, the deflection of which will be proportional to the pressure at any particular instant when contact is made.

In fig. 2,597, GG' are the motor terminals, HH' are connected to the condenser *cc'* through a resistance (to prevent sparking at the commutator) and I, I' are the connections to the service to be measured.

A permanent magnet type of recording galvanometer is employed. Its moving coil E receives the discharges of the condenser in rapid succession and turns slowly from one side to the other.



IG. 2,598.—View of Hospitalier ondograph. **In operation**, a long pivoted pointer carrying a pen and actuated by electromagnets, records on a revolving drum a wave form representing the alternating current, pressure or current wave.

The movable part operates a long needle (separately mounted) carrying a pen F, which traces the curve on the rotating cylinder C. This cylinder is geared to the synchronous motor to run at such a speed as to register three complete waves upon its circumference.

By substituting an electromagnetic galvanometer for the permanent magnet galvanometer, and by using the magnet coils as current coils and the *moving coil as the volt* coil, the instrument can be made to draw *watt curves. Fig. 2,598* shows the general appearance of the ondograph

Cathode Ray Oscillograph.—This type of apparatus for measuring wave form was devised by Braun, and consists of a cathode ray tube having a fluorescent screen at one end, a small

FIG. 2,599.—General Electric **moving coil oscillograph** complete **with tracing table.** The tracing table is employed for observing the waves, and by using a piece of transparent paper, the waves under observation appear as a continuous band of light which can be traced, thus making a permanent record. This is not, however, to be regarded as a recording attachment, and can not be used where instantaneous phenomena are being investigated. **The synchronous motor** for operating the synchronous mirror in connection with tracing and viewing attachment is wound for 100 to 115 volts, 25 to 125 cycles, and should, of course, be run from the same machine which furnishes power to the circuit under observation. A rheostat for steadying and adjusting the current should be connected in series with the motor. **The beam from the vibrator mirrors** *striking this synchronous mirror moves back and forth over the curved glass, and gives the length of the wave; the movement of the vibrator mirror gives the amplitude, and the combination gives the wave complete.* An arc lamp or projection lantern produces the image reflected by the mirrors upon the film, tracing table or screen. For the rotation of the photographic film, a small direct current shunt wound motor is ordinarily used.

diaphragm with a hole in it at its middle, and two coils of a few turns each, placed outside it at right angles to one another.

These coils carry currents *proportional to the* **pressure** *and* **current** *respectively* of the circuit under observation.

The ray then moves so as to produce an energy diagram on the fluorescent screen.

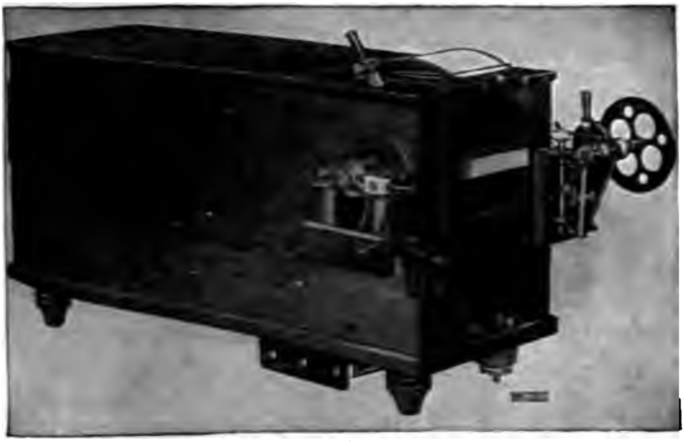


FIG. 2,6[illegible].—General Electric moving coil oscillograph. **The moving elements** consist of ***single loops of flat wire carrying a small mirror and held in tension by small spiral springs.*** The current passing down one side and up the other forces one side forward and the other backward, thus causing the mirror to vibrate on a vertical axis. The vibrator elements fit into chambers between the poles of electro-magnets and are adjustable so as to move the beam from the mirror, both vertically and horizontally. A sensitized paper or film is wrapped around a drum and held by spring clamps. The drum, with film, is placed in a case and a cap then placed over the end, making the case light tight when the index is either up or down. The loading is done in a dark room. A driving dog is screwed into the drum shaft, and **which**, when the drum and case are in place, revolves the film past a slot. **When an exposure is to be made,** the index is moved from the closed position, thus opening the slot in the case and exposing the film to the beam of light from the vibrating mirrors when the electrically operated shutter is open. The slot is then closed by moving the index to **"Exposed."** A slide with ground glass can be inserted in place of the film case or roll holder to arrange the optical system when making adjustments. The shutter operating mechanism is arranged so as to hold the shutter open during exactly one revolution of the film drum. There are two devices connected to the shutter operating mechanism; one opens the shutter at the instant the end of the film passes the slot; the other opens immediately, at any part of the film, and gives true exposure during one revolution. The first is useful when making investigations in which the events are either recurring, or their beginnings known or under control, and the second when the time of the event is not under control, such as the blowing of fuses or opening of circuit breakers.

The instrument is much used in wireless telegraphy, as it **is** apable of showing the characteristics of currents of very **high** ***frequency.***

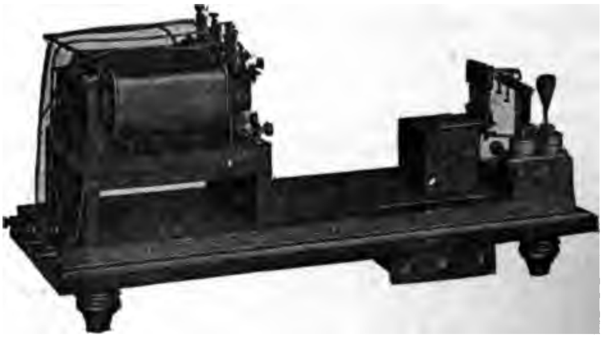


FIG. 2,601.—General Electric **moving coil oscillograph** *with case removed*, **showing** *interior construction and arrangement of parts.* The oscillograph is furnished **complete with** a three element electromagnet galvanometer, optical system, shutter and **shutter operating** mechanism, film driving motor and cone pulleys, photographic and **tracing attachments**, 6 film holders, and the following repair parts, for vibrators: 6 extra **suspension strips**; 6 **vibrator** mirrors: 1 box gold leaf fuses; 1 bottle mirror cement; 1 bottle **damping liquid.**

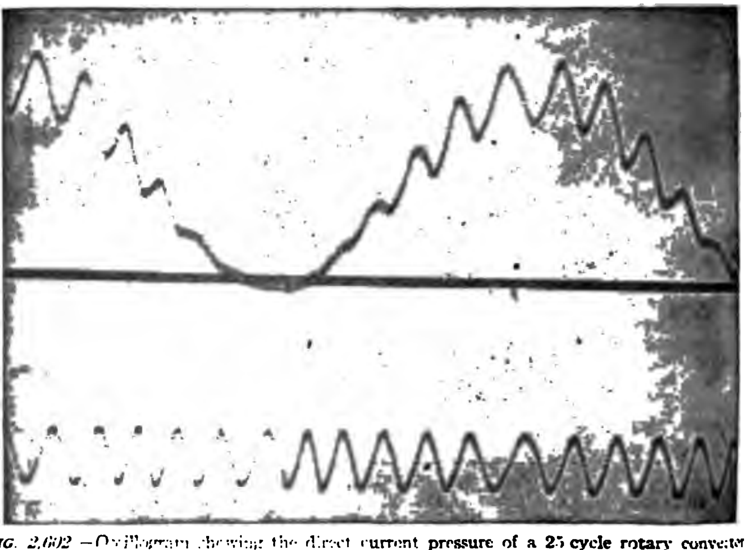


FIG. 2,602.—Oscillogram showing the direct current pressure of a 25 cycle rotary converter (*below*), and *above* the pressure wave taken between one collector ring and one commutator brush. The 12 ripples per cycle in the direct current voltage are due to a 12th harmonic in the alternating current supply.

Glow Light Oscillograph.—This device consists of two aluminum rods in a partially evacuated tube, their ends being about two millimeters apart. When an alternating current of any frequency passes between them a sheath of violet light forms on one of the electrodes, passing over to the other when the current reverses during each cycle. The phenomenon may be observed or photographed by means of a revolving mirror.

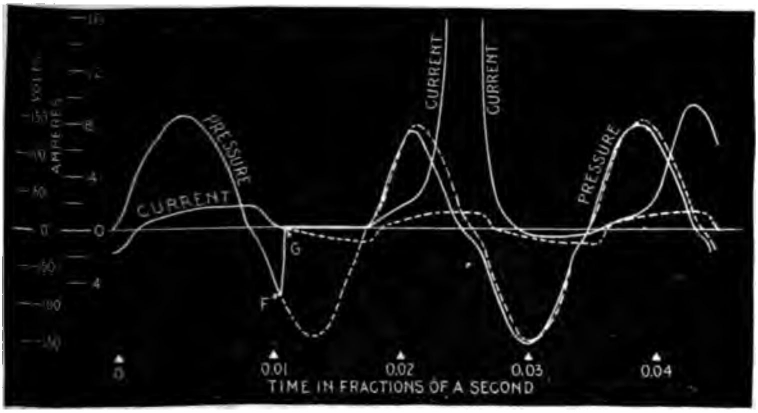


FIG. 2,603.—Curves by Morris, *illustrating the* **dangerous rush of current which may occur when switching on a transformer.** The circuit was broken at F and made again at G. The current was so great as to carry the spot of light right off the photographic plate due to the fact that a residual field was left in the core after switching off, and on closing the switch again the direction of the current was such as to tend to build up the full flux in the same direction as this residual flux. **The dotted lines** have been drawn in *to show how the actual waves were distorted from the normal.*

Moving Iron Oscillograph.—This type is due to Blondel, to whom belongs the credit of working out and describing in considerable detail the principles underlying the construction of oscillographs.

The moving iron type of oscillograph consists of a very thin vane of iron suspended in a powerful magnetic field, thus forming a polarized magnet. Near this strip are placed two small coils which carry the current whose wave form is to be measured.

The moving *iron vane has* a very short period of vibration and can *therefore follow every* variation in the current.

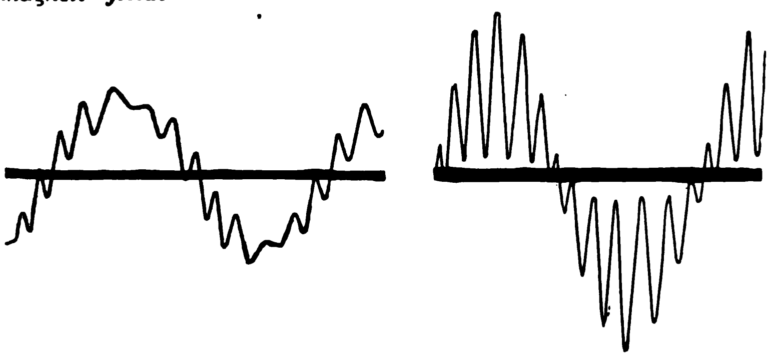
FIG. 2,604.—Siemens-Blondel **moving coil type** oscillograph. The coil is in the shape of a loop of thin wire, which is suspended in the field of an electro-magnet excited by continuous current. The current to be investigated is sent through this loop, which in consequence of the interaction of current and magnetic field, begins to vibrate. The oscillations are rendered visible by directing a beam of light from a continuous current arc lamp onto a small mirror fixed to the loop. The light reflected by the mirror is in the form of a light strip, but by suitable means this is drawn out in respect of time, so that a curve truly representing the current is obtained. The loop of fine wire is stretched between two supports and is kept in tension by a spring. As the spring tension is considerable, the directive force of the vibrating system is large, and its natural periodicity very high. The mirror is fixed in the center of the loop, and has an area of 1 square mm. In order to protect the loops from mechanical injury they are built into special frames. The mirrors are of various sizes, the loop for demonstration purposes (projection device) being provided with the largest mirror and the most sensitive loop with a mirror of the smallest dimensions.

[redacted]

Attached to the vane is a small mirror which reflects a beam of light upon some type of receiving device.

The Siemens-Blondel oscillograph shown in fig. 2,604, is of the *moving coil* type, being a development of the moving iron principle.

Moving Coil Oscillograph.—The operation of this form of oscillograph is based *on the behavior of a movable coil in a magnetic field.*



FIGS. 2,605 and 2,606.—Oscillograms reproduced from a paper by M. B. Field on "A Study of the **Phenomena of Resonance** by the Aid of Oscillograms" (*Journal* of *E. E.*, Vol. XXXII). **The effect of resonance** on the wave forms of alternators has been the subject of much investigation and discussion; it is a matter of vital importance to the engineer in charge of a large alternating current power distribution system. Fig. 2,605 shows the pressure curve of an alternator running on a length of unloaded cable, the 11th harmonic being very prominent. Fig. 2,606 shows the striking alteration produced by reducing the length of cable in the circuit and thus causing resonance with the 13th harmonic.

It consists essentially of a modified moving coil galvanometer combined with a rotating or vibrating mirror, a moving photographic film, or a falling photographic plate. The galvanometer portion of the outfit is usually referred to as the oscillograph as illustrated in figs. 2,608 to 2,612, representing diagrammatically the moving system.

In the narrow gap between the poles S, S of a powerful magnet are stretched two parallel conductors formed by bending a thin strip of phosphor bronze back on itself over an ivory pulley P. A spiral spring attached to this pulley serves to keep a uniform tension on the strips, and a guide piece L *limits the* length of the vibrating portion to the part *actually in the magnetic field.*

A small mirror M bridges across the two strips as shown. The effect of passing a current through such a "vibrator" is to cause one of the strips to advance while the other recedes, and the mirror is thus turned about a vertical axis.

Each strip of the loop passes through a separate gap (not shown in the figure). The whole of the "vibrator," as this part of the instrument is called, is immersed in an oil bath, the object of the oil being to damp

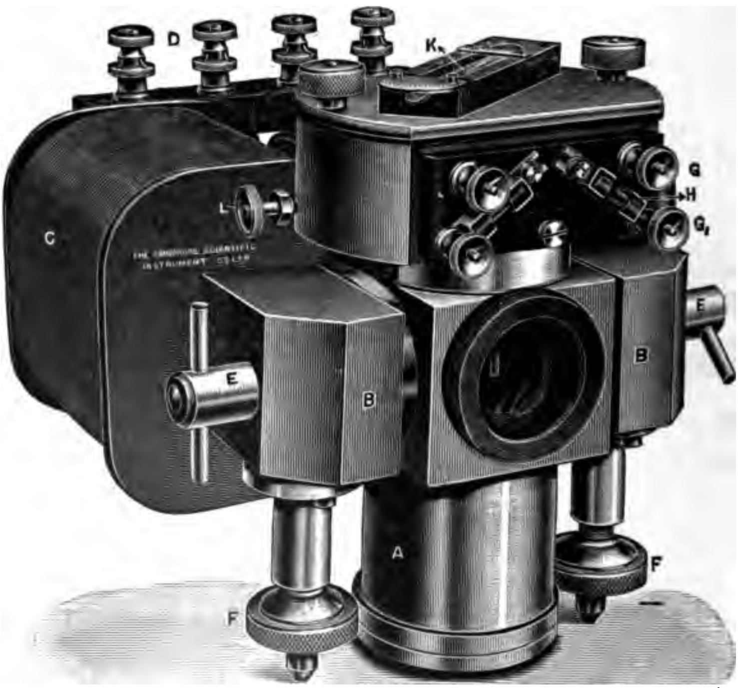
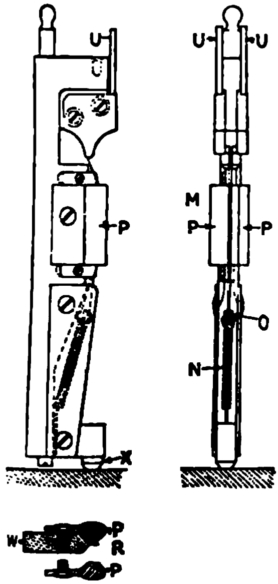
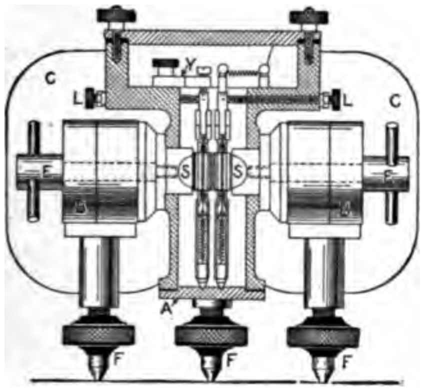


FIG. 2,607. General view of electro-magnet form of Duddell moving coil oscillograph, showing oil bath and electro-magnet. This instrument is specially designed to have a very high natural period of vibration (about $\frac{1}{10,000}$ of a second) so as to be suitable for accurate research work. It is quite accurate for frequencies up to 300 per second. In the figure, A is the base on which the two vibrators are fixed; B, core of electro-magnet which is excited by two coils, one of which, C, is seen. The ends of these two coils are brought out to four terminals at D so that the coils may be connected in series for 200 volt, or in parallel for 100 volt circuits. The bolts, E,E, hold the oil bath in position between the poles of the magnet. F,F,F (one not seen), are levelling screws; G,G, terminals of one vibrator; H, fuse, K, thermometer with bulb in center of oil bath.





IGS. 2,608 to 2,612.—**Vibrator of** Duddell moving coil oscillograph and **section through oil bath** of electromagnet oscillograph. **The vibrator consists of** a brass frame W, which supports two soft iron pole pieces P,P. Between these, a long narrow groove is divided into two parts by a thin soft iron partition, which runs up the center. The current being led in by the brass wire U, passes from an insulated brass plate to the strip, which is led over an ivory guide block, down one of the narrow grooves and over another guide block, the loops round the ivory pulley O, which puts tension on the strip by the spring N, back to the guide block again, up the other narrow groove, and out by way of the insulated brass plate and lead U. Halfway up the grooves the center iron partition R is partially cut away to permit of a small mirror M, bridging across from one strip to the other, being stuck to the strips by a dot of shellac at each corner. The figure illustrates one type of vibrator in which P is removable from W for ease in repairing. In type 1, these pole pieces P,P are not removable. **The vibrators** are placed side by side in the gap between the poles S,S of the electromagnet, see fig. 2,610. Each vibrator is pivoted about vertical centers, the bottom center fitting in the base of the oil bath, and the one at the top being formed by a screw in the cock piece Y. It can thus be easily turned in azimuth, its position being fixed by the adjusting screw L, a spiral spring serving to keep the vibrator always in contact with this screw. Since each cock piece can be independently moved forward or backward, each vibrator can be tipped slightly in either of these directions so that complete control over the mirrors is obtained and reflected spots of light may be made to coincide with that reflected from the fixed zero mirror, which latter is fixed to a brass tongue in between the two vibrators. **A plano-convex lens** of 50 cm. focal length is fixed on the oil bath in front of the vibrator mirrors to converge the reflected beams of light. It will be noticed that this lens is slightly inclined so that no trouble will be given by reflections from its own surface. The normal distance from the vibrator mirrors to the scale of photographic plate is 50 cm., and at this distance, a convenient working deflection on each side of the zero line is 3 to 4cm. This is obtained with a R.M.S. current through the strips of from .05 to .1 of an ampere according to wave form, etc. ***The maximum deflection on each side of the zero line should not exceed 5cm. while the maximum R.M.S. current through the strips should in no case exceed .1 ampere.***

the movement of the strips, and make the instrument dead be also has the additional advantage of increasing by refraction the ment of the spot of light reflected from the vibrating mirrors.

The beam of l'ght reflected from the mirror M is received on a or photographic plate, the instantaneous value of the current bei portional to the linear displacement of the spot of light so form

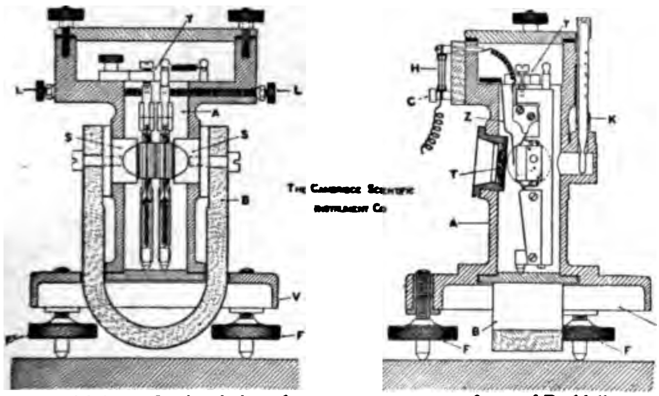
With alternating currents, the spot of light oscillates to and fro current varies and wou'd thus trace a straight line.

To obtain an image of the wave form, it is necessary to trave photographic plate or film in a direction at right angles to the di of the movement of the spot of light.

FIG. 2,613.—Duddell **moving coil oscillograph** *with projection and tracing desk out* outfit is designed for teaching and lecture purposes. **In operation,** *after the bean from the arc lamp has been reflected from the oscillograph mirrors, it falls on a vibratin which gives it a deflection proportional to time in a direction at right angles to the it already has and which is proportional to the current passing through the osci* It is therefore only necessary to place a screen in the path of the reflected beam of obtain a trace of the wave form. Since the vibrating mirror is vibrated by means on the shaft of a synchronous motor, which motor is driven from, or synchronou the source of supply whose wave form is being investigated, the wave form is time after time in the same place on the screen, and owing to the "persistence" o the whole wave appears stationary on the screen. The synchronous motor with its mirror, mentioned above, is located underneath the "tracing desk." When use position a wave a few centimeters in amplitude is seen through a sheet of tracin which is bent round a curved sheet of glass. A permanent record of the wave f thus easily be traced on the paper. A *dark box* which is designed to hold a shee sitized paper in place of the tracing paper, can be fitted in place of the tracing desl an actual photographic record of the wave form is obtained. If the synchronou be transferred from its position underneath the tracing desk to the space reserv close to the oscillograph, the beam of light is then received on a large mirror which i at an angle of about 45 degrees to the horizontal and so projects the wave form large vertical screen which should be fixed about two and a half meters distant. these conditions a wave form of amplitude 50 cm. each side the zero line may be which is therefore visible to a large audience.

Ques. How are the oscillograms obtained in Duddell moving coil oscillograph?

Ans. In all cases the oscillograms are obtained by a s *light tracing* out the curve connecting current or voltage *time.* The source of light is an arc lamp, the light from passes first through a lens, and then, excepting when projecting on a screen, through a rectangular slit about 10 mm. long by 1 mm. wide. The position of the lamp from the lens is adjusted till an image of the arc is obtained covering the three (two moving, one fixed) small oscillograph mirrors. The light is reflected back from these mirrors and, being condensed by a lens which is immediately in front of them, it converges till an image of the slit is formed on the surface where the record is



FIGS. 2,614 and 2,615.—Sectional view of **permanent magnet form** of Duddell **moving coil oscillograph.** This instrument has a lower natural period of vibration ($\frac{1}{3,000}$ second) than the type shown in fig. 2,612, and therefore is not capable of accurately following wave forms of such high frequency, but it is sufficiently quick acting to follow wave forms of all ordinary frequencies with perfect accuracy. It is easier to repair, and more portable, owing to the fact that the magnetic field is produced by a permanent magnet instead of an electro-magnet. This also renders the instrument suitable for use on high tension circuits without earth connection, as, owing to the fact that no direct current excitation is required, the instrument is more easily insulated than other types.

desired. All that is necessary now to obtain a bright spot of light instead of this line image is to introduce in the path of the beam of light a cylindrical lens of short focal length.

Ques. What is the function of the mirrors on the vibrating vane?

Ans. *They simply control* the direction of a beam of light

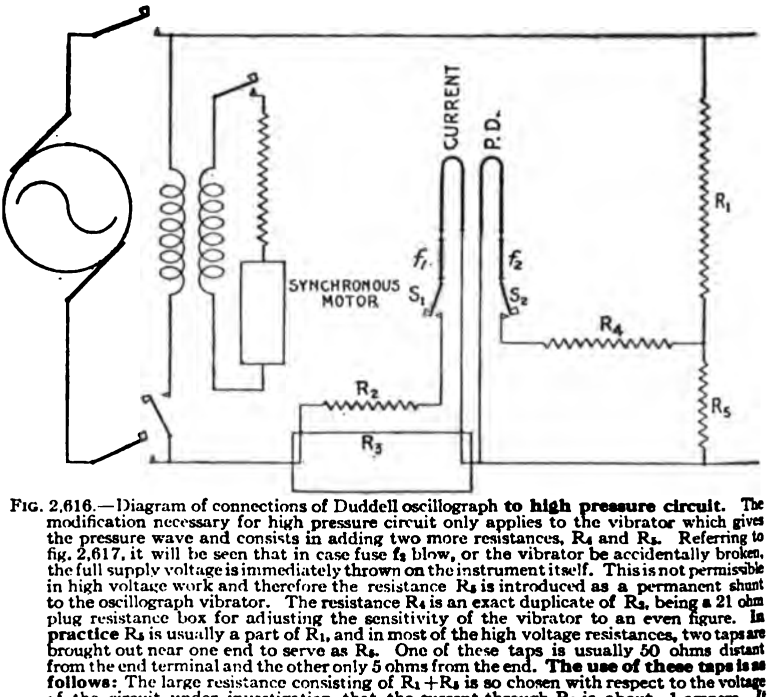


FIG. 2,616.—Diagram of connections of Duddell oscillograph **to high pressure circuit.** The modification necessary for high pressure circuit only applies to the vibrator which gives the pressure wave and consists in adding two more resistances, R_4 and R_5. Referring to fig. 2,617, it will be seen that in case fuse f_2 blow, or the vibrator be accidentally broken, the full supply voltage is immediately thrown on the instrument itself. This is not permissible in high voltage work and therefore the resistance R_5 is introduced as a permanent shunt to the oscillograph vibrator. The resistance R_4 is an exact duplicate of R_3, being a 21 ohm plug resistance box for adjusting the sensitivity of the vibrator to an even figure. **In practice** R_5 is usually a part of R_1, and in most of the high voltage resistances, two taps are brought out near one end to serve as R_5. One of these taps is usually 50 ohms distant from the end terminal and the other only 5 ohms from the end. **The use of these taps is as follows:** The large resistance consisting of R_1+R_5 is so chosen with respect to the voltage of the circuit under investigation that the current through R_1 is about .1 ampere. *It should never be more than this continuously.* Then R_4 is connected to the 50 ohm tap, and since the resistance of the oscillograph vibrator circuit is variable from about 5 to 26 ohms by means of R_4, the current can be controlled through the oscillograph from about .066 to .001 of an ampere, enabling an open wave form to a convenient scale to be obtained. **If it now be desired to record large rises of pressure,** such as may occur in cases of resonance, *the height of the wave must be reduced in order to keep these rises on the plate.* This is accomplished by disconnecting R_4 from the 50 ohm tap and connecting it to the 5 ohm tap, when the current through the vibrator will be from .05 to .016 of an ampere according to whether the resistance R_4 is in or out of circuit. When, instead of using the *falling plate,* the *cinematograph* camera is being used, it becomes necessary always to work on the 5 ohm tap since the width of the film is much less than that of the plate, and the current must therefore be less. **In experiments where sudden rises of voltage are expected** *it is often advisable to keep* R_1 *as great as possible.* That end of the resistance R_1 referred to as R_5 in the diagram should be securely connected to the supply main and no switch or fuse used. A switch may, if desired, be used in series with R_1, provided it be inserted at the point where R_1 joins the supply main remote from R_5. It will be seen that fuses f_1 and f_2 are shown. Provided that the connections are always made in accordance with the diagram, and the vibrators are always shunted by R_5 or R_3 respectively, there is not much objection to the use of these fuses, but on general principles it is wise to avoid fuses in high tension work *and accordingly* with each permanent magnet oscillograph, dummy fuses are supplied *which can be inserted* in place of the ordinary fuses when desired. ***The remark previously made about keeping both vibrators and the frame of the instrument at approximately the same pressure applies with additional emphasis in high pressure work.***

in a horizontal plane in such a manner that its deflection from a zero position depends on the current passing through the instrument, and it is therefore evident that the oscillograph is not complete without means of producing a time scale.

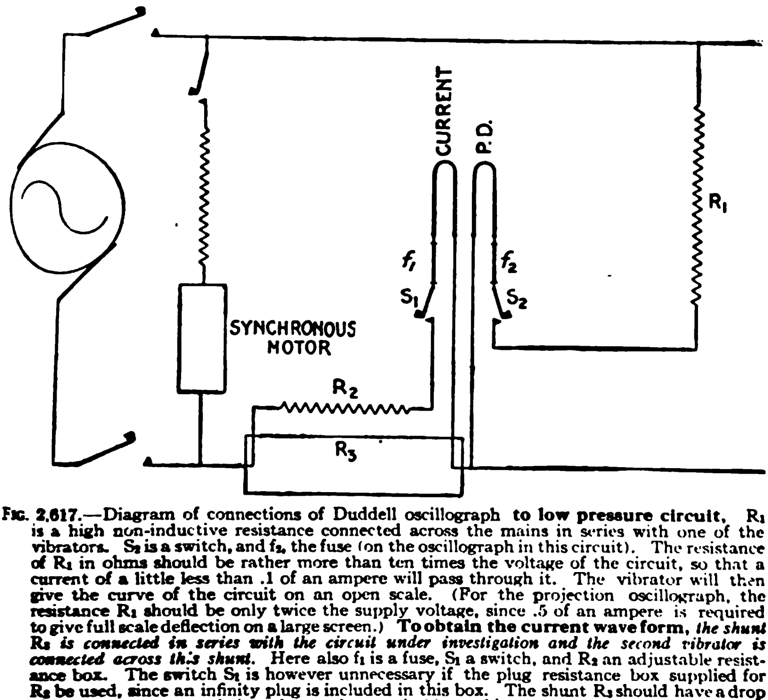


FIG. 2,617.—Diagram of connections of Duddell oscillograph **to low pressure circuit.** R_1 is a high non-inductive resistance connected across the mains in series with one of the vibrators. S_2 is a switch, and f_2, the fuse (on the oscillograph in this circuit). The resistance of R_1 in ohms should be rather more than ten times the voltage of the circuit, so that a current of a little less than .1 of an ampere will pass through it. The vibrator will then give the curve of the circuit on an open scale. (For the projection oscillograph, the resistance R_1 should be only twice the supply voltage, since .5 of an ampere is required to give full scale deflection on a large screen.) **To obtain the current wave form,** *the shunt R_3 is connected in series with the circuit under investigation and the second vibrator is connected across this shunt.* Here also f_1 is a fuse, S_1 a switch, and R_2 an adjustable resistance box. The switch S_1 is however unnecessary if the plug resistance box supplied for R_2 be used, since an infinity plug is included in this box. The shunt R_3 should have a drop of about 1 volt across it in order to give a suitable working current through the vibrator. The resistance R_2 is not absolutely essential, but it is a great convenience in adjusting the current through the vibrator. It is a plug resistance box, the smallest coil being .01 of an ohm and the total 21 ohms. Being designed to carry .5 ampere continuously it can be used with any other type of Duddell oscillograph, and by its use the sensitiveness of the vibrator can be adjusted so that a round number of amperes in the shunt gives 1 mm. deflection. This adjustment is best made with direct current. **It should be noted in** connecting the oscillograph in circuit, that *the two vibrators should be so connected to the circuit that it is impossible that a higher pressure difference than 50 volts should exist between one vibrator and the other, or between either vibrator and the frame.* To ensure attention to this important point, a brass strap is provided which connects the two vibrators together and to the frame of the instrument. This does not mean that this point must necessarily be *earthed since the frame* of the instrument is insulated from the earth. *It is advisable, however,* to earth it when possible.

[redacted]

FIGS. 2,618 and 2,619.—**Two curves** *obtained with the* **falling plate camera** and illustrating *the discharge of a condenser through an inductive circuit.* **When taking curve A** the resistance in the circuit was very small compared to the inductance, while **before taking curve B** an additional non-inductive resistance was inserted in the circuit so that the oscillations were damped out much more rapidly although the periodic time remained approximately constant.

Ques. How is the time scale produced?

Ans. Either the surface on which the beam of light falls may be caused to move in a vertical plane with a certain velocity, so that the intersection of the beam and the plane surface traces out a curve connecting current with time (a curve which becomes a permanent record if a sensitized surface be used); or, the surface may remain stationary and in the path of the horizontally vibrating beam may be introduced a mirror which rotates or vibrates about a horizontal axis, thus superposing a vertical motion proportion to time on the horizontal vibration which is proportional to current, and causing the beam of light to trace out a curve connecting current and time on the stationary surface.

Ques. What kind of recording apparatus is used with the Duddell oscillograph?

Ans. A falling plate camera, or a cinematograph film camera.

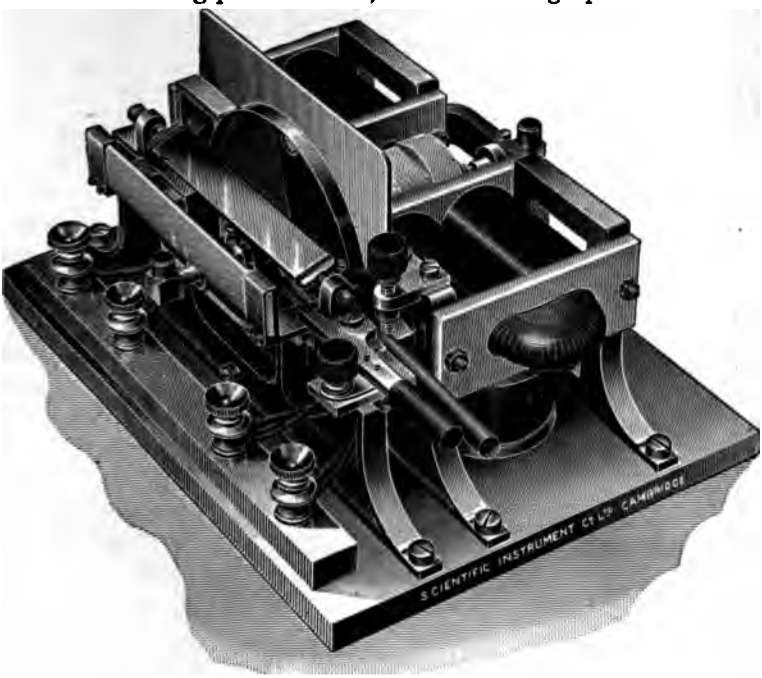


FIG. 2,620.—Synchronous motor with vibrating mirror as used with Duddell moving coil oscillograph. **Since the motor must run synchronously** with the wave form it is required to investigate, *it should be supplied with current from the same source.* The motor can be used over a wide range of frequencies (from 20 to 120). When working at frequencies below 40, it is advisable to increase the moment of inertia of the armature, and for this purpose a suitable brass disc is used. **The armature carries a sector,** *which cuts off the light from the arc lamp during a fraction of each revolution, and a cam which rocks the vibrating mirror.* **It makes one revolution during two complete periods,** and the cam and sector are so arranged *that during* $1\frac{1}{2}$ periods, the mirror is turning with uniform *angular velocity, while during the* remaining half period, the mirror is brought back *quickly to its angular position,* the light being cut off by the sector during this half period

Ques. Explain the operation of the falling plate camera.

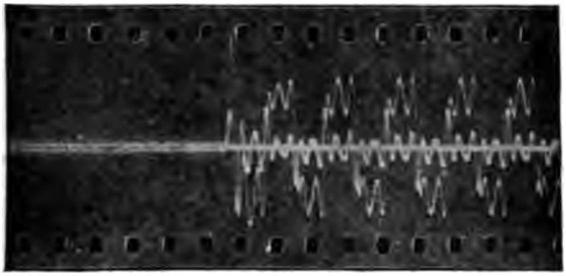
Ans. In this arrangement a photographic plate is allowed to fall freely by the force of gravity down a dark slide. At a certain point in its fall it passes a horizontal slit through which the beams of light from the oscillograph pass, tracing out the curves on the plate as it falls.

The mean speed of the plate at the moment of exposure is about 13 feet per second. This speed is very suitable for use with frequencies of

FIGS. 2,621 to 2,623.—Interior of cinematograph camera as used on Duddell moving coil oscillograph **for obtaining long records.** The loose side of case is shown removed and one of the reels which carry the film lying in front. **The spool of film** which is placed on the loose reel A, passes over the guide pulley B, then vertically downward between the brass gate D (shown open in the figure), and the brass plate C. **The exposure aperture** is in the plate C and can be opened or closed by a shutter controlled by the lever M. The groove in the plate C, and the springs which press the gate D flat on the plate C, prevent the film having any but a vertical motion as it passes the exposure slit. E is the sprocket driving pulley which engages with the perforations on the film and unwinds it from the reel A to reel H. Outside the case on the far side of it is secured to the axle G a three speed cone pulley. This is driven by a motor of about ⅛ horse power, which also drives, through the gears shown, the sprocket pulley E. Close to the grooved cone pulley is a lever carrying a jockey pulley L, and a brake which latter is normally held onto the cone pulley by a spring and so causes the loose belt to slip. By pressing a lever which is attached to the falling plate camera case, the brake can be suddenly released and at the same time the jockey pulley caused to tighten the belt onto the grooved cone pulley, so that the starting and stopping of the film is controlled independently of the driving motor, and being quickly accomplished avoids waste of film. **Both reels** are alike and each is made in two pieces. **The upper reel** is loose on its axle and its motion is retarded slightly by a friction brake. **The lower reel** is also loose on its axle, but it is driven by means of a friction clutch, the clutch always rotating faster than the reel so that the used film delivered by the sprocket pulley E is wound up as fast as delivered. K is the front face of one reel, the boss on it pushes into the tube on the other half H, which serves not only to unite the two halves, but also to secure the end of the film which is doubled through J.

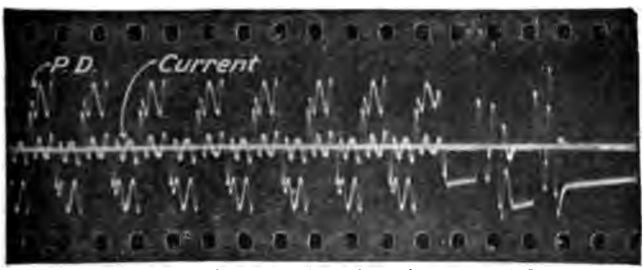
from 40 to 60 periods per second. A cloth bag is used to introduce the plate to the slide.

A catch holds the plate until it is desired to let it fall. Inside the case, is a small motor, 100 or 200 volts direct current, driving four mirrors which are fixed about a common axis with their planes parallel to it.



IGS. 2,624.—Portion of oscillograph record taken with cinematograph film camera, **showing the rush of current** and **sudden rise of voltage** *at the moment of switching on a high pressure feeder.*

By looking through a small slot in the end of the camera into these rotating mirrors, the observer sees the wave form which the oscillograph is tracing out and is thus able to make sure that he is obtaining the particular wave form or other curve desired before exposing the plate.



G. 2,625.—Portion of oscillograph record taken with a cinematograph film camera **showing the effect of switching off a high pressure feeder** and illustrating the violent fluctuations produced by sparking at the switch contacts.

The plate falls into a second red cloth bag which is placed on the bottom of the slide. The plates used are "stereoscopic size," $6^3/_4$" × $3^1/_4$" (17.1 × 8.3 cm.).

Ques. For what use is the cinematograph camera lapted?

Ans. *For long records.*

For instance, in investigations, such as observation on the paralleling of alternators, the running up to speed of motors, and the surges which may occur in switching on and off cable, e:c. The cinematograph camera fits on to the falling plate case and by'means of which a roll of cinematograph film can be driven at a uniform speed past the exposure aperture, enabling records up to 50 metres in length to be obtained. An interior view of the cinematograph camera is shown in fig. 2,621.

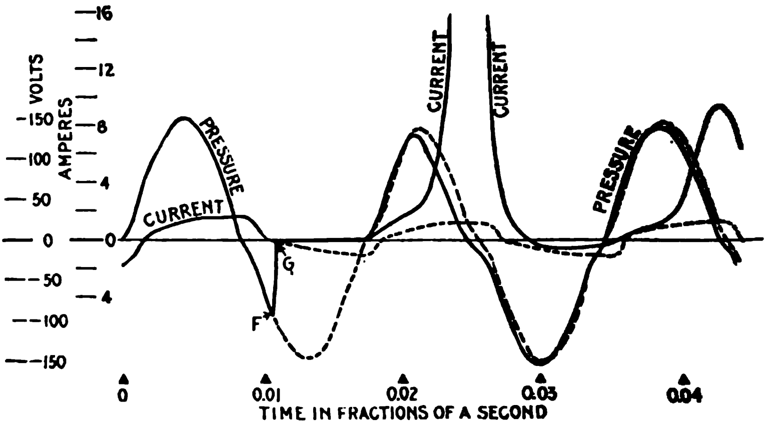
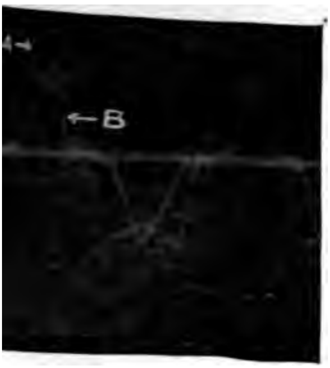


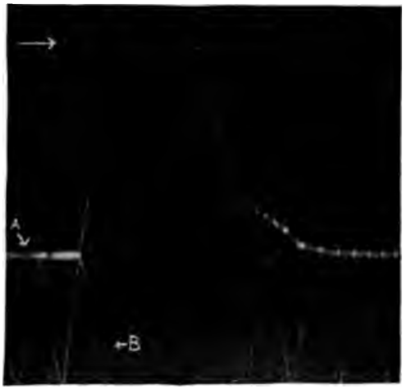
FIG. 2,626.—Curves reproduced from an article by J. T. Morris in the *Electrician*. "On recording transitory phenomena by the oscillograph."

FIG. 2,627.—First rush of current from an alternator when short circuited, showing unsymmetrical initial wave of current, becoming symmetrical after a few cycles. 25 cycles.

FIG. 2,628.—Pressure wave obtained from narrow exploring coil on alternator armature, indicating distribution of field flux. The terminal voltage of the alternator is very nearly *a sign wave.* 60 cycles; about 17 volts.

SOME OSCILLOGRAPH RECORDS





—The waves of voltage and current of an alternating arc. A, voltage wave; B, wave showing low power factor of the arc without apparent phase displacement.
es.

—Rupturing 650 volt circuit. A, current wave; B, 25 cycle wave to mark time scale.

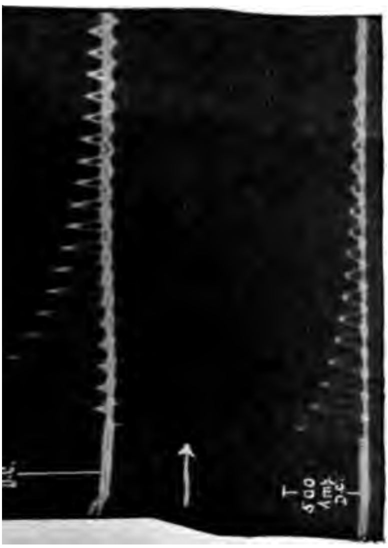


FIG. 2,631.—First rush of current from alternator when short circuited, showing unsymmetrical current wave, also wave of field current caused by short circuit current in armature. Upper curve, armature current; lower curve, field current.

FIG. 2,632.—Mazda (tungsten) lamp, showing rapid decrease to normal current as filament heats up. 25 cycles.

FIG. 2,633.—Current wave in telephone line corresponding to sustained vowel sound "*i*," as in machine; voice pitched at A 110.

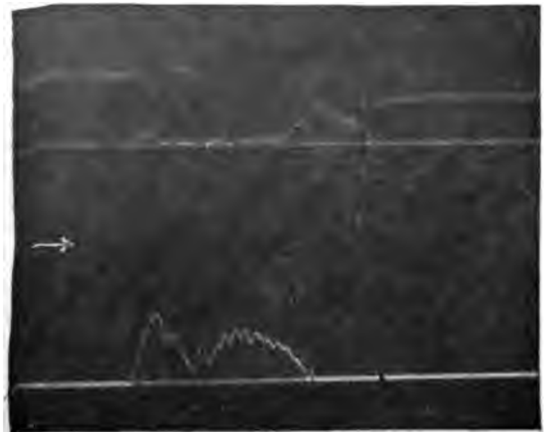


FIG. 2,634.—Carbon lamp, showing rapid increase to normal current as filament heats up. 2.5 cycles.

FIG. 2,635.—Short circuit current on direct current end of rotary converter, 21,500 amperes maximum. Upper curve, direct current voltage; lower curve, direct current amperage. Duration of short circuit about .1 second.

CHAPTER LXIV

SWITCHBOARDS

eneral Principles of Switchboard Connections.—The rconnection of generators, transformers, lines, bus bars, and ches with their relays, in modern switchboard practice is vn by the diagrams, figs. 2,636 to 2,645. The figures being red A to J for simplicity, the generators are indicated by k discs, and the switches by open circles, while each heavy represents a set of bus bars consisting of two or more bus ; according to the system of distribution. It will be underd, also, in this connection, that the number of pole of the ches and the type of switch will depend upon the particular em of distribution employed.

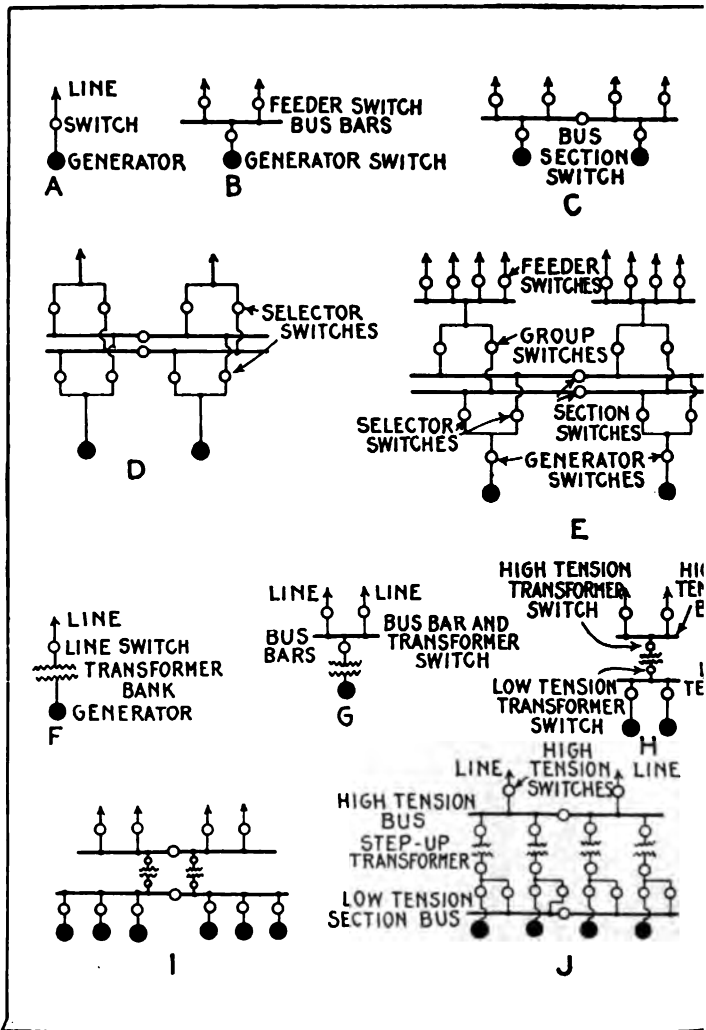
Diagram A, shows the simplest system, or one in which a single generator feeds directly into the line. There are no transformers or bus bars and only one switch is sufficient.

In B, a single generator supplies two or more feeders through a single set of bus bars, requiring a switch for each feeder, and a single generator switch.

In C, two generators are employed and required and the addition of a bus section switch.

D, represents a number of generators supplying two independent circuits. The additional set of bus bars employed for this purpose necessitates an additional bus section switch, and also additional selector switches for both feeders and generators.

E, shows a standard system of connection for a city street railway system having a large number of feeders.



FIGS. 2,645 and 2,646.—Diagrams illustrating general principles of switchboard connectio

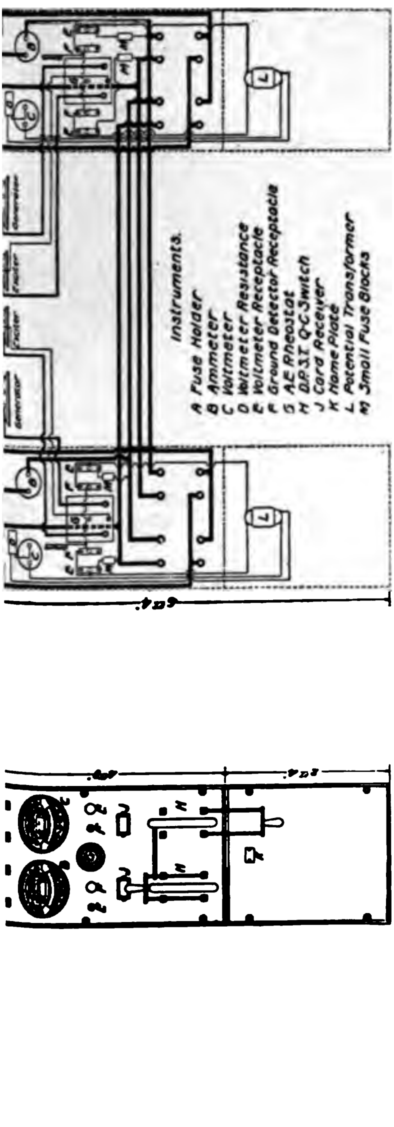


FIG. 2,646.—Fort Wayne switchboard panel for one alternator and one transfer circuit. Diagram giving dimensions, arrangement of instruments of board, and method of wiring. The different forms of standard alternating current switchboard panels for single phase circuits made by the Fort Wayne Electric Works are designed to fulfill all the usual requirements of switchboards for this class of work. The line includes panels equipped for a single generator; for one generator and two circuits; one generator and one transfer circuit; one generator, an incandescent and an arc lighting circuit; and also feeder panels of different kinds.

This arrangement allows any group of feeders to be supplied from any group of generators.

It also permits the addition of a generator switch for each generator.

F, represents the simplest system with transformers.

It requires a single generator transformer bank, switch and line. The arrangement as shown at F is used where a number of plants supply the same system.

G, represen s a system having more than one line.

In this case a bus bar and transformer switch is used on the high tension side.

H, shows a number of generators connected to a set of low tension bus bars through generator switches, and employing a low tension transformer switch.

I, shows the connections of a system having a large number of f supplied by several small generators. In this case, the plant is d into two parts, each of which may be operated independently.

J, represents the arrangement usually employed in modern where the generator capacity is large enough to permit of a gen transformer unit combination with two outgoing lines. By ope

FIG. 2,647.—General Electric **small plant alternating current switchboard,** *desig use in small central stations and isolated plants.* They are for use with one set of bus b which all generators and feeders are connected by means of single throw lever swit circuit breakers, suitable provision being made for the parallel operation of the gene

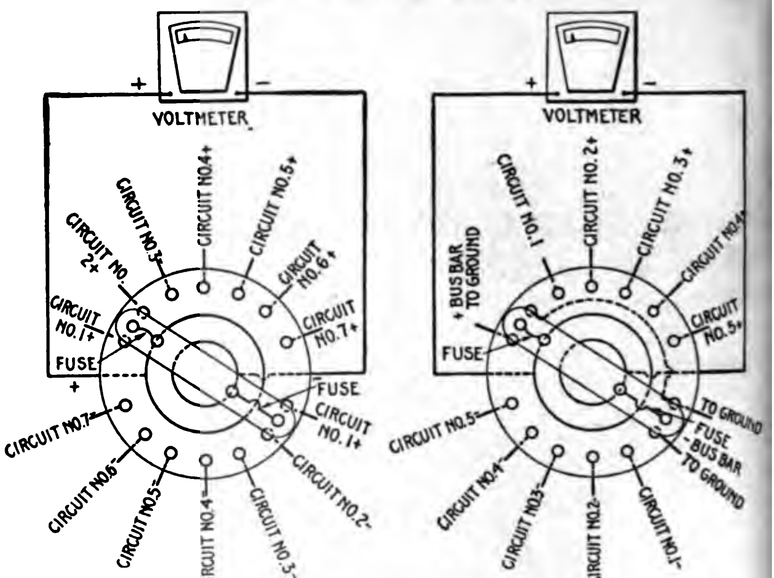
in parallel on the high tension side only, any generator can be run *any transformer.* The whole plant can be run in parallel, or th *parts* can be run separately.

tchboard Panels.—The term "panel" means the slab ·ble or slate upon which is mounted the switches, and the :ing and controlling devices. There are usually several comprising switchboards of moderate or large size, these being classified according to the division of the system hey control, as for instance:

:,648.—Crouse-Hinds **voltmeter and ground detector radial switch,** arranged for ·unting on the switchboard. The switch proper is placed on the rear of the board with and wheel, dial, and indicator only on the front side. The current carrying parts are of ard brass, with contact surfaces machined after assembling. The contact parts are of he plunger spring type, and the cross bar has fuse connections. Ground detector circuits re marked G + and G − for two wire system, and G +, G −, GN +, and GN − for three ire system. When the voltmeter switch is to be used as a ground detector, two circuits re required for a two wire system, and four circuits for a three wire system, that is, a six ircuit voltmeter and ground detector switch for use on a two wire system has two circuits or ground detector and four circuits for voltmeter readings. A six circuit voltmeter and round detector switch, for use on a three wire system, has four circuits for ground de-ctor and two circuits for voltmeter readings.

1. Generator panel;
2. Feeder panel;
3. Regulator panel, etc.

In construction, the marble or slate should be free from metallic veins, and for pressures above, say, 600 volts, live connections, terminals, etc., should preferably be insulated from the panels by ebonite, mica, or removed from them altogether, as is generally the case with the alternating gear where the switches are of the oil type.

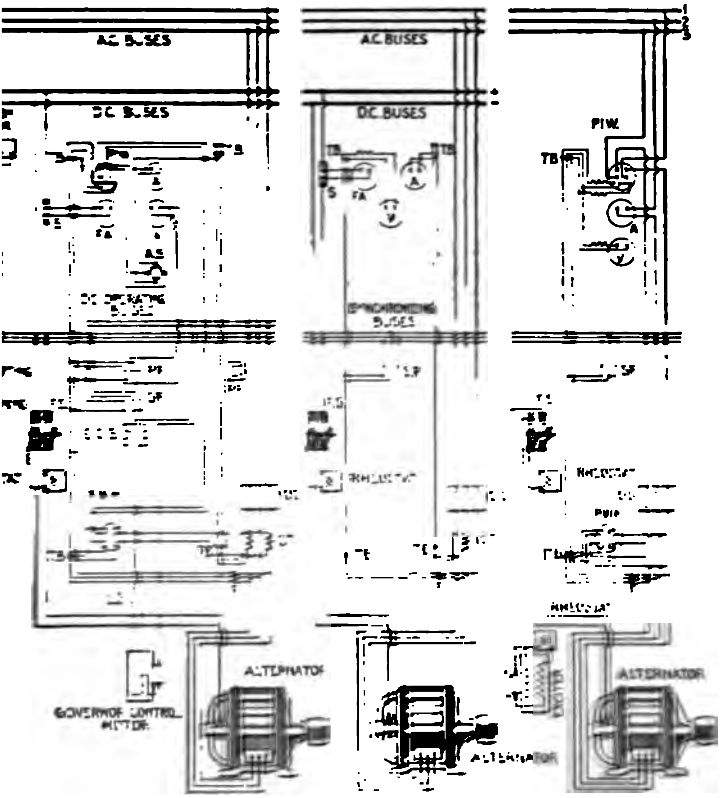


FIGS. 2,649 and 2,650,—Wiring diagrams of Crouse-Hinds voltmeter and ground detector switches. Fig. 2,649 voltmeter switch; fig. 2,650 voltmeter and ground detector switch. A view of the switch is shown in fig. 2,648; it is designed for use on two or three wire systems up to 300 volts.

The bus bars and connections should be supported by the framework at the back of the board, or in separate cells, and the instruments should be operated at low pressure through instrument transformers.

The panels are generally held in position by bolting them to an angle iron, or a strip iron framework behind them.

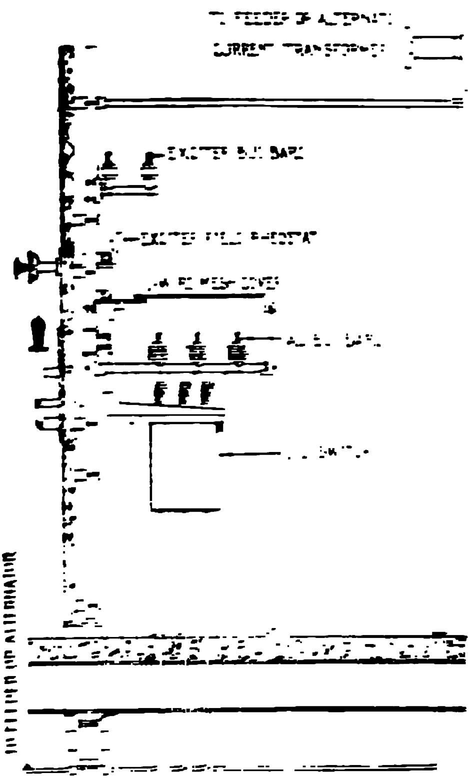
nerator Panel.—This section of a switchboard carries the ıments and apparatus for measuring and electrically con- ıg the generators. On a well designed switchboard each ator has, as a rule, its own panel.



[illegible] 2,6[illegible].—Diagram of connections [illegible] panels. Key to symbols: A [illegible]; A.S., ammeter switch; [illegible]; F., fuse; F.A., direct [illegible] field ammeter; F.S., [illegible]; [illegible] switch [illegible] with governor motor; [illegible]; P.I.W., polyphase ind[illegible] wattmeter; P.W.M., polyphase wattmeter [illegible]; P.R., [illegible]; P.P., [illegible] plug; Rheo., rheostat; S., [illegible]; S.R., [illegible]; S.P., [illegible] plugs; T.B., terminal board [illegible]; V, alternating current voltmeter.

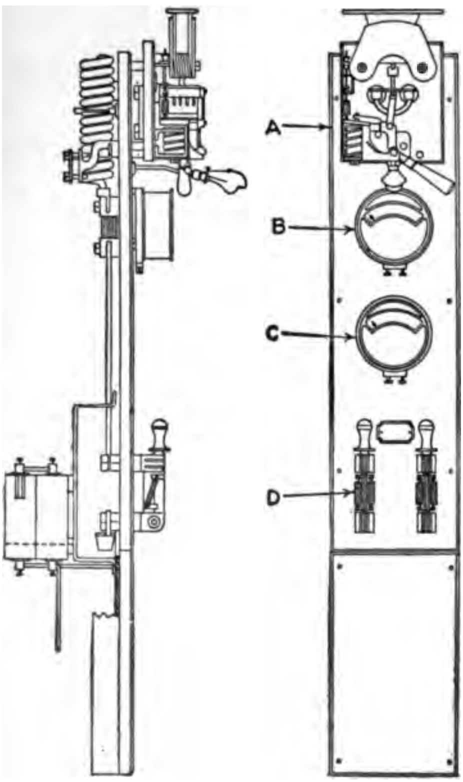
FIGS. 2,654 and 2,655.—Diagrams illustrating **a simple method of determining**
ity as suggested by the General Electric Co. **Fig. 2,654 relates to any panel; th**
as follows: **1.** Make a rough plan of the ***entire board*****, regardless of the numb**
to be ordered. *The order of panels* shown is re**commended, it being most ec**
copper and best adapted to future extensions. **2. To avoid confusion keep**
of board everything pertaining to exciter buses, **and on other side everythin**
to A. C. buses. **3.** With single lines **represent the exciter and A. C. buses**
panels as they actually extend and by means **of arrows indicate that portion**
which is connected to feeders and that portion **which is connected to generators.**
that "Generator" and "Feeder" arrows must always point toward each other**, o**
rules given below do not hold. **Note also that the field circuits of alternato**
treated as D. C. feeders for the exciter bus. **4. On each panel mark its am**
that is, the maximum current it supplies **to or takes from the bus. For A. C. alter**
the D. C. rating is the excitation of the machines. **5. Apply the following rules**
and note their application in fig. 2,654. **(For the sake of clearness ampere**
shown in light face type and bus capacities **in large type.) A. *Always begin***

he case of a dynamo a good representative panel would mounted upon it a reverse current circuit breaker an am-, a double pole main switch or instead a single pole, since the circuit breaker could also be used as a switch le pole socket into which a plug could be inserted to make tion with a voltmeter mounted on a swinging bracket at d of the board; a rheostat handle the spindle of which



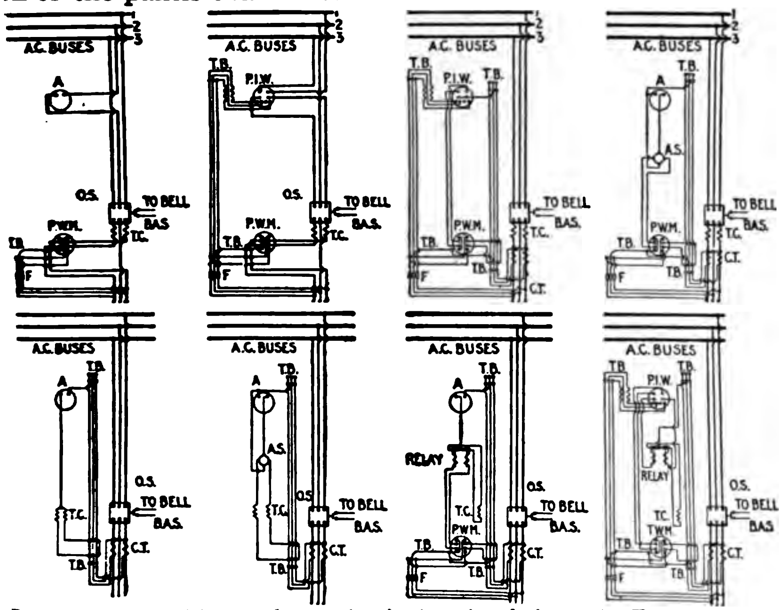
—End view of general arrangement of switchboards for alternating current.

operates the shunt rheostat of the machine, the rheost placed either directly behind the spindle, if of small size, down with chain drive from the hand wheel spindle, if size, a field discharge switch and resistance, a lamp neai of the panel for illumintaing purposes, a fuse for the v socket, and, if desired, a watthour meter. If the dy compound wou equalizing swit generally be on the frame machine, and i cases the field will be operatec pillar mounted of the switchbo lery. If the g be for traction p the circuit bre more often of tl imum current t a lightning arr often added, wi choke coil, the l well as further li arresters being n on the feeder p



FIGS. 2,657 and 2,658.—Two views of a **feeder panel,** *showing general arrangement of the devices assembled thereon. A*, circuit breaker; B, ammeter; C, voltmeter; *D*, *switches.*

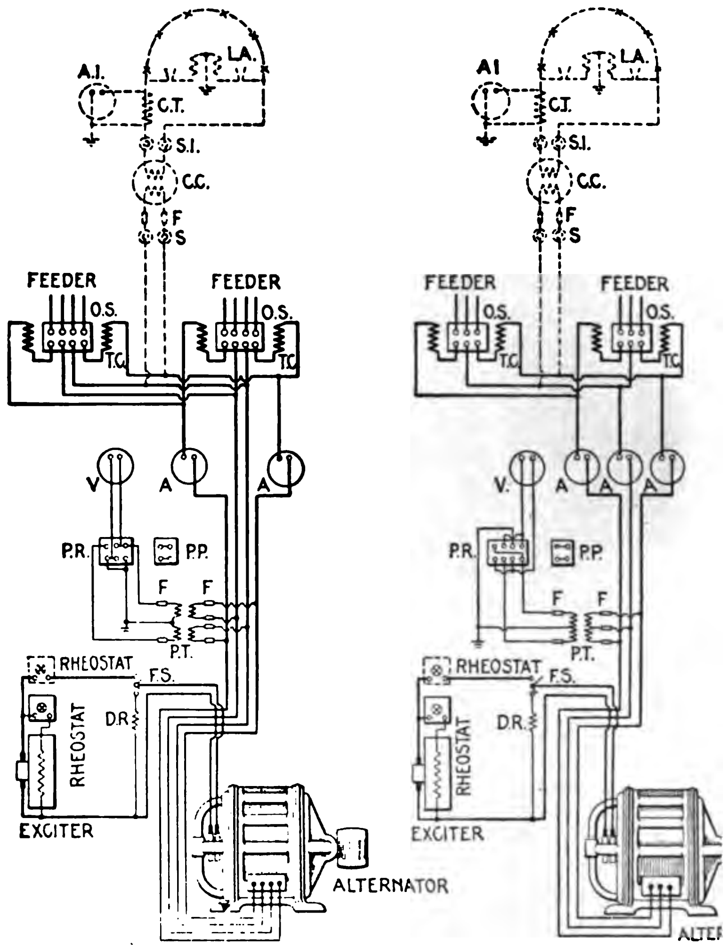
In the case of pressure alternat rent plant of c able size, the b oil switches, a current and ransformers are generally mounted either in stoneware cells, or uilt on a framework in a space guarded by expanded metal walls, and no high pressure apparatus of any sort is brought n to the panels themselves.



FIGS. 2,659 to 2,666.—Diagram of connections for three phase feeder panels. **Key to symbols:** A, ammeter; A.S., three way ammeter switch; B.A.S., bell alarm switch; C.T., current transformer; F, fuse; O.S., oil switch; P.I.W., polyphase indicating wattmeter; P.W.M., polyphase watthour meter; T.B., terminal board; T.C., trip coils for oil switch.

Feeder Panel.—The indicating and control apparatus for a feeder circuit is assembled on a panel called the feeder panel.

The most common equipment in the case of a direct current feeder panel comprises an ammeter, a double pole switch, and double pole fuses or instead of the fuses, a circuit breaker on one or both poles; in the case of a traction feeder a choke coil and a lightning arrester are often added.



Figs. 2,667 and 2,668.—Diagrams of connections for two phase and three phase install
A and A1, ammeter; C.C., constant current transformer; C.T., current transformer
discharge resistance; F, fuse; F.S., field switch; L.A., lightning arrester; O.S., oil
P.P., pressure plug; P.R., pressure receptacle; P.T., pressure transformer; S and S
switches; T.C., oil switch trip coil; V, voltmeter.

ɜ equipment of a typical high pressure three phase feeder is an ammeter (sometimes three ammeters, one in each ·) operated by a current transformer, and oil break switch with ɔverload release coils, or three if the neutral of the circuit ırthed, the releases being operated by current transformers.

669.—Crouse-Hinds radial ammeter switch, arranged for mounting directly on the itchboard. It is designed for use with external shunt ammeters of any make or capacity, d in connection with the required number of shunts, makes possible the taking of current dings of a corresponding number of circuits by means of one ammeter. The wiring gram is shown in fig. 2,670.

e switch when on a large system is often in a cell some ɪce behind the panel, and is then controlled by a system of ;, or by a small motor which is started and stopped by a r over switch on the panel, in which case there is generally p or lamps on the panel to show whether the switch is open ɪsed.

Air brake switches or links are placed between the bus bars and the oil switch to allow of the latter being isolated for inspection purposes, and as a general rule no apparatus carrying high pressure current is allowed on the front of the panel. With both direct and alternating current feeders, a watthour meter is often added to show the total consumption of the circuit.

A typical three phase generator panel is provided with three ammeters, one in each phase, operated from three current transformers, one to each ammeter, a volt meter, a power factor indicator, and an indicating watthour meter, all operated from one or more pressure transformers, and the necessary current transformers, the operating handle of the oil switch, which is connected to the switch itself by means of rods, two maximum releases operated by current transformers, or a reverse relay

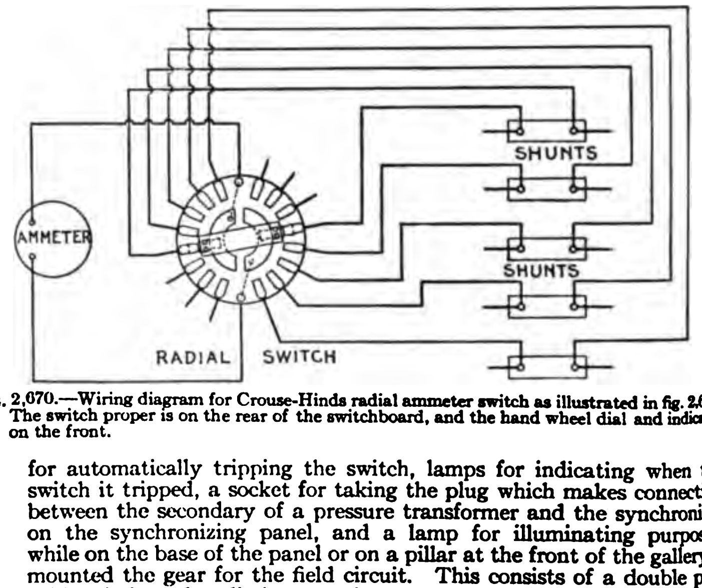


FIG. 2,070.—Wiring diagram for Crouse-Hinds radial ammeter switch as illustrated in fig. 2,069. The switch proper is on the rear of the switchboard, and the hand wheel dial and indicator on the front.

for automatically tripping the switch, lamps for indicating when the switch it tripped, a socket for taking the plug which makes connection between the secondary of a pressure transformer and the synchronizer on the synchronizing panel, and a lamp for illuminating purposes, while on the base of the panel or on a pillar at the front of the gallery is mounted the gear for the field circuit. This consists of a double pole field switch and a discharge resistance, an ammeter, a handle for the rheostat in the generator field, and (if each alternator have its own direct coupled exciter) possibly also a small rheostat for the exciter field.

NOTE.—In some cases where the capacity of the plant is not very great, the oil switch is *mounted on the* back of the panel, and the bus bars, current transformers, &c., on the framework *also just at the* back of the panel, but under no circumstances, in good modern practice, is high *pressure apparatus* permitted on the front of the board. Where the capacity of the plant is very *arge, the oil switches* are operated electrically by means of small motors, and in this case the *nall switch gear* for starting and stopping this motor is mounted on the generator panel, also the *mp or lamps* to indicate when the switch is open, and when closed.

CHAPTER LXV

ALTERNATING CURRENT WIRING

In the case of alternating current, because of its peculiar behaviour, there are several effects which must be considered in making wiring calculations, which do not enter into the problem with direct current.

Accordingly, in determining the size of wires, allowance must be made for

1. Self-induction;
2. Mutual-induction;
3. Power factor;
4. Skin effect;
5. Corona effect;
6. Frequency;
7. Resistance.

Most of these items have already been explained at such length, that only a brief summary of facts need be added, to point out their connection and importance with alternating current wiring.

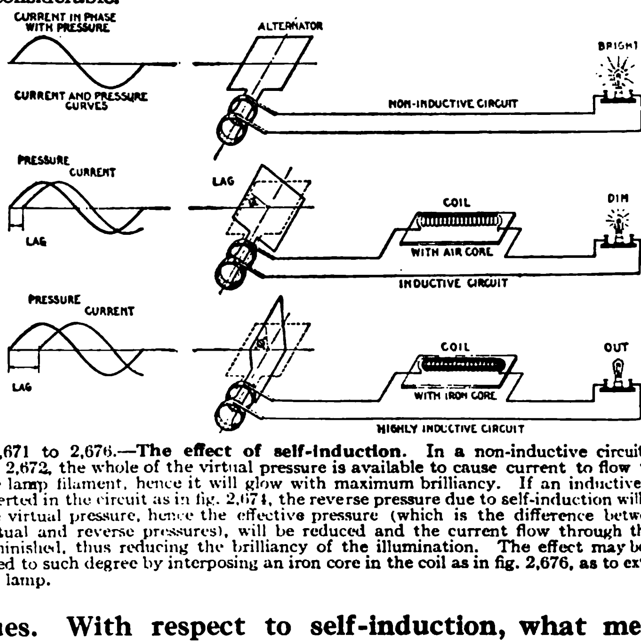
Induction.—The effect of induction, whether self-induction r mutual induction, is to set up a back pressure of *spurious esistance*, which must be considered, as it sometimes materially *ffects the calculation of circuits* even in interior wiring.

Self-induction is the effect produced by the action of the electric curre upon itself during variations in strength.

Ques. What conditions besides variations of current strength governs the amount of self-induction in a circuit?

Ans. The shape of the circuit, and the character of the surrounding medium.

If the circuit be straight, there will be little self-induction, but if coiled, the effect will become pronounced. If the surrounding medium be air, the self-induction is small, but if it be iron, the self-induction is considerable.



FIGS. 2,671 to 2,676.—**The effect of self-induction.** In a non-inductive circuit, as in fig. 2,672, the whole of the virtual pressure is available to cause current to flow through the lamp filament, hence it will glow with maximum brilliancy. If an inductive coil be inserted in the circuit as in fig. 2,674, the reverse pressure due to self-induction will oppose the virtual pressure, hence the effective pressure (which is the difference between the virtual and reverse pressures), will be reduced and the current flow through the lamp diminished, thus reducing the brilliancy of the illumination. The effect may be intensified to such degree by interposing an iron core in the coil as in fig. 2,676, as to extinguish the lamp.

Ques. With respect to self-induction, what method should be followed in wiring?

Ans. When iron conduits are used, the wires of each circuit *should not* be installed in separate conduits, because such *arrangement will* cause excessive self-induction.

The importance of this may be seen from the experience of one contractor, who installed feeders and mains in separate iron pipes. Wh the current was turned on, it was found that the self-induction was so great as to reduce the pressure to such an extent that the lamps, instead cf giving full candle power, were barely red. This necessitated the removal of the feeders and main and re-installing them, so that those of the same circuit were in the same pipe.

Ques. What is mutual induction?

Ans. Mutual induction is the effect of one alternating current ircuit upon another.

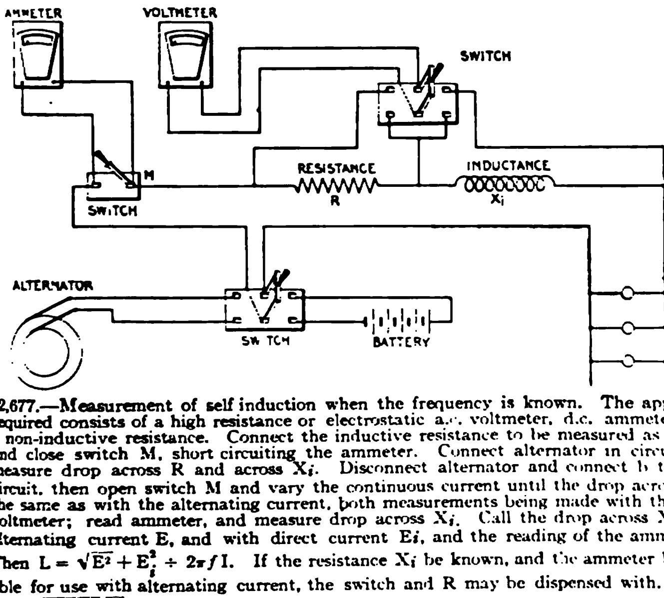


FIG. 2,677.—Measurement of self induction when the frequency is known. The apparatus required consists of a high resistance or electrostatic a.c. voltmeter, d.c. ammeter, and a non-inductive resistance. Connect the inductive resistance to be measured as shown, and close switch M, short circuiting the ammeter. Connect alternator in circuit and measure drop across R and across X_i. Disconnect alternator and connect battery in circuit, then open switch M and vary the continuous current until the drop across R is the same as with the alternating current, both measurements being made with the same voltmeter; read ammeter, and measure drop across X_i. Call the drop across X_i with alternating current E, and with direct current E_i, and the reading of the ammeter J. Then $L = \sqrt{E^2 + E_i^2} \div 2\pi f I$. If the resistance X_i be known, and the ammeter be suitable for use with alternating current, the switch and R may be dispensed with. Then $L = \sqrt{E^2 - X_i^2 I_i^2} \div 2\pi f I$, where I_i is the value of the alternating current. The resistance of the voltmeter should be high enough to render its current negligible as compared with that through X_i.

Ques. How is it caused?

Ans. It is due *to the magnetic* field surrounding a conductor *itting adjacent conductors* and inducing back pressures therein.

This effect as a rule in ordinary installations is negligible.

Transpositions.—The effect of mutual induction between two circuits is proportional to the inter-linkage of the magnetic fluxes of the two lines. This in turn depends upon the proximity of the lines and upon the general relative arrangement of the conductors.

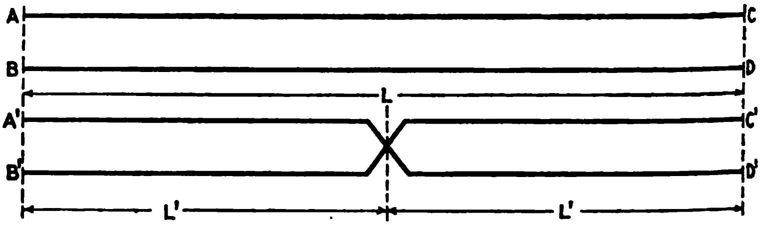


FIG. 2,678.—Transposition diagram for two parallel lines consisting of two wires each.

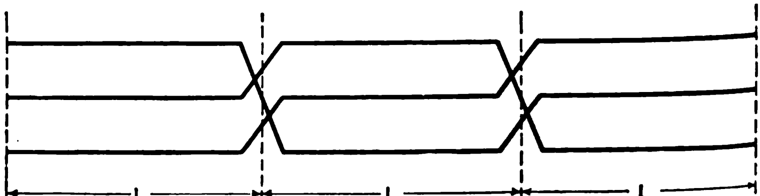


FIG. 2,679.—Transposition diagram for three phase, three wire line, transposing at the vertices of an equilateral triangle. The line is originally balanced and becomes unbalanced on transposing, a procedure which should be resorted to only to prevent *mutual induction.*

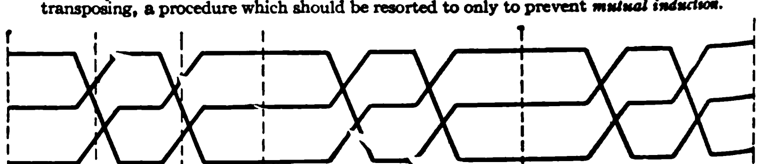


FIG. 2,680.—Transposition diagram of three phase, three wire line, with center arranged in a straight line.

The inductive effect of one line upon another is equal to the *algebraic* sum of the fluxes due to the different conductors of the *first line,* considered separately, which link the secondary line.

[redacted]

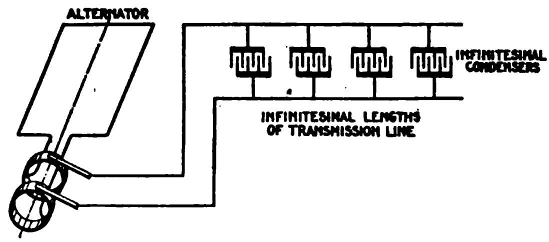
e effect of mutual induction is to induce surges in the line
a difference of frequency exists between the two currents,
o induce high electrostatic charges in lines carrying little
current, such as telephone lines.

INDUCTANCE PER MILE OF THREE PHASE CIRCUIT

S.	Diam. in inch.	Distance *d* in inches.	Self inductance L henrys.	Size B. & S.	Diam. in inch.	Distance *d* in inches.	Self inductance L henrys.
'	.46	12	.00234	4	.204	12	.00280
		18	.00256			18	.00300
		24	.00270			24	.00315
		48	.00312			.8	.00358
)	.41	12	.00241	5	.182	12	.00286
		18	.00262			18	.00307
		24	.00277			24	.00323
		48	.00318			48	.00356
0	.365	12	.00248	6	.162	12	.00291
		18	.00269			18	.00313
		24	.00285			24	.00329
		48	.00330			48	.00369
0	.325	12	.00254	7	.144	12	.00298
		18	.00276			18	.00310
		24	.00293			24	.00336
		48	.00331			48	.00377
1	.289	12	.00260	8	.128	12	.00303
		18	.00281			18	.00325
		24	.00308			24	.00341
		48	.00338			48	.00384
2	.258	12	.00267	9	.114	12	.00310
		18	.00288			18	.00332
		24	.00304			24	.00348
		48	.00314			48	.00389
3	.229	12	.00274	10	.102	12	.00318
		18	.00294			18	.00340
		24	.00310			24	.00355
		48	.00351			48	.00396

This effect may be nullified by separating the lines and by transposing the wires of one of the lines so that the effect produced in one section is opposed by that in another. Of two parallel lines consisting of two wires each, one may be transposed to neutralize the mutual inductance.

Fig. 2,678 shows this method. The length L′ should be an even factor of L so that to every section of the line transposed there corresponds an opposing section.



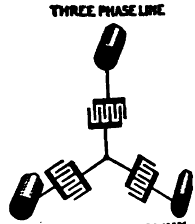


FIG. 2,681.—Capacity effect in single phase transmission line. The effect is the same as would be produced by shunting across the line at each point an infinitesimal condenser having a capacity equal to that of an infinitesimal length of circuit. For the purpose of calculating the charging current, a very simple and sufficiently accurate method is to determine the current taken by a condenser having a capacity equal to that of the entire line when charged to the pressure on the line at the generating end. The effect of capacity of the line is to reduce the pressure drop, that is, improve the regulation, and to decrease or increase the power loss depending on the load and power factor of the receiver.

FIG. 2,682.—Capacity effect in a three phase transmission line. It is the same as would be produced by shunting the line at each point by three infinitesimal condensers connected in star with the neutral point grounded, the capacity of each condenser being twice that of a condenser of infinitesimal length formed by any two of the wires. The effect of capacity on the regulation and efficiency of the line can be determined with sufficient accuracy in most cases by considering the line shunted at each end by three condensers connected in star, the capacity of each condenser being equal to that formed by any two wires of the line. An approximate value for the charging current per wire is the current required to charge a condenser, equal in capacity to that of any two of the wires, to the pressure at the generating end of the line between any one wire and the neutral point.

The self inductance of lines is readily calculated from the following formula:

$$L = .000558 \left\{ 2.303 \log (2\,A \div d) + .25 \right\} \text{ per mile of circuit}$$

where

L = inductance of a loop of a three phase circuit in henrys.

Note.—The inductance of a complete single phase circuit = $L \times 2 \div \sqrt{3}$

A = distance between wires;

d = diameter of wire.

[redacted]

pacity.—In any given system of electrical conductors, a ure difference between two of them corresponds to the nce of a quantity of electricity on each. With the same

ACITY IN MICRO-FARADS PER MILE OF CIRCUIT FOR THREE PHASE SYSTEM

S.	Diam. in inch.	Distance A in inches.	Capacity C in micro-farads	Size B. & S.	Diam. in inch.	Distance A in inches.	Capacity C in micro-farads
	.46	12	.0226	4	.204	12	.01874
		18	.0204			18	.01726
		24	.01922			24	.01636
		48	.01474			48	.01452
	.41	12	.0218	5	.182	12	.01830
		18	.01992			18	.01690
		24	.01876			24	.01602
		48	.01638			48	.01426
)	.365	12	.0124	6	.162	12	.01788
		18	.01946			18	.01654
		24	.01832			24	.01560
		48	.01604			48	.0140
)	.325	12	.02078	7	.144	12	.01746
		18	.01898			18	.01618
		24	.01642			24	.01538
		48	.01570			48	.01374
1	.289	12	.02022	8	.128	12	.01708
		18	.01952			18	.01586
		24	.01748			24	.01508
		48	.0154			48	.01350
2	.258	12	.01972	9	.114	12	.01660
		18	.01818			18	.01552
		24	.01710			24	.01478
		48	.01510			48	.01326
3	.229	12	.01938	10	.102	12	.01636
		18	.01766			18	.01522
		24	.01672			24	.01452
		48	.01480			48	.01304

charges, the difference of pressure may be varied by varying the geometrical arrangement and magnitudes and also by introducing various dielectrics. The constant connecting the charge and the resulting pressure is called the capacity of the system.

All circuits have a certain capacity, because each conductor acts like the plate of a condenser, and the insulating medium, acts as the dielectric. The capacity depends upon the insulation.

For a given grade of insulation, the capacity is proportional to the surface of the conductors, and inversely to the distance between them.

A three phase three wire transmission line spaced at the corners of an equilateral triangle as regards capacity acts precisely as though the neutral line were situated at the center of the triangle.

The capacity of circuits is readily calculated by applying the following formulae:

$$C = \frac{38.83\, sc\, 10^{-3}}{\log (D \div d)}$$ per mile, insulated cable with lead sheath;

$$C = \frac{38.83 \times 10^{-3}}{\log (4h \div d)}$$ per mile, single conductor with earth return;

$$C = \frac{19.42 \times 10^{-3}}{\log (2A \div d)}$$ per mile of parallel conductors forming metallic circuit;

in which

C = Capacity in micro-farads; for a metallic circuit, C = capacity between wires;
sc = Specific inductive capacity of insulating material; = 1 for arc, and 2.25 to 3.7 for rubber;
D = Inside diameter of lead sheath;
d = Diameter of conductor;
h = Distance of conductors above ground;
A = Distance between wires.

Frequency.—The number of cycles per second, or the frequency, has a direct effect upon the inductance reactance in an alternating current circuit, as is plainly seen from the formula.

$$X_i = 2\pi f L$$

In the case of a transmission line alone; the lower frequencies are the more desirable, in that they tend to reduce the inductance drop and charging current. The inductance drop is proportional to the frequency.

The natural period of a line, with distributed inductance and capacity, is approximately given by

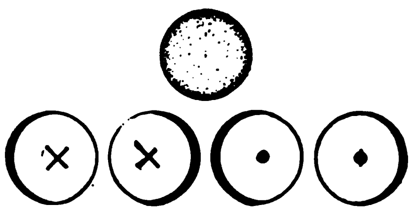
$$P = \frac{7{,}900}{\sqrt{LC}}$$

where L is the total inductance in millihenrys, and C, the total capacity in micro-farads. Accordingly some lower odd harmonic of the impressed frequency may be present which corresponds with the natural *period* of the line. When this obtains, oscillations of dangerous *magnitude may* occur. Such coincidences are less likely with the lower *harmonics* than with the higher.

Skin Effect.—The tendency of alternating current to confine elf to the *outer* portions of a conductor, instead of passing uni- mly through the cross section, is called *skin effect.* The effect proportional to the size of the conductor and the frequency.

Ques. What effect has "skin effect" on the current?

Ans. It is equivalent to an increase of ohmic resistance and erefore opposes the current.



s. 2,683 to 2,687.—Skin effect and shield effect. Fig. 2,683, section of conductor illlustrating skin effect or tendency of the alternating current to distribute itself unequally through the cross section of a conductor as shown by the varied shading, which represents the current flowing most strongly in the outer portions of the conductor. For this reason it has been proposed to use hollow or flat instead of solid round conductors; however, with frequency not exceeding 100, the skin effect is negligibly small in copper conductors of the sizes usually employed. In figs. 2,684 and 2,685, or 2,686 and 2,687, if two adjacent conductors be carrying current in the same direction, concentration will occur on those parts of the two conductors remote from one another, and the nearer parts will have less current, that is to say, they will be **shielded**. In this case, the induction due to one conductor will exert its opposing effect to the greatest extent on those parts of the other conductor nearest to it; this effect decreasing the deeper the latter is penetrated. After crossing the current axis, the induction will still decrease in magnitude, but will now aid the current in the conductor. Hence, the effect of these two conductors on one another will make the current density more uniform than is the case where the two conductors adjacent to one another are carrying current in opposite directions, as in figs. 2,685 and 2,686, therefore, the resistance and the heating for a given current will be smaller. If the two return conductors be situated on the line passing through the center of the conductors just considered, the effect will be to still further concentrate the current; the distribution symmetry will be further disturbed, and the resistance of the conductor system increased. It is therefore difficult to say which of the two cases considered holds the advantage so far as increasing the resistance is concerned. The case, however, in which the phases are mixed has much the smaller reactive drop.

If the conductor be large, or the frequency high, the central portion of the conductor carries little if any current, hence the resistance is therefore greater for alternating current than for direct current.

Ques. For what condition may "skin effect" be neg- cted?

Ans. For frequencies of 60 or less, with conductors having diameter not *greater than 0000* B. & S. gauge.

Ques. How is the "skin effect" calculated for a give wire?

Ans. Its area in circular mils multiplied by the frequenc gives the ratio of the wire's ohmic resistance to its combin resistance.

That is to say, the factor thus obtained multiplied by the resistan of the wire to direct current will give its combined resistance or resi ance to alternating current.

The following table gives these ratio factors for large conductors.

RATIO FACTOR FOR COMBINED RESISTANCE

Cir. mils. × frequency	Ratio factor	Cir. mils. × frequency	Ratio factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

Corona Effect.—When two wires, having a great differen of pressure are placed near each other, a certain phenomen occurs, which is called *corona effect.* When the spacing distance between the wires is small and the difference of pressu in the wires very great, a continuous passage of energy tak place through the dielectric or atmosphere, the amount of th energy may be an appreciable percentage of the power tran mitted. Therefore in laying out high pressure transmissio lines, this effect must be considered in the spacing of the wires.

Ques. How does the corona effect manifest itself?

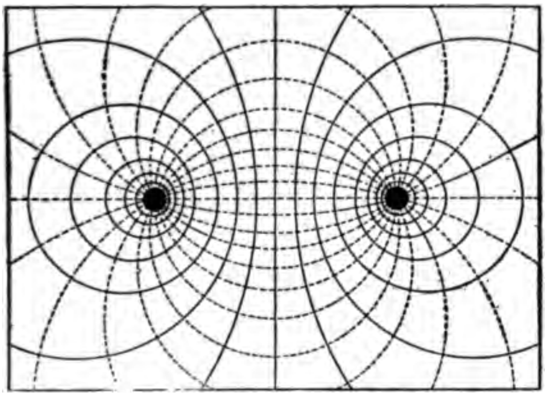
Ans. It is visible at night as a bluish luminous envelope an audible as a hissing sound.

ues. What is the critical voltage?

ıs. The voltage at which the corona effect loss takes place.

ues. Upon what does the critical voltage depend?

ıs. Upon the radius of the wires, the spacing, and the ɔspheric conditions.



2,688.—Electromagnetic and electrostatic fields surrounding the conductors of a transmission line. The electromagnetic field is represented by lines of magnetic force that surround the conductors in circles, (the solid lines), and the electrostatic field by (dotted) circles passing from conductor to conductor across at right angles to the magnetic circles. For any given size of wire and distance apart of wires there is a certain voltage at which the critical density or critical gradient is reached, where the air breaks down and luminosity begins—the critical voltage where corona manifests itself. At still higher voltages corona spreads to further distances from the conductor and a greater volume of air becomes luminous. Incidentally, it produces noise. Now to produce light requires power and to produce noise requires power. Air is broken down and is heated in breaking down, and to heat also requires power; therefore, as soon as corona forms, power is consumed or dissipated in its formation. When this phenomenon occurs on the conductors of an alternating current circuit a change takes place in relation to current and voltage. On the wires of an alternating current transmission line, at a voltage below that where corona forms —at a voltage where wires are not luminous—considerable current, more or less depending on voltage and length of wire, flows into the circuit as capacity current or charging current.

The critical voltage increases with both the diameter of the wires, and the spacing.

The losses due to corona effect increase very rapidly with increasing pressure beyond the critical voltage.

The magnitude of the losses as well as the critical voltage is affected, by atmospheric conditions, hence they probably vary with the particular locality, and the season of the year. Therefore, for a given locality, a voltage *which is* normally below the critical point, may *at times be above it, depending* upon changes in the weather.

Such elements as smoke, fog, moisture, or other particles snow, etc.) floating in the air, increase the losses; rain, howeve parently has no appreciable effect upon the losses. It follow that in the design of a transmission line, the atmospheric con of the particular locality through which the line passes should b sidered.

Ques. How should live wires be spaced?

Ans. They should be so spaced as to lessen the tenden leakage and to prevent the wires swinging together or a towers. The spacing should be only sufficient for safety, increased spacing increases the self-induction of the line while it lessens the capacity, it does so only in a slight degr

The following spacing is in accordance with average practice.

SPACING FOR VARIOUS VOLTAGES

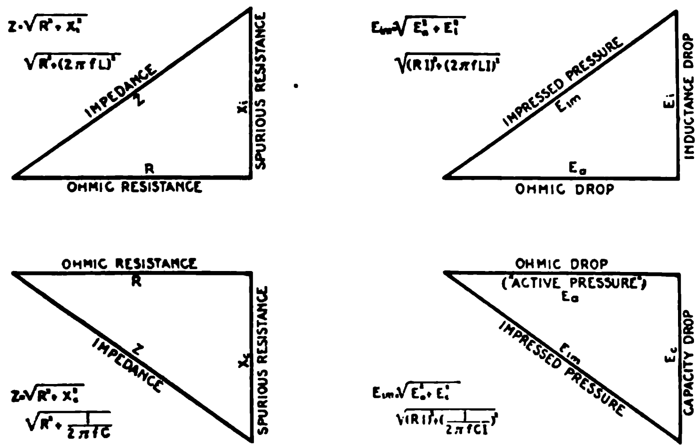
Volts	Spacing	Volts	Spacing	Volts	Spa
5,000	28 ins.	45,000	60 ins.	90,000	96
15,000	40 ins.	60,000	60 ins.	105,000	108
30,000	48 ins.	75,000	84 ins.	120,000	120

Resistance of Wires.—For quick calculation the foll method of obtaining the resistance (approximately) of will be found convenient:

1,000 feet No. 10 B. & S. wire, which is about .1 in diameter (.1019), has a resistance of one ohm, at a temper of 68° F. and weighs 31.4 pounds. A wire three sizes l that is No. 7, has twice the cross section and therefore on the resistance. A wire three sizes smaller than No. 10, t No. 13, has one-half the cross section and therefore twic resistance.

Thus, starting with No. 10, any number three sizes large *double the* cross sectional area and any wire three sizes sr halve the cross sectional area of the preceding wire. This rue to the extreme limits of the table, so that the area, weight l resistance of any wire may be at once calculated to a close proximation from this rule, intermediate sizes being obtained interpolation.

For alternating current, the combined resistance, that is, the al resistance, including skin effect, is obtained by multiplying e resistance, as found above by the "ratio factor" (see table ge 1,894).



s. 2,689 to 2,692.—Triangles for obtaining graphically, impedance, impressed pressure, etc., in alternating current circuits. For a full explanation of this method the reader is referred to Guide 5, Chapter XLVII or. Alternating Current Diagrams. A thorough study of this chapter is recommended.

Impedance.—*The total opposition to the flow of electricity in* *alternating current circuit*, or the impedance may be resolved to two components representing the ohmic resistance and e spurious resistance; these components have a phase difference 90°, and they may be represented graphically by the two legs a right angle triangle, of which the hypothenuse represents e impedance.

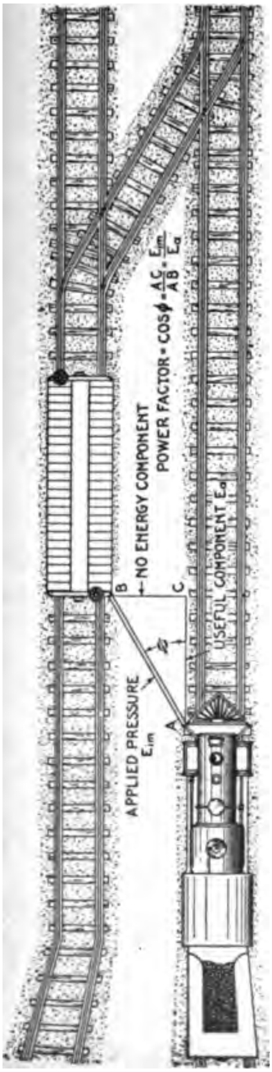


FIG. 2,693.—Mechanical analogy of power factor, as exemplified by a locomotive "poling" a car off a siding. The car and locomotive are shown moving in parallel directions, and the pole AB, inclined at an angle φ. Now, if the length of AB be taken to represent the pressure exerted on the pole by the locomotive, then the imaginary lines AC and BC, drawn respectively parallel and at right angles to the direction of motion will represent respectively the useful and no energy (wattless) components; that is to say, if the pressure AB be applied to the car at an angle φ, only part of it, AC, is useful in propelling the car; the other component, BC, being wasted in tending to push the car off the track at right angles to the rails, being resisted by the flanges of the outer wheels.

Similarly, the **volts l** "drop" in an alternatin cuit may be resolved int components representin spectively

1. The loss due to r ance.
2. The loss due to r ance.

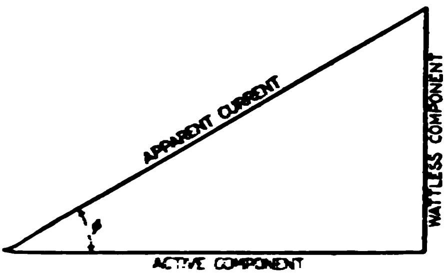
These components ha phase difference of 90° are represented graph similar to the impedance ponents. This has bee plained at considerable l in Chapter XLVII (Guid

Power Factor.—Whe current falls out of step the pressure, as on indu loads, the power facto comes less than unity, the effect is to increas current required for a load. Accordingly, this be considered in calcul the size of the wires. A been explained, the cu flowing in an alternatin rent circuit, as measu an ammeter, can be

[redacted]

into two components, representing respectively the *active component* and the *wattless component* or idle current. These are graphically represented by the two legs of a right triangle, of which the hypothenuse represents the current measured by the ammeter.

This ***apparent*** current, as is evident from the triangle, exceeds the *active* current and lags behind the pressure by an amount represented by the angle ϕ between the hypothenuse and leg representing the energy current as shown in fig. 2,694.



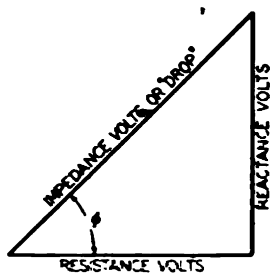


FIG. 2,694.—Diagram showing that the apparent current is more than the active current, the excess depending upon the angle of phase difference.

FIG. 2,695.—Diagram showing components of impedance volts. Compare this diagram with figs. 2,690 and 2,671, and note that the term "reactance" is the difference between the inductance drop and the capacity drop if the circuit contain capacity, for instance, if inductance drop be 10 volts and capacity drop be 7 volts then reactance 10 − 7 = 3 volts.

Ques. What determines the heating of the wires on alternating current circuits with inductive loads?

Ans. The apparent current, as represented by the hypothenuse of the triangle in fig. 2,694.

Ques. How is the apparent current obtained?

Ans. Divide the true watts by the product of the power factor multiplied by the voltage.

Example.—A certain circuit supplies 20 kw. to motors at 220 volts *and .8 power factor.* What is the apparent current?

$$\textit{Apparent Current} = \frac{\text{true watts}}{\text{power factor} \times \text{volts}} = \frac{20,000}{.8 \times 220} = 113.6 \text{ amperes}$$

Ques. What else, besides power factor, should be considered in making wire calculations for motor circuits?

Ans. The efficiency of the motor, and the heavy starting current.

The product of the efficiency of the motor multiplied by the power factor gives the *apparant efficiency*, which governs the size of the wires, apparatus, etc., necessary to feed the motors.

Allowance should be made for the heavy starting current required for some motors to avoid undue drop.

TABLE OF APPROXIMATE AMPERES PER TERMINAL FOR INDUCTION MOTORS

Horse power	Single phase			Two phase four wire			Three phase three wire			
	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	550 volts
.5	6.6	3.4	1.8	3.3	1.7	.9	3.7	1.8	1	
1	14	7	3.5	6.4	3.2	1.6	7.4	3.7	1.9	
2	24	12	6	11	5.7	2.9	13	6.6	3.3	2.5
3	34	17	8.5	16	8.1	4.1	19	9.3	4.7	3.5
4	52	26	13	26	13	6.5	30	15	7.5	6
5	74	37	18.5	38	19	9.5	44	22	11	9
10	94	47	23.5	44	22	11	50	25	12.5	11
15	....	....	....	66	33	16.5	76	38	19	16
20	....	....	....	88	44	22	102	51	25.5	22
25	....	....	....	111	55	28	129	64	32	25
30	....	....	....	134	67	33.5	154	77	38.5	32
40	....	....	....	178	89	44.5	204	107	53.5	44
50	....	....	....	204	102	51	236	118	59	52
75	....	....	....	308	154	77	356	178	89	77
100	....	....	....	408	204	102	472	236	118	100

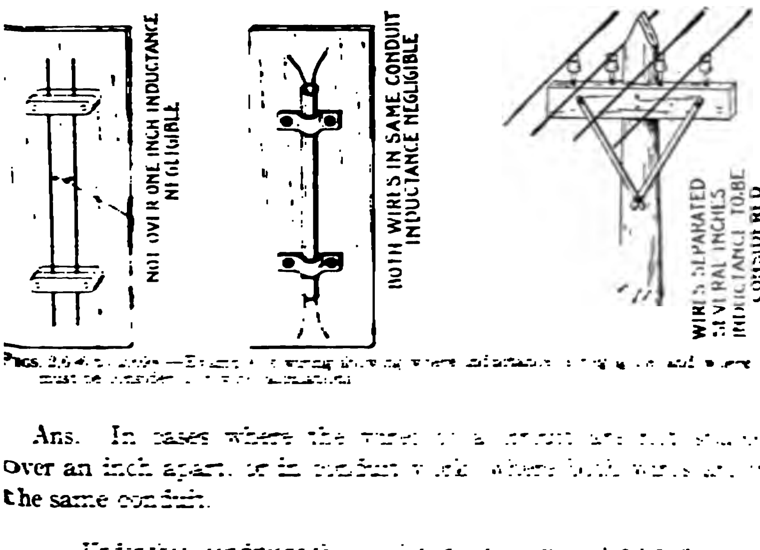
Ques. What are the usual power factors encountered on commercial circuits?

Ans. A mixed load of incandescent lamps and induction motors will have a power factor of from .8 to .85; induction motors above .8 to .85; incandescent and Nernst lamps [illegible] arc lamps, .85.

[redacted]

Wire Calculations.—In the calculation of alternating current circuits, the two chief factors which make the computation different from that for direct current circuits, is *induction* and *power factor*. The first depends on the frequency, and physical condition of the circuit, and the second upon the character of the load.

Ques. Under what conditions may inductance be neglected?



FIGS. [illegible]

Ans. In cases where the wires of a circuit are not spaced over an inch apart, or in conduit work where both wires are in the same conduit.

Under these conditions the calculation is the same as for direct current after making proper allowance for power factor.

Ques. Under what conditions must induction be considered?

Ans. On exposed circuits with wires separated several inches, particularly in the case of large wire.

Sizes of Wire.—The size of wire for any alternating circuit may be determined by slightly modifying the formula used in direct current work, and which, as derived in Guide No. 4, page 748, is

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\text{drop}} \quad \ldots\ldots\ldots (1)$$

The quantity 21.6, is twice the resistance (10.8) of a foot of copper wire one mil in diameter (*mil foot*). This resistance (10.8) is multiplied by 2, giving the quantity 21.6, because the length of a circuit, or feet in the formula, is given as the "run" or distance one way, that is, one-half the total length of wire in the circuit, must be multiplied by 2 to get the total drop, viz.:

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 10.8 \times 2}{\text{drop}} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\text{drop}}$$

It is sometimes however convenient to make the calculation in terms of watts. Formula (1) may be modified for such calculation.

In modifying the formula, the "drop" should be expressed in percentage instead of actual volts lost, that is, instead of the difference in pressure between the beginning and the end of the circuit.

In any circuit the loss in percentage, or

$$\%\ \text{loss} = \frac{\text{drop}}{\text{impressed pressure}} \times 100$$

from which

$$\text{drop} = \frac{\%\ \text{loss} \times \text{impressed pressure}}{100} \quad \ldots (2)$$

Substituting equation (2) in equation (1)

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\dfrac{\%\ \text{loss} \times \text{imp. pressure}}{100}}$$

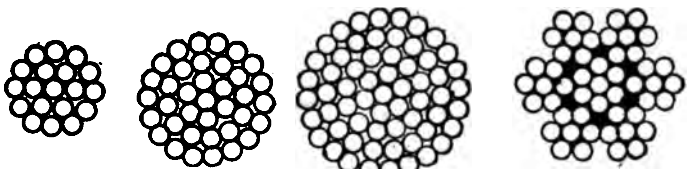
$$= \frac{\text{amperes} \times \text{feet} \times 2{,}160}{\%\ \text{loss} \times \text{imp. pressure}} \quad \ldots\ldots (3)$$

ıtion (3) is modified for calculation in terms of watts as : The power in watts is equal to the *applied voltage* lied by the current, that is to say, the power is equal to *ts at the consumer's end of the circuit* multiplied by the :, or simply

$$\text{watts} = \text{volts} \times \text{amperes}$$

'hich

$$\text{amperes} = \frac{\text{watts}}{\text{volts}} \quad . \quad . \quad . \quad . \qquad (4)$$



)9 to 2,703.—Stranded copper cables. For conductors of large areas and in the smaller where extra flexibility is required it becomes necessary to employ stranded cables e by grouping a number of wires together in either concentric or rope form. The entric cable as here illustrated is formed by grouping six wires around a central wire eby forming a seven wire cable. The next step is the application in a reverse direction ıother layer of 12 wires and a nineteen wire cable is produced. This is again increased third layer of eighteen wires for a 37 wire cable and a fourth layer of 24 wires for a 61 cable. Successive layers, each containing 6 more wires than that preceding, may be lied until the desired capacity is obtained. The cuts show sectional views of conric cables each formed from No. 10 B. & S. gauge wires.

ıstituting this value for the current in equation (3) and nbering that the pressure taken is the volts at the consumer's f the line

$$\text{circular mils} = \frac{\frac{\text{watts}}{\text{volts}} \times \text{feet} \times 2{,}160}{\%\ \text{loss} \times \text{volts}}$$

$$= \frac{\text{watts} \times \text{feet} \times 2{,}160}{\%\ \text{loss} \times \text{volts}^2} \quad . \quad . \qquad (5)$$

This formula (5) applies to a direct current two wire circuit, and to adapt it to any alternating current circuit it is only necessary to use the letter M instead of the number 2,160, thus

$$\text{circular mils} = \frac{\text{watts} \times \text{feet} \times M}{\% \text{ loss} \times \text{volts}^2} \quad . \quad . \quad . \quad (6)$$

in which M is a coefficient which has various values according to the kind of circuit and value of the power factor. These values are given in the following table:

VALUES OF M

SYSTEM	POWER FACTOR									
	1.00	.98	.95	.90	.85	.80	.75	.70	.65	.60
Single phase	2,160	2,249	2,400	2,660	3,000	3,380	3,840	4,400	5,112	6,000
Two phase (4 wire)	1,080	1,125	1,200	1,330	1,500	1,690	1,920	2,200	2,556	3,000
Three phase (3 wire)	1,080	1,125	1,200	1,330	1,500	1,690	1,920	2,200	2,556	3,000

NOTE.—The above table is calculated as follows: For **single phase** M = 2,160 ÷ power factor² × 100; for **two phase** four wire, or three phase three wire, M = ½ (2,160 ÷ power factor²) 100. Thus the value of M for a single phase line with power factor .95 = 2,160 ÷ .95² × 100 = 2,400.

It must be evident that when 2,160 is taken as the value of M, formula (6) applies to a two wire direct current circuit and also to a single phase alternating current circuit when the power factor is unity.

In the table the value of M for any particular power factor is found by dividing 2,160 by the square of that power factor for single phase and twice the square of the power factor for two phase and three phase.

[redacted]

Ques. For a given load and voltage how do the wires a single and two phase system compare in size and ight, the power factor being the same in each case?

\ns. Since the two phase system is virtually two single phase tems, the four wires of the two phase systems are half the of the two wires of the single phase system, and accordingly, weight is the same for either system.

VALUES OF T

System	Power Factor				
	1.00	.98	.90	.80	.70
Single phase..........	1.00	.98	.90	.80	.70
Two phase, 4 wire.....	2.00	1.96	1.80	1.60	1.40
Three phase, 3 wires...	1.73	1.70	1.55	1.38	1.21

NOTE.—This table is for finding the value of the current in line, using the formula = W ÷ (E × T), in which I = current in line; E = voltage between main conductors at ceiving or consumers' end; W = watts. For instance, what is the current in a two phase line insmitting 1,000 watts at 550 volts, power factor .80? I = 1,000 ÷ (550 × 1.60) = 1.13.

Ques. Since there is no saving in copper in using two hases, what advantage has the two phase system over the ne phase system?

Ans. It is more desirable on power circuits, because two hase motors are self-starting.

That is to say, the rotating magnetic field that can be produced by a two phase current, permits an induction motor to start without being *equipped with any special phase* splitting devices which are necessary *on single phase motors,* because the oscillating field produced by a single *phase current does not* produce any torque on a squirrel cage armature *at rest.*

Ques. For equal working conditions, what is the con parison between the single, two and three phase syste as to size and weight of wires?

Ans. Each wire of the three phase system is half the size one of the wires of the single phase system, hence the weight copper required for the three phase system is 75% of that ı quired for the single phase system. Since in the two pha system half of the load is carried by each phase, each wire of t three phase system is the same size as one of the wires of tl two phase system, hence, the copper required by the thr phase system is 75% of that required by the two phase system.

MISCELLANEOUS FORMULÆ FOR COPPER WIRES

Diameter squared		= circular mils
Circular mils	× .7854	= square mils
.000003027	× circular mils	= pounds per foot
.003027	× circular mils	= pounds per 1,000 feet
.0159847	× circular mils	= pounds per mile
.003879	× square mils	= pounds per 1,000 feet
.33033	÷ circular mils	= feet per pound
.0000002924	× circular mils	= pounds per ohm
.342	÷ circular mils	= ohms per pound
.096585	× circular mils	= feet per ohm
10.353568	÷ circular mils	= ohms per foot

Breaking weight of wire ÷ area = breaking weight p: square inch.

Breaking weight per square inch × area = breaking weigh of wire.

The weight of copper wire is $1\frac{1}{7}$ times the weight of iro *wire of* same diameter.

IPLE.—What size wires must be used on a single phase circuit ı length to supply 30 kw. at 220 volts with loss of 4%, the power .9?

ırmula for circular mils is

$$\text{circular mils} = \frac{\text{watts} \times \text{feet} \times \text{M}}{\%\ \text{loss} \times \text{volts}^2} \quad . \quad . \quad . \quad . \quad (1)$$

stituting the given values and the proper value of M from the in (1)

$$\text{circular mils} = \frac{30{,}000 \times 2{,}000 \times 2{,}660}{4 \times 220^2} = 82{,}438$$

erring to the accompanying table of the properties of copper wire, arest *larger* size wire is No. 1 B. & S. gauge having an area of 83,690 ır mils.

BLE OF THE PROPERTIES OF COPPER WIRE

ts. length and resistances of wires of Matthiessen's Standard Conductivity for both own & Sharpe Gauge) and B. W. G. (Birmingham Wire Gauge) from Transactions f the American Institute of Electrical Engineers.

o the nearest fourth significant digit.			Weight. Lbs. per 1,000 feet.	Length.	Resistance.
	Diameter.	Area.		Feet per lb.	Ohms per 1,000 feet.
W, G.	Inches.	Circular mils			@ 68° F.
	0.460	211,600	640.5	1.561	.04893
0000	0.454	206,100	623.9	1.603	.05023
000	0.425	180,600	546.8	1.829	.05732
	0.4096	167,800	508.0	1.969	.06170
00	0.380	144,400	437.1	2.288	.07170
	0.3648	133,100	402.8	2.482	.07780
0	0.340	115,600	349.9	2.858	.08957
	0.3249	105,500	319.5	3.130	.09811
1	0.3000	90,000	272.4	3.671	.1150
	0.2893	83,690	253.3	3.947	.1237
2	0.2840	80,660	244.1	4.096	.1284
3	0.2590	67,080	203.1	4.925	.1543
	0.2576	66,370	200.9	4.977	.1560
4	0.2380	56,640	171.5	5,832	.1828
	0.2294	52,630	159.3	6.276	.1967
5	0.2200	48,400	146.5	6.826	.2139
	0.2043	*41,740*	126.4	7.914	.2480
6	*0.2030*	*41,210*	124.7	8.017	.2513

TABLE OF THE PROPERTIES OF COPPER WIRE

(Continued)

Gauges.		To the nearest fourth significant digit.		Weight. Lbs. per 1,000 feet.	Length.	Resista[nce]
		Diameter.	Area.		Feet per lb.	Ohm[s] per 1,00[0]
B. & S.	B. W. G.	Inches.	Circular mils			@ 6[…]
5		0.1819	33,100	100.2	9.980	.
	7	0.1800	32,400	98.08	10.20	.
	8	0.1650	27,230	82.41	12.13	.
6		0.1620	26,250	79.46	12.58	.
	9	0.1480	21,900	66.30	15.08	.
7		0.1443	20,820	63.02	15.87	.
	10	0.1340	17,960	54.35	18.40	.
8		0.1285	16,510	49.98	20.01	.
	11	0.1200	14,400	43.59	22.94	.
9		0.1144	13,090	39.63	25.23	.
	12	0.1090	11,880	35.96	27.81	
10		0.1019	10,380	31.43	31.82	
	13	0.0950	9,025	27.32	36.60	
11		0.09074	8,234	24.93	40.12	
	14	0.08300	6,889	20.85	47.95	
12		0.08081	6,530	[illegible].77	50.59	
	15	0.07200	5,184	1[illegible].69	63.73	
13		0.07196	5,178	1[illegible].68	63.79	
	16	0.06500	4,225	12.79	78.19	
14		0.06408	4,107	12.43	80.44	
	17	0.0580	3,364	10.18	98.23	
15		0.05707	3,257	9.858	101.4	
16		0.05082	2,583	7.818	127.9	
	18	0.04900	2,401	7.268	137.6	
17		0.045260	2,048	6.200	161.3	
	19	0.042000	1,764	5.340	187.3	
18		0.040300	1,624	4.917	203.4	
19		0.035890	1,288	3.899	256.5	
	20	0.035000	1,225	3.708	269.7	
	21	0.032000	1,024	3.100	322.6	
20		0.031960	1,022	3.092	323.4	
21		0.028460	810.1	2.452	407.8	
	22	0.028000	784.0	2.373	421.4	
22		0.025350	642.4	1.945	514	
	23	0.025000	625.0	1.892	52[illegible]	

[redacted]

TABLE OF THE PROPERTIES OF COPPER WIRE
(*Concluded*)

...es. To the nearest fourth significant digit.				Weight. Lbs. per 1,000 feet.	Length.	Resistance.
		Diameter.	Area.		Feet per lb.	Ohms per 1,000 feet.
...L.	B. W. G.	Inches.	Circular mils			@ 68° F.
[illegible]		0.022570	509.5	1.542	648.4	20.32
	24	0.022000	484.0	1.465	682.6	21.39
		0.020100	404.0	1.223	817.6	25.63
	25	0.020000	400.0	1.211	825.9	25.88
	26	0.018000	324.0	.9808	1,020	31.96
[illegible]		0.017900	320.4	.9699	1,031	32.31
	27	0.016000	256.0	.7749	1,290	40.45
[illegible]		0.015940	254.1	.7692	1,300	40.75
[illegible]		0.014200	201.5	.6100	1,639	51.38
	28	0.014000	196.0	.5933	1,685	52.83
	29	0.013000	169.0	.5116	1,955	61.27
8		0.012640	159.8	.4837	2,067	64.79
	30	0.012000	144.0	.4359	2,294	71.90
9		0.011260	126.7	.3836	2,607	81.70
0		0.010030	100.5	.3042	3,287	103.0
	31	0.010000	100.0	.3027	3,304	103.5
	32	0.009000	81.0	.2452	4,078	127.8
11		0.008928	79.70	.2413	4,145	129.9
	33	0.008000	64.0	.1937	5,162	161.8
12		0.007950	63.21	.1913	5,227	163.8
13		0.007080	50.13	.1517	6,591	206.6
	34	0.007000	49.0	.1483	6,742	211.3
34		0.006305	39.75	.1203	8,311	260.5
35		0.005615	31.52	.09543	10,480	328.4
36	35	0.005000	25.0	.07568	13,210	414.2
37		0.004453	19.83	.06001	16,660	522.2
	36	0.004000	16.	.04843	20,650	647.1
38		0.003965	15.72	.04759	21,010	658.5
39		0.003531	12.47	.03774	26,500	830.4
40		0.003145	9.888	.02993	33,410	1047.

rop.—In order to determine the drop or volts lost in the the following *formula may* be used

$$drop = \frac{\% \text{ loss} \times \text{volts}}{100} \times S \quad . \quad . \quad . \quad ($$

in which the % loss is a percentage of the applied power, that is, the power delivered to the consumer and not a percentage of the power at the alternator. "Volts" is the pressure at the consumer's end of the circuit.

VALUE OF "S" FOR 60 CYCLES

Size of wire B. & S. gauge	Area in circular mils.	.98 power factor					.90 power factor					.80 power factor					.70 power factor				
		Spacing of conductors					Spacing of conductors					Spacing of conductors					Spacing of conductors				
		1″	3″	6″	12″	24″	1″	3″	6″	12″	24″	1″	3″	6″	12″	24″	1″	3″	6″	12″	24″
500,000	500,000	1.21	1.45	1.61	1.77	1.92	1.32	1.80	2.11	2.44	2.75	1.27	1.89	2.25	2.64	3.03	1.14	1.72	2.12	2.53	[illegible]
300,000	300,000	1.15	1.29	1.38	1.48	1.57	1.19	1.47	1.66	1.84	2.02	1.11	1.46	1.68	1.90	2.12	1.00	1.33	1.56	1.78	2.01
0,000	211,600	1.12	1.22	1.28	1.34	1.41	1.13	1.33	1.45	1.58	1.63	1.03	1.27	1.43	1.58	1.75	1.00	1.14	1.29	1.45	1.60
000	167,800	1.09	1.18	1.22	1.28	1.29	1.08	1.23	1.33	1.44	1.53	1.00	1.16	1.28	1.41	.153	1.00	1.02	1.15	1.28	1.50
00	133,100	1.07	1.14	1.18	1.21	1.25	1.03	1.16	1.24	1.32	1.40	1.00	1.07	1.17	1.27	1.36	1.00	1.00	1.03	1.13	1.21
0	105,500	1.05	1.10	1.14	1.17	1.20	1.00	1.09	1.16	1.22	1.28	1.00	1.00	1.07	1.15	1.22	1.00	1.00	1.00	1.01	1.09
1	83,690	1.04	1.08	1.10	1.13	1.15	1.00	1.05	1.09	1.14	1.19	1.00	1.00	1.00	1.05	1.11	1.00	1.00	1.00	1.00	1.00
2	66,370	1.02	1.05	1.08	1.10	1.12	1.00	1.00	1.04	1.08	1.12	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.00
3	52,630	1.02	1.04	1.06	1.07	1.09	1.00	1.00	1.00	1.03	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4 5	41,740 33,100	1.00	1.02	1.03	1.04	1.07	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6 7	26,250 20,820	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8 9 10	16,510 13,090 10,380	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The coefficient S has various values as given in the accompanying tables. As will be seen from the table, the value of S to be used depends upon the size of wire, spacing, power factor and frequency.

These values are accurate enough for all practical purposes, and may be used for distances of 20 miles or less and for voltages up to 25,000.

[redacted]

The capacity effect on very long high voltage lines, makes this :thod of determining the drop somewhat inaccurate beyond the iits above mentioned.

VALUE OF "S" FOR 25 CYCLES

ze f ire & S. uge	Area in circular mils.	.98 power factor					.90 power factor					.80 power factor					.70 power factor				
		Spacing of conductors					Spacing of conductors					Spacing of conductors					Spacing of conductors				
		1"	2"	6"	12"	24"	1"	3"	6"	12"	24"	1"	3"	6"	12"	24"	1"	3"	6"	12"	24"
1,000	500,000	1.01	1.17	1.23	1.29	1.36	1.02	1.22	1.35	1.43	1.61	1.00	1.15	1.30	1.47	1.62	1.00	1.00	1.16	1.33	1.49
,000	300,000	1.04	1.10	1.13	1.18	1.21	1.00	1.08	1.16	1.25	1.31	1.00	1.00	1.09	1.16	1.25	1.00	1.00	1.00	1.02	1.12
,000	211,600	1.03	1.07	1.09	1.11	1.14	1.00	1.02	1.07	1.13	1.15	1.00	1.00	1.00	1.03	1.10	1.00	1.00	1.00	1.00	1.00
000	167,800	1.00	1.05	1.06	1.09	1.10	1.00	1.00	1.02	1.07	1.11	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00
00	133,100	1.00	1.03	1.05	1.06	1.08	1.00	1.00	1.00	1.02	1.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	105,500	1.00	1.01	1.02	1.03	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1 2 3	83,690 66,370 52,630	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4 5 6	41,740 33,100 26,250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7 8 9 10	20,820 16,510 13,090 10,380	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

EXAMPLE.—A circuit supplying current at 440 volts, 60 frequency, with 5% loss and .8 power factor is composed of No. 2 B. & S. gauge wires spaced one foot apart. What is the drop in the line?

According to the formula

$$\text{drop} = \frac{\%\ \text{loss} \times \text{volts}}{100} \times S$$

Substituting the given values, and value of S as obtained from the table for frequency 60

$$\text{drop} = \frac{5 \times 440}{100} \times 1 = 22 \text{ volts}$$

Current.*—As has been stated,* the effect of power factor less *than unity, is to increase* the current; hence, in inductive circuit

[redacted]

calculations, the first step is to determine the current circuit. This is done as follows:

$$\text{current} = \frac{\text{apparent load}}{\text{volts}} \quad . \quad .$$

and

$$\text{apparent load} = \frac{\text{watts}}{\text{power factor}} \quad . \quad .$$

Substituting (2) in (1)

$$\text{current} = \frac{\frac{\text{watts}}{\text{power factor}}}{\text{volts}} = \frac{\text{watts}}{\text{power factor} \times \text{vol}}$$

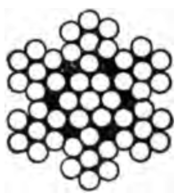


FIG. 2,704.—Rope type of stranded copper cable which is used when a high de is required. The construction of this cable is the stranding together each containing seven wires and producing a total of 49 wires. In case carrying capacity is desired than can be obtained through the use of the cable, the number of groups is increased to nineteen thereby making a t (19 × 7).

EXAMPLE.—A 50 horse power 440 volt motor has a full of .9 and power factor of .8. How much current is required?

Since the brake horse power of the motor is given, it i obtain the electrical horse power, thus

$$\text{E. H. P.} = \frac{\text{brake horse power}}{\text{efficiency}} = \frac{50}{.9} = 55.5$$

which in watts is

$$55.5 \times 746 = 41{,}403$$

which is the actual load, and from which

$$\text{apparent load} = \frac{\text{actual load}}{\text{power factor}} = \frac{41{,}403}{.8} = 51{,}754$$

The current therefore at 440 volts is

$$\frac{\text{apparent load}}{\text{volts}} = \frac{51{,}754}{440} = 117.6 \text{ amperes}$$

EXAMPLE.—A 50 horse power single phase 440 volt motor, having a full load efficiency of .92 and power factor of .8, is to be operated at a distance of 1,000 feet from the alternator. The wires are to be spaced 6 inches apart and the frequency is 60, and % loss 5. Determine: **A**, *electrical horse power;* **B**, *watts;* **C**, *apparent load;* **D**, *current;* **E**, *size of wires;* **F**, *drop;* **G**, *voltage at the alternator.*

A, *Electrical horse power*

$$\text{E. H. P.} = \frac{\text{brake horse power}}{\text{efficiency}} \times \frac{50}{.92} = 54.3$$

or,

$$54.3 \times 746 = 40{,}508 \text{ watts}$$

TABLE OF WIRE EQUIVALENTS

(Brown and Sharpe gauge)

0000	2 No. 0	4 No. 3	8 No. 6	16 No. 9	32 No. 12	64 No. 15
000	2 " 1	4 " 4	8 " 7	16 " 10	32 " 13	64 " 16
00	2 " 2	4 " 5	8 " 8	16 " 11	32 " 14	64 " 17
0	2 " 3	4 " 6	8 " 9	16 " 12	32 " 15	64 " 18
1	2 " 4	4 " 7	8 " 10	16 " 13	32 " 16	64 " 19
2	2 " 5	4 " 8	8 " 11	16 " 14	32 " 17	64 " 20
3	2 " 6	4 " 9	8 " 12	16 " 15	32 " 18	64 " 21
4	2 " 7	4 " 10	8 " 13	16 " 16	32 " 19	64 " 22
5	2 " 8	4 " 11	8 " 14	16 " 17	32 " 20	64 " 23
6	2 " 9	4 " 12	8 " 15	16 " 18	32 " 21	64 " 24
7	2 " 10	4 " 13	8 " 16	16 " 19	32 " 22	64 " 25
8	2 " 11	4 " 14	8 " 17	16 " 20	32 " 23	64 " 26
9	2 " 12	4 " 15	8 " 18	16 " 21	32 " 24	64 " 27
10	2 " 13	4 " 16	8 " 19	16 " 22	32 " 25	64 " 28
11	2 " 14	4 " 17	8 " 20	16 " 23	21 " 26	64 " 29
12	2 " 15	4 " 18	8 " 21	16 " 24	32 " 27	64 " 30
13	2 " 16	4 " 19	8 " 22	16 " 25	32 " 28	....
14	2 " 17	4 " 20	8 " 23	16 " 26	32 " 29	....
15	2 " 18	4 " 21	8 " 24	16 " 27	32 " 30	....
16	2 " 19	4 " 22	8 " 25	16 " 28	....	....
17	2 " 20	4 " 23	8 " 26	16 " 29	....	....
18	2 " 21	4 " 24	8 " 27	16 " 30	....	....
19	2 " 22	4 " 25	8 " 28	....	....	....
20	2 " 23	4 " 26	8 " 29	....	....	....
21	2 " 24	4 " 27	8 " 30	....	....	....

B. *Watts*

$$\text{watts} = \text{E. H. P.} \times 746 = 54.3 \times 746 = 40{,}508$$

C. *Apparent load*

$$\text{apparent load or kva} = \frac{\text{actual load or watts}}{\text{power factor}} = \frac{40{,}508}{.8} = 50{,}635$$

D. *Current*

$$\text{current} = \frac{\text{apparent load or kva}}{\text{volts}} = \frac{50{,}635}{440} = 115 \text{ amperes}$$

E. *Size of wires*

$$\text{cir. mils} = \frac{\text{watts} \times \text{feet} \times \text{M}}{\%\ \text{loss} \times \text{volts}^2} = \frac{40{,}508 \times 1{,}000 \times 3{,}380}{5 \times 440^2} = 141{,}443$$

From table page 1,907, nearest size *larger* wire is No. 00 B. & S. gauge.

F. *Drop*

$$\text{drop} = \frac{\%\ \text{loss} \times \text{volts}}{100} \times \text{S} = \frac{5 \times 440}{100} \times 1.17 = 25.74 \text{ volts}$$

NOTE.—Values of S are given on page 1910.

G. *Voltage at alternator*

$$\text{alternator pressure} = \text{volts at motor} + \text{drop} = 440 + 25.74 = 465.7 \text{ v}$$

CHAPTER LXVI

POWER STATIONS

The term *power station* is usually applied to any building ntaining an installation of machinery for the conversion of ergy from one form into another form. There are three general asses of station:

1. Central stations;
2. Sub-stations;
3. Isolated plants.

These may also be classified with respect to their function as

1. Generating stations;
2. Distributing stations;
3. Converting stations;

and with respect to the form of power used in generating the electric current, generating stations may be classed as

1. Steam electric;
2. Hydro-electric;
3. Gas electric, etc.

Central Stations.—It must be evident that the general type of central station to be adapted to a given case, that is to say, the *general character of the machinery* to be installed depends upon the kind of natural energy available for conversion into electrical energy, and the character of the electrical energy required by the consumers.

This gives rise to a further classification, as

1. Alternating current stations;
2. Direct current stations;
3. Alternating and direct current station.

The alternators or dynamos may be driven by steam or water turbines, reciprocating engines, or gas engines, according to the character of the natural energy available.

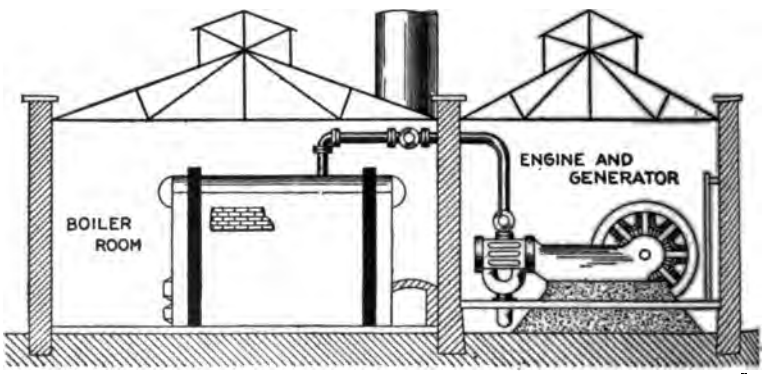


FIG. 2,705.—Elevation of small station with direct drive, showing arrangement of the boiler and engine, piping, etc.

Ques. Why is the reciprocating engine being largely replaced by the steam turbine, especially for large units?

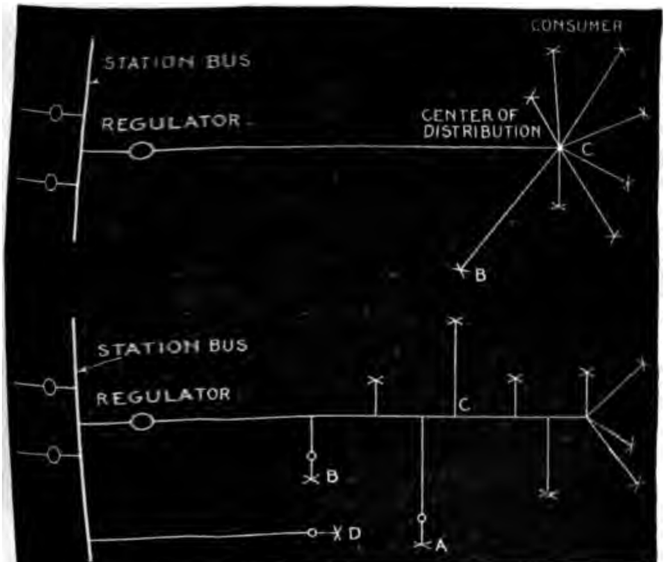
Ans. Because of its higher rotative speed, and absence of a multiplicity of bearings which in the case of a high speed, *reciprocating* engine must be maintained in close adjustment for the proper operation of the engine.

The higher speed of rotation results in a more compact unit, desirable for driving high frequency alternators.

Ques. Is the steam turbine more economical than high duty reciprocating engine?

Ans. No.

Location of Central Stations.—As a rule, central stations hould be so *located* that the average loss of voltage in over-oming the *resistance* of the lines is a minimum, and this point



'IG. 2,706.—Diagram illustrating graphical method of determining the *center of gravity* of a system in locating the central station.

s located at the center of gravity of the system. In fig. 2,706 is shown a graphical method of locating this important spot.

Suppose a rough canvass of prospective consumers in a district to be supplied *with electric light* or power shows the principal loads to be *located at A, B, C, D, E,* etc., and for simplicity assume that these *loads will be approximately* equal, so that each may be denoted by 1 for *example:*

The relative locations of A, B, C, D, E, etc., should be drawn to scale (say 1 inch to the 1,000 feet) after which the problem resolves itself into finding the location of the station with respect to this scale.

The solution consists in first finding the center of gravity of any two of the loads, such as those at A and B. Since each of these is 1, they will together have the same effect on the system as the resultant load of 1 and 1, or 2, located at their center of gravity, this point being so chosen that the product of the loads by their respective distances from this point will in both cases be equal.

The loads being equal in this case the distances must be equal in order that the products be the same, so that the center of gravity of A + B is at G, which point is midway between A and B.

Considering, next, the resultant load of 2 at G and the load of 1 at C, the resultant load at the center of gravity of these will be 3, and this must be situated at a distance of two units from C and one unit from G so that the distance 2 times the load 1 at C equals the distance 1 times the load 2 at G. Having thus located the load 3 at H, the same method is followed in finding the load 4 at I. Then in like manner the resultant load 4 and the load 1 at E gives a load 5 at S.

The point S being the last to be determined represents, therefore, the position of the center of gravity of the entire system, and consequently the proper position of the plant in order to give the minimum loss of voltage on the lines.

FIG. 2,707.—Exterior of central station at Lewis, Ia.; example of very small station located in the principal business section of a town. It also illustrates the use of a direct connected gasoline electric set. The central station is located on Main Street, which is the principal thoroughfare, and is installed in a low one story building for which a mere nominal rental charge is paid, the company having the option to buy the property later at the value of the land plus the cost of the improvements and simple interest on the same. To the front of an old frame building about 16 feet by 28 feet has been built a neat, well lighted concrete block room, about 16 feet by 16 feet, carrying the building to the lot line and affording ample space for the generating set and switchboards, and such desk room as is needed for the ordinary office business of the company. In this room, which is finished in natural pine with plastered walls, has been installed a standard General Electric 25 kw. gasolene electric generating set consisting of a four cylinder, four cycle, vertical water cooled, 43-51 H.P. gasoline engine, direct connected to a three phase, 2,300 volt, 600 R.P.M. alternator with a 125 volt exciter mounted on the same shaft and in the same frame. With the generating set is a slate switchboard panel equipped with three ammeters, one voltmeter, an instrument plug switch for voltage indication, one single pole carbon break switch, one automatic oil circuit breaker line switch and rheostats. Instrument transformers are mounted above and back of the board. For street lighting service a 4 kw. constant current transformer has been installed, and with it a gray marble switchboard panel mounted on iron frames and carrying an ammeter and a four point plug switch. On a board near the generator set are mounted in convenient reach suitable wrenches, spanners, and repair parts and tools. To cool the engine cylinders five 6 × 8 steel tanks have been installed in the old building, a pump on engine giving forced circulation.

Ques. Is the center of gravity of the system, as obtained fig. 2,706, the proper location for the central station?

Ans. It is very rarely the best location.

Ques. Why?

Ans. Other conditions, such as the price of land, difficulty obtaining water, facilities for delivery of coal and removal

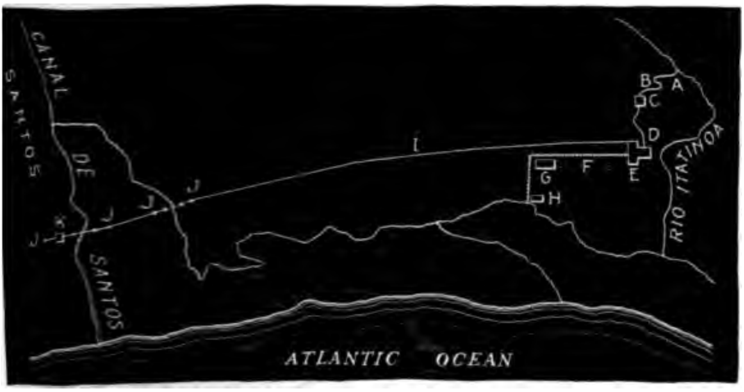


FIG. 2,708.—**Map of Cia Docas de Santos** hydro-electric system; an example of station location remote from the center of distribution. In the figure A is the intake; B, flume; C, forebay; D, penstocks; E, power house; F, narrow gauge railway; G, general store; H, point of debarkation; I, transmission line; J, dead ends; K, sub-station. Santos, in the republic of Brazil, is one of the great coffee shipping ports of the world, and for the development of its water front has required an elaborate system of quays. These have been developed by the Santos Dock Company, which holds a concession for the whole water front. The company, needing electric power for its own use, has developed a system deriving its power from a point about thirty miles from the city, where a small stream plunges down the sea coast from the mountain range that runs along it. The engineers have estimated that 100,000 horse power can be obtained from this source.

of ashes, etc., may more than offset the minimum line losses and copper cost due to locating the station at the center of gravity of the system.

Ques. How then should the station be located?

Ans. The more practical experience the designer has had, and *the more common sense he* possesses, the better is he equipped to handle the problem, as the solution is generally such that it cannot be worked out by any rule of thumb method.

Ques. What are the general considerations with respect to the price of land?

Ans. The cost for the station site may be so high as to necessitate building or renting room at a considerable distance from the district to be supplied.

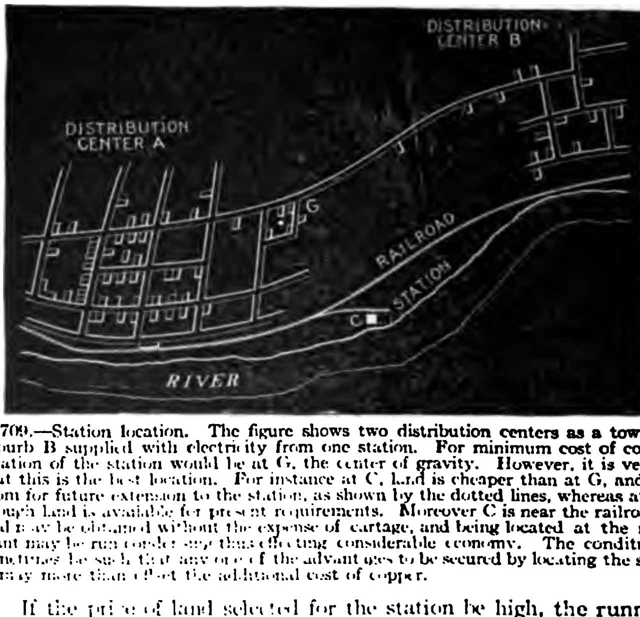


FIG. 2,709.—Station location. The figure shows two distribution centers as a town A and suburb B supplied with electricity from one station. For minimum cost of copper the location of the station would be at G, the center of gravity. However, it is very rarely that this is the best location. For instance at C, land is cheaper than at G, and there is room for future extension to the station, as shown by the dotted lines, whereas at G, only enough land is available for present requirements. Moreover C is near the railroad where coal may be obtained without the expense of cartage, and being located at the river, the plant may be run condensing, thus effecting considerable economy. The conditions may sometimes be such that any one of the advantages to be secured by locating the station at C may more than offset the additional cost of copper.

If the price of land selected for the station be high, the running expenses will be similarly affected, inasmuch as more interest must then be paid on the capital invested.

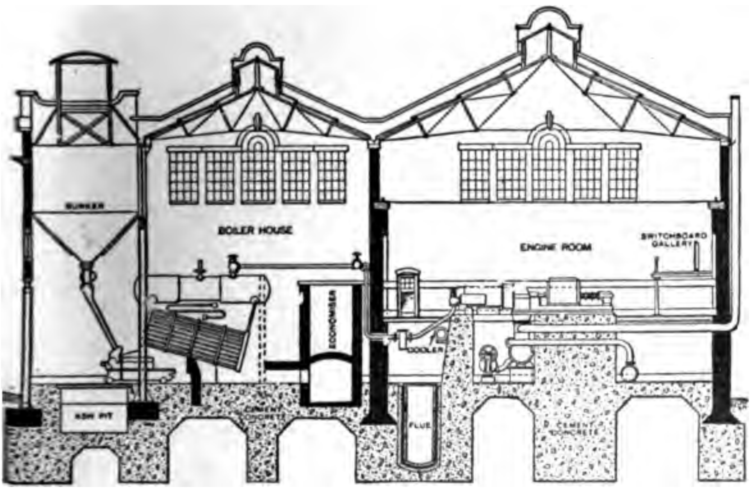
The price or rent of real estate might also in certain instances alter the proposed interior arrangement of the station, particularly so in the case of a company with small capital operating in a city where high prices prevail. In general, however, it may be stated that whatever effect the price of real estate would have upon the arrangement, operation and location of a central station it can quite readily and accurately be determined in advance.

[redacted]

Ques. With respect to the cost of the land what should e especially considered?

Ans. Room for the future extension of the plant.

Although such additional space need not be purchased at the time of the original installation it is well, if possible, to make provision whereby it can be obtained at a reasonable figure when desired. The preliminary canvass of consumers will aid in deciding the amount of space advisable to allow for future extensions; as a rule, however, it



c. 2,710.—Section of the central station or "electricity works" at Derby, showing boiler and engine room and arrangement of bunkers, conveyor, ash pit, grates, boilers (drum, heating surface and superheater), economizer, flue, turbines, condenser pumps, etc.; also location of switchboard gallery and system of piping.

is wise to count on the plant enlarging to not less than twice its original size, as often the dimensions have to be increased four and even six times those found sufficient at the beginning.

Ques. What trouble is likely to be encountered with a illy located plant after it is in operation?

Ans. It may be considered a nuisance by those residing in e vicinity, occasioning many complaints.

2,711.—View of old and new Waterside stations. The new station at the right has an all turbine equipment of ten units, nine Curtis and some Parsons machines, two have a capacity of 14,000 kw., and the remaining eight are of 12,000 kw. each. The old Riverside station, seen at the left is described on page 1940.

Thus, if the plant be placed in a residential section of the community the smoke, noise and vibration of the machines may become a nuisance to the surrounding inhabitants, and eventually end in suits for damage against the company responsible for the same. For these and the other reasons just given a company is sometimes forced to disregard entirely the location of a central station near the center of gravity of the system, and build at a considerable distance; such a proceeding would, if the distance be great, necessitate the installation of a high pressure system.

There might, however, be certain local laws in force restricting the use of high pressure currents on account of the danger resulting to life, that would prevent this solution of the problem. In such cases there could undoubtedly be found some site where the objections previously noted would be tolerated; thus, there would naturally be little objection to locating next to a stable, a brewery, or a factory of any description.

Ques. Why is the matter of water supply important r a central station?

Ans. Because, in a steam driven plant, water is used in the ilers for the production of steam by boiling, and if the engines of the condensing type it is also used in them for creating a cuum into which the exhaust steam passes so as to increase e efficiency of the engine above what it would be if the exhaust eam were obliged to discharge into the comparatively high ressure of the atmosphere.

The force of this will be apparent by considering that the water consumption of the engine ordinarily is from 15 to 25 lbs. of "feed water" per horse power per hour, and the amount of "circulating water" required to maintain the vacuum is about 25 to 30 times the feed water, and in the case of turbines with their 28 or 29 inch vacuum, much more. For instance, a 1,000 horse power plant running on 15 lbs. of feed water and 30 to 1 circulating water would require $(1{,}000 \times 15) \times (30 + 1) =$ 465,000 lbs. or 55,822 gals. per hour at full capacity.

Ques. Besides price what other considerations are nportant with respect to water?

Ans. Its quality and the possibility of a scarcity of supply.

It is quite necessary that the water used in the boilers should be as *free as possible from impurities*, so as to prevent the deposition withi *them of any scale or sediments*. The quality of the water used

condensing purposes, however, is not quite so important, although t
it is the better.

If the plant is to be located in a city, the matter of water sup
not generally be considered, because, as a rule, it can be obtained f
waterworks; there will then, of course, be a water tax to cons
this, if large, may warrant an effort being made to obtain the water
other way. In any event, however, the possibility of a scarcity in th
should be reduced to a minimum.

If the plant be located in the country, some natural source of wat
be utilized unless the place be supplied with waterworks, which is

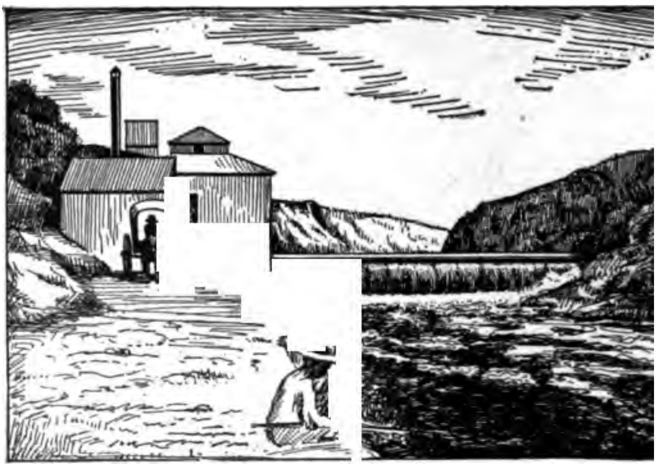


FIG. 2,712.—View illustrating the location of a station as governed by the presence
falls. In such cases the natural water power may be at a considerable distanc
center of gravity of the distribution system because of the saving in generati
case of long distance transmission very high pressure may be used and a t
step down sub-station be located at or near the center of gravity of the system
siderably reducing the cost of copper for the transmission line.

erally the case. It is usual, however, to find a stream, lake or po
vicinity, but if none such be conveniently near, an artesian or othe
well must be sunk.

If abundance of water exist in the vicinity of the proposed installa
only would the location of the plant be governed thereby, but th
power to be used for its operation would depend thereon. Thus, if the
of the water were sufficient throughout the entire year to supply t
sary power, water wheels might be installed and used in place c
and steam engines for driving the generators. The station would
course, be situated close to the waterfall, regardless of the center o
of the system.

[redacted]

Ques. What should be noted with respect to the coal supply?

Ans. The facility for transporting the coal from the supply point to the boiler room.

In this connection, an admirable location, other conditions permitting, is adjacent to a railway line or water front so that coal delivered by car or boat may be unloaded directly into the bins supplying the boilers.

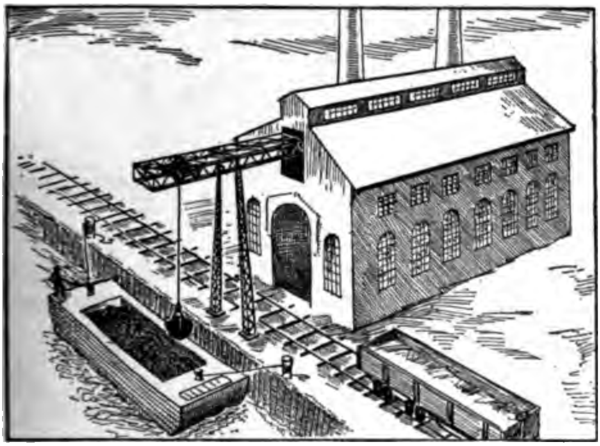
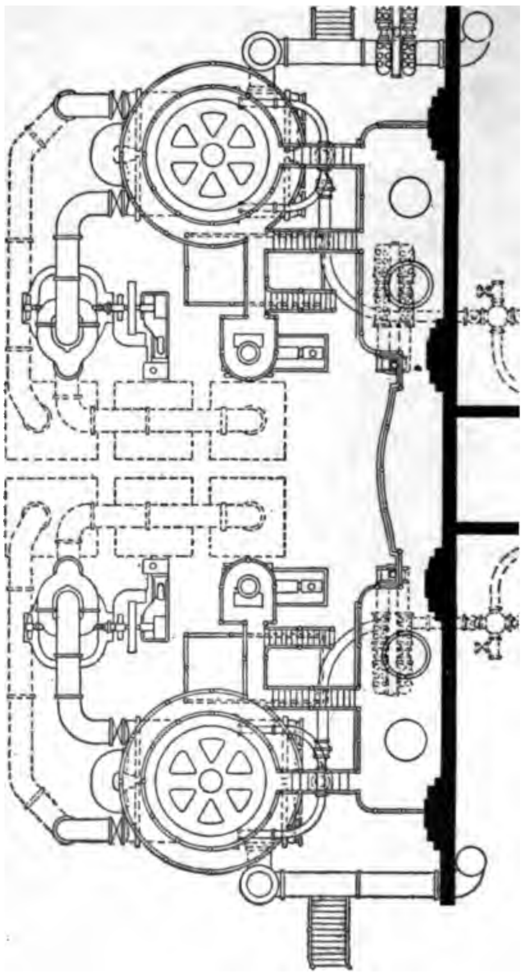


FIG. 2,713.—View of a station admirably located with respect to transportation of the coal supply. As shown, the coal may be obtained either by boat or rail, and with modern machinery for conveying the coal to the interior of the station, the transportation cost is reduced to a minimum.

If the coal be brought by train, a side or branch track will usually be found convenient, and this will usually render any carting of the fuel entirely unnecessary.

In whatever way the coal is to be supplied, the liability of a shortage due to traffic or navigation being closed at any time of the year should be well looked into, as should also the facility for the removal of ashes, before deciding upon the final location for the plant.

Choice of System.—The chief considerations in the design of a central station are *economy* and *capacity*. When the



ıt has to be transmitted long distances for either lighting wer purposes, economy is attainable only by reducing the t of the copper conductors. This can be accomplished by the use of the high voltage currents obtainable from ators.

ıin, where the consumers are located within a radius of niles from the central station, thereby requiring a trans- on voltage of 550 volts or less, dynamos may be employed greater economy.

ernating current possesses serious disadvantages for certain tant applications.

instance, in operating electric railways and for lighting often necessary to transmit direct current at 500 volts a ıce of five or ten miles. In such cases, the excessive drop t be economically reduced by increasing the sizes of the ire, while a sufficient increase of the voltage would cause s variations under changes of load. Hence, it is common ice to employ some form of auxiliary generator or booster, ı when connected in series with the feeder, automatically ains the required pressure in the most remote districts g as the main generators continue to furnish the normal or ng voltage.

e advantage of a direct current installation in such cases a similar plant supplying alternating current line is the hat a storage battery may be used in connection with the r for taking up the fluctuations of the current, thereby tting the dynamo to run with a less variable load, and quently at higher efficiency.

es. Name some services requiring direct current.

s. Direct *current is required* for certain kinds of electrolytic *such as electroplating,* the electrical separation of metals, *o the charging of* storage batteries for electric automobiles.

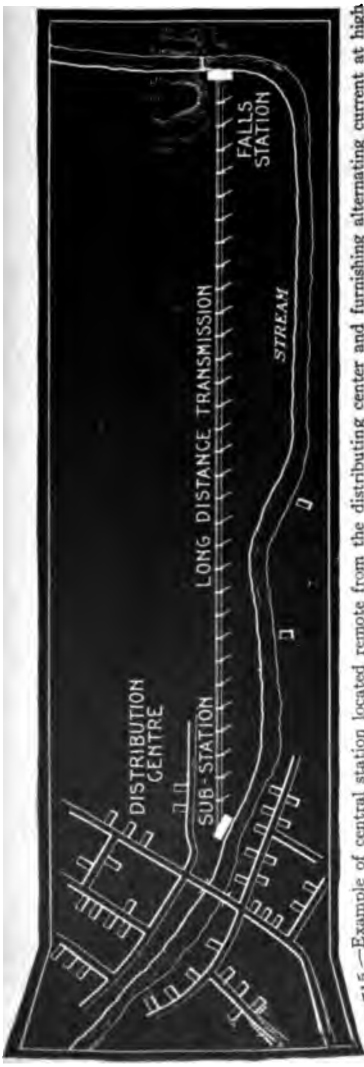


FIG. 2,715.—Example of central station located remote from the distributing center and furnishing alternating current at high pressure to a sub-station where the current is passed through step down transformers and supplied at moderate pressure to the distribution system. In some cases the sub-station contains also converters supplying direct current for battery charging, electro-plating, etc.

Ques. How is dire rent supplied?

Ans. Sometimes th station is equipped with apparatus for supplyi direct and alternating This may be accomp several different ways: stalling both direct a nating current generat central station; by th double current gener dynamotors, from whi current may be taken side and alternating from the other side; stalling, in the sub-stat alternating current ce tion, in addition to t formers usually placed a rotary converter for or converting alterna rent into direct curren

Thus, it is evident tha acter of a central stati governed to a great ext class of services to be

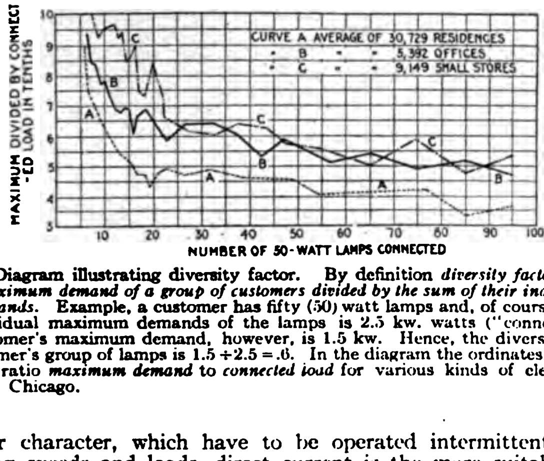
An exception to thi the entire output has t mitted a long distance t of utilization.

In such cases a omy demands the

tension alternating current, and its distribution to consumers may be made directly by means of step down transformers mounted near by or within the consumers' premises, or it may be transformed into low voltage alternating current by a conveniently located sub-station.

Where the current is to be used chiefly for lighting and there are only a few or no motors to be supplied, the choice between direct current and alternating current will depend greatly upon the size of the installation, direct current being preferable for small installations and alternating current for large installations.

If the current is to be used primarily for operating machinery, such as elevators, travelling cranes, machine tools and other devices of a



2,716.—Diagram illustrating diversity factor. By definition *diversity factor = combined actual maximum demand of a group of customers divided by the sum of their individual maximum demands.* Example, a customer has fifty (50) watt lamps and, of course, the sum of the individual maximum demands of the lamps is 2.5 kw. watts ("connected load"). The customer's maximum demand, however, is 1.5 kw. Hence, the diversity factor* of the customer's group of lamps is 1.5 ÷ 2.5 = .6. In the diagram the ordinates of the curves show the ratio ***maximum demand*** to *connected load* for various kinds of electric lighting service in Chicago.

similar character, which have to be operated intermittently and at varying speeds and loads, direct current is the more suitable; but if the motors performing such work can be operated continuously for many hours at a time under practically constant loads, as, for instance in the general work of a pumping station, alternating current may be employed with advantage.

Size of Plant.—Before any definite calculation can be made, plans drawn, the engineer must determine the probable load. ɪis is *usually ascertained* in terms of the number and distances

*NOTE.—*The diversity factor* of a customer's group of lamps, namely, the ratio ...um demand to connected load* is usually called the *demand factor* of the customer.

of lamps that will be required, by making a thorough canvass of the city or town, or that portion for which electrical energy is to be supplied. The probable load that the station is to carry when it begins operation, the nature of this load, and the probable rate of increase are matters upon which the design and construction chiefly depend.

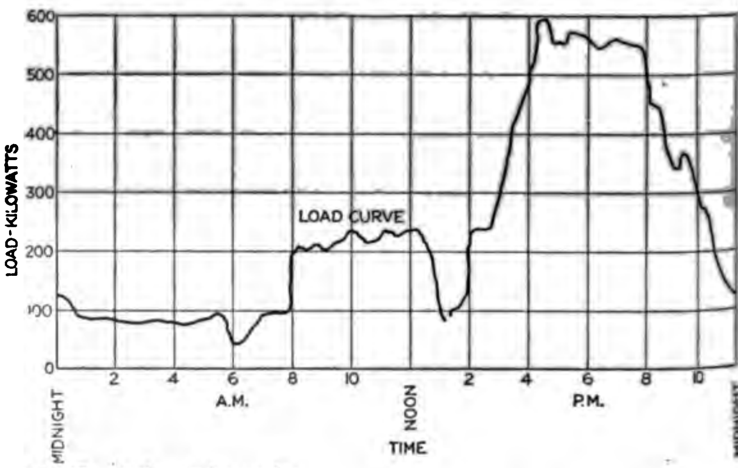


FIG. 2,717.—Load curve for one day.

Ques. What is the nature of the load carried by a central station?

Ans. It fluctuates with the time of day and also with the time of year.

Ques. How is a fluctuating load best represented?

Ans. Graphically, that is to say by means of a curve plotted on coordinate paper of which ordinates represent load values and the corresponding abscissæ time values, as in the accompanying curves.

Ques. What is the nature of a power load?

Ans. Where electricity is supplied for power purposes to a number of factories, the load is fairly steady, dropping, of course, during meal hours. In the case of traction, the average value of the load is fairly steady but there are momentarily violent fluctuations due to starting cars or trains.

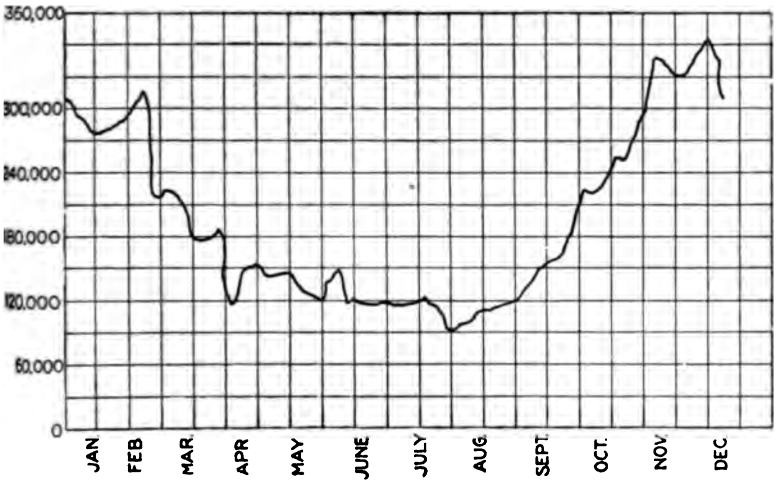


FIG. 2,718.—Load curve for one year.

Ques. What is the peak load?

Ans. The maximum load which has to be carried by the station at any time of day or night as shown by the highest point of the load curve.

Ques. Define *the load* factor.

Ans. The machinery of the station evidently must be larg *ough to carry* the peak load, and therefore considerably

[redacted]

excess of that required for the average demand. T
the average to the maximum load is called the load

There are two kinds of load factor: the annual, and the
The annual load factor is obtained as a percentage by m
number of units sold (per year) by 100, and dividing by
the maximum load and the number of hours in the year.
factor is obtained by taking the figures for 24 hours inste

Ques. What must be provided in additic machinery required to supply the peak load?

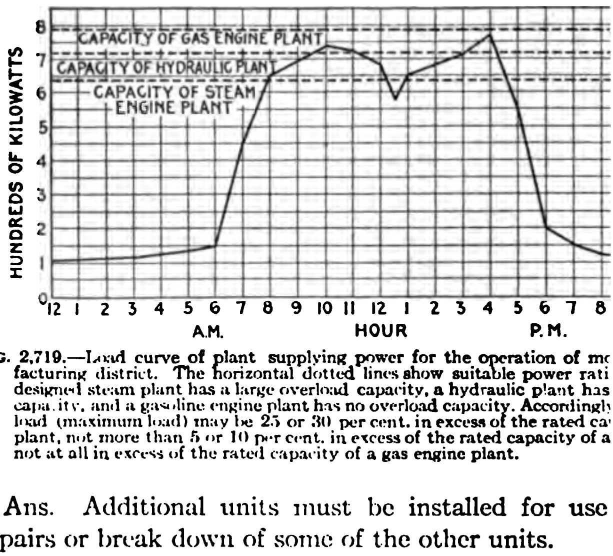


Fig. 2,719.—Load curve of plant supplying power for the operation of mc facturing district. The horizontal dotted lines show suitable power rati designed steam plant has a large overload capacity, a hydraulic plant has capacity, and a gasoline engine plant has no overload capacity. Accordingly load (maximum load) may be 25 or 30 per cent. in excess of the rated ca plant, not more than 5 or 10 per cent. in excess of the rated capacity of a not at all in excess of the rated capacity of a gas engine plant.

Ans. Additional units must be installed for use repairs or break down of some of the other units.

EXAMPLE.—What would be the boiler horse powe generate 5,000 kw. under the following conditions: Effic erators 85%; efficiency of engines 90%; feed water of auxiliaries 15 lbs. per I. H. P.; boiler pressure 175 lbs.; of feed water 150° Fahr? With a rate of combustion of 1 per sq. foot of grate per hour and an evaporation (from *of 8 lbs.* of water per lb. of coal, what area of grate woul *and how* much heating surface?

5,000 kw. = 5,000 ÷ .746 = 6,702 electrical horse

[redacted]

To obtain this electrical horse power with alternators whose efficiency is 85% requires

$$6{,}702 \div .85 = 7{,}885 \text{ brake horse power at the engine}$$

This, with mechanical efficiency of 90% is equivalent to

$$7{,}885 \div .9 = 8{,}761 \text{ indicated horse power}$$

Since 15 lbs. of feed water are required for the engines and auxiliaries per indicated horse power per hour, the total feed water or evaporation required to generate 5,000 kw. is

$$15 \times 8{,}761 = 131{,}415 \text{ lbs. per hour.}$$

that is to say, the boilers must be of sufficient capacity to generate 131,415 lbs. of steam per hour from water at a temperature of 150° Fahr. This must be multiplied by the *factor of evaporation* for steam at 175 lbs pressure from feed water at a temperature of 150°, in order to get the equivalent evaporation *"from and at 212°."*

The formula for the factor of evaporation is

$$\text{factor of evaporation} = \frac{H - h}{965.7} \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

in which

H = total heat of steam at the observed pressure;

h = total heat of feed water of the observed temperature;

965.7 = latent heat, of steam at atmospheric pressure.

Substituting in (1) values for the observed pressure and temperature as obtained from the steam table

$$\text{factor of evaporation} = \frac{1{,}197 - 118}{965.7} = 1.117$$

for which the equivalent evaporation *"from and at 212°"* is

$$131{,}415 \times 1.117 = 146{,}791 \text{ lbs. per hour}$$

FACTORS OF EVAPORATION

Temp. of feed water. Deg. Fahr.	Steam Pressure by Gauge												
	50	60	70	80	90	100	110	120	130	140	150	160	170
32	1.214	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	[illegible]
40	1.206	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	[illegible]
50	1.195	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	[illegible]
60	1.185	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.203	1.205	1.207	1.208	1.210
70	1.175	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	[illegible]
80	1.164	1.167	1.170	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	[illegible]
90	1.154	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	[illegible]
100	1.144	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	[illegible]
110	1.133	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	[illegible]
120	1.123	1.126	1.129	1.131	1.133	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.147
130	1.113	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	[illegible]
140	1.102	1.105	1.108	1.110	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127
150	1.091	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	[illegible]
160	1.081	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	[illegible]
170	1.070	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	[illegible]
180	1.060	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	[illegible]
190	1.050	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074
200	1.039	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064
210	1.029	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053

Temp. of feed water. Deg. Fahr.	Steam Pressure by Gauge												
	180	190	200	210	220	230	240	250	260	270	280	290	300
32	1.240	1.241	1.243	1.244	1.245	1.246	1.247	1.248	1.250	1.251	1.252	1.253	1.254
40	1.232	1.233	1.234	1.236	1.237	1.238	1.239	1.240	1.241	1.242	1.243	1.244	1.245
50	1.221	1.223	1.224	1.225	1.226	1.228	1.229	1.230	1.231	1.232	1.233	1.234	1.235
60	1.211	1.212	1.214	1.215	1.216	1.217	1.218	1.219	1.220	1.221	1.222	1.223	[illegible]
70	1.200	1.202	1.203	1.205	1.206	1.207	1.208	1.209	1.210	1.211	1.212	1.213	1.214
80	1.190	1.192	1.193	1.194	1.195	1.196	1.198	1.199	1.200	1.201	1.202	1.203	1.204
90	1.180	1.181	1.183	1.184	1.185	1.186	1.187	1.188	1.189	1.190	1.191	1.192	[illegible]
100	1.170	1.171	1.172	1.174	1.175	1.176	1.177	1.178	1.179	1.180	1.181	1.182	1.183
110	1.159	1.160	1.162	1.163	1.164	1.166	1.167	1.168	1.169	1.170	1.171	1.172	1.173
120	1.149	1.150	1.151	1.153	1.154	1.155	1.156	1.157	1.158	1.159	1.160	1.161	1.162
130	1.138	1.140	1.141	1.142	1.144	1.145	1.146	1.147	1.148	1.149	1.150	1.151	1.152
140	1.128	1.129	1.131	1.132	1.133	1.134	1.135	1.136	1.137	1.138	1.139	1.140	1.141
150	1.118	1.119	1.120	1.121	1.123	1.124	1.125	1.126	1.127	1.128	1.129	1.130	1.131
160	1.107	1.108	1.110	1.111	1.112	1.113	1.115	1.116	1.117	1.118	1.119	1.120	1.121
170	1.097	1.098	1.099	1.101	1.102	1.103	1.104	1.105	1.106	1.107	1.108	1.109	1.110
180	1.086	1.088	1.089	1.090	1.091	1.093	1.094	1.095	1.096	1.097	1.098	1.099	1.100
190	1.076	1.077	1.078	1.080	1.081	1.082	1.083	1.084	1.085	1.086	1.087	1.088	[illegible]
200	1.065	1.067	1.068	1.069	1.071	1.072	1.073	1.074	1.075	1.076	1.077	1.078	1.079
210	1.055	1.056	1.057	1.059	1.060	1.061	1.062	1.063	1.064	1.065	1.066	1.067	1.068

One boiler horse power being equal to *an evaporation of* 34½ *lbs. of water from a feed water temperature of* 212° *Fahr., into steam at the same temperature*, the boiler capacity is accordingly

$$148{,}105 \div 34\tfrac{1}{2} = 4{,}293 \text{ boiler horse power.}$$

The rate of evaporation is given at 8 lbs. of water (from and at 212° Fahr.), for which the fuel required is

$$148{,}105 \div 8 = 18{,}513 \text{ lbs. of coal per hour.}$$

For a rate of combustion of 15 lbs. of coal per hour per square foot of grate,

$$\text{grate area} = 18{,}513 \div 15 = 1{,}234 \text{ sq. ft.}$$

For stationary boilers the usual ratio of heating surface to grate area is 35:1, accordingly the heating surface corresponding to this ratio is

$$1{,}234 \times 35 = 43{,}190 \text{ sq. ft.}$$

The above calculation is based on a rate of evaporation of 8 lbs. of water per lb. of coal and a rate of combustion of 15 lbs. of coal per sq. ft. of grate. For other rates the required grate area may be obtained from the following table:

GRATE SURFACE PER HORSE POWER (KENT)

	Pounds of water from and at 212° per pound of coal	Pounds of coal per h.p. per hour	Pounds of coal burned per square foot of grate per hour — Square feet grate per horse power								
			8	10	12	15	20	25	30	35	40
Good coal and boiler	10	3.45	.43	.35	.28	.23	.17	.14	.11	.10	.09
	9	3.83	.48	.38	.32	.25	.19	.15	.13	.11	.10
Fair coal or boiler	8.61	4.	.50	.40	.33	.26	.20	.16	.13	.12	.10
	8	4.31	.54	.43	.36	.29	.22	.17	.14	.13	.11
	7	4.93	.62	.49	.41	.33	.24	.20	.17	.14	.12
Poor coal or boiler	6.9	5.	.63	.50	.42	.34	.25	.20	.17	.15	.13
	6	5.75	.72	.58	.48	.38	.29	.23	.19	.17	.14
	5	6.9	.86	.69	.58	.46	.35	.28	.23	.22	.17
Lignite and poor boiler	3.45	10.	1.25	1.00	.83	.67	.50	.40	.33	.29	.25

General Arrangement of Station.—In designing an electrical station, it is preferable that whatever rooms or divisions of the interior space are desired should determine the total

SAVING DUE TO HEATING THE FEED WATER

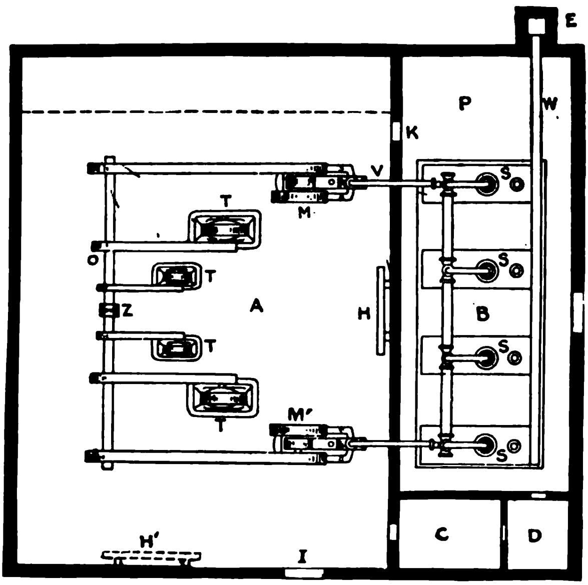
Table showing the percentage of saving for each degree of increase in temperature of feed water heated by waste steam.

Initial temp. of feed	PRESSURE OF STEAM IN BOILER, LBS. PER SQ. INCH ABOVE ATMOSPHERE											
	0	20	40	60	80	100	120	140	160	180	200	Initial temp. of feed
32°	.0872	.0861	.0855	.0851	.0847	.0844	.0841	.0839	.0837	.0835	.0833	32
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0841	.0839	40
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846	50
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853	60
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860	70
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868	80
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875	90
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883	100
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891	110
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899	120
130	.0954	.0941	.0954	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907	130
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916	140
150	.0973	.0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924	150
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933	160
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941	170
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951	180
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960	190
200	.1022	.1008	.0900	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969	200
210	.1033	.1018	.1000	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979	210
220	...	.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989	220
230	...	.1039	.1031	.1024	.1018	.0112	.1010	.1007	.1003	.1001	.0999	230
240	...	.1050	.1041	.1031	.1029	.1024	.1020	.1017	.1014	.1011	.1009	240
250	...	.1062	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019	250

outside dimensions of the plant in the original plans of the building than that these latter dimensions be fixed and the rooms, etc., be fitted in afterward.

NOTE.—An approximate rule for the conditions of ordinary practice is a saving of 1 per cent. made by each increase of 11° in the temperature of the feed water. This corresponds to .0909 per cent. per degree. The calculation of saving is made as follows: Boiler pressure, 100 lbs. gauge; total heat in steam above 32° = 1,185 B.T.U. feed water, original temperature 60°, final temperature 209°F. Increase in heat units, 150. Heat units above 32° in feed water of original temperature = 28. Heat units in steam above that in cold feed water, 1,185−28 = 1,157. Saving by the feed water heater = 150 ÷ 1,157 = 12.96 per cent. The same result is *obtained by* the use of the table. Increase in temperature 150° × tabular figure .0864 = 12.96 *per cent.* Let total heat of 1 lb. of steam at the boiler pressure = H; total heat of 1 lb. of feed *water before* entering the heater = h', and after passing through the heater = h''; then the saving *made by* the heater is $\frac{h'' - h'}{H - h'}$

ıder usual conditions the plans of an electrical station are ily drawn, as they are generally of a simple nature. The ıes and generators will occupy the majority of the space, these are usually placed in one large room; in some stations, ›ver, they are located respectively in two adjacent rooms. boilers are generally located in a room apart from the engines



720.—Floor plan of an electrical station having a belted drive with counter shaft.

lynamos, and in some cases a separate building is provided ıem; the pumps, etc., must be installed not far from the 's, and space must also be allowed near the boilers for coal ıshes.

Fig. 2,720 *shows the floor* plan of an electrical station, in which a *ountershaft and belted* connections are used between the engines and generators. Referring first to the plan of the building sents the engine and dynamo room, B denotes the boil office, D the store room, and E the chimney connected by means of the uptake w. Referring next to the appa S, S, S, S represents a battery of four boilers; these ar steam piping VV to the two steam engines, M and M, w to the countershaft O. Belted to the countershaft are T, T, T, T, the circuits from which are controlled on the s

Ques. What are the objections to the ai shown in fig. 2,720.

Ans. The large space required by the belt dri

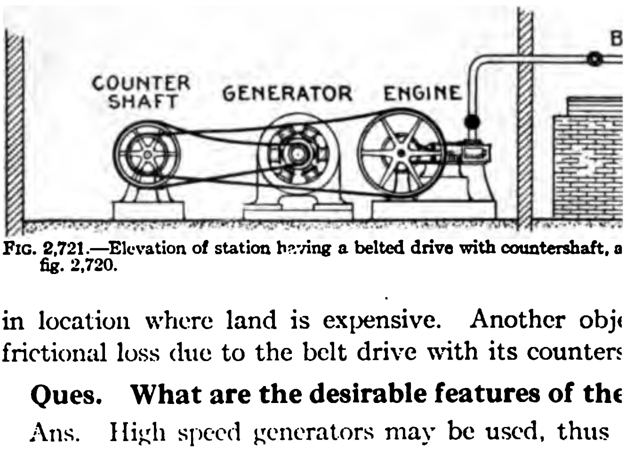


FIG. 2,721.—Elevation of station having a belted drive with countershaft, a fig. 2,720.

in location where land is expensive. Another obj frictional loss due to the belt drive with its counters

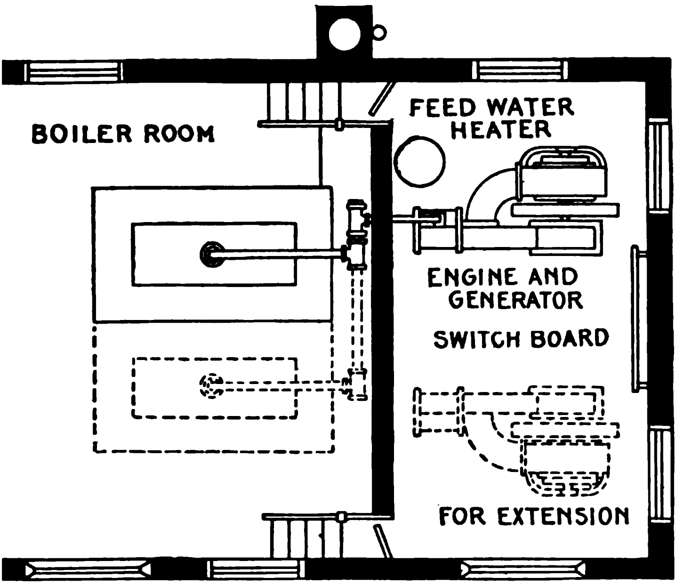
Ques. What are the desirable features of the

Ans. High speed generators may be used, thus first cost, and the multiplicity of speeds and flexi system resulting from the use of a friction clutch.

Thus in fig. 2,720, each pulley may be mounted on th O with a friction clutch. A jaw clutch may also be prov permitting the shaft O to be divided into two sections. possible by this arrangement to cause either of the engin one of the generators, or all of them, or both of the engi of the generators simultaneously.

***Ques.* Under what condition is the cou *belt drive* particularly valuable?**

s. In case of a break down of any one of the engines or ators, and also when it becomes necessary to clean them ut interrupting the service.



22.—Plan of station arranged for extension. The space required for a central station ends upon the number and kind of lights to be supplied, and upon the character and ngement of the machinery. In calculating the size of building required, two things t be carefully considered: first, the building must be adapted to the plant to be alled in the beginning; and second, it must be arranged so that enlargement can be le without disarranging or interfering with the plant already in existence. This is ally best secured by providing for expansion in one or two definite directions, the ding being made large enough to accommodate additional units that will be necessary ome future time because of the growth of the community and consequent increased nand for electric current.

es. How may the design in fig. 2,720 be modified he installation of a storage battery?

s. If a storage battery be necessary, a partition may be ructed across the room A, as indicated by the dotted lines, *he battery installed in* the room thus formed.

Ques. Mention a few details in the general arrangement of the building fig. 2,720.

Ans. Two doors to the room A may conveniently be provided at K and L, the former connecting with the boiler room B, and the latter serving as the main entrance to the station. There is little that need be added to what has already been stated regarding the boiler room B. The door at F provides for the entrance of coal and the removal of ashes, while at P, the pump and heaters may conveniently be located. In the office C, visitors may be received, the station reports made out, bulletins issued from time to time, and whatever engineering problems arise may here be solved on paper by the engineer in charge of the plant. The store room D will be found convenient for various supplies, tools and appliances needed in the operation of the station. These may here be kept under lock and key and the daily waste and loss resulting from carelessness avoided.

Ques. What important point should be noted in locating the engines and boilers?

Ans. They should be so placed that the piping between them will be as short and direct as possible.

Ques. Why?

Ans. The steam pipe should be short to reduce the loss of heat between engine and boiler to a minimum, and both short and direct to avoid undue friction and consequent drop in pressure of the steam in passing through the pipe to the engine.

Entirely too little attention is given to this matter on the part of designers and it cannot be too strongly emphasized that, for economy, the steam pipe between an engine and boiler should be as short and direct as possible, having regard of course, for proper piping methods.

Ques. What should be provided for the steam pipe?

Ans. *A heavy covering* of approved material should be

placed around the pipe to reduce the loss of heat by radiati For this purpose hair felt, mineral wool and asbestos are us

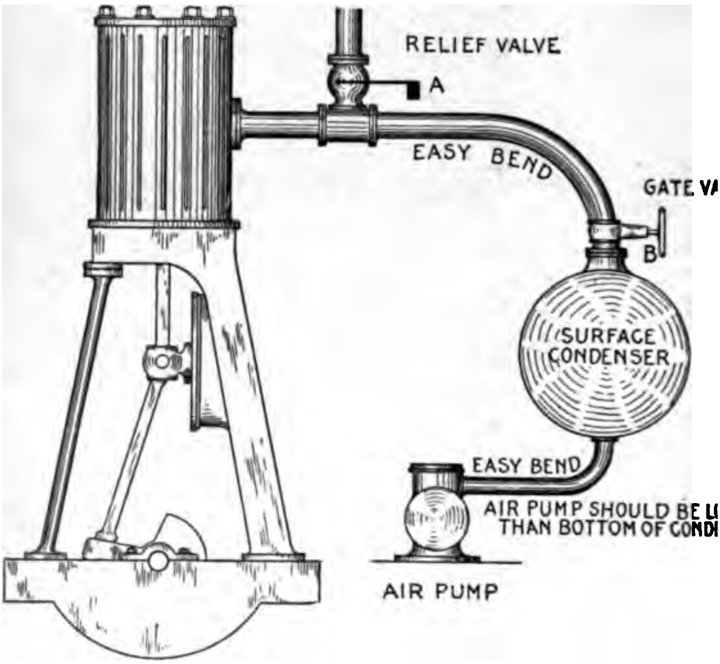


FIG. 2,724.—View of engine and condenser, showing how to arrange the piping to good vacuum. *Locate the condenser as near the engine as possible;* **use easy bends** *of elbows; place the pump* **below** *bottom of condenser so the water will drain to pum* A is a relief valve, for protection in case the condenser become flooded through fai the pump, and at B is a gate valve to shut off condenser in case atmospheric exh desired to permit repairs to be made to condenser during operation. **A water seal** be maintained on the relief valve and **special attention** *should be given to the stuf* of the gate valve **to prevent air leakage.** *The discharge valve of the pump sh water sealed.*

Ques. How should the piping be arranged between engine and condenser, and why?

Ans. It should be as short and direct as possible; espec *should* elbows be avoided so that the back pressure on the en *piston* will be reduced as near as can be to that of the conde

is to say, in order to
y the full effect of the
in the condenser the
l resistance of the pip-
ld be reduced to a
n.

90° turns are neces-
bends should be used
f sharp elbows. The
his argument must be
by noting the prac-
team turbine builders
g the turbine right up
he condenser, and re-
ng that a high vacuum
ary to the economical
of a turbine. See fig.
ge 1,182.

What are the ations respect- number and engine to be

In the illustration), two engines M are employed, one each end of the aft O. These en- uld be of similar al pattern; for a put they may be ple or compound, ditions of fuel ex- may dictate, but put be large, triple engines or tur- *advisable.*

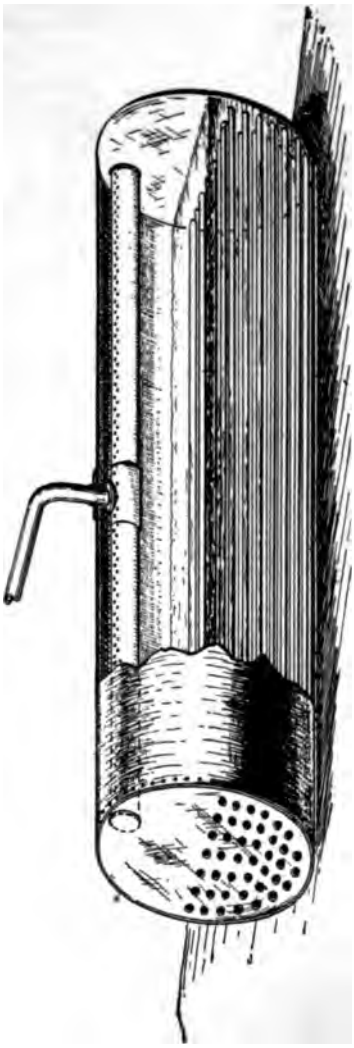


FIG. 2,725.—"Dry pipe" for horizontal boiler; it is connected to the main outlet and its upper surface is perforated with small holes, the far end being closed. With this arrangement steam is taken from the boiler over a large area, so that it will contain very little moisture. *All horizontal boilers without a dome should be fitted with a dry pipe;* most engineers do not realize the importance of obtaining dry steam for engine operation.

Corliss or similar slow speed engines may advantageously be used either case. In all cases the engine should be run condensing unless t cost for circulating water is prohibitive; even in such cases cooli towers may be installed and effect a saving.

In operation, during the greater part of the day, one engine runni two or perhaps three of the generators, will carry the load, but when t load is particularly heavy, as in the morning and evening, both engi and all the generators may be required to meet the demands.

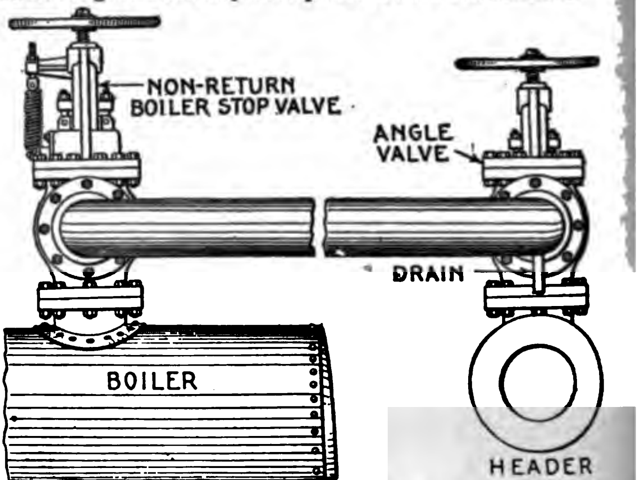


FIG. 2,726.—Method of connecting a header to a battery of boilers. Where two or more b are connected to a single header, the use of a reliable non-return boiler stop valve is essary, and in some countries their installation is compulsory. A non-return boiler valve will instantly close should the pressure in the boiler to which it is attached sudd decrease below that in the header, and thereby prevent the entrance of steam from other boilers of the battery. This sudden decrease in pressure may be caused by a rupt fitting or the blowing out of a tube, in which event an ordinary stop valve taking the of a non-return boiler stop valve would be inadequate, as the loss of steam from the boilers of the battery would be tremendous before an ordinary valve could be ma and closed, assuming that it would be possible to do so, which in the majority of it is not. Should it be desired to cut out a boiler for cleaning or repairs, the non-r boiler stop valve will not permit steam to enter the boiler from the header, even sh the handwheel be operated for this purpose, as it cannot be opened by hand, but however, be closed. A non-return boiler stop valve should be attached to each boiler connected to an angle valve on the header. A pipe bend should be used for connecting valves, as this will allow for expansion and contraction. The pipe should slope a downward toward the header and a suitable drain provided. This drain should be op and all water permitted to escape before the angle valve is opened, thereby preve any damage due to water hammer.

By exercising a little ingenuity in shifting the load on different machi at different times, both engines and dynamos, may readily be cleaned repaired without interrupting the service.

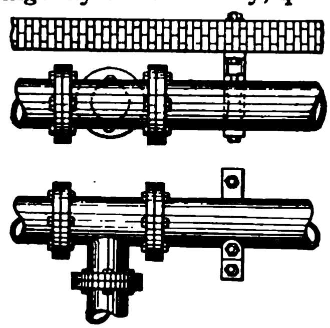
›s. For economy what kind of steam should be used?

Super-heated steam.

The saving due to the use of superheated steam is about 1% for every n degrees Fahr. of super-heat. It should be used in all cases.

s. How should the machines be located?

Sufficient space should be allowed between them that g and repairing may be done easily, quickly and effectually.



?7 and 2,728.—Method of preventing vibration and of supporting pipes. The figures top and side views of a main header carried in suitable frames fitted with adjustable . While the pipe is illustrated as resting on the adjustable rollers, nevertheless the s may also be placed at the sides or on top of the pipe to prevent vibration, or in where the thrust from a horizontal or vertical branch has to be provided for. This ugement will take care of the vibration without in any way preventing the free expan- and contraction of the pipe.

›s. How should the switchboard be located?

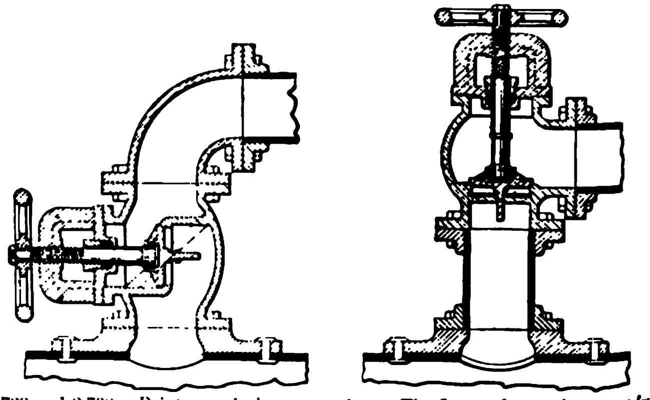
. In fig. 2,720, the switchboard H is mounted against the ividing the room A from the room B, and is in line with achines.

The advantages arising from a switchboard thus installed are, that ie switchboard attendant working thereon can obtain at any time an nobstructed view of the performance of each individual machine, and e has in consequence a much better control of them; then, too, while e is engaged at the engines or generators he can also see the measuring istruments on the switchboard, and ascertain approximately the eadings upon them.

In cases of emergency it is sometimes necessary for the engineer in harge of a plant to be in several places at the same time in order to prevent an accident, and that this seemingly impossibility may t approximated as nearly as possible, it is essential that the controllin devices be located as closely together as is consistent, and that no movi belt or pulley intervene between them.

These conditions are well satisfied in fig. 2,720, and owing to tl short distances between the generators and the switchboard the drop voltage in each of the conducting wires between them will be low.

This latter advantage is worthy of notice in a station generating lar currents at a low pressure. To offset the advantages just mentione the location of the switchboard in line with the machines introduc an element of danger to the switchboard, its apparatus, and t



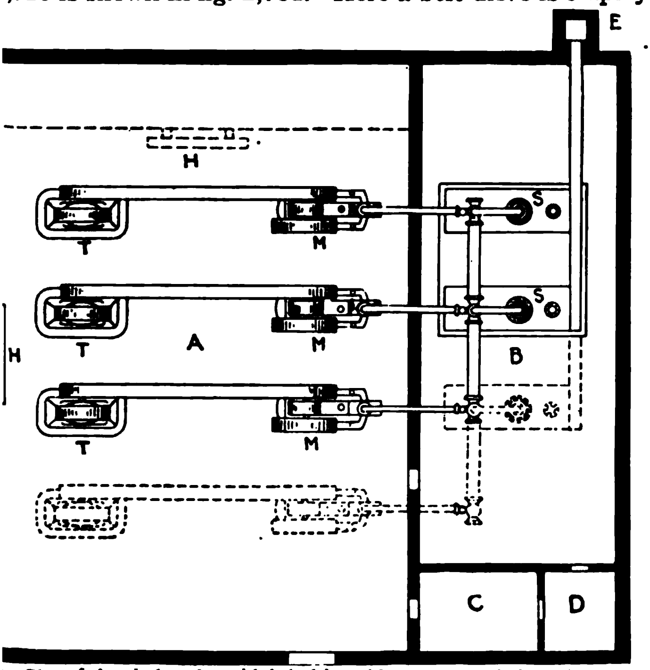
FIGS. 2,729 and 2,730. Points on placing stop valves. The first and most important fe is to ascertain whether the valve will act as a water trap for condensed steam. Fig. illustrates a common error in the placing of valves, as this arrangement permits accumulation of condensed steam above the valve when closed, and should the eng be careless and open the valve suddenly, serious results might follow owing to w hammer. Fig. 2,730 illustrates the correct method of placing the valve. It somet occurs, however, that it is not convenient to place the valve as shown in fig. 2,730 and fig. 2,729 is the only manner in which the valve can be placed. In such cases, the should have a drain, and this drain should always be opened before the large val opened.

attendant, on account of the possible bursting of a flywheel or o parts of the machines from centrifugal force.

If the switchboard be placed in the dotted position at H', or, in at the opposite end of the room A, the damage to life and prop that might result from the effects of centrifugal force would be el *nated*, but in place thereof would be the disadvantages of an obstru *view of* the machines from the switchboard, an obstructed view of *switchboard* from the machines, inaccessibility between these tw *a greater drop* of voltage in the majority of the conducting wires *the generators* and the switchboard.

;. Describe a second arrangement of station with ;ive and compare it with the design shown in fig.

A floor plan somewhat different from that presented ;,720 is shown in fig. 2,731. Here a belt drive is employed,



;.—Plan of electrical station with belt drive without counter shaft. The installation represented consists of two boilers, S, etc., and three sets of engines and generators, , etc. Sufficient allowance has been made in the plans, however, for future increase siness, as additional space has been provided for an extra engine and generator set, licated by the dotted lines.

; countershaft is used. Each generator, therefore, is *ent upon its respective* engine, and in consequence the *v obtained by the* use of a countershaft is lost. On th *id, there is less* loss of mechanical power between

engines and generators in the driving of the latter, and less floo
space is necessary in the room A. If, however, the floor are
of this room be made the same as in the previous arrangem
and the same number of machines are to be installed, they m
be spaced further apart, affording in consequence consideral
more room for cleaning and repairing them.

In operation, the normal conditions should be such that any two
the engine and generator sets may readily carry the average load,
third set to be used only as a reserve either to aid the other two wh
the load is unusually heavy or to replace one of the other sets when
becomes necessary to clean or repair the latter.

The switchboard may perhaps be best located at H, as a similar p
tion on the opposite side of the room A would bring it beneath one
more of the steam pipes and thus endanger it should a possible leak
occur from these pipes. If located at H, however, it will be in line w
the machines, and therefore will be subject to the disadvantages p
viously mentioned for such cases; consequently it might be as wel
place it at the further end of the room, either against the parti
(shown dotted) of the storage battery room if this be built, or else
no storage battery is to be installed), against the end wall itself. T
nearer end of the room A would not be very desirable for the swit
board installation on account of being so far removed from the machin
and therefore more or less inaccessible from them. Outside of wh
has now been mentioned, the division of the floor plan and the arrang
ment therein is practically the same as in fig. 2,720, accordingly wh
has already been stated regarding the former installation applies, the
fore, with equal force to the present installation.

Ques. Describe a plant with direct drive.

Ans. This type of drive is shown in fig. 2,732. Each engin
is directly connected to a generator, that is, the main shafts o
both are joined together in line so that the generator is driven
without the aid of a belt.

Ques. What is the advantage of direct drive?

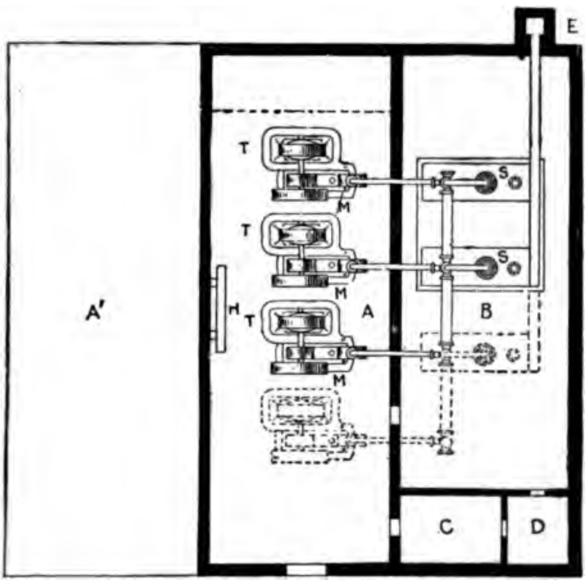
Ans. The great saving in floor space, which is plainly show
in fig. 2,732, the portion A' representing the saving which re
sults over the installations previously illustrated in figs. 2,7
and 2,731.

ues. How could the floor space be further reduced?

ıs. By employing vertical instead of horizontal engines.

ıes. What should be done before drawing the plans he station?

s. The types of the various machines and apparatus to stalled should, as nearly as possible, be selected in advance



732.—Plan of electrical station containing direct connected units. As shown, space is ıvided for an extra boiler and engine and generator set, as indicated by the dotted lines. ıce also exists for a storage battery room if necessary, and the partition dividing this ɑn from the engine and dynamo room is shown by a dotted line as in previous cases.

at their approximate dimensions may serve as a guide in ing up the plans of the building.

Owing to the great difference in these dimensions for the various types, and in fact for the same types as manufactured by different ɔncerns, no definite rules regarding the necessary space required ca here be given. In a general way, however, the author has endeav to indicate by the drawings the relative amounts of space that ordin would be considered sufficient.

Ques. What is the disadvantage of direct drive?

Ans. A more expensive generator is required because it m run at the same speed as the engine, which is relatively low compared with that of a belted generator.

Station Construction.—The construction or rearrangem of the building intended for the plant is a problem that und ordinary conditions would be solved by an architect, or at le by an architect with the assistance of an electrical or mechani engineer, still there are many installations where the electri engineer has been compelled to design the building.

In such instances he should be equipped with a gene knowledge of the construction of buildings.

Foundations.—The foundation may be either natural artificial; that is, it may be composed of rock or soil sufficie solid to serve the purpose unaided, or it may be such as to requ strengthening by means of wood or iron beams, etc. In eith case any tendency toward a considerable settling or shifting the foundation due to the action of water, frost, etc., after th station has been completed must be well guarded against. T this end special attention should be given to the matter drainage.

Ques. How should the foundation be constructed the machines?

Ans. The foundations constructed for the machines sh
...te from that built for the walls of the buil
...er will not affect the latt

If there be several engines and dynamos to be installed, it is best to construct two foundations, one for the engines and one for the dynamos. If, however, there be considerable distance between the units, it may be advisable to build a separate foundation for each engine and for each dynamo. The material of which these foundations are composed should if the machines be of 20 horse power or over, possess considerable strength and be impervious to moisture. Brick, stone and concrete are desirable for the purpose, and only the best quality of cement mortar should be employed. Care must be taken that lime mortar is not used in place of cement mortar, as the former is not well adapted to withstand the vibrations of the machines without crumbling.

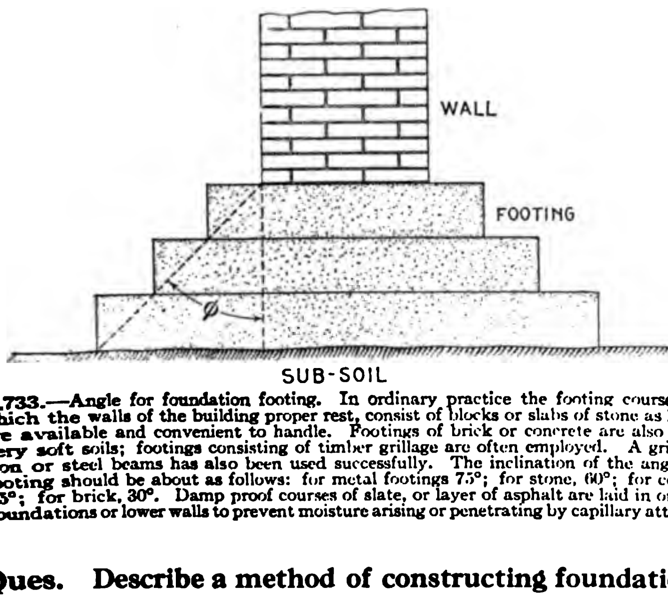


FIG. 2,733.—**Angle for foundation footing.** In ordinary practice the footing courses upon which the walls of the building proper rest, consist of blocks or slabs of stone as large as are available and convenient to handle. Footings of brick or concrete are also used in very soft soils; footings consisting of timber grillage are often employed. A grillage of iron or steel beams has also been used successfully. The inclination of the angle ϕ, of footing should be about as follows: for metal footings 75°; for stone, 60°; for concrete, 45°; for brick, 30°. Damp proof courses of slate, or layer of asphalt are laid in or on the foundations or lower walls to prevent moisture arising or penetrating by capillary attraction.

Ques. Describe a method of constructing foundations.

Ans. An excavation is made to the desired depth and a form inserted corresponding to the desired dimensions for the foundation. A template is placed on top locating all the centers, with iron *pipes suspended from* these centers, two or three sizes *larger than the anchor bolts.* At the lower end of the pipes are *core boxes.* *Concrete* is poured into the mould thus forme and when hard, the forms are removed thus leaving the solid foundation. The anchor bolts are inserted through the pipe and passed through iron plates at the lower end as shown in fig. 2,734, being secured by nuts. By using pipe of two or three bolt diameters a margin is provided for adjustment so the bolt will pass through the holes in the frame of the machine thus allowing for any slight errors in laying out the centers on the template.

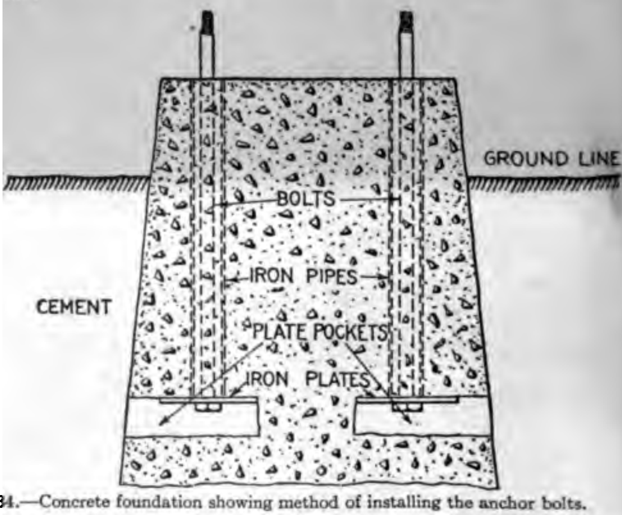
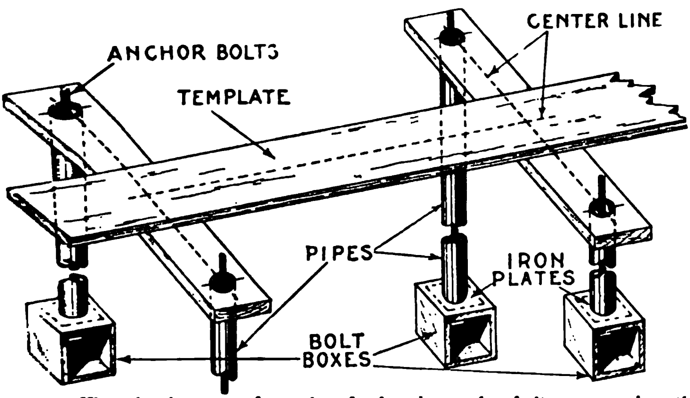


FIG. 2,734.—Concrete foundation showing method of installing the anchor bolts.

Ques. What is the object of the openings in the bott of the foundation?

Ans. In case of a defective bolt it may be replaced by new one without injury to the foundation.

Walls.—Regarding the material for the walls of the stat iron, stone, brick and wood may be considered. Of these, i in the form of sheets or plates would be entirely firepr itself a conductor would introduce difficulties in main-g a high insulation resistance of the current carrying ts; it would also make the building difficult to heat in r and to keep cool in summer. Stone in the form of lime-, granite or sandstone, as a building material is desirable olidity and attractiveness; it is also fireproof and an insu-, but the high cost of such a structure for an electrical on usually prohibits its use except in private plants or in rical stations located in large cities.



2,735.—View showing part of template for locating anchor bolt centers, pipes through which the bolts pass and bolt boxes at lower end of bolts. The completed foundation is shown in fig. 2,734, with template removed. The template is made of plain boards upon which the center lines are drawn, and bolt center located. Holes are bored at the bolt centers to permit insertion of the pipes as shown.

Brick is a good material and is readily obtained in nearly all rts of the country; it is comparatively cheap, and is also an sulating and fireproof material. The bricks selected for this rpose should possess true sharp edges, and be hard burned.

Ques. What are the features of wood?

Ans. Wood *forms the cheapest* material that can be used *r the walls of electrical* stations, and it usually affords satis-*tion. but has the disadvantage* of high fire risk.

Roofs.—In fig. 2,736 is shown one form of construct the roof of an electrical station. The end view here pr shows the upper portion of the walls at B and D; these the iron trusses C, and the roof proper MN. In many there is provided throughout the length of the building, a or raised structure on the peak of the roof for ventilat light. The end view of the monitor is shown at S in the its sides should be fitted with windows adjustable from tl

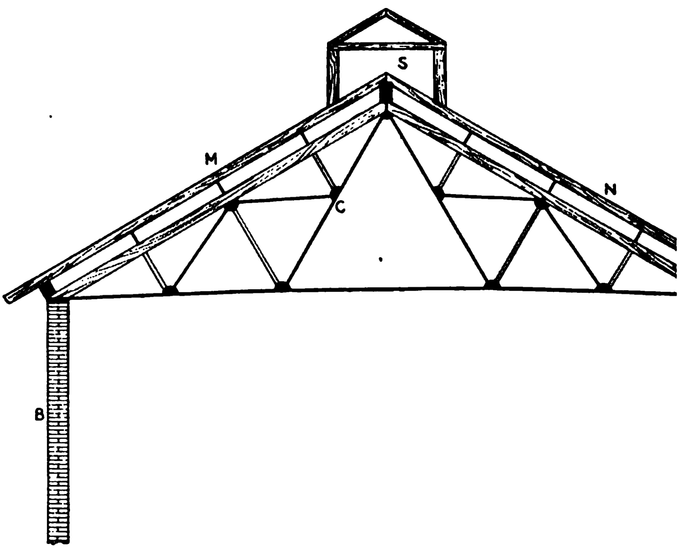


FIG. 2,736.—One form of roof construction.

Floors.—The floor of the station should be so design it will be capable of supporting a reasonable weight, but weights of the machines are borne entirely by their re foundations the normal weight upon the floor will not b for short periods, however, it may be called upon to supp or two machines while they are being placed in pos

[redacted]

ıged, and due allowance must be made for such ces.

ı floors for engine and dynamo rooms are, as a rule, ed of wood. Where very high currents are generated, insulated floors of special construction mounted on necessary as a protection from injurious shocks. Brick, cement, and other substances of a similar nature are

TICAL DRAFT PRESSURE IN INCHES OF WATER IN A CHIMNEY 100 FEET HIGH

(For other heights the draft varies directly as the height)

ure in Fahr.	TEMP. OF EXTERNAL AIR. (BAROMETER 30 INCHES)										
	0°	10°	20°	30°	40°	50°	60°	70°	80	90°	100°
....	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
....	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
....	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
....	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
....	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
....	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
....	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
....	.662	.638	.593	.563	.530	.50	.472	.443	.419	.392	.367
....	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
....	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
....	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
....	.753	.718	.684	.653	.620	.59	.563	.534	.509	.482	.457
....	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
....	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
....	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
....	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

able as a floor material for engine and dynamo rooms nt of the grit from them, caused by constant wear, ɔle to get into the bearings of the machines.

there are no moving parts, however, as in the boiler e materials just mentioned possess no disadvantages ɔreferable to wood on account of being fireproof.

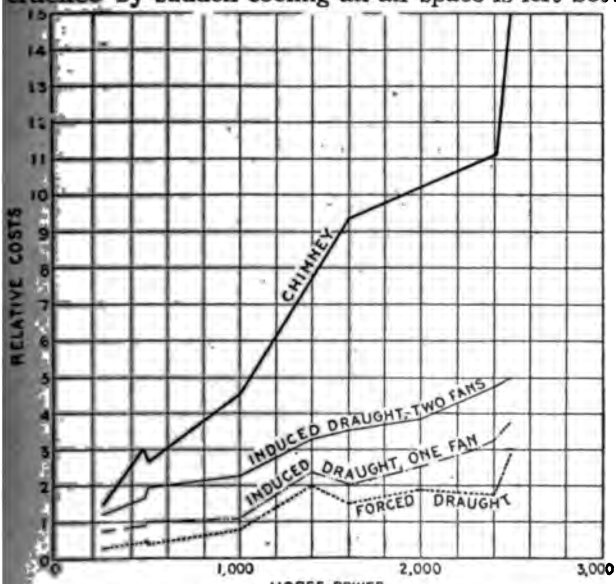
ıeys.—These are generally constructed of brick and ıetimes of concrete. *Iron* chimneys cost less than brick

FIG. 2,737. An example of direct connected unit with gas engine power. Th Westinghouse 200 kva., 4,000 volt, three phase, 60 cycle alternator direc gas engine.

[redacted]

ys, necessitate less substantial foundations, and are m the liability of cracking. They must be painted to t corrosion, are less substantial, and lose considerably eat by radiation than do brick chimneys.

brick and iron chimneys, require an inner wall or lining , which forms the flue proper, and in order that this wall cracked by sudden cooling an air space is left between it



.—Curves showing comparative costs of chimney and mechanical draft. In certain se, the cost of the existing chimney is known, and that of the complete mechanical plant is estimated, while in others, the cost of mechanical draft installation is deter- d from the contract price, and the expense of a chimney to produce equivalent re- is calculated. Costs are shown for both single, forced and induced engine driven and for duplex engine driven plants, in which either fan may serve as a relay. An s of the latter type is the most expensive, and finds its greatest use where ers are employed.

e outer wall. In a brick chimney the inner wall need not much *beyond half* the height of the chimney, but when *used it should reach to the top.*

Ques. Upon what does the force of natural in a chimney depend?

Ans. It depends upon the difference between the the column of hot gases inside the chimney and the a like column of the cold external air.


FIGS. 2,739 and 2,740.—Substituting mechanical draught in place of chimney proportions of a brick chimney, and of the smoke pipe required when mec introduced are forcibly shown in the illustrations, which show the work Sturtevant Co., at Jamaica Plain, Mass. The removal of the boilers to a distant from the existing chimney to permit of its longer fulfilling its of substitution of an induced draft fan and the subsequent removal of the present stack or smoke pipe, barely visible in fig. 2,740, extends only 31 ground, and no trouble is experienced from smoke.

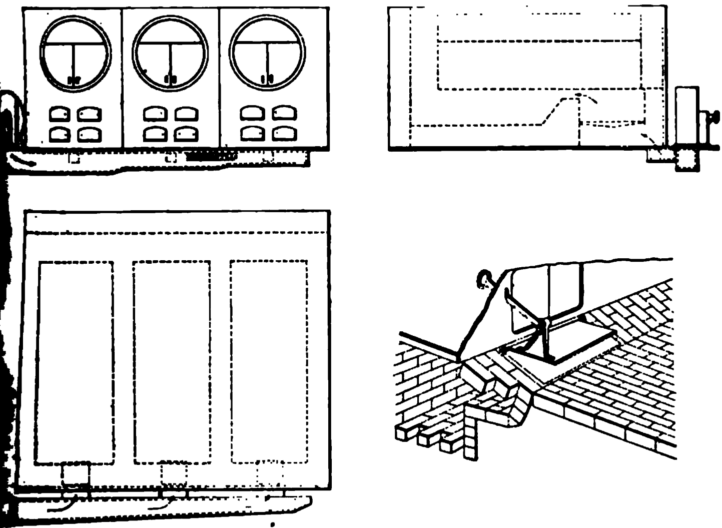
Ques. How is the intensity of the draught exp

Ans. In terms of the number of inches of a wat sustained by the pressure produced.

Ques. Are high chimneys necessary?

Ans. No.

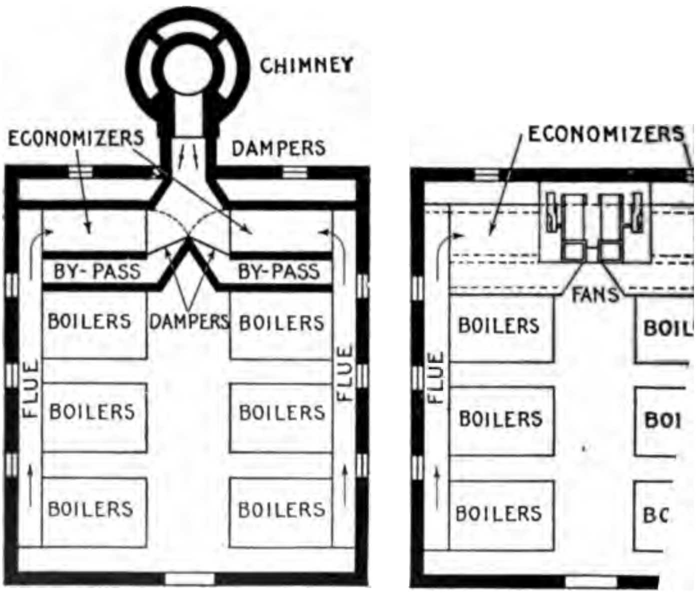
Chimneys above 150 feet in height are very costly, and their increased cost is not justified by increased efficiency.



741 to 2,744.—Installation of forced draft system to old boiler plant. The figures **trate the simplest method.** The fan which is of steel plate with direct connected **ble cylinder engine, is placed** immediately over the end of a brick duct into which the **is discharged.** This duct is carried under ground across the front of the boilers, to **ash pits** of each of which connection is made through branch ducts. Each branch **duct opening** is provided with special ash pit damper, operated by notched handle bar, **as illustrated** in the detail. This method of introduction serves to distribute the air within **the ash** pit, and to secure even flow through the fuel upon the grate above. Of course, the **ash** pit doors must remain closed in order to bring about this result. A chimney of sufficient height to merely discharge the gases above objectionable level is all that is absolutely necessary with this arrangement. Although the introduction of a fan in an old plant is usually evidence of the insufficiency of the existing chimney to meet the requirements, such a chimney, will, however, usually serve as a discharge pipe for the gases when the fan is employed. The fan thus becomes more than a mere auxiliary to the chimney; it practically supplants it so far as the method of draught production is concerned.

The latest chimney practice is to build two or more small chimneys instead of one large one. A notable example is the Spreckels Sugar *Refinery in Philadelphia,* where three separate chimneys are used for one boiler plant of 7,500 horse power. The three chimneys are have cost several thousand dollars less than an equivalent single ch

Very tall chimneys have been characterized by one writer a uments to the folly of their builders."*



FIGS. 2,745 and 2,746.—Comparison of chimney draft and mechanical draft. tions show a plant of 2,400 H. P. of modern water tube boilers, 12 in number, equipped with economizers. Fig. 2,745 indicates the location of a chin internal diameter by 180 feet high, designed to furnish the necessary d represents the same plant with a complete duplex induced draught appara for the chimney, and placed above the economizer connections. Each of driven by a special engine, direct connected to the fan shaft, and each is ducing draft for the entire plant. A short steel plate stack unites the two discharges the gases just above the boiler house roof. All of the room chimney is saved, and no valuable space is required for the fans.

Ques. How is mechanical draft secured?

Ans. In two ways, known respectively as *ind* and *forced draught.*

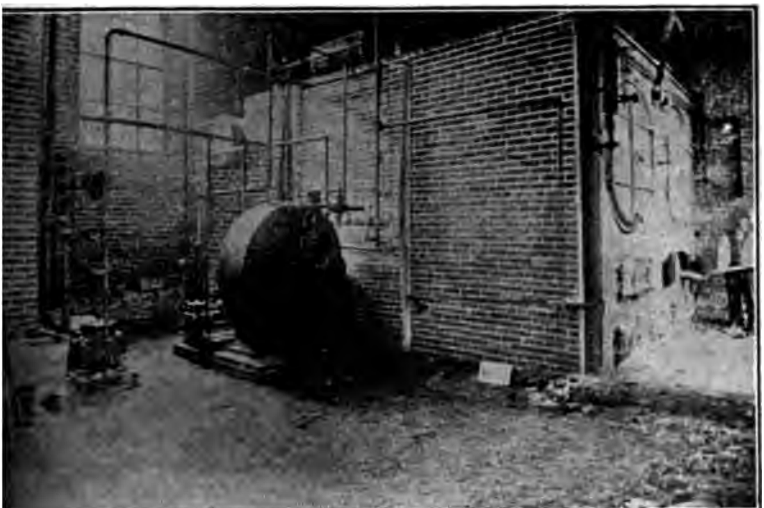
Ques. Describe the method of induced dr

A fan is located in the smoke flue,

peration draws the gases through the furnace and discharges
em into a *short* chimney.

Ques. Describe the method of forced draft.

Ans. In this method, air is forced into the furnace under-
ath the grate bars by means of a fan or a steam jet blower.



. 2747.—Forced draft plant with hollow bridge wall at the Crystal Water Co., Buffalo, N. Y. The air is delivered to the ash pit via the hollow bridge wall, being supplied under pressure by the blower seen at the side of the boiler setting. As shown, the blower is operated by a small reciprocating engine; however, compact blowing units with steam turbine drive can be had and which are designed to be placed in the boiler setting.

Ques. What is the application of the two systems?

Ans. Induced draft is installed mostly in new plants, while
orced draft is better adapted to old plants.

Steam Turbines.—It is not the author's intention to discuss
: length the steam end of the electric plant, because too much
ace would be required, and also because the subject belongs
operly *to the field of* mechanical engineering rather than

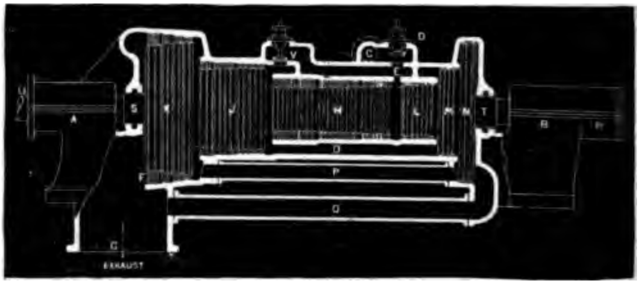
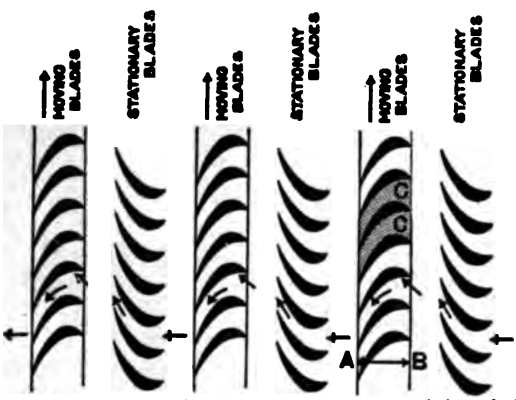


FIG. 2,748.—Longitudinal section of elementary Parsons type steam turbine. The turl consists essentially of a fixed casing, or cylinder, and a revolving spindle or drum. ends of the spindle are extended in the form of a shaft, carried in two bearings A and and, excepting the small parts of the governing mechanism and the oil pump, these t ings are the only rubbing parts in the entire turbine. Steam enters from the steam at C and passes through the main throttle or regulating valve D, which, as actually structed, is a balanced valve. This valve is operated by the governor through sui controlling mechanism. The steam enters the cylinder through the passage E and, tu to the left passes through alternate stationary and revolving rows of blades, finally ex ing from them at F and flowing through the connection G to the condenser or t atmosphere, depending upon whether the turbine is condensing or non-condensing. row of blades, both stationary and revolving, extends completely around the turbin the steam flows through the full annulus between the spindle and the cylinder. ideal turbine the lengths of the blades and the diameter of the spindle which carries would continuously and gradually increase from the steam inlet to the exhaust. tically, however, the desired effect is produced by making the spindle in steps, there generally three such steps or stages, H, J and K. The blades in each step are arr in groups of increasing length. At the beginning of each of the larger steps, the l are usually shorter than at the end of the preceding smaller step, the change being in such a way that the correct relation of blade length to spindle diameter is sec The steam, acting as previously described, produces a thrust tending to force the sp toward the left, as seen in the cut. This thrust, however, is counteracted by the "ba pistons," L, M and N, which are of the necessary diameter to neutralize the thrust o spindle steps, H, J and K, respectively. These elements are called "pistons" for venience, although they do not come in contact with the cylinder, but both the piston the cylinder are provided with alternate rings which form a labyrinth packing to r the leakage of steam. In order that each balance piston may have the proper pressu both sides, equalizing passages O, P and Q are provided connecting the balance pi with the corresponding stages of the blading: The end thrust being thus practi neutralized by means of the balance pistons, the spindle "floats" so that it can be moved in one direction or the other. In order to definitely fix the position of the spi a small adjustable collar bearing is provided at R, inside the housing of the main beari This collar bearing is adjustable so as to locate and hold the spindle in such positio that there will be such a clearance between the rings of the balance piston and those o cylinder, that the leakage of steam will be reduced to a minimum and, at the same t prevent actual contact under varying conditions of temperature. Where the passes out of the cylinder, at S and T, it is necessary to provide against in-leakage o or out-leakage of steam by means of glands. These glands are made tight by water p ing without metallic contact. The shaft of the turbine is extended at U and couple the shaft of the alternator by means of a flexible coupling. The high pressure turb are so proportioned that, when using steam as previously described, they have eco capacity to take care of the ordinary fluctuations of load when controlled by the gove through the valve D, thus insuring maximum economy of steam consumption a proximately the rated load. To provide for overloads, the valve V is supp admit steam to an intermediate stage of the turbine. This valve shown diag cally in the illustration, is arranged to be operated by the governor and is, accor cumstances, located either as shown by the illustration, or at another stage of ical engineering. However, because of the recent intro- on of the steam turbine for the direct driving of large ators, and the fact that it is now almost universally used in central stations, a detailed explanation of its principles and ruction may not be out of place.

urbine is a machine in which a rotary motion is obtained ansference of the *momentum* of a fluid or gas. In general



19.—Arrangement of blading in Parsons type turbine, consisting of alternate moving stationary blades. The path taken by the steam is indicated by the arrows

uid is guided by fixed blades, attached to a casing, and, ging on other blades mounted on a drum or shaft, causing itter to revolve.

rbines are classed in various ways as : 1, *radial flow*, when team enters near the center and escapes toward the cir- erence; and 2, *parallel flow*, when the steam travels *axially* rallel to the length of the turning body.

rbines are commonly, yet erroneously classed as:

mpulse;

action.

Ques. What is the distinction between these types?

Ans. In the so called impulse type, *steam enters and the passages between the vanes at the same pressure.* In t called reaction type, *the pressure is less on the exit side vanes than on the entrance side.*

Fig. 2,750 is a sectional view of the Parsons-Westinghouse flow turbine. Steam from the boiler enters first a receiver in wh the governor controlled admission valves. These valves are a by a centrifugal governor.

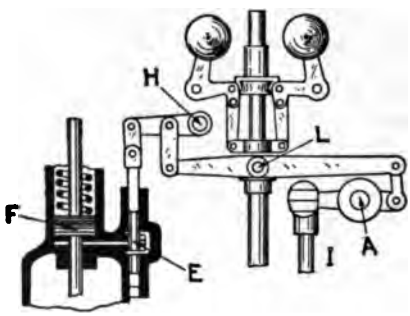


FIG. 2,750.—Sectional view of Parsons-Westinghouse turbine, showing rotor and g

Steam does not enter the turbine in a continuous blast, but interm or in puffs. The speed regulation is therefore accomplished l portioning the duration of these puffs to the load of the engi being effected by the governor, fig. 2,752.

The governor of the turbine has only to move a small pilot or slide, E, which admits steam under the piston F, and lifts the valve proper off its seat.

As soon as the pilot valve closes, the spring shifts the main valve. Thus, at light loads, the main throttle or admission v continually opening and shutting at uniform intervals, the le time during which it remains open depending upon the load.

As the load increases, the duration of the valve opening also in until at full load the valve does not reach its seat at all and the flows steadily through the turbine. The steam thus admitt into the annular passage A, fig. 2,750, by the opening S, and the blades, revolving the rotor.

When the load increases above the normal rated amount a secondary pilot valve is moved by the same means, this in turn admitting steam to a piston, similar to F, which lifts another throttle valve. This admits steam into the annular space I, so that it acts upon the larger diameter of the drum or rotor, giving largely increased power for the time being.

The levers or arms of the governor are mounted upon knife edges instead of pins, making it extremely sensitive. The tension spring may be adjusted by hand while the turbine is running.

The governor does not actually move the pilot valve, but shifts the point L in fig. 2,752. A reciprocating motion is given to the rod I by a small eccentric on the governor shaft; this is driven by worm gearing shown near O in fig. 2,750, so that the eccentric makes one revolution to about eight of the turbine. Thus, with a turbine running 1,200

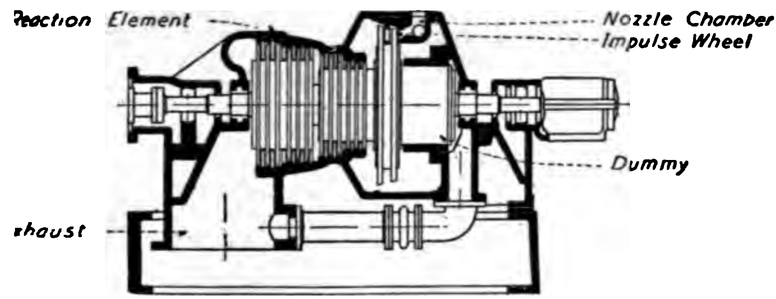


FIG. 2,751.—Sectional view of a combination impulse and reaction single flow turbine. This is a modification of the single flow type, in which the smallest barrel of reaction blading is replaced by an impulse wheel. Steam is admitted to the nozzle block A, is expanded in the nozzles and discharged against a portion of the periphery of the impulse wheel. The intermediate and low pressure stages are identical with the corresponding stages in the single flow type. The substitution of the impulse element for the high pressure section of reaction blading has no influence one way or another on the efficiency. That is to say the efficiency of an impulse wheel is about the same at the least efficient section of reaction blading. This design is attractive, however, in that it shortens the machine materially, and gives a stiffer design of rotor. The entering steam is confined in the nozzle chamber until its pressure and temperature have been materially reduced by expanding through the nozzles. As the nozzle chamber is cast separately from the main cylinder, the temperature and pressure differences to which the cylinder is subjected are correspondingly lessened. However, probably on account of its small diameter at the high pressure section, the straight Parsons type has always shown itself to be adequate for all of the steam pressures and temperatures encountered in ordinary practice.

revolutions, the rod I would be moved up and down 150 times per minute. As the points A and H are fixed, the motion is conveyed to the small pilot valve E, thus giving 150 puffs a minute. The governor in shifting the point L brings the edge of the pilot valve nearer the port and so cuts off *the steam earlier.*

The annular diameter or space between the rotor and the stator is *gradually increased* from inlet to exhaust, the blades being made long *in each ring. When* the mechanical limit is reached, the diameter

the rotor is increased as at I and D so as to keep the length of blad within bound.

Balance pistons as at B, C, F are attached to the rotor, their offic being to oppose end thrust upon those blades in corresponding diamete of the rotor. Communication is established through the passage and pipe M between the eduction pipe and the back of these pistor thus increasing the efficiency of their balancing and also taking care any leakage past them.

A small thrust bearing T prevents end play of the rotor, and is justable to maintain the proper clearance between the rings of blad this varies from ⅛ inch at the admission to 1 inch at the exhaust. T bearing also takes up any extra unbalanced thrust. A turbine sho operate with a high vacuum, because without this it does not comp favorably with an ordinary reciprocating engine from the point of econo

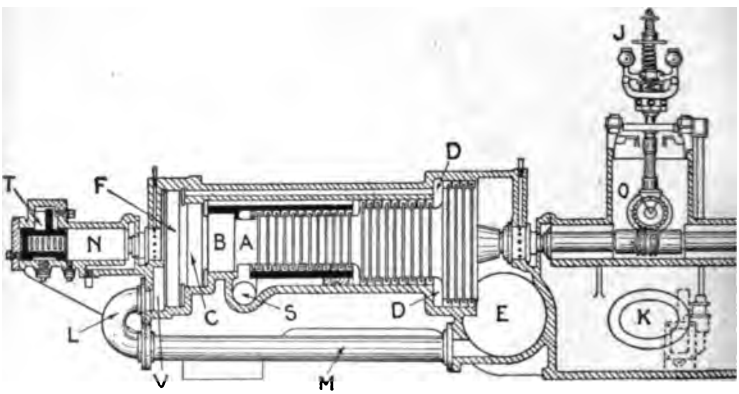


Fig. 2,752.—Sectional view of governor of the Parsons-Westinghouse turbine.

Separate air pumps are provided to create the vacuum.

Where the ordinary type of vertical air pump is employed, a boos or *vacuum increaser* is added, as nothing below 26 inches is advisal 28 and 29 inches being always striven for. It is also prefera to use a certain amount of *superheat* with steam turbines.

To assist in producing the high vacuum, exhaust passages are ma large, the eduction passage E in fig. 2,750 being nearly twenty-th times the area of the steam pipe.

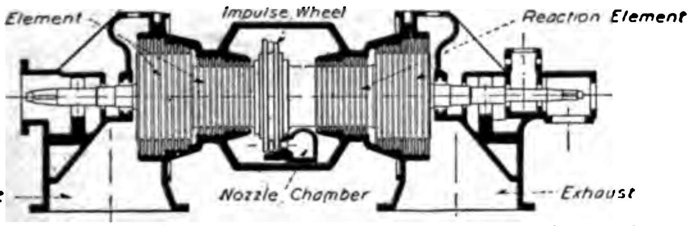
Among other details, a noteworthy feature is a small oil pump which circulates oil through bearings of the machinery, the oil be drawn from the tank under the governor shaft and gravitating th after use. No pressure of oil is employed. Stuffing rings prevent age; these consist of alternate grooves and collars in shaft and be like the grooves in an indicator piston.

Ques. Why is a high vacuum desirable?

Ans. Because the turbine is capable of expanding the steam to a very low terminal pressure, and this is necessary for economy.

Ques. What may be said of the working pressures for turbines?

Ans. To meet the varied conditions of service, turbines are designed to operate with: 1, high pressure, 2, low pressure, or 3, mixed pressure.



2,753.—Sectional view of a double flow turbine. The maximum economical capacity of a single flow turbine is limited by the rotative speed. The economical velocity at which the steam may pass through the blades of the turbine depends on the velocity of the moving blades. The capacity of the turbine depends on the weight of the steam passed per unit of time, which in turn depends on the mean velocity and the height of the blades. For a given rotative speed, the mean diameter of blade ring practicable is limited by the allowable stresses due to centrifugal force, and there is a practical limit for the height of the blades. Now if the rotative speed be taken only half as great, the maximum diameter of the rotor may be doubled and, without increasing the height of the blades, the capacity of the turbine will be doubled. So with the single flow steam turbine as well as with the single crank reciprocating engine, there is a practical limiting economical capacity for any given speed. If this limit be reached with a single crank reciprocating engine, a unit of double the power may be produced at the same speed by coupling two single crank engines to one shaft. Similar results are secured making a double flow turbine which is in effect, as will be seen from the figure, two single flow turbines made up in a single rotor in a single casing with a common inlet and two exhaust. Steam enters the nozzle block, acts on the impulse element, and then the current divides, one-half of the steam going through the reaction blading at the left of the impulse wheel; the remainder passes over the top of the impulse wheel and through the impulse blading at the right.

High pressure turbines operate at about the same initial pressure as triple expansion engines.

Low pressure, as here applied, means the exhaust pressure of the *reciprocating engine* from which the exhaust steam passes through the *turbine before entering* the condenser.

Mixed pressure implies that the exhaust steam is supplemented, for *heavy loads*, by the admission of live steam.

Ques. What determines the working press

Ans. When all the power is furnished by the t designed for high pressure; when operated in comb

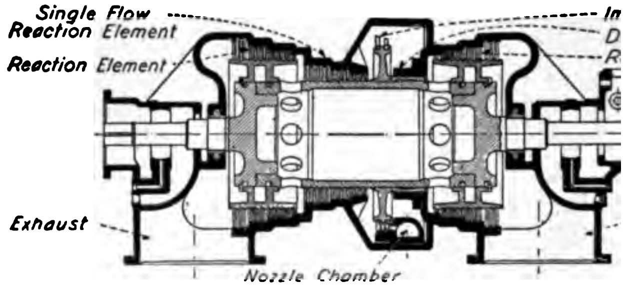


FIG. 2,754.—Sectional view of a semi-double flow turbine. **This is a modific** intermediate section of reaction blading is single flow, **and the low press** double flow. This would be analogous to a four cylinder triple expans one with one high pressure, one intermediate pressure and two low p a design not at all uncommon in very large engines in which the requir single low pressure cylinder would be prohibitive. Such turbines are u greater than is desirable for a single flow turbine, and which are still b possibilities of a double flow turbine of the same speed. In such machine is secured by making the intermediate blading in a single section large entire quantity of steam. A "dummy" similar to those used on the type, shown at the right of the impulse wheel, compels all of the steam single intermediate section of the reaction blading, and balances the this section. When the steam issues from the intermediate section, the one-half passing directly to the adjacent low pressure section, while th through the holes shown in the periphery of the hollow rotor and throu beyond the dummy ring, into the other low pressure section at the le turbine.

NOTE. There are logical engineering reasons for the existence of th turbine, viz., single flow, double flow, and semi-double flow. The double inherently superior to the single flow design, but is used under conditions f flow machine is unsuitable. Similarly, the semi-double flow is recommended which it can meet more satisfactorily than either of the other types.

NOTE. Low pressure turbines use exhaust steam from non-condensi valuable as an adjunct to existing plants for the purpose of increasing econ with a minimum outlay for new equipment.

NOTE. Bleeder turbines are for use in plants which are required to *power, but also considerable and varying quantities of low pressure steam fo In these turbines a part of the steam after it has done work in the high pres diverted to the heating system, and the remainder expanded through the l and exhausted into the condenser. In this way none of the energy of the h the difference of pressure between the boiler and the heating system is w hand if no steam is required for heating purposes, the turbine operat though the bleeder feature were absent.*

a reciprocating engine, low pressure is used for constant load, and mixed pressure for variable load.

The De Laval steam turbine is termed by its builders a high speed rotary steam engine. It has but a single wheel, fitted with vanes or buckets of such curvature as has been found to be best adapted for receiving the impulse of the steam jet. There are no stationary or guide blades, the angular position of the nozzles giving direction to the jet. The nozzles are placed at an angle of 20 degrees to the plane of motion of the buckets. The best energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000

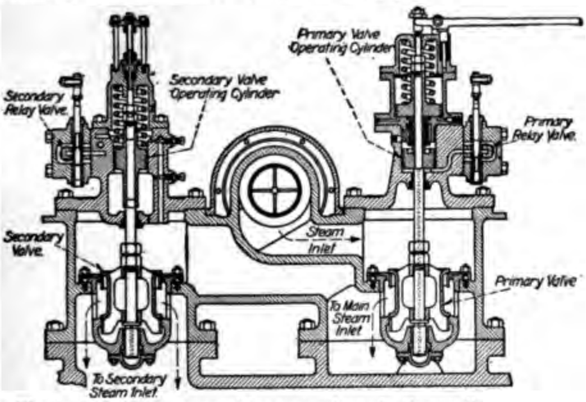


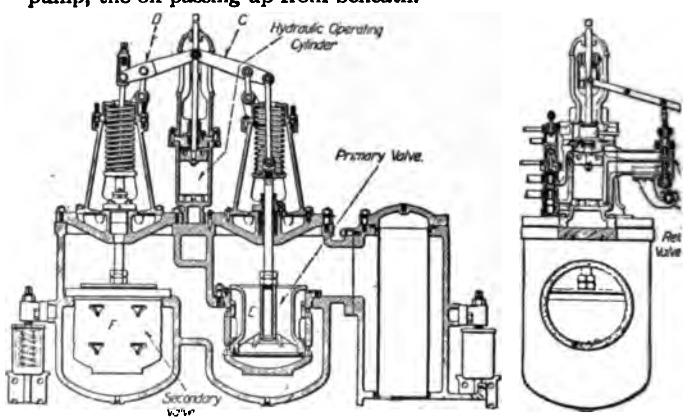
FIG. 2,755.—Westinghouse valve gear with steam relay. In the smaller turbines, the governor acts directly on the steam admission valves, opening first the primary valve, and then, if necessary, the secondary valve, after the primary is fully open. In turbines of the single flow Parsons type, the governor actuates two small valves controlling ports leading to steam relay cylinders which operate the admission valves. The little valve controlling the relay cylinder for the secondary valve has more lap than the other and consequently does not come into action until the primary valve has attained its maximum effective opening. The figure shows the general design of this type of valve gear.

feet per second. To attain the maximum efficiency, the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 feet per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 feet per second.

It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic energy. Theoretically this is what occurs in the De Laval nozzle. The expandi steam acquires great velocity, and the energy of the jet of steam is from the nozzle is equal to the amount of energy that would be deve if an equal volume of steam were allowed to adiabatically expan hind the piston of a reciprocating engine, a condition, however, whi obvious reasons has never yet been attained in practice with the recip ing engine. But with the divergent nozzle the conditions are differ

The Curti: turbine is built by the General Electric Company at works in Schenectady, N. Y., and Lynn. Mass. They are of the zontal and vertical types. In the vertical type the revolving parts upon a vertical shaft, the diameter of the shaft corresponding to tl of the machine.

The shaft is supported by and runs upon a step bearing at the b This step bearing consists of two cylindrical cast iron plates b upon each other and having a central recess between them into lubricating oil is forced under pressure by a steam or electrically pump, the oil passing up from beneath.



FIGS. 2,756 and 2,757.—Westinghouse valve gear with oil relay. Governors for the larger tu particularly those of the combination impulse and reaction double, or single doub type, employ an oil relay mechanism, as shown in the figure, for operating the steam In these turbines the lubricating oil circulating pump, maintains a higher pressur is required for the lubricating system. The governor controls a small relay valve A admits pressure oil to, or exhausts it from the operating cylinder. When oil is ad to the operating cylinder raising the piston, the lever C lifts the primary valve E lever D moves simultaneously with C, but on account of the slotted connection wi stem of the secondary valve F, the latter does not begin to lift until the primary v raised to the point at which its effective opening ceases to be increased by further u travel. In the Westinghouse designs, the operating valve, A is connected not o the governor, but also to a vibrator, which gives it a slight but continuous recipro motion, while the governor controls its mean position. The effect of this is manife a slight pulsation throughout the entire relay system, which, so to speak, keeps it" and ready to respond instantly to the smallest change in the position of the v The oil relay can be made sufficiently powerful to operate valves of any size, an in effect a safety device in that any failure of the lubricating oil supply will a and immediately shut off the steam and stop the turbine.

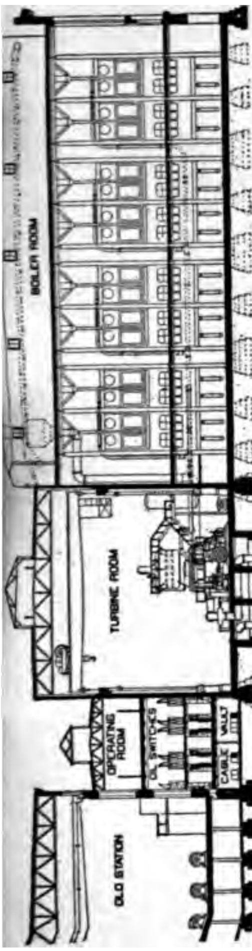


FIG. 2,758.—Elevation of new turbine central station erected by the Boston Edison Co. The turbine room is 68 feet, 4 inches wide and 650 feet long from outside to outside of the walls. The boiler room is 149 feet, 6 inches by 640 feet and equipped with twelve groups of boiler, one group consisting of eight 512 H.P. boilers for each turbine. The switching arrangements are located in a separate building as shown in the elevation. The total floor space covered by boiler room, turbine room and switchboard room is 2.64 square feet per kw. The boilers are all on the ground floor. See fig. 2,714 for plan.

A weighted accumulator is sometimes installed in connection with the oil pipe as a convenient device for governing the step bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as the step bearing pumps have proven after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings one just above the step, one between the turbine and generator, and the other near the top.

These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a consequence, therefore, the clearances are reduced to the minimum.

The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades bolted to the inner walls of the cylinder or casing.

The governing of speed is accomplished in the first set of nozzles and the control of the admission valves here is effected by means of a centrifugal governor attached to the top end of the shaft. Th

FIG. 2,759.—Illustration of a weir. To make a weir, place a board across the stre

Speed regulation is effected by varying the number of nozzles in flow, that is, for light loads fewer nozzles are open and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges against the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

WEIR TABLE

cubic feet of water per minute that will flow over a weir one inch wide and from 1/8 to 20 7/8 inches deep.

		1/8	1/4	3/8	1/2	5/8	3/4	7/8
	.00	.01	.05	.09	.14	.19	.26	.32
	.40	.47	.55	.64	.73	.82	.92	1.02
	1.13	1.23	1.35	1.36	1.58	1.70	1.82	1.95
	2.07	2.21	2.34	2.48	2.61	2.76	2.90	3.05
	3.20	3.35	3.50	3.66	3.81	3.97	4.14	4.30
	4.47	4.64	4.81	4.98	5.15	5.33	5.51	5.69
	5.87	6.06	6.25	6.44	6.62	6.82	7.01	7.21
	7.40	7.60	7.80	8.01	8.21	8.42	8.63	8.83
	9.05	9.26	9.47	9.69	9.91	10.13	10.35	10.57
	10.80	11.02	11.25	11.48	11.71	11.94	12.17	12.41
	12.64	12.88	13.12	13.36	13.60	13.85	14.09	14.34
	14.59	14.84	15.09	15.34	15.59	15.85	16.11	16.36
	16.62	16.88	17.15	17.41	17.67	17.94	18.21	18.47
	18.74	19.01	19.29	19.56	19.84	20.11	20.39	20.67
	20.95	21.23	21.51	21.80	22.08	22.37	22.65	22.94
	23.23	23.52	23.82	24.11	24.40	24.70	25.00	25.30
	25.60	25.90	26.20	26.50	26.80	27.11	27.42	27.72
17	28.03	28.34	28.65	28.97	29.28	29.59	29.91	30.22
18	30.54	30.86	31.18	31.50	31.82	32.15	32.47	32.80
19	33.12	33.45	33.78	34.11	34.44	34.77	35.10	35.44
20	35.77	36.11	36.45	36.78	37.12	37.46	37.80	38.15

NOTE.—The weir table on this page contains figures 1, 2, 3, etc., in the first vertical **mn which indicates the inches depth** of water running over weir board notches. Frequently **lepths measured represent** also fractional inches, between 1 and 2, 2 and 3, etc. The hori- **al line of fraction** at the top represents these fractional parts, and can be applied between **of the numbers** of inches depth, from 1 to 25. The body of the table shows the cubic feet, **the fractional** *parts of a cubic foot,* which will pass each minute for each inch in depth, ***or each fractional part of an inch*** *by eighths* for all depths from 1 to 25 inches. Each of these ***s is for only one inch*** *width of weir.* To estimate for any width of weir the result obtained ***inch width must be multiplied*** *by* the number of inches constituting the whole horizontal ***of weir.***

FIGS. 2,760 and 2,761.—Samson vertical runner and shaft, and complete Samson vertical turbine. The runner is composed of two separate and distinct types of wheel, having thereby also two diameters. Each wheel or set of buckets receives its separate quantity of water from one and the same set of guides, but each set acts only once and singly upon the water used, and the water does not act twice upon the combined wheel, as some suppose. **In construction**, the lower or main set of buckets is made of flanged plate steel, and cast solidly into a heavy ring surrounding the outer and lower edges, and into a heavy diaphragm, separating the two sets of buckets.

ater discharging from a needle nozzle due to a pressure of 169 lbs. per sq. in.

Electric Plants.—The economy with which elec-
be transmitted long distances by high tension alterna-
its, has led to the development of a large number of
rers in more or less remote regions.

otograph of an operating tangential water wheel equipped with Pelton

This economy is possible by the facility with which alterna can be transformed up and down. Thus at the hydro-electr current generated by the water wheel driven alternator is t to very high pressure and transmitted with economy a long the distributing point where it is transformed down to the j sure for distribution.

A water wheel or turbine is a machine in which a rotar obtained by transference of the momentum of water; broadl the fluid is guic blades, attach casing, and im other blades m drum or shaft, latter to revolv

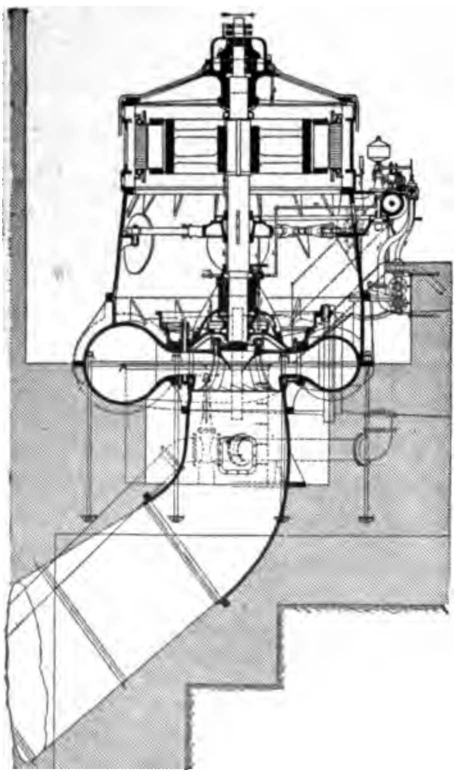


FIG. 2,764.—Sectional elevation of one of the 5,000 horse power vertical Pelton-Francis turbines direct connected to generator, as installed for the Schenectady Power Co.

There are t classes of turbir

1. Impulse tu
2. Reaction t

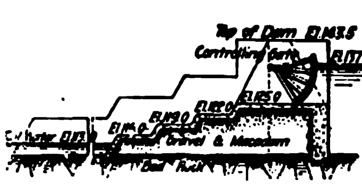
Ques. Wh impulse turb

Ans. One the fluid is di means of a seri zles against va it drives.

Ques. Wh reaction turb

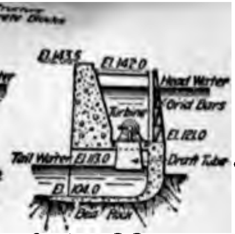
Ans. One the pressure o the water is rather than its The current is upon the whee action of suit posed guide bl

... teen Samson turbines: The section C-D gives an end view of the generator room showing the locations of the generators below the head level water. They are secure against flood water, or leakage, by well constructed stuffing boxes in the iron bulkheads, through which the



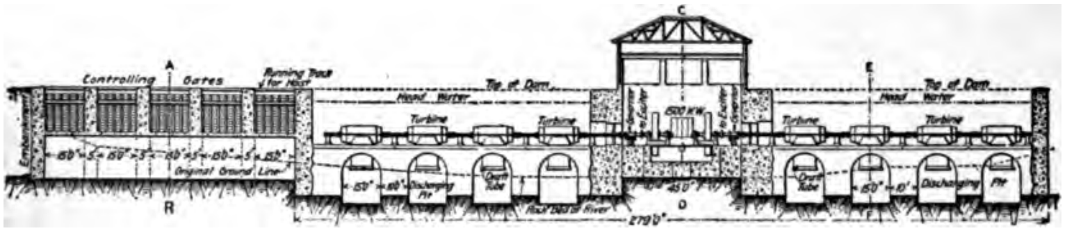
Section A-B.

Section C-D.



Section E-F.

turbine wheel shafts pass and connect to the generators. Section E-F gives an end view of one of these wheel rooms or penstocks, and shows the extension of the draft tube from wheel case into tail water. The section A-B shows the sub-structure of gravel and macadam under the controlling gates, this forming also a portion or extension of the dam proper. These gates turn on



an axis made of two 15 inch I beams securely riveted together with plates and angle irons to which the wooden frame is attached. The radius of the gates is 14 feet. They are designed to allow the water to pass underneath the gate, thus controlling any height of head water. They are intended to take care of an excess of water at unusual stages of the river. The whole affair has been well designed and executed. This plant furnishes a good example of a secure, and level foundation, since the wheel houses and generator room are immediately on the rock. It is necessary in all tandem plants to provide a very secure, substantial super-structure so that the long line of turbines and shaft will always remain straight and in proper alignment with the generator and the turbine cases. Users cannot be reminded of this too often.

passages being full of water. Rotary motion is obt
change in the direction and momentum of the fluid

Ques. Name three classes of reaction turbi

Ans. Parallel flow, inward flow, and outward fl

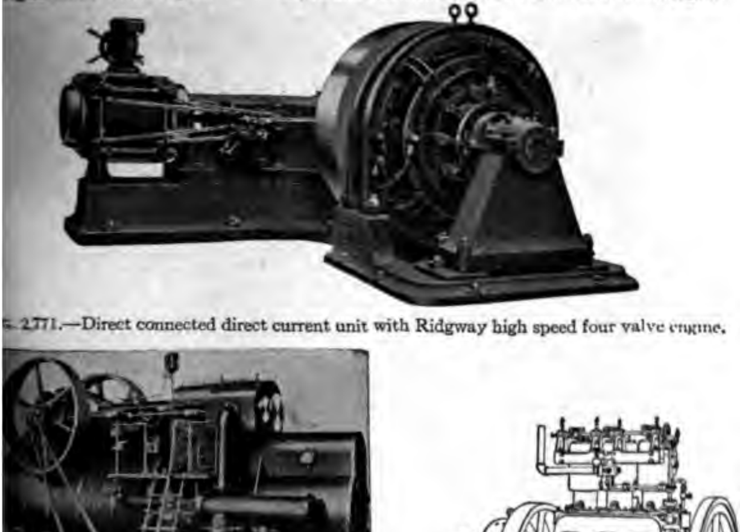
Parallel flow turbines have an efficiency of about 70%
for low falls not over 30 feet. Inward and outward flow t
efficiency of about 85%. Impulse turbines are suitable

Figs. 2,769 and 2,770.—Exterior and interior of hydro-electric plant at Har
located on the south fork of the Shenandoah River, twelve and one-
A dam 720 feet long and 15 feet high was built on a limestone ledge
river; which with a fall of 5 feet from the dam to the power house, a
distant, secured an effective head pressure of 20 feet. The power hous
generator room and the wheel room, also the machinery room, are here s
room, which is 20 × 40 feet, extends across the head race, and rests u
walls, forming the sides and ends of the wheel pits. The end wall is
bottom, and 4½ feet at the top. It has three arched openings, each 8 fe
high, through which the water escapes after leaving the turbines.
tected by a wrought iron rack 40 feet long. The power is obtained by thr
shaft Samson turbines, with a 20 inch Samson for an exciter. The th
have a rating of 1,350 horse power; and are connected to the main hori
bevel mortise gears 7 feet diameter and 15 inches face. The couplings
have 48 inch friction clutch hubs, permitting either or each turbine
shut down independently of the others. The main shaft is 85 feet long a
eter; making 280 revolutions. This shaft carries two pulleys 70 inches
inches face for driving the generators. The accompanying illustration
work, gears, pulleys, etc., furnished with the turbines. The 20 inch
Samson turbine of 72 horse power is direct connected to an exciter ge
running 700 rev. per min. The two large generators are driven 450 revol
by belts producing a three phase current of 60 cycles of 11,500 volts f
one-half miles transmission. The line consists of three strands of No. 4
This current is used for lighting and power purposes, and the plant is
proved design and construction.

Isolated Plants.—When electric power transn
central stations first came into commercial use,
from the station at which current could be obtained
able cost was exceedingly limited.

2,769.—Triumph direct rent generator set with right slide valve engine.

FIG. 2,770.—Murray alternating current direct connected unit with high speed Corliss engine and belt driven exciter. 50, 75 and 100 kva. alternator and 150 R.P.M. engine.



. 2,771.—Direct connected direct current unit with Ridgway high speed four valve engine.

IG. 2,772.—Buckeye mobile, or self contained unit consisting of compound condensing engine, boiler, superheater, reheater, feed and air pumps; it produces one horse power on 1½ lbs. of coal, built in sizes from 75 to 600 horse power.

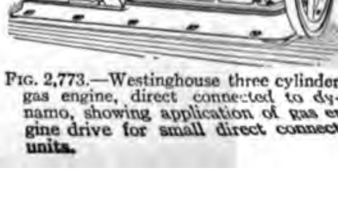


FIG. 2,773.—Westinghouse three cylinder gas engine, direct connected to dynamo, showing application of gas engine drive for small direct connected units.

Consequently, persons desiring electrical power were in the majori of cases forced to install their own apparatus for producing it, this bei the origin of isolated plants.

From the nature of the case it is evident that an isolated plant is a rule smaller and more simple in construction than a central station, and consequence much more readily operated and managed. It is genera owned by a private individual or a corporation and operated in conju tion with other affairs of a similar character. A basement or ot portion of a building is usually set aside in which the necessary appara is installed.

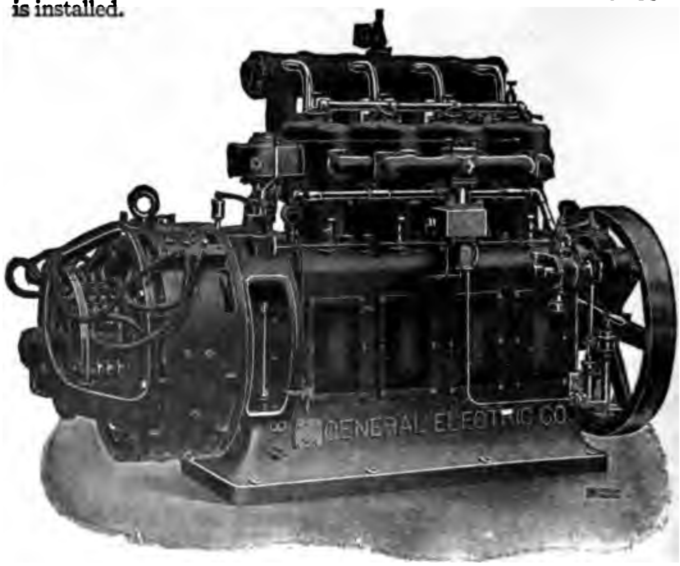
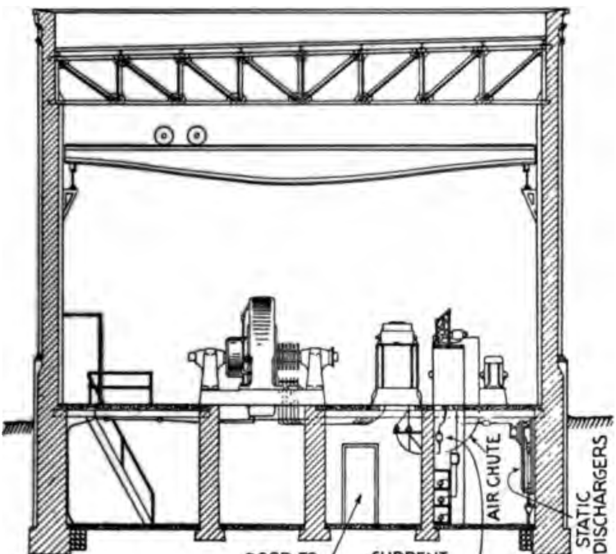


FIG. 2,774.—General Electric 25 kw., gasoline electric generating set for lighting and pow The engine has four cylinders 7¼ × 7½, and runs at a speed of 560 revolutions per min The total candle power capactiy in Mazda lamps is 20,000. The ignition is by low tens magneto, coil and battery. Carburetter is of the constant level type to which gaso is delivered by a pump driven by the engine. Forced lubrication; five crank shaft beari babbitted; valves in side; overall dimensions 96 × 34 × 60 high; weight 5,000.

Although electricity is now transmitted economically to great distan from central stations, there is still a field for the isolated plant.

The average type of isolated plant has enlarged from a small dyna driven by a little slide valve engine located in an out of the way corn to direct connected generators and engines of hundreds and even t sands of horse power assembled in a large room specially adapted purpose.

In the more modern of these, the electrical outputs are each frequently equal to that of a town central station of respectable size, and the auxiliary equipments are similar in every particular. As a matter of fact, in certain modern isolated plants the only feature that distinguishes them from central stations is that in the former case the owner of the plant represents the sole consumer and conducts other business in connection with it, whereas in the latter case there are a large number of consumers uninterested financially in the enterprise, which is itself generally owned and operated by a company conducting no other business.



. 2,775.—Plan of sub-station with air blast transformers and motor operated oil switches and underground 11,000 or 13,200 volt high tension lines.

Sub-Stations.—According to the usual meaning of the m, a sub-station is a building provided with apparatus for anging high pressure alternating current received from the ntral station into direct current of the requisite pressure, h in the case of railways is 550 to 600 volts.

here traffic is heavy and the railway system of considerab

[redacted]

distance, sub-stations are provided at intervals along the line, each receiving high pressure current from one large central station and converting it into moderate pressure direct current for their districts.

Ques. Upon what does the arrangement of the sub-station depend?

Ans. Upon the character of the work and the type of ap-

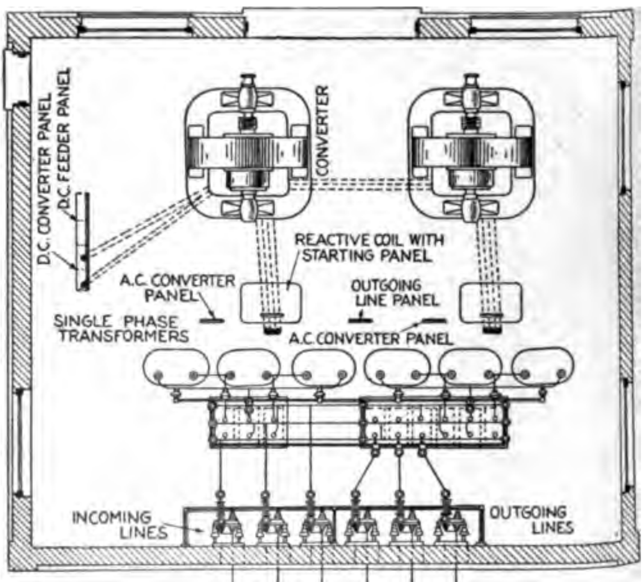


FIG. 2,776.—Plan of small sub-station with single phase oil insulated self-cooling transformers and hand operated oil switches 11,000 or 13,200 volts, overhead high tension lines.

paratus employed for converting the high pressure alternating current into direct current.

In general it should be substantial, convenient to install or replace the heavy machines, and the layout arranged so that the apparatus can be readily operated by those in attendance.

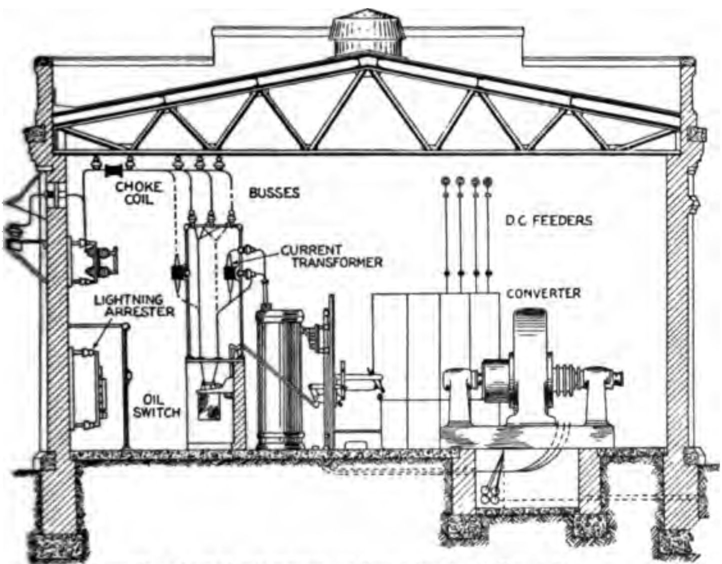
[redacted]

An overhead traveling crane is the most convenient method of handling the heavy machinery, and is frequently used in large sub-stations.

Fig. 2,776 shows a sectional view, and fig. 2,777, a plan for a small sub-station containing two rotary converters and two banks of three single phase static transformer operating on a three phase system at 11,000 or 13,200 volts, together with the auxiliary apparatus.

Ques. For three phase installations, what are the erits of separate and combined transformers?

Ans. With separate transformer for each phase, repairs are



2,777.—Elevation of small sub-station, as shown in plan in Fig. 2,776.

re readily made in case of accident or burnouts in the coils. e three phase units have the advantage of low first cost.

Sub-station transformers produce considerable heat, due to the hysteresis and eddy currents, and it is necessary to get rid of it.

Small *transformers radiate* the heat from the shell and the medium *sizes have corrugated shells* which increase the surface and provid *more rapid radiation.*

Ques. State the effect of strengthening converter fiel

Ans. A leading current is set up which gives a rise of volta in the reactance coil.

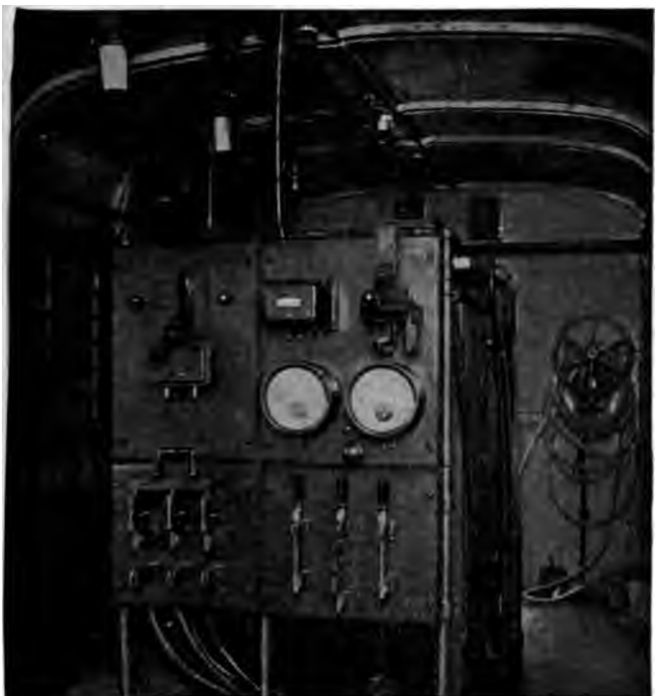
Hence when a heavy current passes through the series coil of a co pound wound converter and tends to produce a leading current, the rea ance coil will balance it, and improve the power factor of the whole li

FIG. 2,780.—Westinghouse 300 kw. converter in portable sub-station.

Portable Sub-Stations.—A portable sub-station constitut a spare equipment for practically any number of permane *sub-stations* and renders unnecessary the installation of spa equipment in each.

It can be used to increase the capacity of a permanent sub-station when the load is unusually heavy, or to provide service while a permanent sub-station is being overhauled or rebuilt.

The transformer can be used for emergency lighting, the primary being connected to a high pressure line and the secondary to the load, if special provision be made at the time the transformer is built to adapt it for these applications.



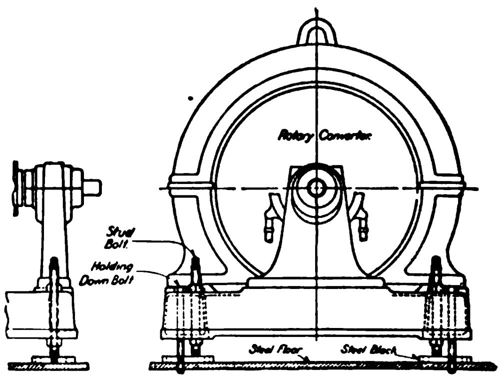
G. 2,781.—Switchboard end of Westinghouse portable sub-station.

When an electric railway has a portable sub-station, direct current can be provided at any point on the system where there is track at the high pressure line. The direct current can be made available very quickly as its production involves only the

transferring of the sub-station, and its connection to t pressure line.

Portable sub-stations range in capacity from 200 to 500 kw all alternating current voltages up to 66,000, and frequen and 60 cycles.

Although portable sub-stations usually must be of more or l design to adapt them to the conditions under which they mu there are certain general features that are common to all. All are readily accessible and there are no unnecessary parts. T and dimensions are a minimum insuring ease of transportati parts are so protected that the danger of accidental contact is minimized.



FIGS. 2,782 and 2,783.—Views of levelling device for Westinghouse converter.

Ques. What are the advantages of using transformers on portable sub-stations?

Ans. All high pressure wiring is kept out of the ca transformer is more effectively cooled and the heat di by the transformer does not warm the interior of the ca transformer is much more accessible. The car can be ru a crane and the transformer coils pulled out with a hoist.

Taps for different high and low pressure voltages can be re vided at the time the transformer is being built.

CHAPTER LXVII

MANAGEMENT

The term "management," broadly speaking, includes not only : actual skilled attention necessary for the proper operation the machines, after the plant is built, but also other duties ich must be performed from its inception to completion, and ich may be classified as

1. Selection;
2. Location;
3. Erection;
4. Testing;
5. Running;
6. Care;
7. Repair.

That is to say, someone must select the machinery, determine ere each machine is to be located, install them, and then tend to the running of the machines and make any necessary pairs due to the ordinary mishaps likely to occur in operation.

These various duties are usually entrusted to more than one dividual; thus, the selection and location of the machinery is ne by the designer of the plant, and requires for its proper ecution the services of an electrical engineer, or one possessing re *than simply a practical* knowledge of power plants.

The erection of the machines is best accomplished by those making a specialty of this line of work, who by the nature of the undertaking acquire proficiency in methods of precision and an appreciation of the value of accuracy which is so essential in the work of aligning the machines, and which if poorly done will prove a constant source of annoyance afterward.

The attention required for the operation of the machines embracing the running care and repair, is left to the "man in charge," who in most cases of small and medium size plants is the chief steam engineer. He must therefore, not only understand the steam apparatus, but possess sufficient knowledge of electrical machinery to operate and maintain it in working order.

The present chapter deals chiefly with alternating current machinery, the management of direct current machines having been fully explained in Guide No. 3, however, some of the matter here presented is common to both classes of apparatus.

Selection.—In order to intelligently select a machine so that it will properly harmonize with the conditions under which it is to operate, there are several things to be considered.

1. Type;
2. Capacity;
3. Efficiency;
4. Construction.

The general type of machine to be used is, of course, dependent on the system employed, that is, whether it be direct or alternating, single or polyphase.

Thus, the voltage in most cases is fixed except on transformer systems where a choice of voltage may be had by selecting a transformer to suit.

In alternating current constant pressure transmission circuits, an average voltage of 2,200 volts with step down transformer ratios of $\frac{1}{10}$ and $\frac{1}{20}$ is in general use, and is recommended.

For long distance, the following average voltages are recommended 6,000; 11,000; 22,000; 33,000; 44,000; 66,000; 88,000; and higher, depending on the length of the line and degree of economy desired.

In alternating circuits the standard frequencies are 25, and 60 cycles. These frequencies are already in extensive use and it is recommended to adhere to them as closely as possible.

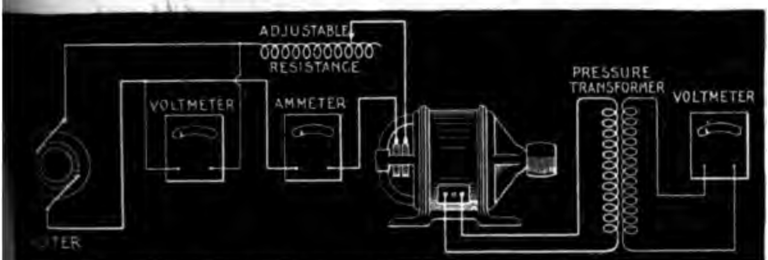


FIG. 2,784.—Diagram of connections for testing to obtain the saturation curve of an alternator. The saturation curve shows the relation between the volts generated in the armature and the amperes of field current (or ampere turns of the field) for a constant armature current. The armature current may be zero, in which case the curve is called *no load saturation curve*, or sometimes the *open circuit characteristic curve*. A saturation curve may be taken with full load current in the armature; but this is rarely done, except in alternators of comparatively small output. If a full load saturation curve be desired, it can be approximately calculated from the no load saturation curve. The figure shows the connections. If the voltage generated is greater than the capacity of the voltmeter, a multiplying coil or a step down pressure transformer may be used, as shown. A series of observations of the voltage between the terminals of one of the phases, is made for different values of the field current. Eight or nine points along the curve are usually sufficient, the series extending from zero to about fifty per cent. above normal rated voltage. The points should be taken more closely together in the vicinity of normal voltage than at other portions of the curve. Care must be taken that the alternator is run at its rated speed, and this speed must be kept constant. Deviations from constant speed may be most easily detected by the use of a tachometer. If the machine be two phase or three phase, the voltmeter may be connected to any one phase throughout a complete series of observations. The voltage of all the phases should be observed for normal full load excitation by connecting the voltmeter to each phase successively, keeping the field current constant at normal voltage. This is done in order to see how closely the voltage of the different phases agree.

In fixing the capacity of a machine, *careful consideration should be given to the conditions of operation both* **present** *and* **future** in order that the resultant efficiency may be maximum.

Most machines show the best efficiency at or near full load. If the *load be always constant*, as for instance, a pump forcing water to a

given head, it would be a simple matter to specify the proper machine, but in nearly all cases, and especially in electrical plai load varies widely, not only the daily and hourly fluctuations, varying demands depending on the season of the year and gr the plant's business. All of these conditions tend to complic matter, so that intelligent selection of capacity of a machine not only calculation but mature judgment, which is only obtai long experience.

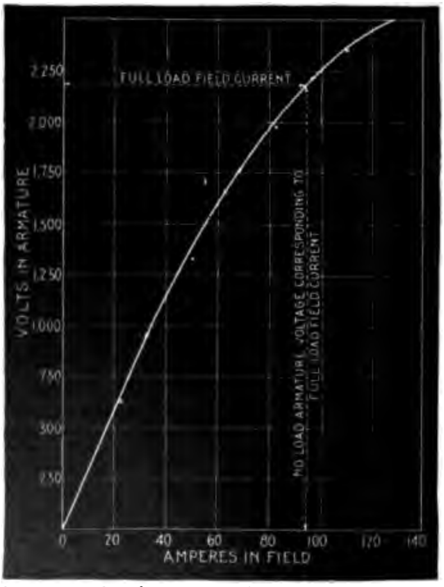


Fig. 2,785.—Saturation curve taken from a 2,000 kw., three phase alternator of the field type, having 16 poles, and generating 2,000 volts, and 576 amperes per ph run at 300 R.P.M.

In selecting a machine, or in fact any item connectec the plant *its construction should be carefully considered.*

Standard construction should be insisted upon so that in the of damage a new part can be obtained with the least possible de

The parts of most machines are interchangeable, that is to sa the refined methods of machinery a duplicate part (usually ca stock) may be obtained at once to replace a defective or bro and made with such precision that little or no fitting will b importance of standard construction cannot be better ted than in the matter of steam piping, that is, the fittings selected for a given installation.

the exception of the exhaust line from engine to con- where other than standard construction may sometimes d to reduce the frictional resistance to the steam, the would adhere to standard construction except in very onal cases. Those who have had practical experience fitting will appreciate the wisdom of this.

installations in places remote from large supply houses, re usual forms of standard fittings should be employed, ordinary T's, 45° and 90° elbows, etc.

uch locations, where designers specify the less usual of standard fittings such as union fittings, offset s, etc., or special fittings made to sketch, it simply in the first instance that they usually cannot be d of the local dealer making it necessary to order some large supply house and resulting in vexatious

rule, those who specify special fittings have found that aking requires an unreasonable length of time and the be several times that of the equivalent in standard

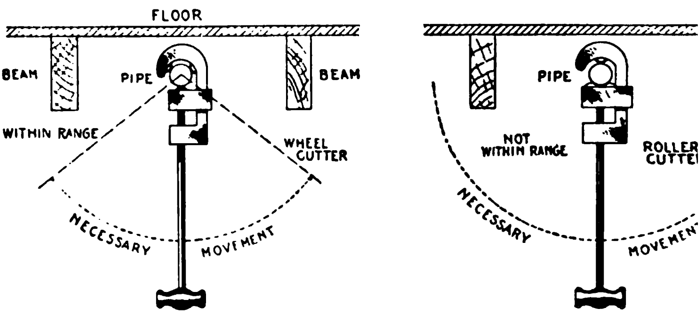
examination of a few installations will usually show us special and odd shape fittings which are entirely ssary.

over, a standard design is generally better than a design, because the pattern has been tried out and any [illegible] or weakness [illegible] and where thousands of of a kind are turned out a better article is usually as compared with a special casting.

In the matter of construction, in addition to the items mentioned, it should be considered with respect to

1. Quality;
2. Range;
3. Accessibility;
4. Proportion;
5. Lubrication;
6. Adjustment.

It is poor policy, excepting in very rare instances, to "cheap" article, as, especially in these days of commercial the best is none too good.



FIGS. 2,786 and 2,787.—Wheel and roller pipe cutters illustrating **range**. The ill show the comparative movements necessary with the two types of cutter to perf function. The wheel cutter requiring only a small arc of movement will cut a p inaccessible place as shown, which with a roller cutter would be impossible. Acc the wheel cutter is said to have a greater *range* than the roller cutter.

Perhaps next in importance to quality, at least in most is *range*. This may be defined as *scope of operation, effecti* or *adaptability*. The importance of range is perhaps mos nounced in the selection of tools, especially for plants r from repair shops.

For instance, in selecting a pipe cutter, there are two general wheel cutters, and roller cutters. A wheel cutter has three w a roller cutter one wheel and two rollers, the object of the r

[illegible]

[illegible]	Diameter, actual inside	Diameter, actual outside	[illegible]	Circumference, external	Circumference, internal	Transverse areas, external	Transverse areas, internal	Transverse areas, metal	Length of pipe per square foot of external surface	Length of pipe per square foot of internal surface	Length of pipe containing one cubic foot	Nominal weight per foot	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

The design should be such that there is ample strength, and th ings for moving parts should be of liberal proportions to avoid with minimum attention.

A comparison of the proportions used by different manufacture machine of given size might profitably be made before a selection i

The matter of lubrication is important.

Fast running machines, such as generators and motors, sh provided with ring oilers and oil reservoirs of ample capacity, as in figs. 2,788 to 2,794.

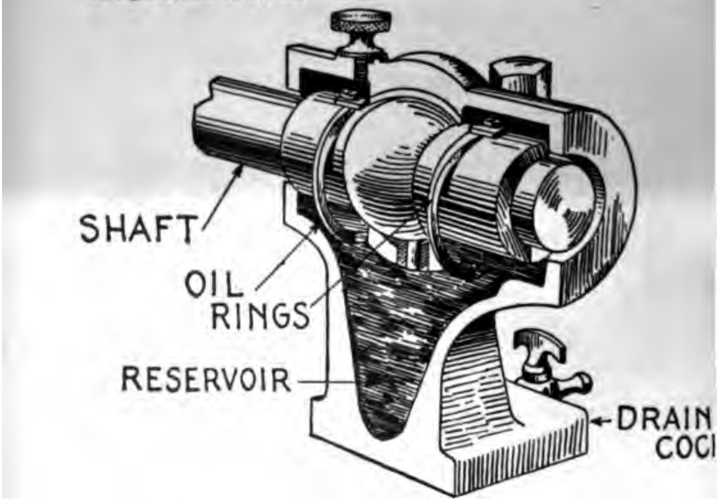
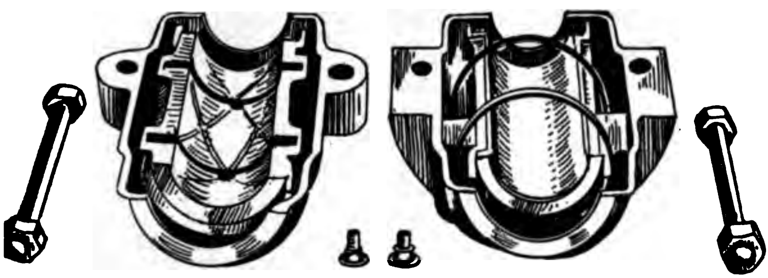


FIG. 2,788.—Sectional view showing a ring oiler or self oiling bearing. As shown th or bearing standard is cored out to form a reservoir for the oil. The rings are contact with the shaft, and dip at their lower part into the oil. In operation, oil is b by the rings which revolve because of the frictional contacts with the shaft. Th this way brought up to the top of the bearing and distributed along the shaft descending by gravity to the reservoir, being thus used over and over. A drai provided in the base so that the oil may be periodically removed from the rese strained to remove the accumulation of foreign matter. This should be freque to minimize the wear of the bearing.

All bearings subject to appreciable wear should be adjustable so that lost motion may be taken up from ti time and thus keep the vibration and noise of operation proper limits.

Selection of Generators.—This is governed by the class of work to be done and by certain local conditions which are liable to vary considerably for different stations.

These variable factors determine whether the generators must be of the direct or alternating current type, whether they must be wound to develop a high or a low voltage, and whether their outputs in amperes must be large or small. Sufficient information has already been given to cover these various cases; there are, however, certain general rules that may advantageously be observed in the selection of generators designed to fill any of the aforementioned conditions, and it is well to possess certain facts regarding their construction.



FIGS. 2,789 to 2,794.—Self oiling self aligning bearing open. Views showing oil grooves, rings, bolts etc.

Ques. Name an important point to be considered in selecting a generator.

Ans. Its efficiency.

Ques. What are the important points with respect to efficiency?

Ans. *A generator* possessing a high efficiency at the average *load is more desirable* than a generator showing a high efficienc *full load.*

Ques. Why?

Ans. The reason is that in station practice the i limit is seldom reached, the usual load carried by a g ordinarily lying between the one-half and three-qua points.

Ques. How do the efficiencies of large an generators compare?

Ans. There is little difference.

FIG. 2,795.—Rotor of Westinghouse type T turbine dynamo set. The dynamo i mutating pole type either shunt or compound wound. The turbine is of th impulse type. The wheel is mounted directly on the end of the shaft as sho used two or more times on the wheel to secure efficiency. A fly ball goveın with weights hung on hardened steel knife edges. In case of over speeding. safety stop throttle valve is tapped shutting off the steam supply. This ty dynamo set is especially applicable for exciter service in modern, super generating stations where the steam pressure exceeds 125 pounds. Westingl turbines operate directly (that is, without a reducing valve) on pressures up t per square inch with steam superheated to 150 degrees Fahrenheit.

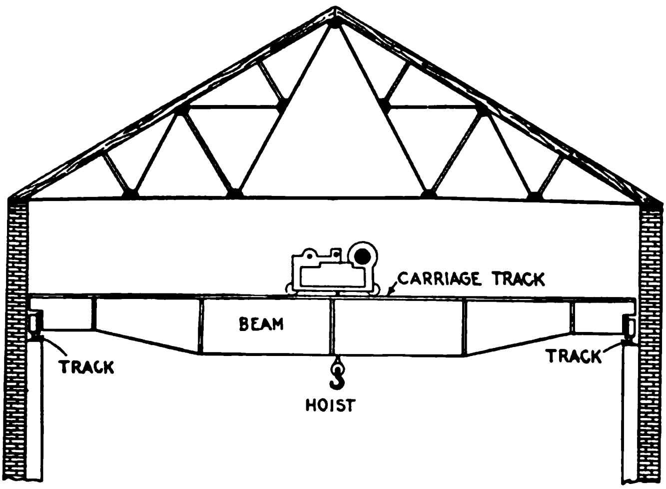
Ques. How are the sizes and number of g determined?

Ans. The sizes and number of generator to be *should* be such as to permit the engines operating th *worked* at nearly full load, because the efficiencies of machines decrease rapidly when carrying less than t

Ques. What is understood by regulation?

Ans. The accuracy and reliability with which the pressure or current developed in a machine may be controlled.

It is generally possible if purchasing of a reputable concern, to obtain access to record sheets on which may be found results of tests conducted on the generator in question, and as these are really the only means of ascertaining the values of efficiency and regulation, the purchaser has a right to inspect them. If, for some reason or other, he has not been afforded this privilege, he should order the machine installed in the station on approval, and test its efficiency and regulation before making the purchase.



'IG. 2,796.—Cross section of electrical station showing small traveling crane.

Installation.—The installation of machines and apparatus n an electrical station is a task which increases in difficulty rith the size of the plant. When the parts are small and com'aratively light they may readily be placed in position, either *y hand, by erecting* temporary supports which may be moved *m place to place* as desired, or by rolling the parts along c the floor upon pieces of iron pipe. If, however, the parts be large and heavy, a traveling crane such as shown in fig. 2,797, becomes necessary.

Ques. What precaution should be taken in moving the parts of machines?

Ans. Care should be taken not to injure the bearings and

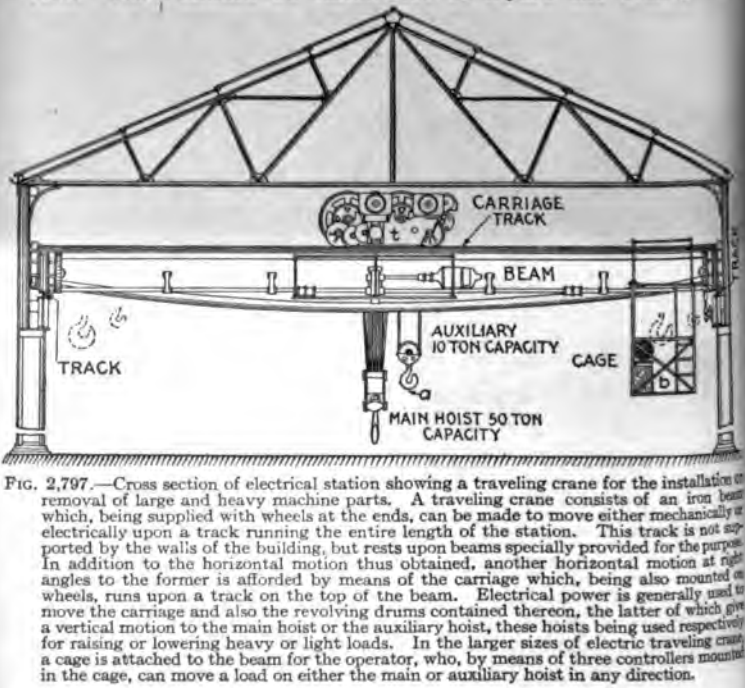


FIG. 2,797.—Cross section of electrical station showing a traveling crane for the installation or removal of large and heavy machine parts. A traveling crane consists of an iron beam which, being supplied with wheels at the ends, can be made to move either mechanically or electrically upon a track running the entire length of the station. This track is not supported by the walls of the building, but rests upon beams specially provided for the purpose. In addition to the horizontal motion thus obtained, another horizontal motion at right angles to the former is afforded by means of the carriage which, being also mounted on wheels, runs upon a track on the top of the beam. Electrical power is generally used to move the carriage and also the revolving drums contained thereon, the latter of which give a vertical motion to the main hoist or the auxiliary hoist, these hoists being used respectively for raising or lowering heavy or light loads. In the larger sizes of electric traveling cranes a cage is attached to the beam for the operator, who, by means of three controllers mounted in the cage, can move a load on either the main or auxiliary hoist in any direction.

shafts, the joints in magnetic circuits such as those between frame and pole pieces, and the windings on the field and armature.

The insulations of the windings are perhaps the most vital parts of a generator, and the most readily injured. The prick of a pin or tack, a bruise, or a bending of the wires by resting their weight upon them or by their coming in contact with some hard substance, will often render a field coil or an armature useless.

Owing to its costly construction, it is advisable when transporting armatures by means of cranes to use a wooden spreader, as shown in fig. 2,798 to prevent the supporting rope bruising the winding.

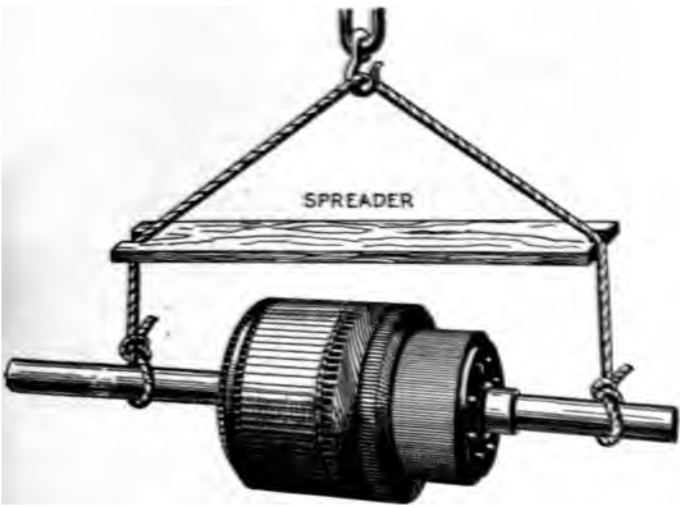


Fig. 2,798.—View of armature in transit showing use of a wooden spreader as a protection. If a chain be used in place of the rope, a padding of cloth should be placed around the armature shaft and special care taken that the chain does not scratch the commutator.

Ques. If an armature cannot be placed at once in its final position what should be done?

Ans. It may be laid temporarily upon the floor, if a sheet of cardboard or cloth be placed underneath the armature as a protection for the windings; in case the armature is not to be used for some time, it is better practice to place it in a horizontal position on two wooden supports near the shaft ends.

Ques. What kind of base should be used with ε driven generator or motor?

Ans. The base should be provided with V ways and adj screws for moving the machine horizontally to take up sl the belt, as shown in fig. 2,799.

Owing to the normal tension on the belt, there is a moment equal in amount to the distance from the center of gravity of

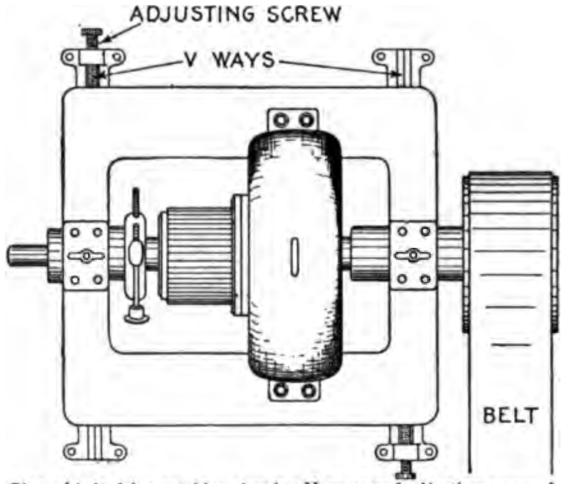


FIG. 2,799.—Plan of belt drive machine showing V ways and adjusting screws for m machine forward from the engine or counter shaft to take up slack in the belt.

chine to the center of the belt, multiplied by the effective pull belt. This force tends to turn the machine about its center of By placing the screws as shown, any turning moment, as ju tioned, is prevented.

Ques. How should a machine be assembled?

Ans. The assembling should progress by the aid of *print, or by* the information obtained from a photograph *complete* machine as it appears when ready for service. *part should* be perfectly clean when placed in position, [illegible]hose parts between which there is friction when the machine is in operation, or across which pass lines of magnetic force. In both cases the surfaces in contact must be true and slightly oiled before placing in position.

Contact surfaces forming part of electrical circuits must also be clean and tightly screwed together. An important point to bear in mind when assembling a machine is [illegible] that the parts that it will not be necessary to remove any one of them in order to get some other part in its proper position. By remembering this, much [illegible]

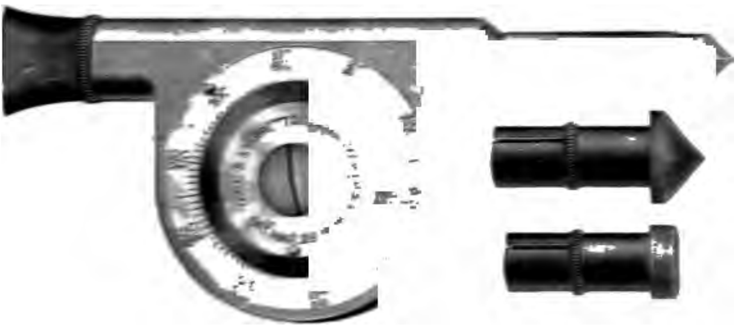


FIG. 2,502.—Starrett [illegible] speed indicator. [illegible]

[illegible]

Ques. What should be noted with respect to speed of generator?

Ans. Each generator [illegible]

in order to develop the voltage at which the machine is rated. The speed, in revolutions per minute, the pressure in volts, and the capacity or output in watts (volts × amperes) or in kilo-watts (thousands of watts) are generally stamped on a name-plate screwed to the machine.

This requirement frequently requires calculations to be made by the erectors to determine the proper size pulleys to employ to obtain the desired speed.

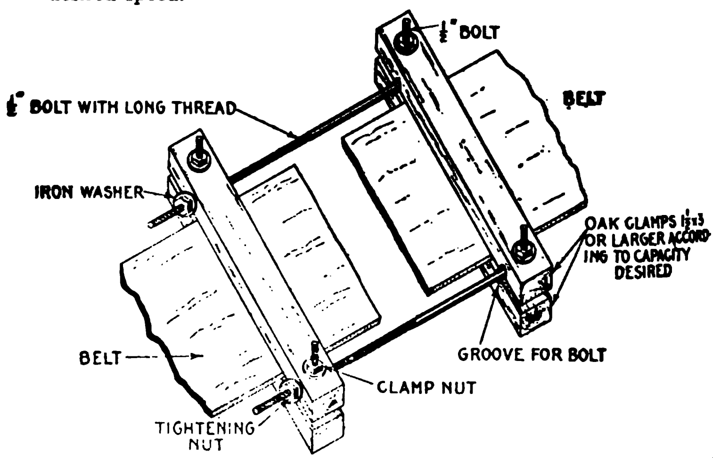


FIG. 2,803.—Home made belt clamp. It is made with four pieces of oak of ample size to firmly grip the belt ends where the bolts are tightened. The figure shows the clamp complete and in position on the belt and clearly illustrates the details of construction. In making the long bolts the thread should be cut about three-quarter length of bolt and deep enough so that the nuts will easily screw on.

Example.—What diameter of engine pulley is required to run a dynamo at a speed of 1,450 revolutions per minute the dynamo pulley being 10 inches in diameter and the speed of engine, 275 revolutions per minute?

The diameter of pulley required on engine is

$$10 \times \frac{1,450}{275} = 53 \text{ inches, nearly.}$$

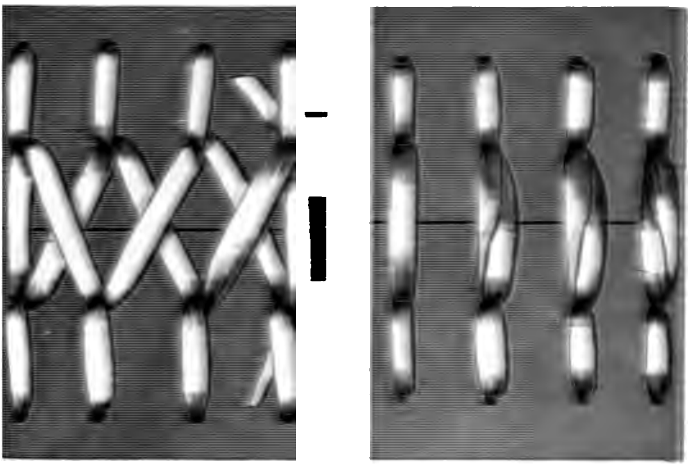
Rule.—To find the diameter of the driving pulley, *multiply the speed of the driven pulley by its diameter, divide the product by the speed of the driver and the answer will be the size of the driver required.*

Example.—If the speed of an engine be 325 revolutions per minute, diameter of engine pulley 42 inches, and the speed of the dynamo 1,400 revolutions per minute, how large a pulley is required on dynamo?

The size of the dynamo pulley is

$$42 \times \frac{325}{1{,}400} = 9\frac{3}{4} \text{ inches}$$

Rule.—*To find the size of dynamo pulley, multiply the speed of engine by the diameter of engine wheel and divide the product by the speed of the dynamo.*



2,844 and 2,845.—A good method of lacing a belt. The view at the left shows outer side of belt, and at the right, inner or pulley side.

Example.—If a steam engine running 300 revolutions per minute, have a belt wheel 48 inches in diameter, and be belted to a dynamo having a pulley 12 inches in diameter, how many revolutions per minute will the dynamo make?

The speed of dynamo will be

$$300 \times \frac{48}{12} = 1{,}200 \text{ rev. per min.}$$

Rule.—When the speed of the driving pulley and its diameter are known, *and the diameter of the driven pulley is known, the speed of the driven pulley is found by multiplying the speed of the driver by its diameter in inches and dividing the product by the diameter of the driven pulley.*

Example.—What will be the required speed of an engine ha belt wheel 46 inches in diameter to run a dynamo 1,500 revol per minute, the dynamo pulley being 11 inches in diameter?

The speed of the engine is

$$1{,}500 \times \frac{11}{46} = 359 \text{ rev. per min. nearly.}$$

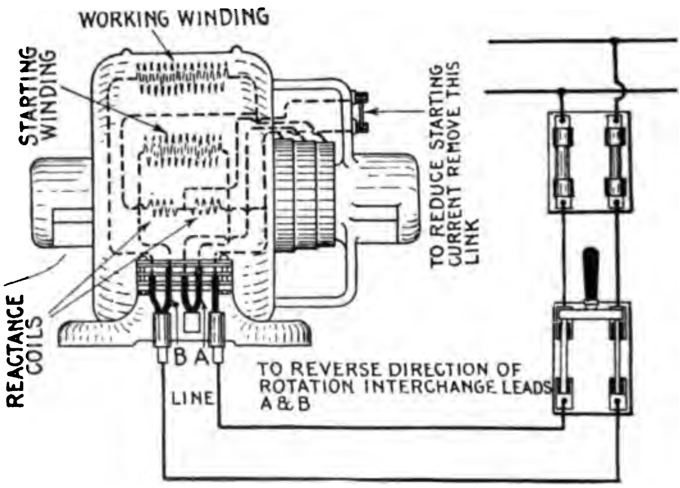
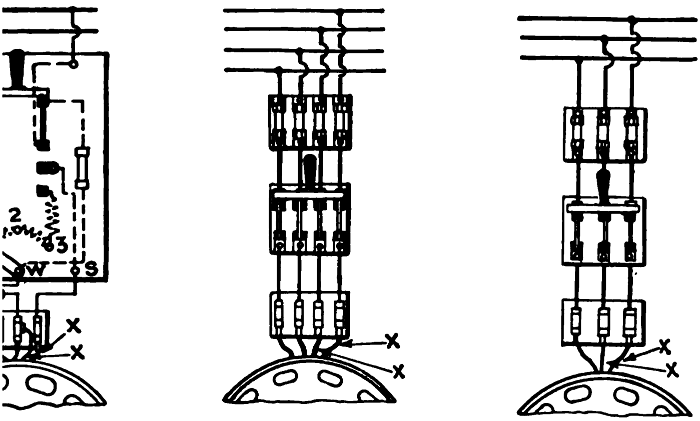


FIG. 2,806.—Wiring diagram and directions for operating Holzer-Cabot single ph starting motor. **Location:** The motor should be placed in as clear and dry a lo possible, away from acid or other fumes which would attack the metal parts or in and should be located where it is easily accessible for cleaning and oiling. **Erectio**: motor should be set so that the shaft is level and parallel with the shaft it is to that the belt will run in the middle of the pulleys. Do not use a belt which is t or too tight for the work it has to do, as it will materially reduce the output of th The belt should be from one-half to one inch narrower than the pulley. **Rotati** order to reverse the direction of rotation, interchange leads A and B. **Suspended** Motors with ring oil bearings may be used on the wall or ceiling by taking off end revolving 90 or 180 degrees until the oil wells come directly below the bearings. S Motors are provided with link across two terminals on the upper right hand br the front of the motor and with this connection should start considerable overl the starting current be too great with this connection, it may be reduced by r the link. **Temperatures:** At full load the motor will feel hot to the hand, bu far below the danger point. If too hot for touch, measure temperature with a ther by placing bulb against field winding for 10 minutes, covering thermometer with waste. The temperature should not exceed 75 degrees Fahr. above the surroun **Oiling:** Fill the oil wells to the overflow before starting and keep them full. the oil rings turn freely with shaft. **Care:** The motor must be kept clean. collector rings with sandpaper and see that the brushes make good cont brushes become worn they may be reversed. When fitting new brushes or ch always sandpaper them down until they make good contact with the colle passing a strip of sandpaper beneath the brush.

Rule.—To find the speed of engine when diameter of both pulleys, ıd speed of dynamo are given, *multiply the dynamo speed by the diamer of its pulley and divide by the diameter of engine pulley.*

:s. How are the diameters and speeds of gear wheels d?

The same as belted wheels, using either the pitch circle :ers or number of teeth in each gear wheel.



.E PHASE TWO PHASE THREE PHASE

:07 to 2,809.—Wiring diagrams and directions for operating Holzer-Cabot slow l alternating current motors. **Erecting**: In installing the motor, be sure the transer and wiring to the motor are large enough to permit the proper voltage at the inals. If too small, the voltage will drop and reduce the capacity of the motor. ıg: Maintain oil in wells to the overflow. **Starting**: **Single phase** motors are ed by first throwing the starting switch down into the starting position, and when the r is up to speed, throwing it up into the running position. *Do not hold the switch in ng position over 10 seconds.* Starter for single phase motors above ½ H.P. are ıged with an adjusting link at the bottom of the panel. The link is shown in the ion of least starting torque and current. Connect from W to 2 or W to 3 for starteavier loads. *Two or three phase* motors are started simply by closing the switch. e motors start full load without starters. The motor should start promptly on ıg the switch. It should be started the first time without being coupled to the line . If the motor start free, but will not start loaded, it shows either that the load the motor is too great, the line voltage too low, or the frequency too high. The ge and frequency with the motor running should be within 5% of the name plate g and the voltage with 10 to 15% while starting. If the motor do not start free, r it is getting no current or something is wrong with the motor. In either case an ician *should be consulted.* **Solution**: To reverse the direction of rotation inter*ge the leads marked "XX" in* the diagrams. **Temperature**: At full load the motor *l not heat over 75 degrees Fahr.* above the temperature of the surrounding air. *a small enclosed space* with no ventilation, the temperature will be somewh

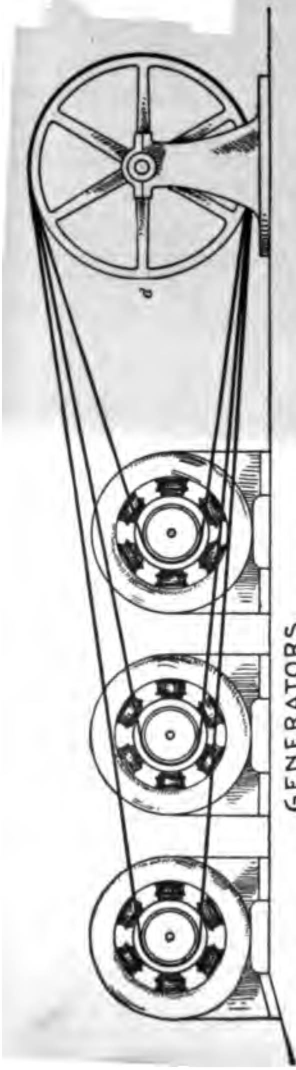


FIG. 2,810.—Tandem drive for economizing floor space with belt transmission. Belts of [illegible] hs are used, as shown, each of which passes over the driving wheel *d* of the engine, and then over the [illegible] of the generators. In such an arrangement the belts would be run lengthwise through the room in whic[illegible] laced, and it is obvious that since the width of the room would be governed by the width of the mac[illegible] this method is a very efficient one for accomplishing the end in view.

Ques. What should be noted with respect to generator pulleys?

Ans. A pulley of certain size is usually supplied with each generator by its manu-cturer, and it is not gener-ly advisable to depart much om the dimensions of this ulley. Accordingly, the so-ution of the pulley problem sually consists in finding the ecessary diameter of the riving pulley relative to that of the pulley on the generator in order to furnish the required speed.

Ques. What is the chi[illegible] objection to belt drive?

Ans. The large amount floor space required.

Ques. How may t[illegible] amount of space th[illegible] would ordinarily be [illegible]quired for belt drive, reduced?

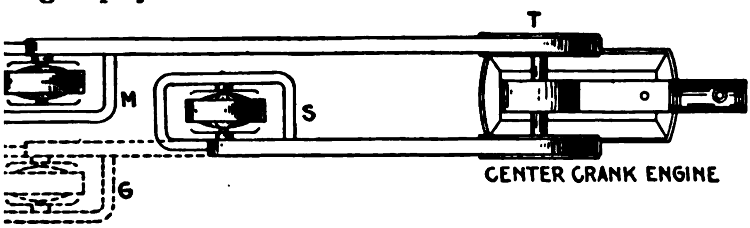
Ans. By driving mach[illegible] in tandem as in fig. 2,810 by the double pulley driv[illegible] in fig. 2,811.

Ques. What is the objection to the tandem method?

Ans. The most economical distance between centers cannot employed for all machines.

Ques. What is the objectionable tendency in resorting floor economy methods with belt transmission?

Ans. The tendency to place the machines too closely together. is is poor economy as it makes the cleaning of the machines lifficult and dangerous task; it is therefore advisable to allow ficient room for this purpose regardless of the method of lting employed.



. 2,811.—Double pulley drive for economizing floor space with belt transmission. Where a center crank engine is used both pulleys may be employed by belting a machine to each as shown. Although considerable floor space would be saved by the use of this scheme if the generators thus belted were placed at M and G yet still more floor space would be saved by having them occupy the positions indicated at M and S.

Ques. What is the approved location for an alternator citer?

Ans. To economize floor space the exciter may be placed tween the alternator and engine at S in fig. 2,811.

Belts.—In the selection of a belt, the quality of the leather ould be first under consideration. The leather must be firm, t pliable, free from wrinkles on the grain or hair side, and of *even thickness throughout.*

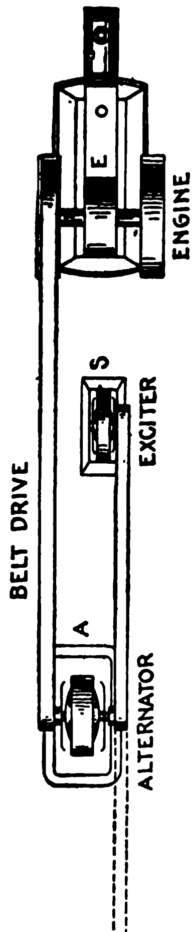


FIG. 2,812.—Separately excited belt driven alternator showing approved location of exciter. In an electrical station where alternating current is generated, the alternators for producing the current generally require separate excitation for their field windings; that is, it is usually necessary to install in conjunction with an alternator a small dynamo for supplying current to the alternator field. The exciter is a comparatively small machine; in fact, it requires only about 1 per cent. of the capacity of the alternator which it excites, and so being small is often belted to an auxiliary pulley mounted on the alternator shaft. Considerable floor space would be occupied by an installation of this nature if the exciter be placed at M, and belted to the alternator as indicated by the dotted lines. By locating the exciter at S, between the alternator and the engine, much floor space will be saved and the general appearance of the installation improved.

If the belt be well sele
properly handled, it shoul
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then if the worn part b
the remaining portion m
made and used again as a
and shorter belt.

Besides leather belts, the
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In addition to leather
belts, there are belts comp
ton, of a combination of
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however, is the standard s
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Equally important with
ity of a belt is its size in
transmit the necessary pc

The average strain unde
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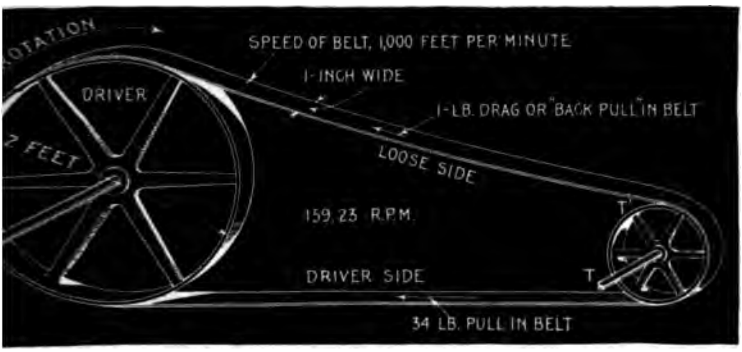
many experiments to be 3,
per square inch of cross
good quality of leather wi
somewhat greater strain.
the pulleys, belts should
jected to a greater strain
eleventh their tensile streng
290 pounds to the square i
section. This will be abo
average strain for every
of single belt three-
thick. The strain

widths of belting—single, light double, and heavy double—is in direct proportion to the thickness of the belt.

Ques. How much horse power will a belt transmit?

Ins. The capacity of a belt depends on, its width, speed, thickness. *A single belt one inch wide and travelling* 1,000 *per minute will transmit one horse power; a double belt under ame conditions, will transmit two horse power.*



2,813.—One horse power transmitted by belt to illustrate the rule given above. A pulley s driven by a belt by means of the friction between the surfaces in contact. Let T be he tension on the driving side of the belt, and T', the tension on the loose side; then the riving force $=T-T'$. In the figure T is taken at 34 lbs. and T' at 1 lb.; hence driving orce $=34-1=33$ lbs. Since the belt is travelling at a velocity of 1,000 feet per minute he power transmitted $=33$ lbs. $\times 1{,}000$ ft. $=33{,}000$ ft. lbs. per minute $=1$ horse power.

This corresponds to a working pull of 33 and 66 lbs. per inch of width respectively.

Example.—What width double belt will be required to transmit 50 horse power travelling at a speed of 3,000 feet per minute?

The horse power transmitted by each inch width of double belt travelling at the stated speed is

$$\left(1\times\frac{3{,}000}{1{,}000}\right)\times 2=6,$$

ce the width of belt required to transmit 50 horse power is

$$50\div 6=8.33, \text{ say 8 inches.}$$

Ques. At what velocity should a belt be run?

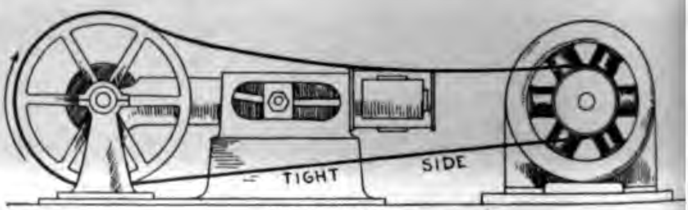
Ans. At from 3,000 to 5,000 feet per minute.

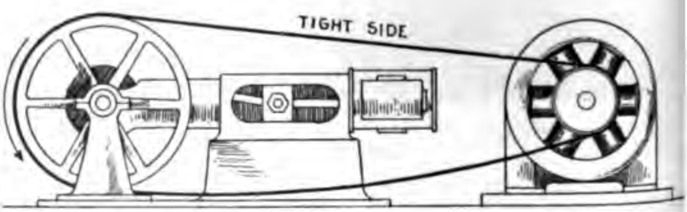
Ques. How may the greatest amount of power transmitting capacity be obtained from belts?

Ans. By covering the pulleys with leather.

Ques. How should belts be run?

Ans. With the tight side underneath as in fig. 2,814.





FIGS. 2,814 and 2,815.—Right and wrong way to run a belt. The tight side should be underneath so as to increase the arc of contact and consequently the adhesion, that is to say *better grip*, is in this way obtained.

Ques. What is a good indication of the capacity of belt in operation?

Ans. Its appearance after a few days' run.

If the side of the belt coming in contact with the pulley assume mottled appearance, it is an indication that the capacity of the belt considerably in excess of the power which it is transmitting, as the spotted portions of the belt do not touch the pulley; and in consequence of this there is liable to be more or less slipping.

Small quantities of a mixture of tallow and fish oil which have previously been melted together in the proportion of two of the former to one of the latter, will, if applied to the belt at frequent intervals, do much toward softening it, and thus by permitting its entire surface to come in contact with the pulley, prevent any tendency toward slipping. The best results are obtained when the smooth side of the belt is used next to the pulley, since tests conducted in the past prove that more power is thus transmitted, and that the belt lasts longer when used in this way.

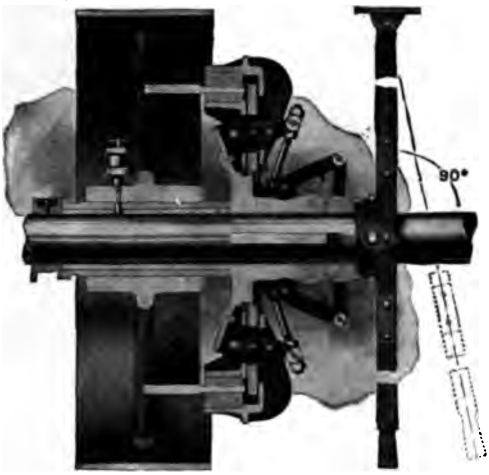


FIG. 2,816.—The Hill friction clutch pulley for power control. The clutch mechanism will start a load equivalent to the double belt capacity of the pulley to which the clutch is attached.

Ques. What is the comparison between the so called endless belts and laced belts?

Ans. With an endless belt there is no uneven or noisy action as with laced belts, when the laced joint passes over the pulleys, and the former is free from the liability of breakage at the joint.

Ques. How should a belt be placed on the pulleys?

Ans. The belt should first be placed on the pulley at rest d then run on the other pulley while the latter is in motion.

The best results are obtained, and the strain on the belt is less, when the speed at which the moving pulley revolves is comparatively low. With heavy belts, particular care should be taken to prevent any portion of the clothing being caught either by the moving belt or pulleys, as many serious accidents have resulted in the past from carelessness in regard to this important detail. The person handling the belt should, therefore, be sure of a firm footing, and when it is impossible to secure this, it is advisable to stop the engine and fit the belt around the engine pulley as well as possible by the aid of a rope looped around the belt.

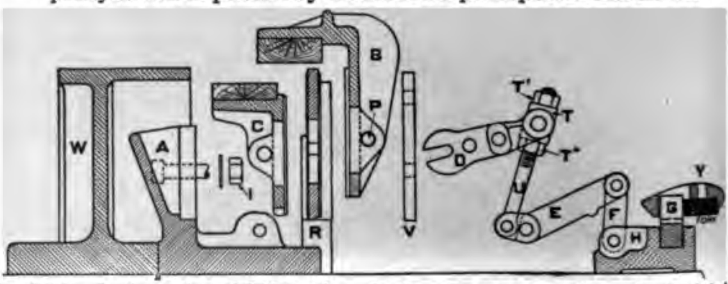


FIG. 2,817.—Sectional view of Hill clutch mechanism. In every case the mechanism hub A, and in a clutch coupling the ring W, is permanently and rigidly secured to the shaft and need not be disturbed when removing the wearing parts. When erected, the adjustment should be verified, and always with the clutch and ring engaged and at rest. If the jaws do not press equally on the ring, or if the pressure required on the cone be abnormal, loosen the upper adjusting nuts T′ on eye bolts and set up the lower adjusting nuts T″ until each set of jaws is under the same pressure. Should the clutch then slip when started it is evident that the jaw pressure is insufficient and a further adjustment will be necessary. All clutches are equipped throughout with split lock washers. Vibration or shock will not loosen the nuts if properly set up. The jaws can be removed parallel to the shaft as follows: Remove the gibs V, and withdraw the jaw pins P, then pull out the levers D. Do not disturb the eye bolt nuts T′ and T″. The outside jaws B can now be taken out. Remove the bolt nuts I allowing the fulcrum plates R to be taken off. On the separable hub pattern the clamping bolts must be taken out before fulcrum plate is removed. The inside jaws C may now be withdrawn. Always set the clutch operating lever in the position as shown in fig. 2,816 to avoid interference with mechanism parts. Oil the moving parts of the clutch. Keep it clean. Examine at regular intervals.

Ques. Under what conditions does a belt drive give the best results?

Ans. When the two pulleys are at the same level.

If the belt must occupy an inclined position it should not form a greater angle than 45 degrees with the horizontal.

Ques. What is a characteristic feature in the operation of belts, and why?

Ans. **Belts in motion will always run to the highest side of a**

illey; this is due partially to the greater speed in feet per inute developed at that point owing to the greater circum- ence of the pulley, and also to the effects of centrifugal force.

If, therefore, the highest sides of both pulleys be in line with each other, and the shafts of the respective pulleys be parallel to each other, there will be no tendency for the belt to leave the pulleys when once in its proper position. In order that these conditions be maintained, the belt should be no more than tight enough to prevent slipping, and the distance between the centers of the pulleys should be approximately 3.5 times the diameter of the larger one.

. 2,818.—Hill clutch mechanism Smith type. The friction surfaces are wood to iron, the wood shoes being made from maple. All parts of the toggle gear are of steel and forgings with the exception of the connection lever which is of cast iron.

Ques. What minor appurtenances should be provided a station?

Ans. Apparatus should be installed as a prevention against cidents, such as fire, and protection of attendants from danger.

In every electrical station there should be a pump, pipes and hose; the pump may be either directly connected to a small electric motor or belted to a countershaft, while the pipes and hose should be so placed that *no water can accidentally* reach the generators and electrical *circuits.*

A number of fire bucket filled with water should be placed on bracket around the station, and with these there should be an equal number o bucket containing dry sand, the water being used for extinguishin fire occurring at a distance from the machines and conductors, and th sand for extinguishing fire in current carrying circuits where wate would cause more harm than benefit. To prevent the sand being blow about the station, each sand bucket, when not in use, should be provide with a cover.

Neat cans and boxes should be mounted in convenient places fo greasy rags, waste, nuts, screws, etc., which are used continually an which therefore cannot be kept in the storeroom.

While it is important to guard against fire in the station, it is equall necessary to provide for personal safety. All passages and dark pit

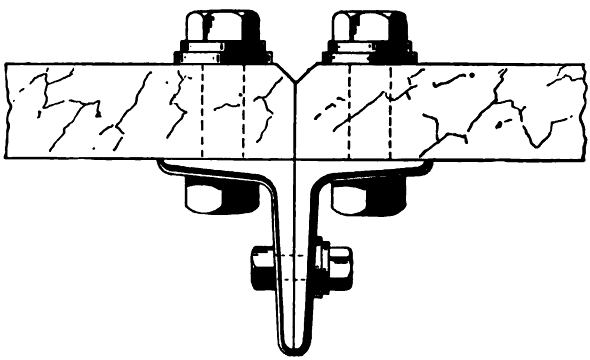


FIG. 2,819.—Method of joining adjacent switchboard panels.

should therefore be thoroughly lighted both day and night, and obstacl of any nature that are not absolutely necessary in the operation of th station, should be removed. Moving belts, and especially those passin through the floor, should be enclosed in iron railings. If high voltag be generated, it is well to place a railing about the switchboard to preve accidental contact with current carrying circuits, and in such cases it also advisable to construct an insulated platform on the floor in front the switchboard.

Switchboards.—The plan of switchboard wiring for alte *nating* current work depends upon the system in use and th r may be r of the phase, two ͤ, three , or mono- c types. general ples in all cases, ver, are cally iden-

g. 2,820 s the switch- l wiring for a phase alter- . As an aid ding the dia- , the conduc- carrying al- ting current represented olid lines, those carry- lirect cur- by dotted

e exciter n at the is a shunt d machine. eans of the r rheostat, voltage for ng the field ng of the al- tor is varied; in turn, va- the voltage oped in the

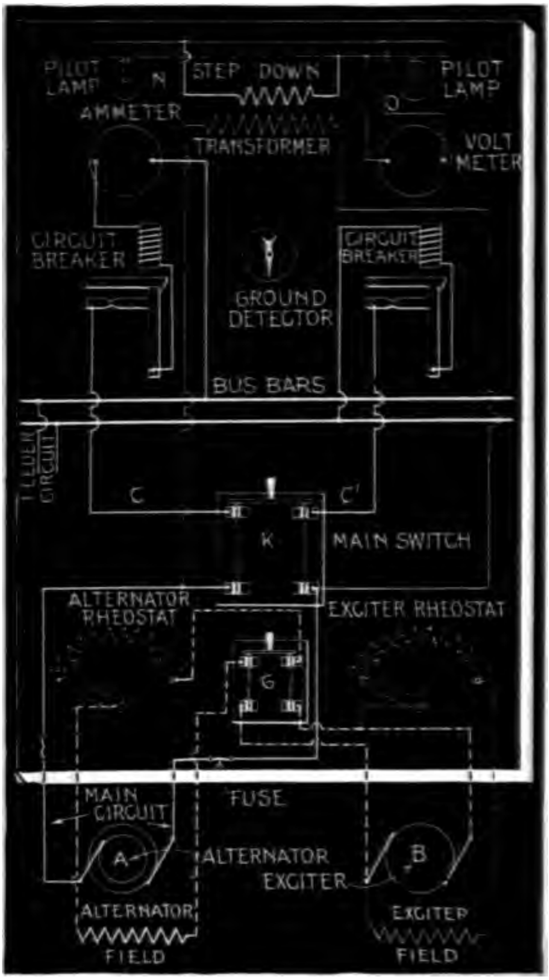
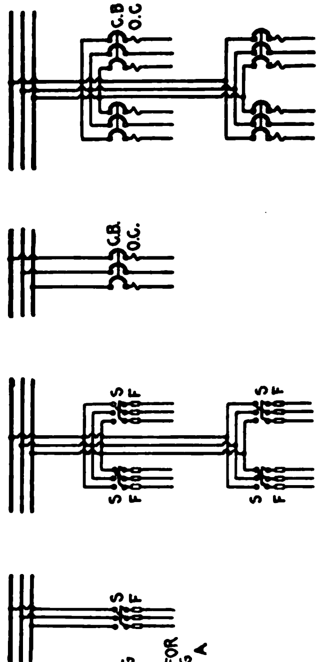
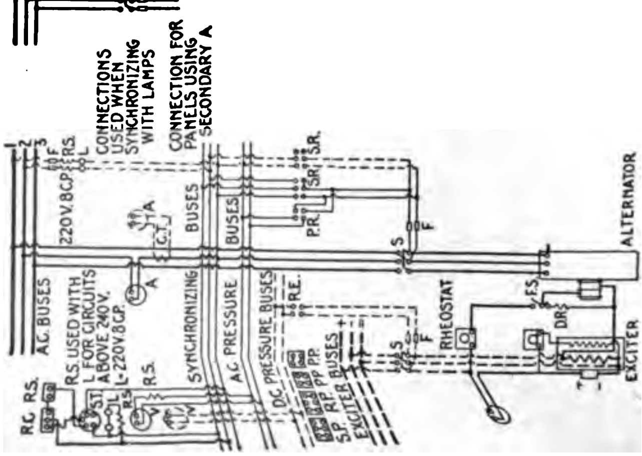


FIG. 2,820.—Switchboard wiring for a single phase separately excited alternator. The direct current circuits are represented by dotted lines, and the alternating current circuit, by solid lines.





FIGS. 2,821 to 2,825.—General Electric diagrams of connections. A, ammeter; C.B, circuit breaker; C.P, candle power; C.T, current transformer; D.R, discharge resistance; F, fuse; F.S, field switch; L, lamp; O.C, overload coil; P.P, pressure plug; P.R, pressure receptacle; R.C, reactance; rheo, rheostat; R.P, synchronizing plug, running; R.S, resistance; S, switch; S.I, synchronism indicator; S.P, synchronizing plug, starting; S.R, synchronizing receptacle; V, voltmeter.

alternator since the main leads of the exciter are connected through a double pole switch G to the field winding of the alternator.

A rheostat is also introduced in the alterantor field winding circuit to adjust the alternator pressure. It may seem unnecessary to employ a rheostat in each of two separate field circuits to regulate the voltage of the alternator, but these rheostats are not both used to produce the same result. When a considerable variation of pressure is required, the exciter rheostat is manipulated, whereas for a fine adjustment of voltage the alternator rheostat is preferably employed.

Sometimes a direct current ammeter is introduced in the alternator's field circuit to aid in the adjustment.

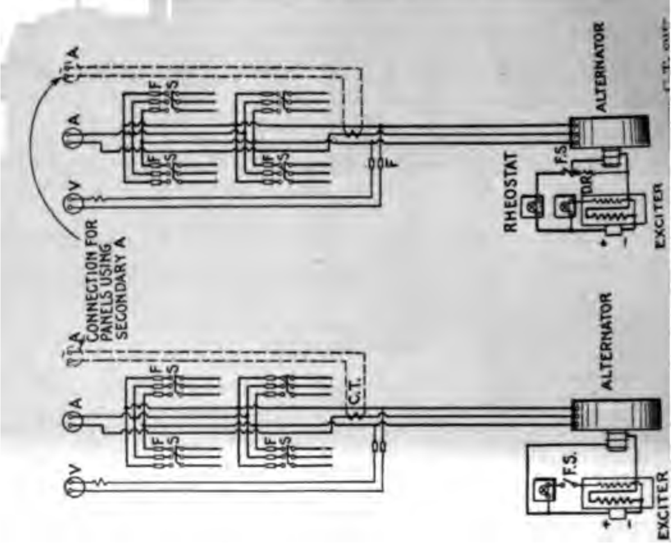
The main circuit of alternator after being protected on both sides by fuses, runs to the double pole switch K. These fuses serve as a protection to the alternator in case of a short circuit at the main switch. It will be noticed the fuses are of the single pole type and are mounted a considerable distance apart; this is to prevent any liability of a short circuit between them in case of action. Enclosed fuses are now used entirely for such work, since in these there is no danger of heated metal being thrown about and causing damage when the fuse wire is melted. Enclosed fuses are also more readily and quickly replaced than open fuses, the containing tube of each being easy to adjust in circuit, and when the fuse wire within is once melted the tube is discarded for a new one.

The main circuit after passing through the main switch is further protected on both sides by circuit breakers. Leaving these protective devices, the left hand side of the circuit includes the alternating current ammeter, and then connects with one of the bus bars. The right hand side of the circuit runs from the circuit breaker to the other bus bar. As many feeder circuits may be connected to the bus bars and supplied with current by the alternator as the capacity of this machine will permit. If, however, there be more than one feeder circuit, each must be wired through a double pole switch.

In alternating current work the pressures dealt with are much greater than those in direct current installations, so that proportionate care must be taken in the wiring to remove all possibility of grounds.

To locate such troubles, however, should they occur, a ground detector is provided. For this class of work the ground detector must be an instrument especially designed for high pressure circuits. Two of its terminals should be connected to the line wires and the third, to ground; in case of a leak on the line, a current will then flow through the detector and by the position of the pointer the location and seriousness of the leak may be judged.

A step down transformer is also rendered necessary for the voltmeter and the pilot lamps, owing to the high voltage in use. The primary *winding of the transformer* is connected across the main circuit of the *alternator. This connection* should never be made so that it will be cu *out of circuit when the main* switch is open, for it is always advisable *consult the voltmeter* before throwing on the load by closing this swi


CONNECTION FOR PANELS USING SECONDARY A
ALTERNATOR
ALTERNATOR
RHEOSTAT
F.S.
DR.
EXCITER
EXCITER
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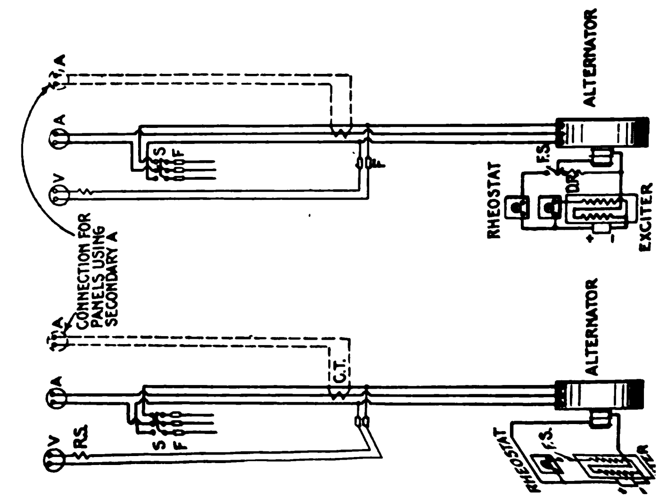
CONNECTION FOR PANELS USING SECONDARY A
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EXCITER
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Ques. How does the switchboard wiring for a two ase system differ from the single phase arrangement own in fig. 2,820?

Ans. It is practically the same, except for the introduction an extra ammeter and a compensator in each of the outside es, and in the use of a four pole switch in place of the two e main switch.

The ammeters, of course, are for measuring the alternating currents in each of the two phases or legs of the system, and the compensators are two transformers with their primary coils in series with the outside wires and their secondary coils in series with each other across the outside wires. The transformers thus connected are known as compensators or pressure regulators, and as such compensate for the drop in pressure on either side of the system.

Ques. How is the four pole main switch wired?

Ans. Its two central terminals which connect directly with e line wires, are joined together by a conductor, and from is point one wire is led off. This wire, together with the two tside wires, form the feeders of the system.

Ques. How many voltmeters are required for the two ase system?

Ans. One voltmeter is sufficient on the board if a proper itching device be employed to shift its connections across ther of the two circuits; otherwise, two voltmeters will be cessary, one bridged across each of these respective circuits.

The same reasoning holds true in regard to ground detectors, so that one or two of these will be required, depending upon the aforementioned conditions.

Ques. What are the essential points of difference etween the single phase switchboard wiring as shown fig. 2,820, and that required for a three wire three phase stem?

ns. The three phase system requires the use of a three p switch in place of the two pole switch; the insertion of an am ter, a circuit breaker, and a compensator in each of the tl wires of the system; the presence of two ground detectors stead of one, and the addition of a voltmeter switch if but voltmeter be provided, or else the installation of two voltmel connected the one between the middle wire and outer right h wire, and the other between the middle wire and outer hand wire.

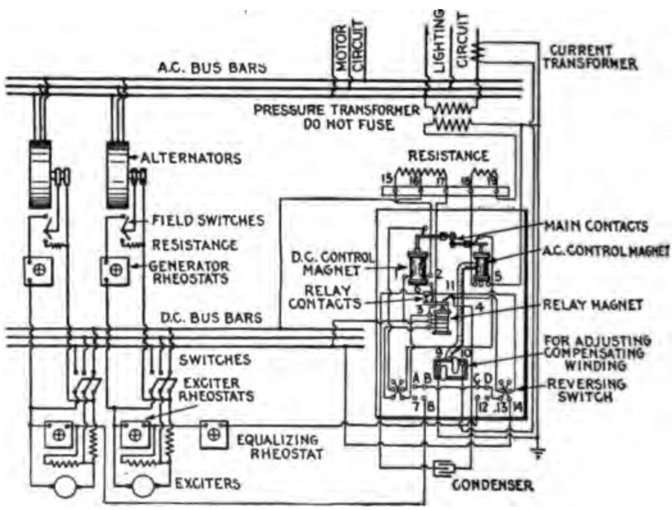
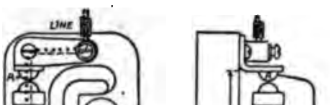


FIG. 2,830.—Diagram of switchboard connections for General Electric automatic w regulator with two exciters and two alternators.

Ques. Mention a few points relating to lightn arresters.

Ans. In most cases where direct current is used they mounted on the walls of the station near the place at which line wires enter. If they be mounted outside the station a point, special precautions should be taken to keep the and 2,832.—Garton-Daniels alternating ightning arrester; diagram showing con- . A lightning discharge takes the path l by the dotted line, across the upper air ırough resistance rod B, C, D, across cop- R on the base, thence flowing to ground the movable plunger M, lower on gap ground binding post L. The discharge practically straight, contains an air gap, of but 3-32 inch, a series resistance g but 225 ohms. The lightning dis- loes not flow through the flexible lead ng band D on the lower end of the re- rod with the top of the movable plunger. wo points are electrically connected by y copper strip R, and lightning discharges r, if not always, take the path across this strip in preference to flowing through ctance of the one turn of flexible cable. discharge occurs from line to ground any lightning arrester, the air gaps arc d so there is offered a path from line to for the line current. This flow of line following the lightning discharge to may vary anywhere from a small capac- ent where the arrester is installed on an ded circuit, a moderately heavy flow on lly grounded circuit, to a very heavy ı grounded circuit—either a circuit oper- a dead grounded circuit, or a circuit as become accidentally grounded during . The path taken by this flow of line from line to ground may be traced by g the path shown by the dashed line. en, crosses upper air gap A, flows through B of the resistance rod to band C. Leav- d C it flows through the magnet winding ıce to band D on the resistance rod, flexible lead to upper end of mov- ınger, through movable plunger, across ir gap N, to ground binding post L, to ground. The function of the short of resistance rod CD is as follows: It has an ohmic resistance of about 30 ohms non-inductive. Magnet winding H, connected to bands C and D on the ends of this ngth of rod has an ohmic resistance of 3 ohms, but is *highly inductive.* Lightning ges being of *high frequency* take the higher resistance *but non-inductive* path CD passage from line to ground. The flow of normal current from line to ground being y low frequency, 25 or 60 cycles in ordinary alternating current circuits, zero in urrent circuits—takes the *low resistance* path through coil H in its path to ground. CD of the rod is used therefore simply to shunt the inductance of winding H to quency lightning discharges, leaving the lightning discharge path in the arrester nductive highly efficient path. In all Garton-Daniels A. C. lightning arresters ıg on non-grounded or partially grounded circuits, the action of the air gaps and sistance are together sufficient to extinguish the flow of normal current to ground ero point of the generator voltage wave. If, however, as frequently happens, the unds accidentally during a storm, then the arrester does not have to depend for its operation on the arc extinguishing properties of the air gaps and resistance, but the flow of line current through the arrester energizes the movable plunger, which pward in the coil, opening the circuit between the discharge point M and the lower the plunger. To limit the flow of line current to ground the resistance rod B is l, there being *approximately 225* ohms between the discharge point A and clamp C *500 volt arrester. This feature is particularly effective where the circuit is tem- or accidentally grounded.* The series resistance prevents a heavy short circuit *he arrester and limits the* current to a value that is readily broken by the cut out *enough to impede the* passage of the discharge.



FRONT VIEW SIDE VIEW

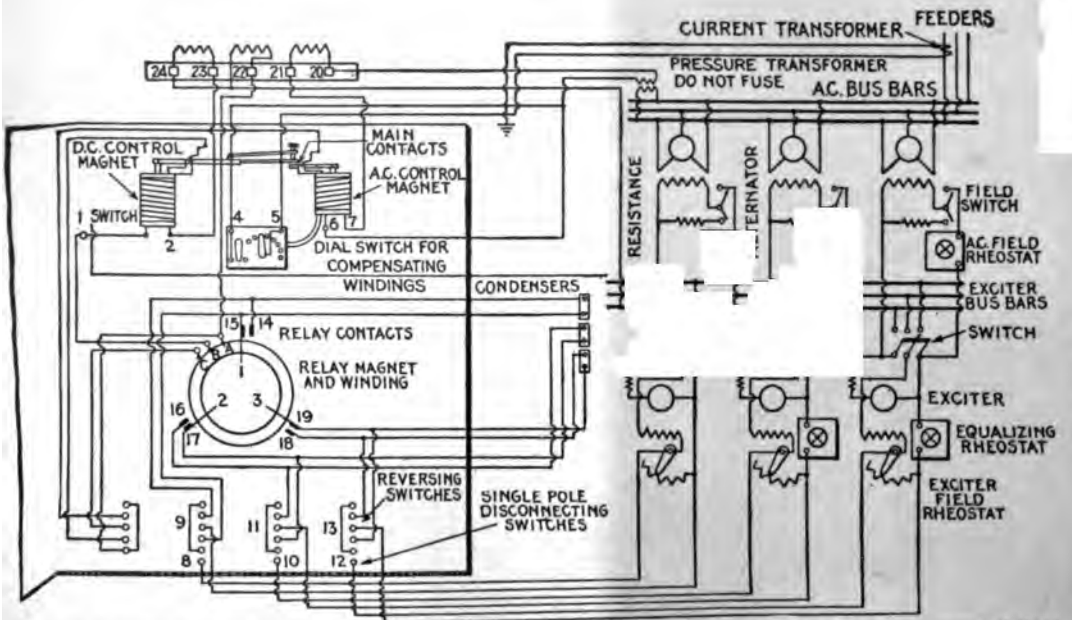


FIG. 2,833.—Diagram of switchboard connections for General Electric automatic voltage regulator with three exciters and three alternators.

m moisture by enclosing them in iron cases, but no matter ere they are located it is necessary that they be dry in order work properly.

If possible, one place should be set aside for them and a marble or slate panel provided on which they may be mounted.

Wooden supports are undesirable for lightning arresters on account of the fire risk incurred; this, however, may be reduced to a minimum by employing skeleton boards and using sheets of asbestos between the arresters and the wood.

In parts of the country where lightning is of common occurrence and where overhead circuits are installed which carry high pressures, heavy currents, and extend over considerable territory, it is advisable to have the station well equipped with lightning arresters of the most improved types.

In each side of the main circuit, between the lightning arrester connections and the switchboard apparatus there should be connected a choke coil or else each of the main conductors at this point should be tightly coiled up part of its length to answer the same purpose.

A quick and effective way of coiling up a wire consists in wrapping around a cylindrical piece of iron or wood that part of the conductor in which it is desired to have the coils, the desired number of times, and then withdrawing the cylindrical piece. The coils, each of which may contain 50 or 200 turns, thus inserted in the main circuit introduce a high resistance or reluctance to a lightning current, and thus prevent it passing to the generator; there will, however, be an easy path to earth afforded it through the lightning arrester, and so no damage will be done. Coils of the nature just mentioned may advantageously be introduced between the generator and switchboard to take up the reactive current developed upon the opening of the circuit, and in the case of suspended conductors, the coils may be used to take up the slack by the spring-like effect produced by them.

The safety of the operator should be especially considered in the design of high pressure alternating current switchboards.

Such protection may be secured by screening all the exposed terminals, or preferably by mounting all the switch mechanism on the back of the board with simply the switch handle projecting through to the front; by pushing or pulling the switch handle, the connections can thus be shifted either to one side of the system or to the other.

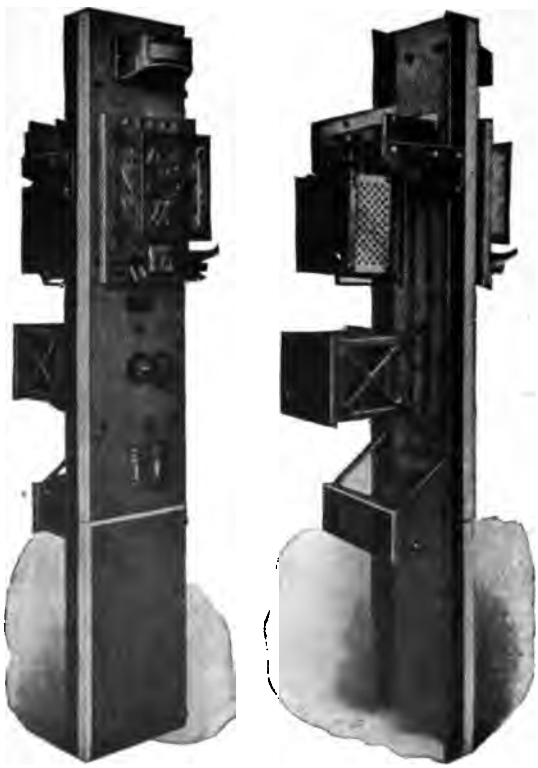
Ques. Upon what does the work of assembling a switch-ard depend?

Ans. *It depends almost* entirely upon the size of the plar varying from the simple task of mounting a single pane case of an isolated plant, to the more difficult prot supporting a large number of panels in a central station.

Ques. When the material chosen for a switc must be shipped a considerable distance, what f board should be used?

Ans. Tl units or should be dimensio avoid the of breaka expense of when a u comes cra machine in

Ordinari boards var to eight fee and the the panels five to six some bo seams bet slabs run and in ot zontally. to render t bling of tl board as possible, appearance finished t artistic, the should run tally rather tically. Th each of t should also lered so tl



Figs. 2,834 and 2,835.—Front and rear views showing General Electric automatic voltage regulator mounted on switchboard panel.

will be less danger of their breaking out when being mounted on the framework.

Ques. In assembling a swtichboard, how should the lower slabs be placed, and why?

Ans. They should be suspended a little distance from the floor to prevent contact with any oil, dirt, water or rubbish that might be on the floor.

Ques. How are the slabs or panels supported?

Ans. They are carried on an iron or wooden framework with braces to give stability.

The braces should be securely fastened at one end to the wall of the station, and at the other end to the framework of the board, as shown in fig. 2,836.

To fasten the switchboard end of the brace directly to the slate, marble or other material composing the board is poor practice and should never be attempted.

If the station be constructed of iron, these switchboard braces must be such that they will thoroughly insulate the board and its contents from the adjoining wall.

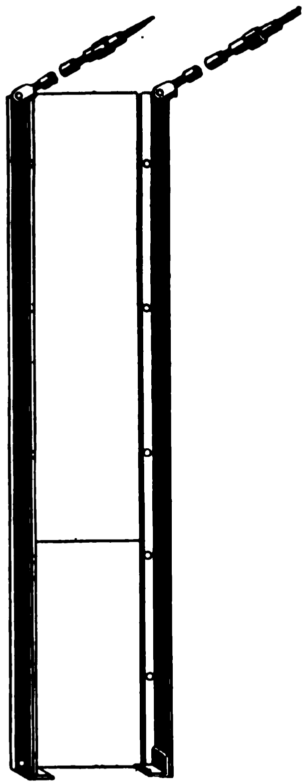


FIG. 2,836.—Method of supporting the framework of a switchboard.

Ques. What is the usual equipment of a switchboard?

Ans. It comprises switching devices, current or pressure limiting devices, indicating devices, and fuses for protecting the *apparatus and circuits.*

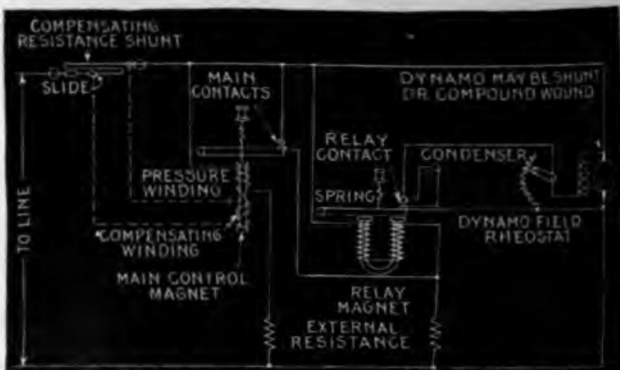


FIG. 2,837.—Diagram showing elementary connections of General Electric automatic regulator for direct current. It consists essentially of a main control magnet with two independent windings and a differentially wound relay magnet. One winding, known as the pressure winding, of the main control magnet is connected across the dynamo terminals, the other across a shunt in one of the load mains. The latter is the "compensating winding" and it opposes the action of the pressure winding so that as the load increases, a higher pressure at the dynamo is necessary to "over compound" for line drop. In ordinary practice, the voltage terminals are connected to the bus bars, and the compensating shunt inserted in one of the principal feeders of the system. In operation the shunt circuit across the dynamo field rheostat is first opened by means of a switch provided for that purpose on the base of the regulator and the rheostat turned to a point that will reduce the generator voltage 35 per cent below normal. The main control magnet is at once weakened and allows the spring to pull out the movable core until the main contacts are closed. This closes the second circuit of the differential relay, thus neutralizing its windings. The relay spring then lifts the armature and closes the relay contacts. The switch in the shunt circuit across the dynamo field rheostat is now closed, practically short circuiting the rheostat, and the dynamo voltage at once rises. As soon as it reaches the point for which the regulator has been adjusted, the main control magnet is strengthened, which causes the main contacts to open, which in turn open the relay contacts across the rheostat. The rheostat is now in the field circuit, the voltage at once falls off, the main contacts are closed, and relay armature released, and shunt circuit across the rheostat again completed. The voltage then starts to rise and this cycle of operation is continued at a high rate of vibration, maintaining not a constant but a steady voltage at the bus bars. When neither the compensating winding nor pressure wires are used, there will be no "over compounding" effect due to increase of load and a constant voltage will be maintained at the bus bars. The compensating winding on the control magnet, which opposes the pressure winding is connected across an adjustable shunt in the principal feeder circuit. As the load increases the voltage drop across the shunt increases and the effect of the compensating winding becomes greater. This will require a higher voltage on the pressure winding to open the main contacts and the regulator will therefore cause the dynamo to compensate for line drop, maintaining at the bus bars a steady voltage without fluctuations, which rises and falls with a load on the feeders, giving a constant voltage at the lamps or center of distribution. The compensating shunt may be adjusted so as to compensate for any desired line drop up to 15 per cent; it is preferably placed in the principal lighting feeder, but may be connected to the bus bars so that the total current will pass through it. The latter method, however, is sometimes desirable, as large fluctuating power loads on separate feeders might disturb the regulation of the lighting feeders. Adjustment is made by sliding the movable contact at the center of the shunt. This contact may be clamped at any desired point and determines the pressure across the compensating winding of the regulator's main control magnet. Where pressure wires are run back to the central station from the center of distribution they may be connected directly to the pressure winding of the main control magnet, and it is unnecessary to use the compensating shunt. The pressure wires take the place of the leads from the ...l magnet to the bus bars and maintain a constant voltage at the center of distribution.

On some switchboards are also mounted small transformers for raising or lowering the voltages, and lightning arresters as a protection from lightning. In addition to the apparatus previously mentioned nearly all switchboards carry at or near their top two or more incandescent lamps provided with shades or reflectors, for lighting the board.

Ques. What should be done before wiring a switchboard?

Ans. The electrical connections between the various ap-

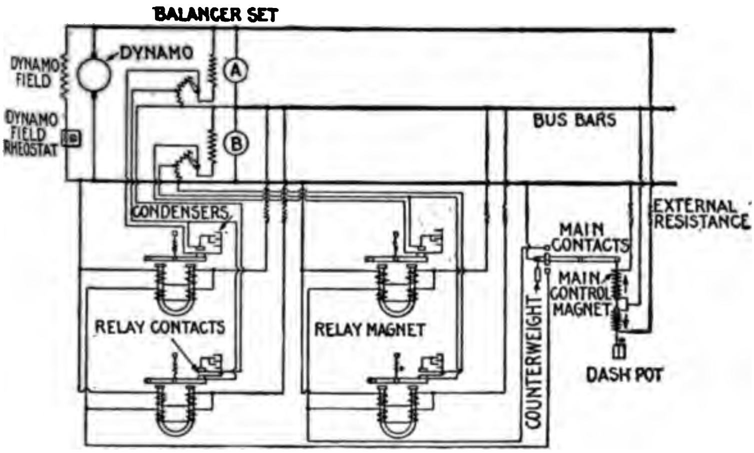


FIG. 2,838.—Diagram showing connections of General Electric automatic voltage regulator for direct current as connected for maintaining balanced voltage on both sides of a three wire system using a balancer set. In operation, should the voltage on the upper bus bars become greater than that on the lower ones, the middle and upper contacts on the regulator will close, thus opening the relay contacts to the left and closing those to the right. This inserts all the resistance in the field of balancer A, and short circuits the resistance in the field of balancer B. A will then be running as a motor, and B as a dynamo, thereby equalizing the two voltages until that on the lower bus bars becomes greater than that of the upper ones; then the regulator contacts operate in the opposite direction and balancer A is run as a dynamo, and balancer B as a motor. This cycle of operation is repeated at the rate of from three to four hundred times per minute, thus maintaining a balanced voltage on the system.

paratus mounted on the face or front of the board, are made on *the back of the board.* It is necessary that these connection *properly made* else considerable electrical power will wasted at this point. The wiring on the back of the board should therefore be planned out on paper before commencing the work.

In laying out the plan of wiring care must be taken to allow sufficient contact surface at each connection; there should be not less than one square inch of contact surface allowed for each 160 amperes of current transmitted.

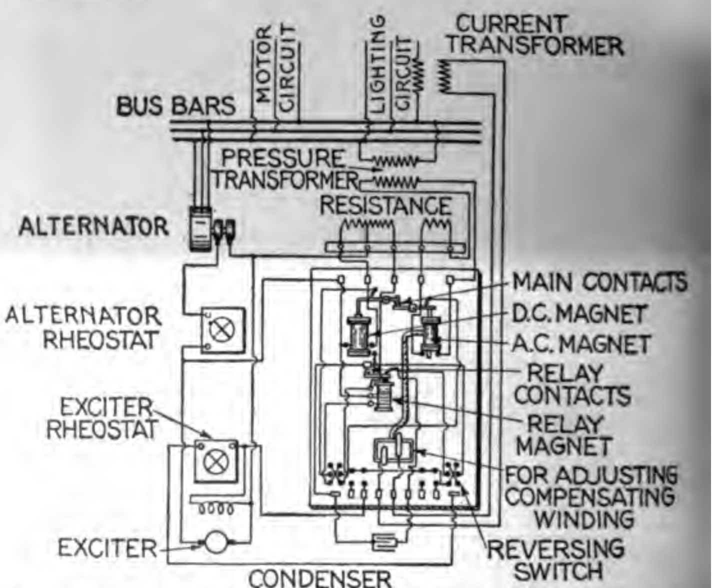


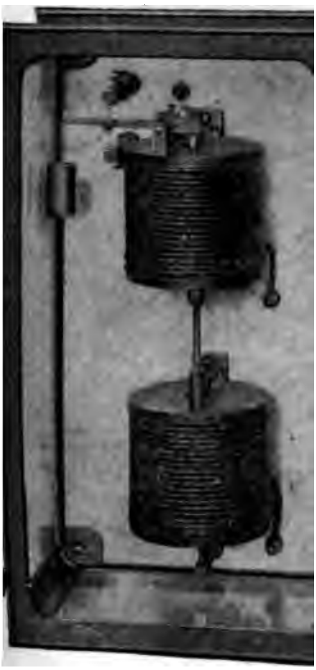
FIG. 2,839.—Diagram of connections of General Electric voltage regulators for one or more alternators using one exciter.

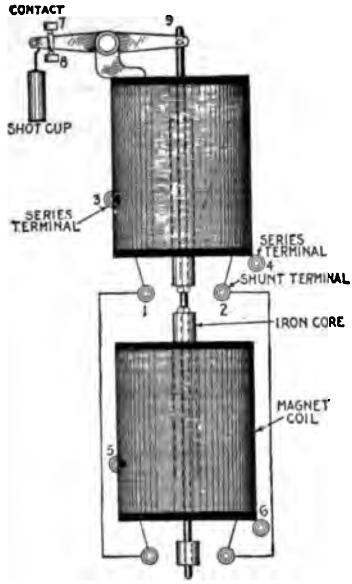
For the bus bars, which by the way are always of copper, one square inch per 1,000 amperes is the usual allowance; this is equal to 1,000 circular mils of cross sectional area per ampere.

Every effort should be made to give the bus bars the greatest amount of radiation consistent with other conditions, in order that their resistances may not become excessive owing to the heat developed by the large currents they are forced to carry. Suppose, for instance, the number of amperes to be generated is such as to require bus bars having each a cross sectional area of one square inch. If the end dimensions of these bars were each 1 inch by 1 inch, there would be less radiating surface than if their dimensions were each 2 inches by ½ inch.

Operation of Alternators.—The operation of an alternator when run singly differs but little from that for a dynamo.

As to the preliminaries, the exciter must first be started. This is done in the same way as for any shunt dynamo. At first only a small current should be sent through the field winding of the alternator; then, if the





FIGS. 2,840 and 2,841.—General Electric equalizer regulator designed to equalize the load on two machines, and diagram of connections.

exciter operates satisfactorily and the field magnetism of the operator show up well, the load may gradually be thrown on until the normal current is carried, the same method of procedure being followed as in the similar case of a dynamo.

On loading an alternator, a noticeable drop in voltage occur

oss its terminals. This drop in voltage is caused in p y the demagnetization of the field magnets due to the armature urrent, and so depends in a measure upon the position and form of the pole pieces as well as upon those of the teeth in the rmature core. The resistance of the armature winding also causes a drop in voltage under an increase of load.

Another cause which tioned is the inductance of the armature winding, which to the positions of the armature coils with respect to each other with respect to the field magnets.

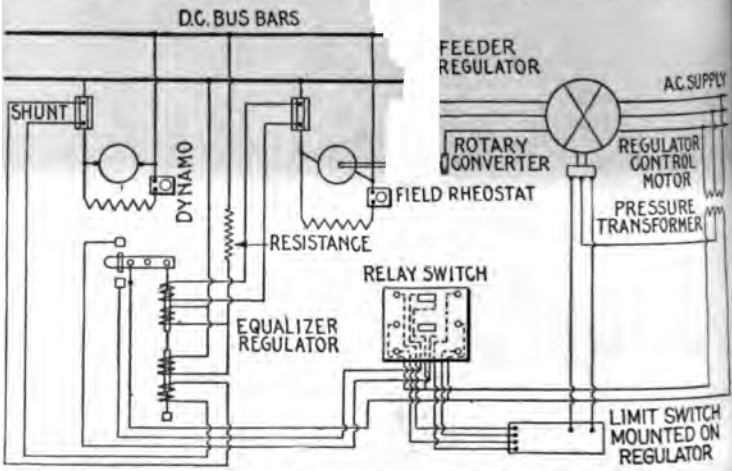


FIG. 2,842.—Connection of General Electric equalizing regulator for equalizing loads on an engine driven dynamo and rotary converter running in parallel. Should the load on the dynamo become greater than that on the rotary converter, the middle and upper contacts on the regulator close, and thus by means of the relay switch and control motor, cause the feeder regulator to boost the voltage on the rotary until the loads again become equal. Should the load on the rotary converter become greater than that on the generator, the regulator contacts operate in the reverse direction and the feeder regulator is caused to buck the rotary voltage.

Alternators in Parallel.—When the load on a station increases beyond that which can conveniently be carried by one alternator, it becomes necessary to connect other alternators in parallel with it. To properly switch in a new machine in parallel with one already in operation and carrying load, require a complete knowledge of the situation on the part of the attendant, and also some experience.

The connections for operating alternators in parallel are shown in fig. 2,843. In the illustration the alternator A is in operation and is supplying current to the bus bars. The alternator B is at rest. The main pole switch B′ by means of which this machine can be connected into circuit is therefore open.

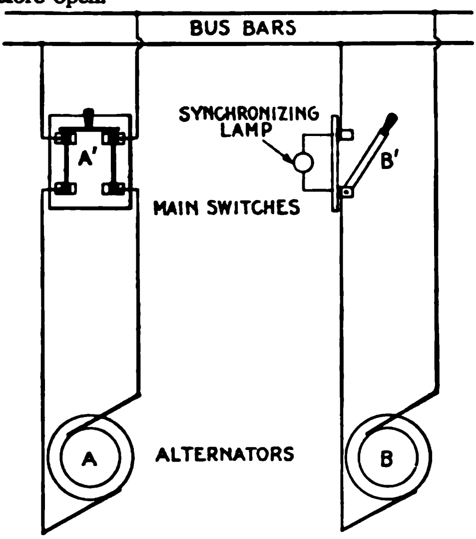


FIG. 2,843.—Method of synchronizing with one lamp; *dark lamp method*. Assuming A to be in operation, B, may be brought up to approximately the proper speed, and voltage. Then if B, be run a little slower or faster than A, the synchronizing lamp will glow for one moment and be dark the next. At the instant when the pressures are equal and the machines in phase, the lamp will become dark, but when the phases are in quadrature, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The nearer alternator approaches synchronism, in adjusting its speed, the slower the flickering, and when the flickering becomes very slow, the incoming machine may be thrown in the moment the lamp is dark by closing the switch. The machines are then in phase and tend to remain so, since if one slow down, the other will drive it as a motor.

Now, if the load increase to such extent as to require the service of the second alterantor B, it must be switched in parallel with A. In order that *both machines* may operate properly in parallel, three *conditions must be satisfied* before they are connected together, or else the *one alternator will* be short circuited through the other, and serious *results will undoubtedly* follow.

A ... before closing main switch B, it is necessary that
1. ... uencies of both machines be the same;
2. ... hines must be in synchronism;
3. The vo..ages must be the same.

Ques. How are the frequencies made the same?

Ans. By speeding up the alternator to be cut in, or change the speed of both unti ... both machines is the same

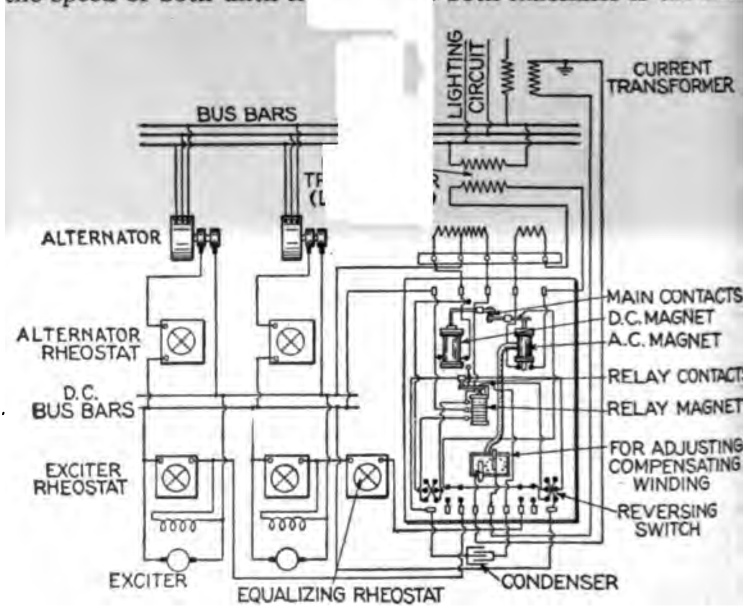


FIG. 2,844.—Diagram of connections of General Electric automatic voltage regulator fo several alternators running in parallel with exciters in parallel.

Ques. How are the alternators synchronized or brought in phase?

Ans. The synchronism of the alternators is determined by employing some form of synchronizer, as by the single lamp method of fig. 2,843, or the two lamp method of fig. 2,845.

Ques. In synchronizing by the one lamp method, when should the incoming machine be thrown in?

Ans. It is advisable to close the switch when the machines are approaching synchronism rather than when they are receding from it, that is to say, the instant the lamp becomes dark.

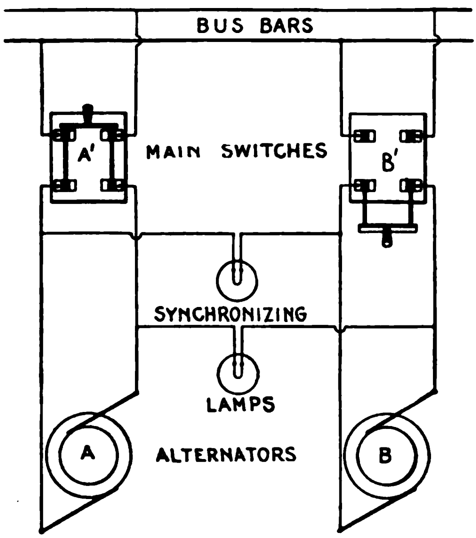


FIG. 2,845.—Method of synchronizing with two lamps; *dark lamp method*. The two synchronizing lamps are connected as shown, and each must be designed to supply its rated candle power at the normal voltage developed by the alternators. Now since the alternators are both running under normal field excitation the left hand terminals of each of them will alternately be positive and negative in polarity, while the right hand terminals are respectively negative and positive in polarity. If, however, the alternators be in phase with each other, the left hand terminals of both of them will be positive while the right hand terminals are negative, and when the left hand terminals of both machines are negative the right hand terminals will be positive. Hence, when the machines are in phase there will be no difference of pressure between the left hand terminals or between the right hand terminals of the two machines. Hence, if the synchronizing lamps be connected as shown, both will be dark. The instant there is a difference of phase, both lamps will glow attaining full candle power when the difference of phase has reached a maximum. As the alternators continue to come closer in step, the red glow will gradually fade away until the lamps become dark. Then the switch may be closed, thereby throwing the two machines in parallel. If the intervals between the successive lighting up of the lamps are of short duration it is advisable to wait until these become longer even though the other conditions are satisfied, because where the phases pass each other rapidly there is a greater possibility of not bringing them together at the proper instant. An interval of not less than five seconds should therefore be allowed between the successive lighting up of the lamps, before closing the switch.

Ques. What are the objections to the on method?

Ans. The filament of the lamp may break, an

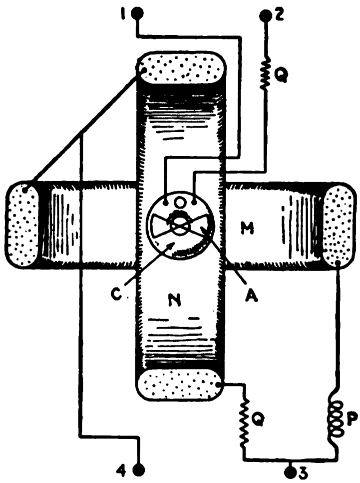
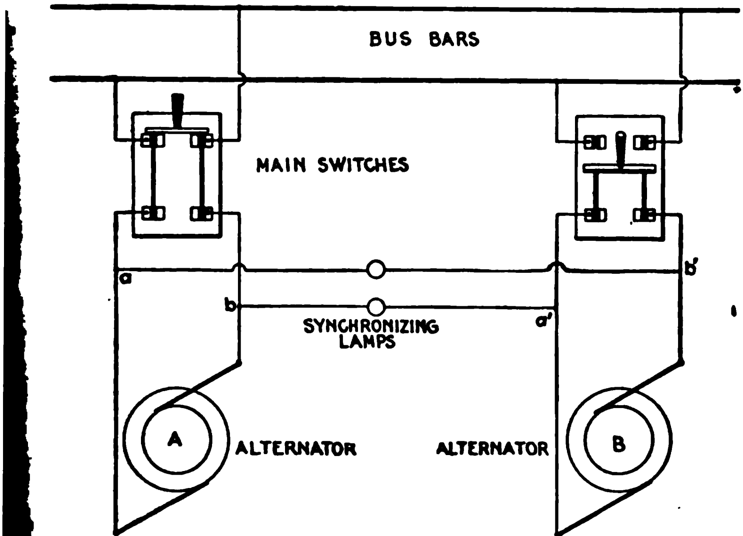


FIG. 2,846.—I synchroscope is especially where pre formers are stalled for u meters. A only about watts it ma the same with other m are three sta N, M and C ing system, c iron armatu attached t suitably p i mounted in pointer is a to the shaft ing system and is not any restraini as a spring control. Th coils N and same vertic 90 degrees a axis of C is r plane. The coils N and M are connected in "split phase" relation through an in ance P and non-inductive resistance Q, and these two circuits are parallel acro terminals 3 and 4 of the synchroscope. Coil C is connected through a non- sistance across the upper machine terminals 1 and 2 of the synchroscope. In current in the coil C magnetizes the iron core carried by the shaft and the tw marked A and "iron armature." There is however, no tendency to rotate t current be passed through one of the other coils, say M, a magnetic field will parallel with its axis. This will act on the projections of the iron armature, turn so that the positive and negative projections assume their appropriat the field of the coil M. A reversal of the direction in both coils will obviou the position of the armature, hence alternating current of the same frequen in the coils C and M cause the same directional effect upon the armature as if were passed through the coils. If current lagging 90 degrees behind that in and C be passed through the coil N, it will cause no rotative effect upon t because the maximum value of the field which it produces will occur at the the pole strength of the armature is zero. The two currents in the coils M ar a shifting magnetic field which rotates about the shaft as an axis. As all assumed to be of the same frequency, the rate of rotation of this field is such t tion corresponds with that of the armature projections at the instant when duced in them by the current in the coil C are at maximum value, and th through 180 degrees in the same interval as is required for reversal of the p the essential feature of the instrument, namely, that the armature projec position in the rotating magnetic field which corresponds to the direction of th instant when the projections are magnetized to their maximum strength by in the coil C. If the frequency of the currents in the coils which produce t be less than that in the coil which magnetized the armature, then the arm in order that it may be parallel with the field when its poles are at maxim darkness, or the lamp may be dark with considerable voltage as it takes over 20 volts to cause a 100 volt lamp to glow.

Ques. What capacity of single lamp must be used?

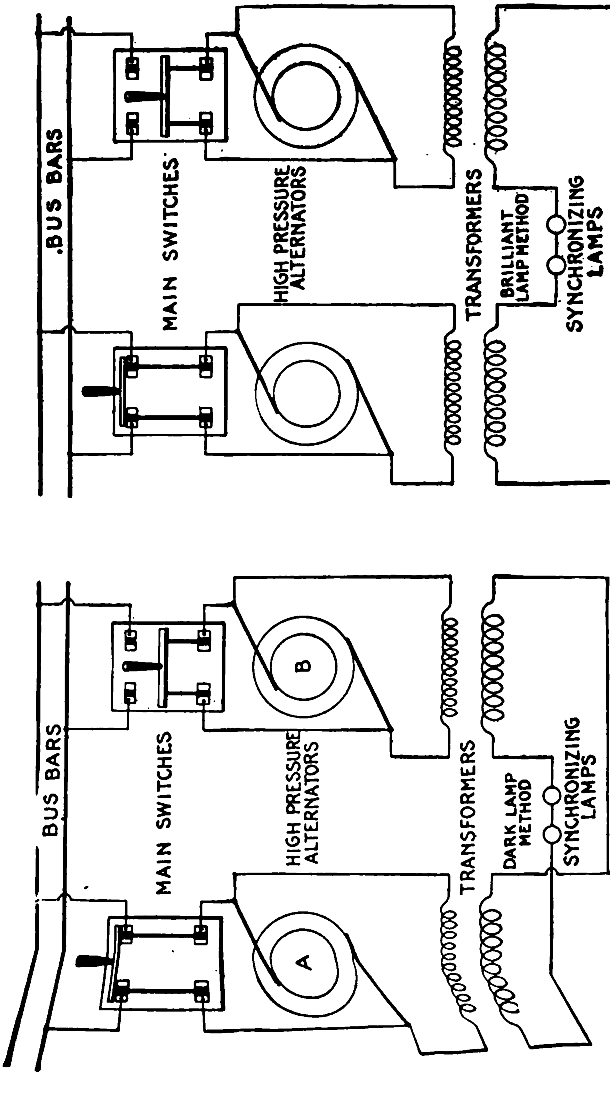
Ans. It must be good for twice the voltage of either machine.



2,947.—Brilliant lamp method of synchronizing. The synchronizing lamps are connected as shown, and must be of the alternator voltage. When the voltages are equal and the machines in phase, the difference of pressure between *a* and a given point is the same as that between *a'* and the same point; this obtains for *b* and *b'*. Accordingly, a lamp connected across *a b'* will burn with the same brilliancy as across *a' b*; the same holds for the other lamp. When the voltages are the same and the phase difference is 180° the lamps are dark, and as the phase difference is decreased, the lamps glow with increasing brightness until at synchronism they glow with maximum brilliancy. Hence the incoming alternator should be thrown in at the instant of maximum brilliancy.

Ques. What modification of the synchronizing methods shown in the accompanying illustrations is necessary when high pressure alternators are used?

Ans. Step *down transformers* must be used between the *alternators and the lamps to obtain* the proper working voltage *for the lamps.*



2,848.—Synchronizing with high pressure alternators; dark and brilliant lamp methods. In both methods the primaries of

Ques. How is the voltage of an incoming machine ad-usted so that it will be the same as the one already in peration?

Ans. By varying the field excitation with a rheostat in the ternator field circuit.

Ques. How may two or more alternators be started multaneously?

Ans. After bringing each of them up to its proper speed so to obtain equal frequencies, the main switches may be closed, ereby joining their armature circuits in parallel. As yet, wever, their respective field windings have not been supplied th current, so that no harm can result in doing this. The citers of these machines after being joined in parallel, should en be made to send direct current simultaneously through the ld windings of the alternators, and from this stage on the rections previously given may be followed in detail.

Ques. What are the conditions when two or more alter-tors are directly connected together?

Ans. If rigidly connected together, or directly connected to e same engine, they must necessarily run in the same manner all times.

When machines connected in this way are once properly adjusted so that they are in phase with each other, their operation in parallel is even a simpler task than when they are all started together but are not directly connected.

Ques. When an alternator is driven by a gas engine, hat provision is sometimes made to insure successful peration in parallel?

Ans. An amortisseur winding is provided to counteract the *dency to "hunting."*

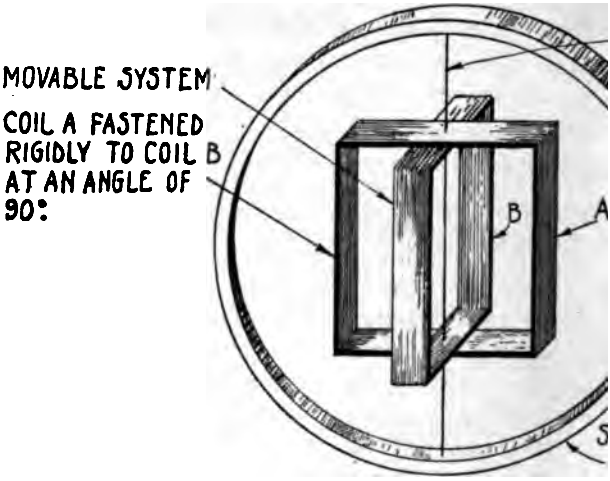


FIG. 2,849.—Diagram of Lincoln Synchronizer. **In construction, a station** pended within it a coil A, free to move about an axis in the planes of both a diameter of each. If an alternating current be passed through both c position with its plane parallel to F. If now the currents in A and l respect to each other, coil A will take up a position 180° from its former p of the relative directions of currents in A and F is equivalent to changin tion by 180°, and therefore this change of 180° in phase relation is foll sponding change of 180° in their mechanical relation. Suppose now, ir the relative direction of currents in A and F, the change in phase relatio made gradually and without disturbing the current strength in either c that when the phase difference between A and F reaches 90°, the force will become reduced to zero, and a movable system, of which A may be condition to take up any position demanded by any other force. Let a this movable system consist of coil B, which may be fastened rigidly plane 90° from that of coil A, and the axis of A passing through diamet suppose a current to circulate through B, whose difference in phase rela is always 90°. It is evident under these conditions that when the d between A and F is 90°, the movable system will take up a position, suct to F, because the force between A and F is zero, and the force between I mum; similarly when the difference in phase between B and F is 90°, A F. That is, beginning with a phase difference between A and F of zero 90° will be followed by a mechanical change on a movable system of 90°, a change of 90° in phase will be followed by a corresponding mechanical ch intermediate phase relation, it can be proved that under certain condi of equilibrium assumed by the movable element will exactly represent th That is, with proper design, the mechanical angle between the plane o and also between the plane of F and that of B, is always equal to the ph the current flowing in F and those in A and B respectively. **As commerci** coil F consists of a small laminated iron field magnet with a winding w connected with binding posts. The coils A and B are windings practica laminated iron armature pivoted between the poles of the magnet. Thes joined, and a tap from the junction is brought out through a slip ring t binding posts. The two remaining ends are brought out through two of which is connected to the remaining binding post, through a non-ind the other to the same binding post through an inductive resistanc hand attached to the armature shaft marks the position assumed b

Ques. What is the action of the amortisseur winding?

Ans. Any sudden change in the speed of the field, generates a current in the amortisseur winding which resists the change of velocity that caused the current.

The appearance of an amortisseur winding is shown in the cut below (fig. 2,850) illustrating the field of a synchronous condenser equipped with amortisseur winding.

FIG. 2,850.—General Electric field of synchronous condenser provided with amortisseur winding. Hunting is accompanied by a shifting of flux across the face of the pole pieces due to the variation in the effect of armature reaction on the main field flux as the current varies and the angular displacement between the field and armature poles is changed. Copper short circuited collars placed around the pole face have currents induced in them by this shifting flux, which have such a direction as to exert a torque tending to oppose any change in the relative position of the field and armature. This action is similar to that of the running torque of an induction motor and the damping device has been still further developed until in its best form it resembles the armature winding of a "squirrel cage" induction motor. The pole pieces are in ducts, and low resistance copper bars placed in them with their ends joined by means of a continuous short circuiting ring extending around the field. Such a device has proven very effective in damping out oscillations started from any cause, the same winding doing duty as a damping device and to assist the starting characteristics.

Ques. How are three phase alternators synchronized?

Ans. In a manner similar to the single phase method.

Thus the synchronizing lamps may be arranged as in fig. 2,581, which is simply an extension of the single phase method.

Ques. Are three lamps necessary?

Ans. Only to insure that the connections are properly made *after which one lamp* is all that is required.

Ques. How is it known that the connections of fig. 2,851 are correct?

Ans. If, in operation, the three lamps become bright or dark *simultaneously*, the connections are correct; if, this action take place *successively*, the connections are wrong.

If wrong, transpose the leads of one machine until simultaneou action of the lamps is secured.

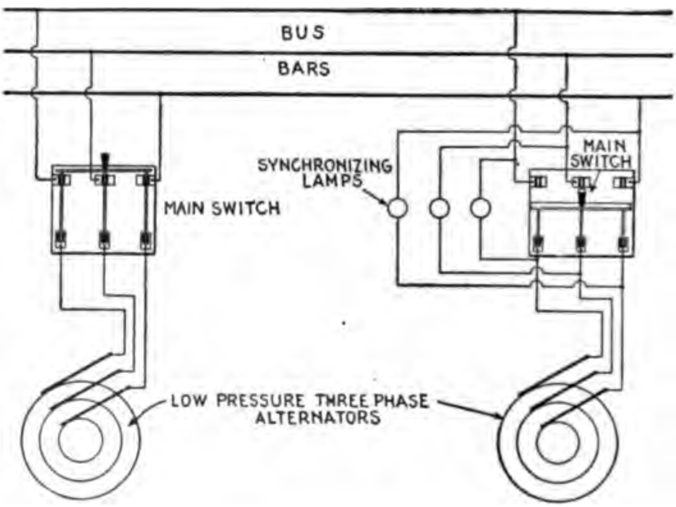


FIG. 2,851.—Method of synchronizing three phase alternators with, three lamps, being extension of the single phase method.

Ques. What is the disadvantage of the lamp methc of synchronizing?

Ans. Lack of sensitiveness.

Ques.* Which is the accepted lamp method, dark** ***brilliant?

Ans. In the United States it is usual to make the connec for a dark lamp at synchronism, while in England the opposite practice obtains.

With the dark lamp method, the breaking of a filament might cause the machines to be connected with a great phase difference, whereas, with the brilliant lamp it is difficult to determine the point of maximum brilliancy. This latter method, therefore may be called the safer.

Ques. What may be used in place of lamps for synchronizing?

Ans. Some form of synchroscopes, or synchronizers.

Ques. How does the Lincoln synchronizer work?

Ans. The construction is such that a hand moves around a dial so that the angle between the hand and the vertical is always the phase angle between the two sources of electric pressure to which the synchronizer is connected.

If the incoming alternator be running too slow, the hand deflects in one direction, if too fast, in the other direction. When the hand shows no deflection, that is, when it stands vertical, the machines are in phase. A complete revolution of the hand indicates a gain or loss of one cycle in the frequency of the incoming machine, as referred to the bus bars.

Cutting Out Alternator.—When it is desired to cut out of circuit an alternator running in parallel with others, the method of procedure is as follows:

1. Reduce driving power until the load has been transferred to the other alternators, adjusting field rheostat to obtain minimum current;
2. Open main switch;
3. Open field switch.

Ques. What precaution should be taken?

Ans. Never open field switch before main switch.

FIG. 2,862.—General Electric 500 kw., horizontal mixed pressure Curtis turbine connected to a 500 kw. dynamo. In a Curtis turbine it is not necessary to use the whole periphery of the first stage for low pressure steam nozzles. A section can be partitioned off and equipped with special expanding nozzles to receive steam at high pressure direct from the boilers. Such nozzles deliver their steam against the same wheel as do the low pressure nozzles, but occupy only a small portion of its periphery. The steam is expanded in these nozzles from high pressure all the way down to the normal pressure of the first stage, and in such expansion acquires a high velocity and consequently contains a great deal of energy—much more than does an equal quantity of low pressure steam. In consequence of this, high pressure steam is used with a far lower water rate than is obtained with low pressure steam, or with high pressure steam reduced to low pressure in a reducing valve. This construction is called "mixed pressure." Its function is the same as that of the reducing valve, that is, it makes up for a deficiency of low pressure steam by drawing direct on the boilers. With this construction, the full power of the turbine can be developed with: All low pressure steam, all high pressure steam, or, any necessary proportion of steam of each pressure. [illegible] from all low pressure to all high pressure, through all the conditions intermediate between these [illegible] of low pressure steam causes the high pressure

Ques. What is the ordinary method of cutting out an lternator?

Ans. The main switch is usually opened without any preminaries.

Ques. What is the objection to this procedure?

Ans. It suddenly throws all the load on the other alternators, id causes "hunting."

Ques. What forms of drive are especially desirable for mning alternators in parallel, and why?

Ans. Water turbine or steam turbine because of the uniform rque, thus giving uniform motion of rotation.

With reciprocating engines, the crank effect is very variable during the revolution, resulting in pulsations driving the alternator too fast or too slow, and causing cross current between the alternators.

Ques. Is a sluggish, or a too sensitive governor prefable on an engine driving alternators in parallel?

Ans. A sluggish governor.

Alternators in Series.—Alternators are seldom if ever concted in series, for the reason that the synchronizing tendency culiar to these machines causes them to oppose each other and ll out of phase when they are joined together in this way. If, wever, they be directly connected to each other, or to an gine, so that they necessarily keep in phase at all times, and

NOTE.—According to the practice of the General Electric Co., 2½ degrees of phase erence from a mean is the limit allowable in ordinary cases. It will, in certain cases, be sible to operate satisfactorily in parallel, or to run synchronous apparatus from machines ose angular variation exceeds this amount, and in other cases it will be easy and desirable obtain a better speed control. The 2½ degree limit is intended to imply that the maximum arture from the *mean position during* any revolution shall not exceed 2½ ÷ 360 of an angle esponding *to two poles of a machine.* The angle of circumference which corresponds to *2½ degree of phase variation* can be ascertained by dividing 2½ by ½ the number of *thus, in a 20 pole machine,* the allowable angular variation from the mean would b *10 = ¼ of one degree.*

thus add their respective voltages instead of counteracting t series operation is possible.

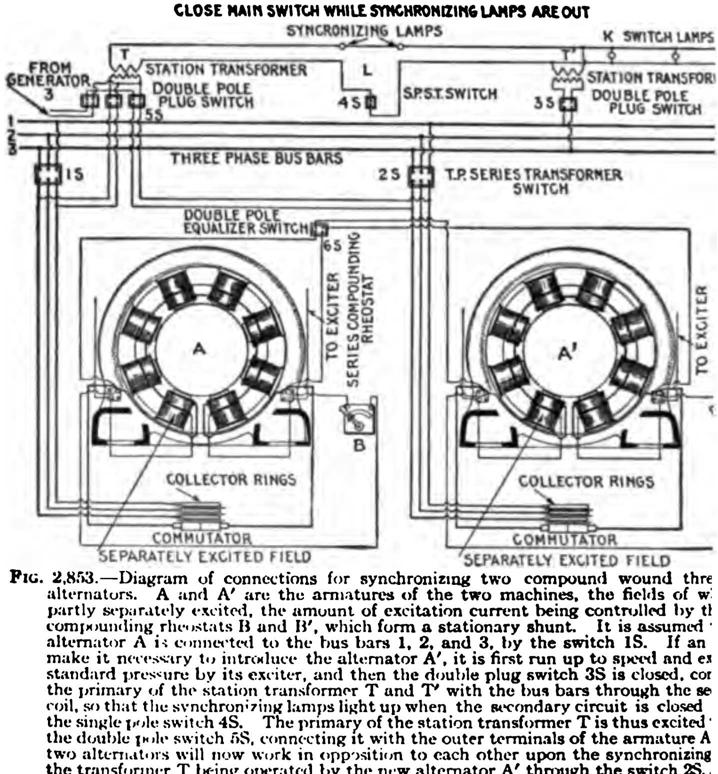


FIG. 2,853.—Diagram of connections for synchronizing two compound wound thre alternators. A and A′ are the armatures of the two machines, the fields of w partly separately excited, the amount of excitation current being controlled by tl compounding rheostats B and B′, which form a stationary shunt. It is assumed alternator A is connected to the bus bars 1, 2, and 3, by the switch 1S. If an make it necessary to introduce the alternator A′, it is first run up to speed and ex standard pressure by its exciter, and then the double plug switch 3S is closed, cor the primary of the station transformer T and T′ with the bus bars through the se coil, so that the synchronizing lamps light up when the secondary circuit is closed the single pole switch 4S. The primary of the station transformer T is thus excited the double pole switch 5S, connecting it with the outer terminals of the armature A two alternators will now work in opposition to each other upon the synchronizing the transformer T being operated by the new alternator A′ through the switch 2S, transformer T′ being operated by the working alternator A, from the bus bars. new alternator be not in step with the working alternator, the synchronizing lamps w growing brighter and dimmer alternately with greater or lesser rapidity. In this c armature speed of the new alternator must be controlled in such a manner that the bı ing and dimming will occur more and more slowly, until the lamps cease to glow or extinguished for a decided interval of time. The extinction of the light is due to th pearance of the secondary current, and indicates that the alternators are in step. The 2S should now be thrown, thus coupling the two machines electrically, and both will continue to operate in step. The double pole equalizer switch 6S should now b connecting the two field windings in parallel and equalizing the compounding, s variations of load will affect the two alternators equally. After the alternator connected in parallel, the switches 4S and 5S, may be opened leaving the swit to operate the switchboard lamps K, K, as pilot lights from the bus bars.

Transformers.—These as a whole are simple in construction, high in efficiency and comparatively inexpensive. Their principles of operation are also readily understood.

The efficiency of a transformer, that is, the ratio between full load primary and full load secondary is greatest when the load on it is such that the sum of the constant losses equals the sum of the variable losses.

In general, transformers designed for high frequencies and large capacities are more efficient than those designed for low frequencies and small capacities. As a whole, however, a transformer leaves but little to be desired as regards efficiency. A modern 60 cycle transformer of 50 kilowatts capacity or more possesses an efficiency of approximately 98 per cent. at full load and an efficiency of about 97 per cent. at half load.

Ques. How should a transformer be selected, with respect to efficiency?

Ans. One should be chosen whose parts are so proportioned that the point of maximum efficiency occurs at that load which the transformer usually carries in service.

In many alternating current installations, comparatively light loads are carried the greater part of the time, the rated full load or an overload being occurrences of short durations. For such purposes special attention should be given to the designing or selecting of transformers having low core losses rather than low resistance losses, because the latter are then of relatively small importance.

Ques. What kind of efficiency is the station manager interested in?

Ans. The "all day efficiency."

This expression, as commonly met with in practice, denotes *the percentage that the amount of energy actually used by the consumer is of the total energy supplied to his transformer during 24 hours.* The formula for calculating the all day efficiency of a transformer is based upon the supposition that the amount of energy used by the consumer [illegible]

[redacted]

24 hours is equivalent to full load on his transformer during five hours and is as follows:

$$E = \frac{5w}{24c + 5r + 5w}$$

where

E = the all day efficiency of the transformer,
w = the full load in watts on the primary,
c = the core loss in watts,
r = the resistance loss in watts.

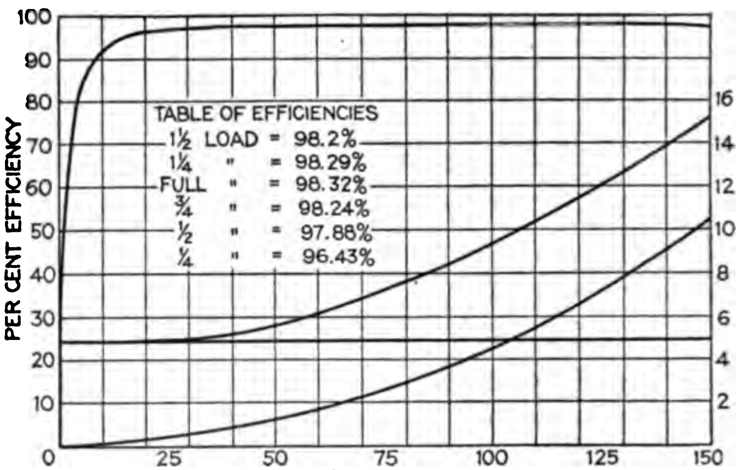


FIG. 2,854.—Performance curves of Westinghouse air blast 550 kw, 10,500 volt transformer. 3,000 alternations.

Ques. What are the usual all day efficiencies?

Ans. The average is about 85 per cent. for those of 1 kilowatt capacity, 92 per cent. for those of 5 kilowatts capacity, 94 per cent. for those of 10 kilowatts capacity, and about 94.5 per cent for those of 15 kilowatts capacity.

***Ques.* What becomes of the energy lost by a transformer?**

Ans. It reappears as heat in the windings and core.

This heat not only increases the resistances of the windings and core, producing thereby a further increase of their respective losses, but in addition causes in time a peculiar effect on the iron core which is intensified by the reversals of magnetism constantly going on within it.

After about two years' service, the iron apparently becomes fatigued or tired, and this phenomenon is called aging of the iron. Since the life of the transformer depends to a great extent upon this factor, the conditions responsible for its existence should as far as possible be removed. Means must therefore be provided in the construction to radiate the heat as quickly as it is generated.

Ques. What kind of oil is used in oil cooled transformers?

Ans. Mineral oil.

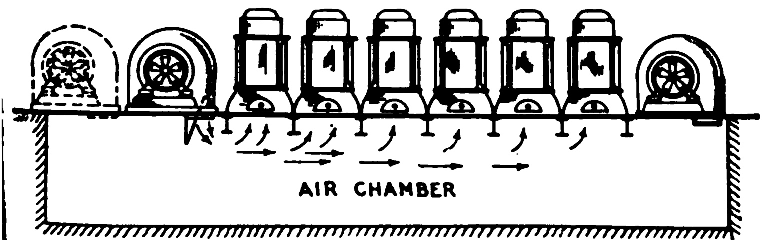


FIG. 2,856.—General arrangement of air blast transformers and blowers.

Ques. How is it obtained?

Ans. By fractional distillations of petroleum unmixed with any other substances and without subsequent chemical treatment.

Ques. What is the important requirement for transformer oil?

Ans. It should be free from moisture, acid, alkali or sulphur compounds.

Ques. How may the presence of moisture be determined?

Ans. By thrusting a red hot iron rod in the oil; if it "crackles" *moisture is present.*

Ques. Describe the Westinghouse method of drying oil.

Ans. It is circulated through a tank containing lime, and afterwards, through a dry sand filter.

Ques. What is the objection to heating the oil (raising its temperature slightly above boiling point of water) to remove the moisture?

Ans. The time consumed (several days) is excessive.

FIG. 2,856.—Small Curtis turbine generator set as made by the General Electric Co., in sizes from 5 kw., to 300 kw. It can be arranged to operate either condensing or non-condensing, and at any steam pressure above 80 lbs. for the smaller sizes and 100 lbs. for the larger. There are only two main bearings. A thrust bearing, consisting of roller bearings and running between hardened steel face washers located at either end of the main bearings is provided solely for centering the rotor so as to equalize the clearance. A centrifugal governor is provided (in the smaller sizes) completely housed, and mounted directly on the main shaft end. It controls a balanced poppet valve through a bell crank. In the larger sizes (75 kw. and above) the governor is mounted on a vertical secondary shaft geared to the main shaft and controls a cam shaft which opens or closes a series of valves in rotation, admitting the steam to different sections of the first stage nozzles. In this way throttling of the steam is avoided. There is also an emergency governor which closes the throttle valve in the event of the speed reaching a predetermined limit. The speeds of operation range from 5,000 R.P.M. for the smallest size to 1,500 R.P.M. for the largest. The lubrication system is enclosed and is automatic. Air leakage where the shaft passes through the wheel casing is prevented by steam seal.

Ques. What effect has moisture?

Ans. It reduces the insulation value of the oil. .06 per cent. of moisture has been found to reduce the dielectric strength of oil about 50 per cent. "dry" oil will withstand a pressure of 25,000 volts between two 9½ inch knobs separated .15 inch.

Ques. What is understood by transformer regulation

Ans. It is the difference between the secondary voltage ɛ io load and at full load, and is generally expressed as a peı ɛentage of the secondary voltage at no load.

Ques. What governs its value?

Ans. The resistance and reactance of the windings.

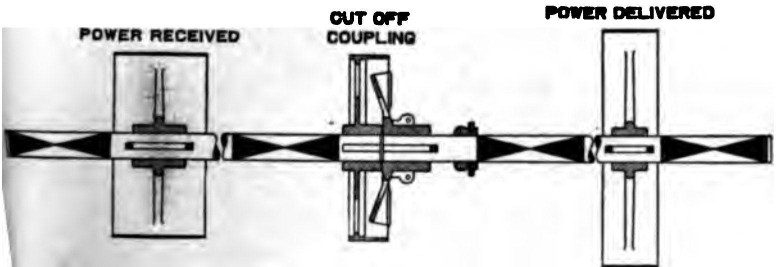


FIG. 2,857.—Cut off coupling for power transmission by line shafting. It is used to cut off a driving shaft from a driven shaft. Its use obviates the use of a *quill*, such as is shown in fig. 2,858.

Ques. How may the regulation be improved?

Ans. By decreasing the resistances of the windings by embying conductors of greater cross section, or decreasing their ɜctance by dividing the coils into sections and closely intersing those of the primary between those of the secondary.

NOTE.—*The term "regulation"* as here used is synonymous with "drop." The *voltage* n a transformer denotes the drop of voltage occurring across the secondary terminals of a ormer with load. This drop is due to two causes: 1, the resistance of the windings; and reactance or magnetic leakage of the windings. On non-inductive load, the reactive drop, n quadrature, produces but a slight effect, but on inductive loads it causes the voltage , and on *leading current loads* it causes the voltage to rise. As the voltage drop of a good mer is very small even on inductive load, direct accurate measurement is difficult. ıt to measure the copper loss with short circuited secondary by means of a wattmeter, he same time the voltage required to drive full load current through. From the watts, tance drop can be found, and from this and the impedence voltage, the reactive drop calculated. From these data a simple vector diagram will give, near enough foı all purposes, the drop for any power factor, or the following formula may be used which deduced from *the vector diagram.* $D = \sqrt{(W + X)^2 + (R + P)^2} - 100$ where R = % *drop; X = % reactive drop; P = %* power factor of load; W = % wattless factor of *- P²); D = % resultant* secondary drop. For non-inductive loads where P = 100 and $\sqrt{X^2 + (100 + R)^2} - 100$. In the case of leading currents it should be consider

In transformers where there is a great difference in voltage t the primary and secondary windings, however, this remedy limitations on account of the great amount of insulation whic necessarily be used between the windings, and which therefore the distances between them to become such as to cause cons leakage of the lines of force.

Ques. How does the regulation vary for difl transformers, and what should be the limit?

Ans. Those of large capacity usually have a better regı

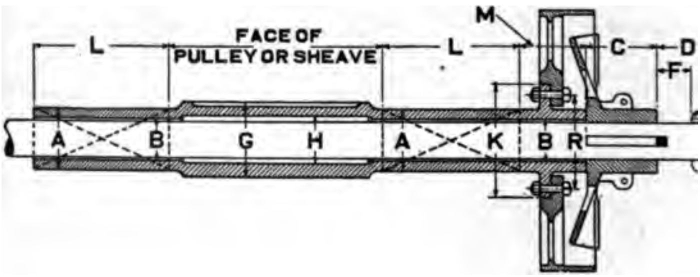


FIG. 2,858.—Quill drive. This is the proper transmission arrangement substitute i service, requiring large pulleys, sheaves, gears, rotors, etc. It is a hollow shaft by independent bearings. The main driving shaft running through the quill i lieved of all transverse stresses. The power is transmitted to the quill by m friction or jaw clutch. When the clutch is thrown out the pulley or sheave stand the driving shaft revolves freely within the quill. As there is no contact betwee parts there is no wear. Jaw clutches should be used for drives demanding positiv displacement. They can only be thrown in and out of engagement when at rest. large clutch pulleys, sheaves, or gears designed to run loose on the line shaft are mounted on quills. The letters A, B, C, etc., indicate the dimensions to be s ordering a quill.

than those of small capacity, but in no case should its va ceed 2 per cent.

Ques. What advantages have shell type transfo over those of the core type?

Ans. They have a larger proportion of core surface e for radiation of heat, and a shorter magnetic circuit w duces the tendency for a leakage of the lines of force in

Both types have advantages and disadvantages as compared with the other. In the shell type, there is less magnetic leakage, but also less surface exposed for radiation, and greater difficulty in providing efficient insulation between the two circuits; in the core type there is more surface exposed for radiation and less difficulty in insulating the windings, but there is also a great leakage of the lines of magnetic force into the outer air.

Ques. How are the windings usually arranged?

Ans. As a rule, there is only one primary winding but the econdary winding is generally divided into two equal sections, ie four terminals of which are permanently wired to four conection blocks which may be connected so as to throw the econdary sections either in parallel or in series with each other t will.

Ques. What is necessary for satisfactory operation of ransformers in parallel?

Ans. They must be designed for the same pressures and apacities, their percentages of regulation should be the same nd they must have the same polarity at a given instant.

One may satisfy himself as to the first of these conditions by examining the name plates fastened to the transformers, whereon are stamped the values of the respective pressures and capacities of each.

Although equal values of regulation is given as one of the conditions to be satisfied, transformers may be operated in parallel when their percentages of regulation are not the same. Ideal operation, however, can be attained only under the former state of affairs. Suppose, for instance, a transformer having a regulation of two per cent. be operated in parallel with another of similar size and design but having a regulation of one per cent. The secondary pressures of these transformers at no load will of course be the same, but at full load if the secondary pressure of the one be 98 volts, that of the other will be 99 volts. There will, therefore, be a difference of pressure of one volt between them which will tend to force a current backward through the secondary winding of the transformer delivering 98 volts. This reversed current, although comparatively small in value, lowers the efficiency of the installation by causing a displacement of phase and a decrease in the combined power factor of the transformers.

Ques. Describe the polarity test.

Ans. The test for polarity consists in joining to; means of a fuse wire, a terminal of the secondary w each transformer, and then with the primary winding: with normal voltage, connecting temporarily the terminals of the secondary windings. The melting of wire thus connected indicates that the secondary joined together are of opposite polarities, and that the cc

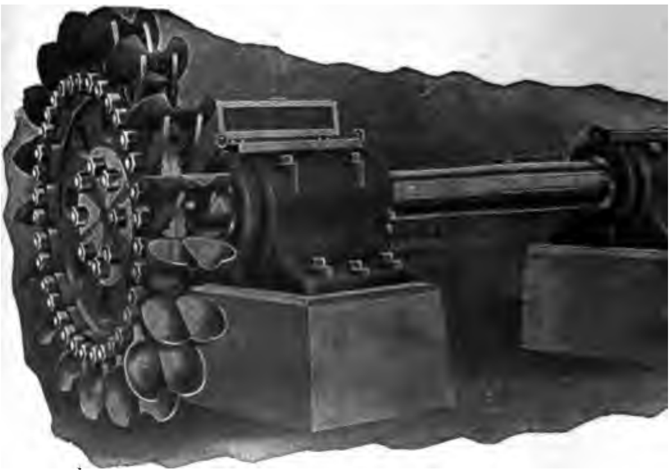
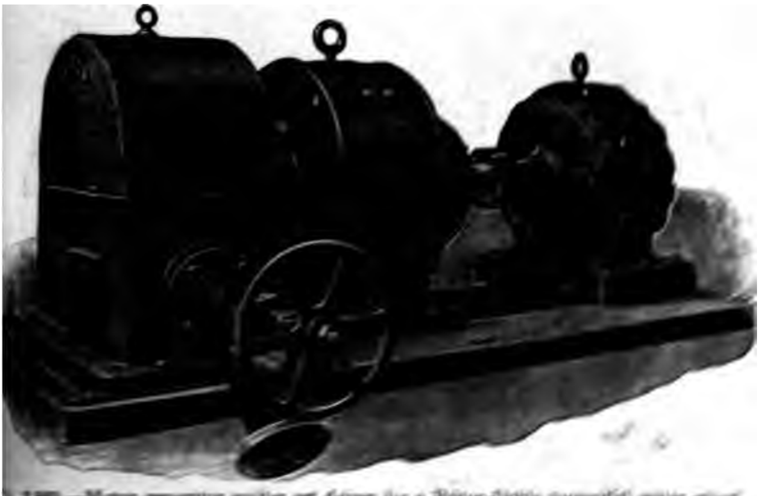


FIG. 2,859.—Single overhung tangential water wheel equipped with Doble ell ets. The central position of the front entering wedge or lip of the bucket the form of a semi-circular notch, which allows a solid circular water jet to d the central dividing wedge of the bucket without being split in a horizonta

must therefore be reversed, whereas if the fuse wire do it shows that the proper terminals have been joined *the* connections may be made permanent.

The object of this test is, obviously, not to determi polarity of each secondary terminal, but merely to ind them are of the same polarity.

Motor Generators.—In motor generator sets, either the
ınt or series wound type of motor may be employed at the
wer producing end of the set, but the field of the generator
either shunt or compound wound, depending upon whether
not it is desired to maintain or to raise the secondary voltage
ar full load. In either case a rheostat introduced in the shunt



this means ample space surrounds all of the working parts, and repairs can readily be made.

Motor generators are frequently used as boosters to raise or boost the voltage near the extremities of long distance, direct current transmission lines. Of these, electric railway systems in which it is desired to extend certain of the longer lines, form a typical example.

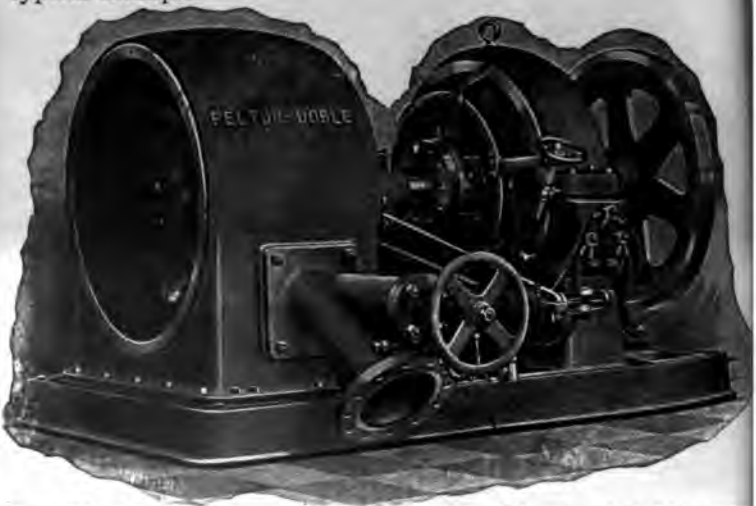


FIG. 2,861.—Automatically governed Pelton-Doble tangential water wheel driving exciter dynamo. The water wheel is mounted on one end of the shaft, while the opposite end is extended to carry a fly wheel of suitable design to compensate for the low fly wheel effect of the direct current armature. Two bearings support the shaft which carries the rotating elements of the unit. A needle nozzle actuated by a direct motion Pelton-Doble governor (designed for operation by either oil or water pressure) maintains constant speed.

Owing to the great cost of changing such a system over to one employing alternating current, or storage batteries, or of constructing an additional power station, these solutions of the problem are usually at variance with good judgment and the amount of money at hand. The choice then remains between the purchase of additional wire for feeders, the connection of a ooster in the old feeders, or the installation of both larger eders and a booster. Of these, it is generally found that either ie second or the third mentioned alternative meets the contions most satisfactorily.

A booster installed in a railway system for the purpose just mentioned, would have a series wound motor, and the conditions to which it must conform would be as follows: The motor having a series winding must provide for the full feeder current passing through both armature and field windings.

Owing to the varying loads on a railway system, due to the frequent starting and stopping of cars, the feeder current varies between zero and some such value as 150 amperes. This fluctuation of current through the field winding will, in ordinary cases, vary the magnetization of the pole pieces from zero almost to the point of saturation; that is, the maximum feeder current will so nearly fill the magnet cores with lines of force that it would be quite difficult to cause more lines of magnetic force to pass through them.

So long as the point of saturation is not reached, however, the proportion of current to field strength remains constant, and therefore the ratio of amperes to volts will not vary.

The severe fluctuations of the feeder current would, if the motor were shunt or compound wound, cause most serious sparking and various other troubles, but in a series motor where the back ampere turns on the armature that react on the field vary in precisely the same proportion as the ampere turns in the field, there exists at all times a tendency to balance the active forces and produce satisfactory operation. If, however, the field magnet cores be very large, they cannot so quickly respond, magnetically, to changes in the strength of the current, and there is then greater liability of the armature reaction momentarily weakening the field and thereby producing temporary sparking.

Ques. Are motor generators always composed of lrect current sets?

Ans. No.

Ques. Describe conditions requiring a different comination.

Ans. For purposes where for instance direct currents of widely fferent voltages are to be obtained from an alternating current cuit, and it is desired to install but one set, a motor generat consisting of an alternating current motor such as an induction motor, and a dynamo must necessarily be employed.

In such sets, it is common to find both motor and dynamo armatures mounted on a common shaft, and the respective field frames resting on a single base, although for connection on a very high pressure alternating current circuit, separate armature shafts insulated from each other but directly connected together, and separate bases resting on a single foundation, are usually employed to afford the highest degree of insulation between the respective circuits of the two machines.

Ques. What is the objection to a set composed of alternating current motor and alternator?

Ans. The commercial field that would be naturally covered by such a set is better supplied by a transformer.

Ques. Why?

Ans. Because a transformer contains no moving parts, and is therefore simpler in construction, cheaper in price, and less liable to get out of order.

Dynamotors.—A dynamotor differs from a motor generator in that the motor armature and the generator armature are combined into one, thereby requiring but one field frame. Since the motor and generator armature windings are mounted on a single core, the armature reaction due to the one winding is neutralized by the reaction caused by the other winding. There is, consequently, little or no tendency for sparking to occur at the brushes, and they therefore need not be shifted on this account for different loads.

Ques. How is a dynamotor usually constructed?

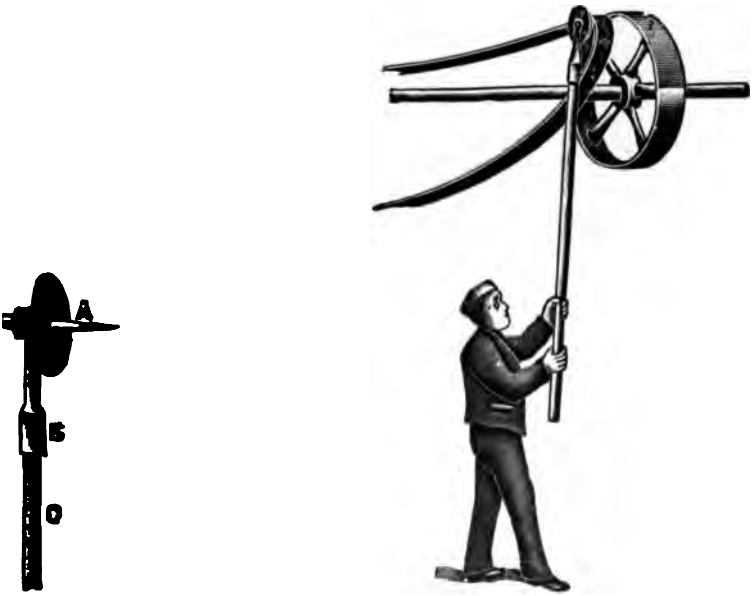
Ans. It is usually built with two pole pieces which are shunt *wound.*

Ques. Why does the voltage developed fall off slightly under an increase of load?

Ans. Because a compound winding cannot be provided.

Ques. Describe the armature construction and operation.

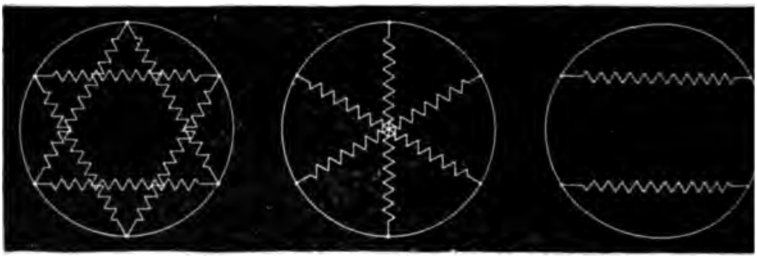
Ans. It consists of two separate windings; one of which is



FIGS. 2,862 and 2,863.—Method of putting on belts when the driver is in motion, and device used. The latter is called a *belt slipper*, and consists, as shown in fig. 2,862, of a cone and shield, which revolve upon the stem, B, thus yielding easily to the pull of the belt. A staff or handle C of any convenient length can be fastened to the socket. The mode of operation is illustrated in fig. 2,863, which is self explanatory.

joined to a commutator mounted on one side of the armature for motor purposes, and the other to the commutator on the *other side of the* armature for generator purposes.

By means of two studs of brushes pressing on the motor commuta-current from the service wires is fed into the winding connected this commutator, and since the shunt field winding is also excit by the current from the service wires, there is developed in the generat winding on the rotating armature a direct voltage which is pı portional to the speed of rotation of the armature in revolutions ı



FIGS. 2,864 to 2,866.—Converter connections; fig. 2,864 double delta connection; fig. 2,865 d metrical connection; fig. 2,866 two circuit single phase connection. For six phase synch nous converter, two different arrangements of the connections are generally used. One called the *double delta*, and the other the *diametrical* connection. Let the armature wir ing of the converter be represented by a circle as in figs. 2,864 and 2,865, and let the ı equidistant points on the circumference represent collector rings, then the secondary the supply transformers can be connected to the collector rings in a *double delta* as fig. 2,864, or across diametrical pairs of pointer as in fig. 2,865. In the first instan the voltage ratio is the same as for the three phase synchronous converter and simp consists of two delta systems. The transformers can also be connected in double sta and in such a case the ratio between the three phase voltage between the terminals each star, and the direct voltage will be the same as for double delta, while the vol age of each transformer coil, or voltage to neutral, is $1 \div \sqrt{3}$ times as much. Wi the diametrical connection, the ratio is the same as for the two ring single pha converter, it being analogous to three such systems. Hence six phase double delt $E_1 = \sqrt{3}E \div 2\sqrt{2} = .612E$. Six phase diametrical, $E_1 = E \div \sqrt{2} = .707E$. The ratio o the virtual voltage E_0 between any collector ring and the neutral point is alway $E_0 = E \div 2\sqrt{2} = .354E$. For single phase synchronous converters, consisting of a close circuit armature winding tapped at two equidistant points to the two collector ring the virtual voltage is $1 \div \sqrt{2} \times$ the direct current voltage. While such an arrangement of the single phase converter is the simplest, requiring only two collector rings, it is undesirable, especially for larger machines, on account of excessive heating of the armature conductors. In fig. 2,866, which represents the armature winding of a single phase converter, the supply circuits from two secondaries of the step down transformers are connected to four collector rings, so that the two circuits are in phase with each other, but each spreads over an arc of 120 electrical degrees instead of over 180 degrees as in the single phase circuit converter. To distinguish the two types, it is generally called a two circuit single phase synchronous converter. The virtual voltage E_2 bears to the direct voltage the same relation as in the three phase converter, that is single phase two circuit, $E_1 = \sqrt{3} \div 2\sqrt{2} = .612E$.

second, the number of conductors in series which constitute the generator winding, and the total strength of the field in which the armature revolves. This pressure causes current to pass through the generator winding and the distributing circuit when the distributing circuit which this winding is connected by means of its respective commuta brushes, etc., is closed.

Ques. How is a dynamotor started?

Ans. It is connected at its motor end and started in the same manner as any shunt wound motor on a constant pressure circuit.

Ques. What precautions should be taken in starting a dynamotor?

Ans. The necessary precautions are, to have the poles strongly magnetized before passing current through the motor winding on the armature; to increase gradually the current through this winding, and not to close the generating circuit until normal conditions regarding speed, etc., are established in the motor circuit.

Ques. How is the current developed in the machine regulated?

Ans. It can be regulated by the introduction of resistance in one or the other of the armature circuits, or by a shifting of the brushes around the commutator.

Ques. Are dynamotors less efficient than motor generators of a similar type?

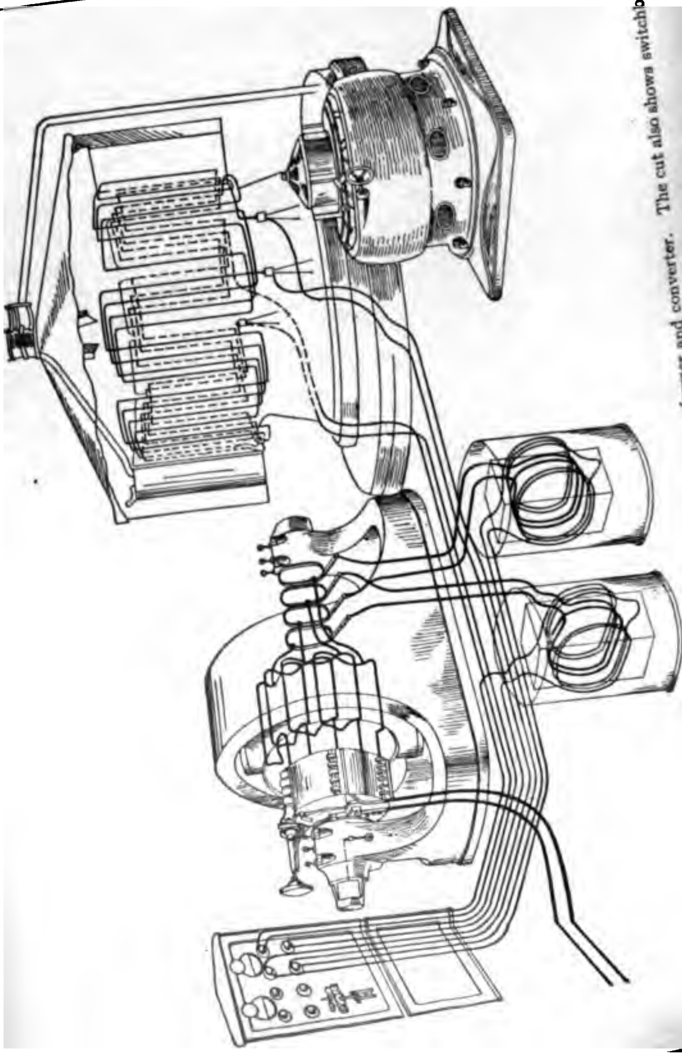
Ans. No, they are more efficient.

Ques. Why?

Ans. Because they have only one field circuit and at least one bearing less than a motor generator.

A motor generator has at least three bearings, and occasionally, four, where the set consists of two independent machines directly connected together.

Rotary Converters.—An important modification of the *dynamotor is the rotary* converter. This machine forms, as it *were, a link between* alternating and direct current systems.



...howing wiring of alternator, exciter, transformer and converter. The cut also shows switchboard eing in general a combination of an alternating current motor nd a dynamo.

It has practically become a fixture in all large electric railway ystems and in other installations where heavy direct currents f constant pressure are required at a considerable distance rom the generating plant. In such cases a rotary converter is nstalled in the sub-station, and being simpler in construction, higher in efficiency, more economical of floor space, and lower in price than a motor generator set consisting of an alternating current motor and a dynamo which might be used in its place, it has almost entirely superseded the latter machine for the class of work mentioned.

Ques. What is the objection to the single phase rotary converter?

Ans. It is not self-starting.

Ques. What feature of operation is inherent in a rotary converter?

Ans. A rotary converter is a reversible machine.

That is to say, if it be supplied with direct current of the proper voltage at its commutator end, it will run as a direct current motor and deliver alternating current to the collector rings. While this feature is sometimes taken advantage of in starting the converter from rest, the machine is not often used permanently in this way, its commercial application being usually the conversion of alternating currents into direct currents.

Ques. How does a rotary converter operate when driven by direct current?

Ans. The same as a direct current motor, its speed of rotation depending upon the relation existing between the strength of the field and the direct current voltage applied.

If the field be weak with respect to the armature magnetism resulting from the applied voltage, the armature will rotate at a high speed, increasing until the conductors on the armature cut the [illegible] force in the field so as to develop a voltage which will be equal to that applied.

Again, if the field be strong with respect to the armature magnetism, resulting from the applied voltage, the armature will rotate at a low speed. If, therefore, it be desired to operate the converter in this manner and maintain an alternating current of constant frequency, the speed of rotation must be kept constant by supplying a constant voltage not only to the brushes pressing on the commutator, but also to the terminals of the field winding.

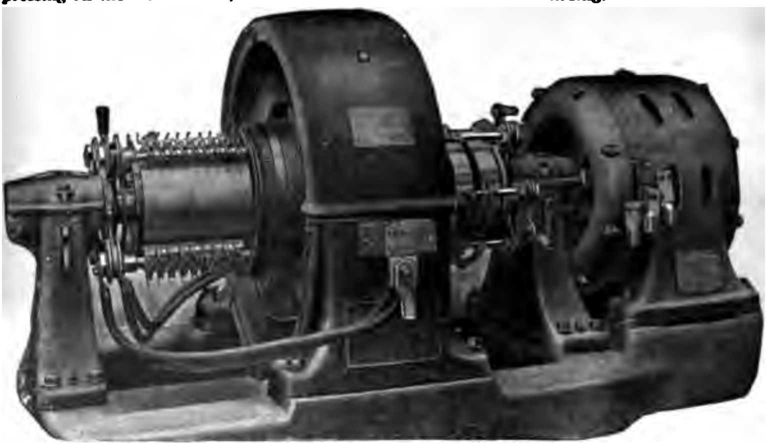


FIG. 2,868.—General Electric synchronous converter with series booster. This type of converter generally consists of an alternator with revolvong field mounted on the same shaft as the converter armature. The armature of the alternator, or booster, as it is usually called, is stationary and connected electrically in series between the supply circuit and the collector rings of the synchronous converter. The booster field has the same number of poles as the converter and is generally shunt wound. A change in the booster voltage will correspondingly change the alternating voltage impressed on the converter and this regulation can, of course, be made so as to either increase or decrease the impressed voltage by means of strengthening or weakening the booster field. The voltage variation can be made either non-automatic or automatic, and in the latter case, it becomes necessary to provide a motor operated rheostat controlled by suitable relays, or the booster can be provided with a series field. By means of a booster, it is possible to vary the direct voltage of the converter with a constant alternating supply voltage, and this voltage regulation is obtained without disturbance of the power factor or wave shape of the system. Synchronous converters are frequently installed in connection with Edison systems, where three wire direct current is required. The three wire feature is obtained either by providing extra collector rings and compensator, as with ordinary direct current generators, or also by connecting the neutral wire directly to the neutral point of the secondary winding of step down transformers, if such be furnished.

Ques. How does it operate with alternating current drive?

Ans. The same as a synchronous motor.

Ques. What is the most troublesome part and why?

Ans. The commutator, because of the many pieces of which it is composed and the necessary lines along which it is constructed, its peripheral speed must be kept within reasonable limits.

Ques. What should be the limit of the commutator speed?

Ans. The commutator speed, or tangential speed at the brushes should not exceed 3,000 feet per minute.

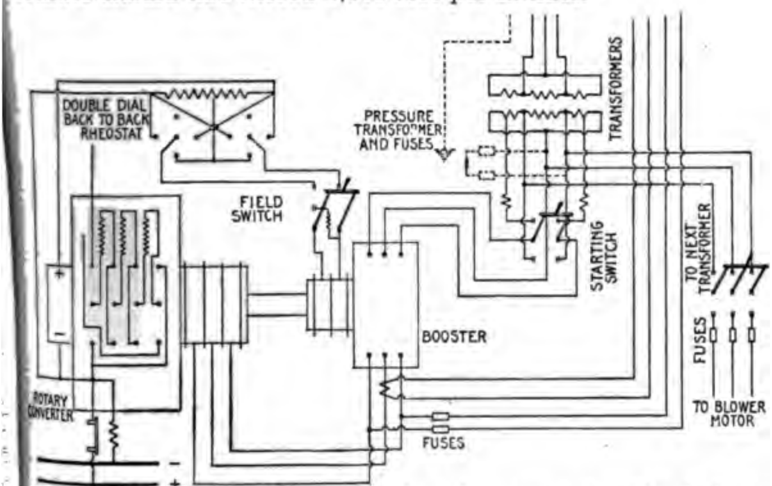


FIG. 2,869.—Wiring diagram for General Electric synchronous converter with series booster as illustrated in fig. 2,868.

Ques. Name another limitation necessary for satisfactory operation.

Ans. The pressure between adjacent commutator bars should not exceed eight or ten volts.

If the commutator bars be made narrow in order to obtain the necessary number for the desired voltage with the minimum circumference and therefore low commutator speed, the brushes employed to collect the current are liable to require excessive width in order to provide the proper cross section and yet not cover more than two bars at once.

Ques. How can the commutator speed be kept within reasonable limits, other than by reducing the width of the commutator bars?

Ans. By using alternating current of comparatively low frequency.

For a rotary converter delivering 500 volt direct current, the proper frequency for the alternating current circuit has been found to be 25 cycles per second.

Ques. When a rotary converter is operated in the usual manner on an alternating current circuit, how can the direct current be varied?

Ans. It may be varied (from zero to a maximum) by changing the value of the alternating pressure supplied to the machine, or it may be altered within a limited range by moving the brushes around the commutator, or in a compound wound converter by changing the amount of compounding.

Under ordinary conditions, varying the voltage developed by changing the voltage at the motor end is not practical, hence the voltage developed can be varied only over a limited range. In addition to this, the voltage developed at the direct current end bears always a certain constant proportion to the alternating current voltage applied at the motor end; this is due to the same winding being used both for motor and generator purposes. In all cases the proportion is such that the alternating current voltage is the lower, being in the single phase and in the two phase converters about .707 of the direct current voltage, and in the three phase converter about .612 of the direct current voltage. It is thus seen that whatever value of direct current voltage be desired, the value of the applied alternating current voltage must be lower, requiring in consequence the installation of step down transformers at the sub-station for reducing the line wire voltage to conform to the direct current pressure required.

Ques. What is the efficiency of a rotary converter?

Ans. It may be said to have approximately the same *efficiency* as that in the average of the same output, although *in reality* the converter is a trifle more efficient on account of affording a somewhat shorter average path for the current in the armature, reducing in consequence the resistance loss and the armature reaction.

Ques. May a converter be overloaded more than a dynamo of the same output, and why?

Ans. Yes, because there is usually less resistance loss in the armature of the converter than in the armature of the dynamo.

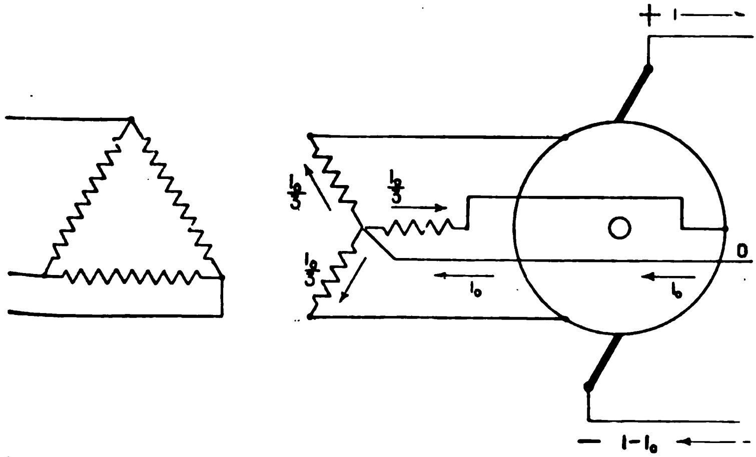


FIG. 2,870.—Wiring diagram for three wire synchronous converter with delta-Y connected step down transformer with the neutral brought out. It is evident that in this case each transformer secondary receives ⅓ of the neutral current, and if this current be not so small, as compared with the exciting current of the transformer, it will cause an increase in the magnetic density.

Thus, a two phase converter may be overloaded approximately 60 per cent., and a three phase converter may be overloaded about 30 per cent. above their respective outputs if operated as dynamos.

Ques. Describe how a converter is started.

Ans. There are several methods any one of which may be employed, the choice in any given case depending upon which of them may best be followed under the existing conditio

If it be found advisable to start the converter with direct current, the same connections would be made between the source of the direct current and the armature terminals on the commutator side of the converter as would be the case were a direct current shunt motor of considerable size to be started; this naturally means that a starting rheostat and a circuit breaker will be introduced in the armature circuit.

The shunt field winding alone is used, and this part of the wiring may be made permanent if, as is usually the case, the same source of direct current is used normally for separate field excitation.

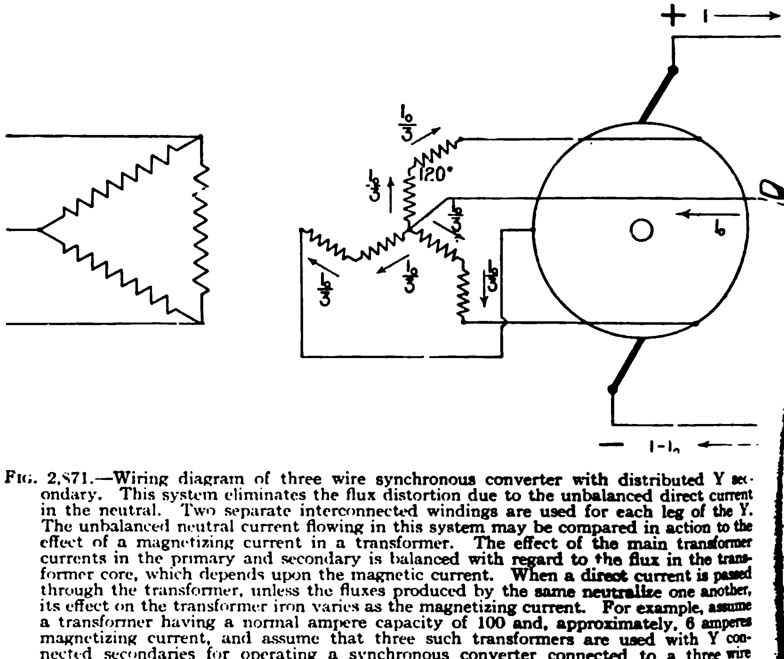


FIG. 2,871.—Wiring diagram of three wire synchronous converter with distributed Y secondary. This system eliminates the flux distortion due to the unbalanced direct current in the neutral. Two separate interconnected windings are used for each leg of the Y. The unbalanced neutral current flowing in this system may be compared in action to the effect of a magnetizing current in a transformer. The effect of the main transformer currents in the primary and secondary is balanced with regard to the flux in the transformer core, which depends upon the magnetic current. When a direct current is passed through the transformer, unless the fluxes produced by the same neutralize one another, its effect on the transformer iron varies as the magnetizing current. For example, assume a transformer having a normal ampere capacity of 100 and, approximately, 6 amperes magnetizing current, and assume that three such transformers are used with Y connected secondaries for operating a synchronous converter connected to a three wire Edison system. Allowing 25 per cent. unbalancing, the current will divide equally among the three legs giving 8.33 amperes per leg, which is more than the normal magnetizing current. The loss due to this current is, however, inappreciable, but the increased core losses may be considerable. If a distributed winding be used, the direct current flows in the opposite direction, around the halves of each core thus entirely *neutralizing* the flux distortion. Whether the straight Y connection is to be used is *merely* a question of balancing the increased core loss of the straight Y connection *against* the increased copper loss and the greater cost of the interconnected Y system. *The straight Y connection is much simpler, and it would be quite permissible to use it for transformers of small capacities where the direct current circulating in the neutral is less than 30 per cent. of the rated transformer current.*

[redacted]

The direct current may be derived from a storage battery, from a separate converter, or from a motor generator set installed in the substation for the purpose.

An adjustable rheostat will, of course, be connected in the field circuit for regulation. Before starting the converter, however, it is necessary to do certain wiring between the terminals on the collector side of the machine and the alternating current supply wires, in order that the change over from direct current motive power to alternating current motive power may be made when the proper phase relations are established between the alternating current in the supply wires and the alternating current in the armature winding of the converter.

In order that proper phase relations exist, the armature of the converter must rotate at such a speed that each coil thereon passes its proper reversal point at the same time as the alternating current reverses in the supply wires. This speed may be calculated by doubling t: e frequency of the supply current and then dividing by the number of pole pieces on the converter, but a far more accurate method of judging when the converter is in step or in sy chronism with the supply current consists in employing incandescent lan ps as shown in fig. 2,872.

Ques. How is a polyphase converter started with lternating current?

Ans. This may be done by applying the alternating pressure rectly to the collector rings while the armature is at rest. here need be no field excitation; in fact the field windings on e separate pole pieces should be disconnected from each other fore the alternating voltage is applied to the armature, else high voltage will be induced in the field windings which may ove injurious to their insulation. The passage of the alter-ting current through the armature winding produces a mag-tic field that rotates about the armature core, and induces in e pole pieces eddy currents, which, reacting on the armature, ert a sufficient torque to start the converter from rest and use it to speed up to synchronism.

Ques. How much alternating current is required to art a polyphase converter?

ns. *About 100 per* cent. more than that required for full loa

Ques. How may this starting current be reduced?

Ans. Transformers may be switched into circuit temporari to reduce the line wire voltage until the speed become norma

In conjunction with this method, the method of synchronizing sho in fig. 2,872 may be used, thus, in starting, there is an alternating curr between the brushes which pulsates very rapidly, but when synchroni

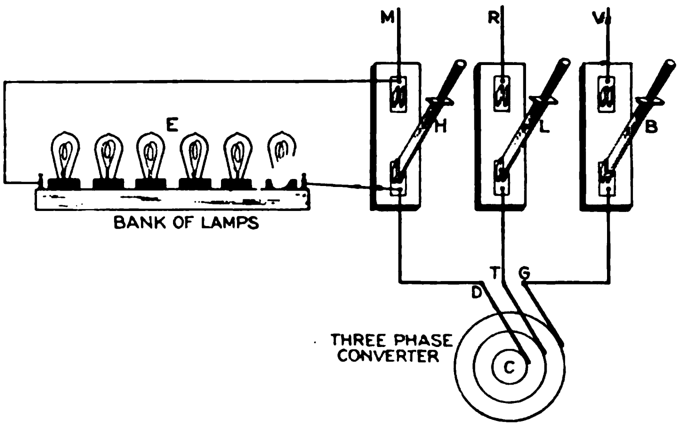


FIG. 2,872.—Wiring diagram showing arrangement of incandescent lamps for determinin the proper phase relations in starting a rotary converter. The alternating current side of three phase converter is shown at C. The three brushes, D, T and G pressing on its collec or rings are joined in order to the three single pole switches H, L and B which can be mad to connect with the respective wires M, R, and V, of the alternating current supply circuit Across one of the outside switches, H, for example, a number of incandescent lamps ar joined in series as indicated at E, while the three pole switch (not shown) in the main cir cuit, between the alternator and the single pole switches is open. If then the main switcl just mentioned and the middle switch L be both closed, and the armature of the alternato be brought up to normal speed by running it as a direct current motor, the lamps at E wil light up and darken in rapid succession; the lighting and darkening of the lamps will con tinue until, by a proper adjustment of the speed, the correct phase relations be establishec between the alternating current in the supply circuit and the alternating current developec in the armature of the converter. As this condition is approached, the intervals betweer the successuve lighting up and darkening of the lamps will increase until they remain per perfectly dark. There is then no difference of pressure between the supply circuit M R V and the rotary converter armature circuit, so the source of the direct current may at that instant be disconnected from the machine, and the switches H and B, closed. If the change over has been accomplished before the phase relations of the two circuits differed the converter will at once conform itself to the supply circuit and run thereon as a synchro nous motor without further trouble. The opening of the direct current circuit and the closing of the alternating current supply circuit may be done by hand, but preferabl by employing a device that will automatically trip the circuit breaker in the direct curr circuit at the instant the switches in the alternating current circuit are closed.

is approached, the pulsations become less rapid until finally with the converter in step with the alternator the pulsations entirely disappear.

The light given by the lamps thus connected indicates accurately the condition of affairs at any one time, varying from a rapidly fluctuating light at the beginning to one of constant brilliancy at synchronism.

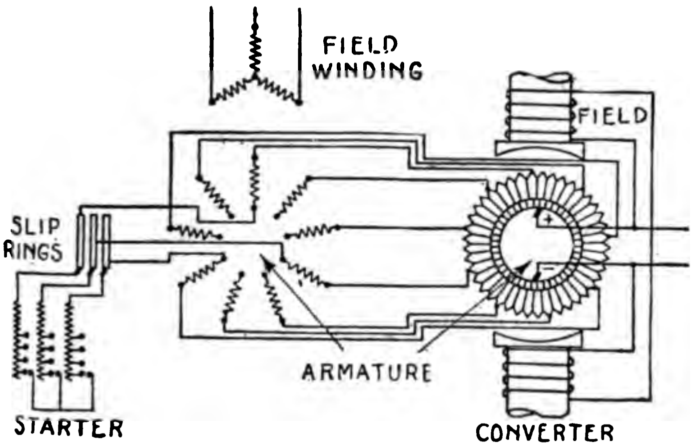


FIG. 2,873.—Diagram of motor converter. This machine which is only to be used for converting from alternating to direct current, consists of an ordinary induction motor with phase wound armature, and a dynamo. The revolving parts of both machines are mounted on the same shaft and from the figure it is seen that the armature of the motor and the armature of the dynamo are also electrically connected. The motor converter is a synchronous machine, but the dynamo receives the current from the armature of the motor at a frequency much reduced from that impressed upon the field winding of the motor. Assuming that the motor and the converter have the same number of pole, the motor will rotate at a speed corresponding to one-half the frequency of the supply circuit. The motor will operate half as a motor and half as a transformer, and the converter, half as a dynamo and half as a synchronous converter, in that one-half of the electrical energy supplied to the motor will be converted into mechanical power for driving the converter, while the other one-half is transferred to the secondary motor windings and thereby to the converter armature in the form of electrical power. The capacity of the motor is theoretically only half what it would be if it were to convert the whole of the electrical energy into mechanical power because the rating depends upon the speed of the rotating field and not on that of the rotor. If the two machines have a different number of pole, or are connected to run at different speeds, the division of power is at a different but constant ratio. The machine starts up as an ordinary polyphase induction motor and the field of the converter is built up as though it were an ordinary dynamo. Motor converters are occasionally used on high frequency systems, as their commutating component is of half frequency, and thus permits better commutator design than a high frequency converter. The advantage of this type of machine is that for phase control it requires no extra reactive coils, the motor itself having sufficient reactance. It is, however, larger than standard converters, but smaller than motor generators, as half the power is converted in each machine. Its efficiency is less than for synchronous converters, and the danger of reaching double speed in case of a short circuit on the direct current side is *very great. It has been* used abroad to some extent for 60 cycle work, in preference to *synchronous converters,* but with the present reliable design of 60 cycle converters, and *the general use of 25 cycles,* where severe service conditions are met, as in railroading *motor converters should* not be recommended.

[redacted]

Ques. If the armature of the starting motor starting resistance, how must this be connected?

Ans. It should be connected in series with the a: inductors before the alternating voltage is applied.

As the motor increases in speed, the starting resistance is short circuited until it is entirely cut out of circuit.

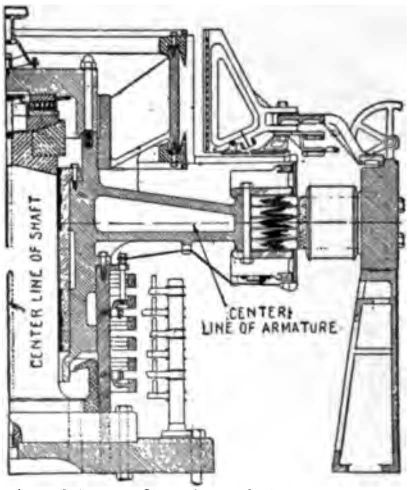


FIG. 2,874.—Sectional view of General Electric vertical synchronous converter. I struction, the field frame carrying the poles is mounted on cast iron pedes split vertically. This allows the two halves of the frame to be separated for or repairs of the armature. The armature, including commutator and coll is mounted on a vertical stationary shaft, which is rigidly supported from the f The thrust of the armature is carried on a roller bearing attached to the top c and upper side of the armature spider. The under side of the lower plate o bearing is made spherical and fits into a corresponding spherical cup on the shaft, making the bearing self aligning. The armature spider has a babbited s the fit of the vertical shaft, which acts as a guide bearing and has to take only due to the unbalancing effect of the rotating parts. A circulating pump furn the roller bearing, the oil draining off through the guide bearing. A marked of this type of construction is the accessibility of the commutator for adjustn brushes, etc., as there is no pit or pedestal bearing to interfere.

NOTE.—Some converters are provided with a small induction motor fo mounted on an iron bracket cast in the converter frame, and whose shaft is keyed the converter. Allowing for a certain amount of slip in the induction motor, the fi machine must possess a less number of magnet poles than the converter in order to latter machine to be brought to full synchronism. To start the induction motor, i necessary to apply to its field terminals the proper alternating voltage. The therefore the motor, is usually mounted outside the armature bearing on the of the converter.

Ques. Describe the usual wiring for the installation of a rotary converter in a sub-station.

Ans. Commencing at the entrance of the high pressure cables, first there is the wiring for the lightning arresters, then for

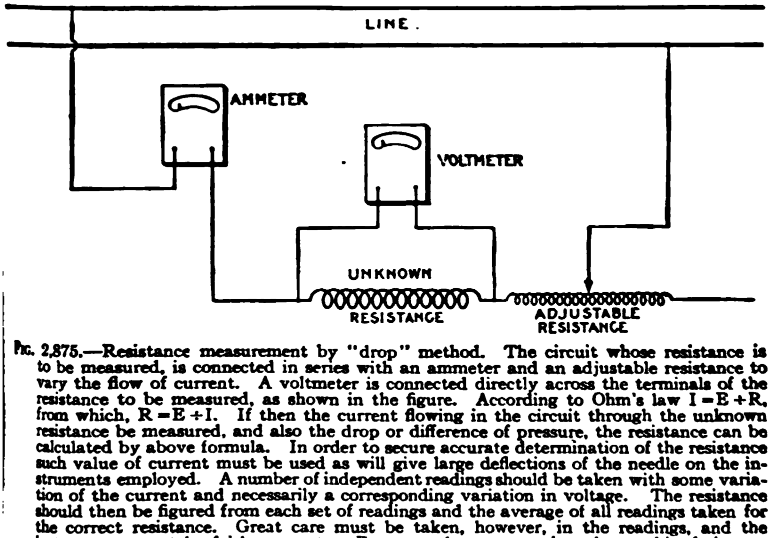
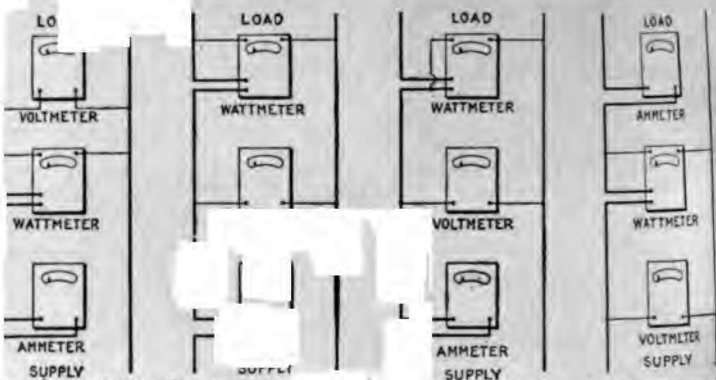


FIG. 2,875.—Resistance measurement by "drop" method. The circuit whose resistance is to be measured, is connected in series with an ammeter and an adjustable resistance to vary the flow of current. A voltmeter is connected directly across the terminals of the resistance to be measured, as shown in the figure. According to Ohm's law $I = E \div R$, from which, $R = E \div I$. If then the current flowing in the circuit through the unknown resistance be measured, and also the drop or difference of pressure, the resistance can be calculated by above formula. In order to secure accurate determination of the resistance such value of current must be used as will give large deflections of the needle on the instruments employed. A number of independent readings should be taken with some variation of the current and necessarily a corresponding variation in voltage. The resistance should then be figured from each set of readings and the average of all readings taken for the correct resistance. Great care must be taken, however, in the readings, and the instruments must be fairly accurate. For example, suppose that the combined instrument error and the error of the reading in the voltmeter should be 1 per cent., the reading being high, while the corresponding error of the ammeter is 1 per cent. low. This would cause an error of approximately 2 per cent. in the reading of the resistance. In making careful measurements of the resistance, it is also necessary to determine the temperature of the resistance being measured, as the resistance of copper increases approximately .4 of 1 per cent. for each degree rise in temperature. Use is made of this fact for determining the increase in temperature of a piece of apparatus when operating under load. The resistance of the apparatus at some known temperature is measured, this being called the cold resistance of the apparatus. At the end of the temperature test the hot resistance is taken. Assume the resistance has increased by 15 per cent. This would indicate a rise in temperature of 37 ½ degrees above the original or cold temperature of the apparatus. Suppose then that in measuring the cold resistance, results are obtained which are 2 per cent. low, and that in measuring the hot resistance, there be 2 per cent error in the opposite direction. This would mean that a total error of 4 per cent. had been made in the difference between the hot and cold resistances, or an error of 10 degrees. The correct rise in temperature is, therefore, about 27 ½ instead of 37 ½ degrees. In other words, an error of *2 per cent. in measuring* each resistance has caused an error of approximately 36 ⅓ *per cent. in the measurement* of the rise in temperature. The constant .4 which has been *used above is only approximate* and should not be used for exact work. For detail *instructions of making* calculations of resistance and temperature, see "Standardization *Rules of the A. I. E. E.*"



GS. 2,876 to 2,879.—How to connect [illegible] power measurement. There are several ways of connecting an ammeter, [illegible] ttmeter in the circuit for the measurement of power. A few of the m[illegible] sed below. With some of the connections it is necessary to correct th[illegible] wattmeter for the losses in the coil, or coils, of the wattmeter, or for losses [illegible] or voltmeter. This is necessary since the instruments may be so connected t[illegible]e wattmeter not only measures the load but includes in its indications some of the instrument losses. If the load measured be small, or considerable accuracy is required, these instrument losses may be calculated as follows: Loss in pressure coil is $E^2 \div R$, in which E is the voltage at the terminals of the pressure coil and R is the resistance. Loss in current coil is $I^2 R$ in which I is the current flowing and R the resistance of the current coil. In general let E_v = voltage across terminals of the voltmeter; E_w = voltage across the terminals of the pressure coil of the wattmeter; I_w = current through current coil of wattmeter; I_a = current through current coil of ammeter; R_v = resistance of pressure coil of voltmeter; R_w = resistance of pressure coil of wattmeter; R'_w = resistance of current coil of wattmeter; R_a = resistance of current coil of ammeter. Then the losses in the various coils will be as follows: $E^2_v \div R_v$ = loss in pressure coil of voltmeter. $E^2_w \div R_w$ = loss in pressure coil of wattmeter. $I^2_w R^1_w$ = loss in current coil of wattmeter. $I^2_a R_a$ = loss in current coil of ammeter. If connection be made as in fig. 2,876, the correct power of the circuit will be the wattmeter reading $W - (E^2_v \div R_v + E^2_w \div R_w)$ in which $E_v = E_w$. In fig. 2,877, the power is $W - E^2_w \div R_w$. In fig. 2,878, the power is $W - I^2_w R^1_w$, or the correct power is the wattmeter reading minus the loss in the current coil of the wattmeter. In fig. 2,879, the power is $W - (E^2_w + R_w + I^2_a R_a)$. The usual method of connection is either as in fig. 2,876 or fig. 2,877. In either case the current reading is that of the load plus the currents in the pressure coils of the voltmeter and wattmeter. Unless the current being measured, however, is very small, or extreme accuracy is desired, it is unnecessary to correct ammeter readings. In fig. 2,877 a small error is introduced due to the fact that the actual voltage applied to the load is that given by the voltmeter minus the small drop in voltage through the current coil of the wattmeter. If an accurate measure of the current in connection with the power consumed by the load be required, the connections shown in fig. 2,879 are used, and if extreme accuracy is required, the wattmeter reading is reduced by the losses in the ammeter and in the pressure coil of the wattmeter. The loss in the pressure coil of a wattmeter or voltmeter may be as high as 12 or 15 watts at 220 volts. The loss in the current coil of a wattmeter with 10 amperes flowing may be 6 or 8 watts. It can be easily seen that if the core or copper losses of small transformers are being measured, it is quite necessary to correct the wattmeter readings, for the instrument losses. In measuring the losses of a 25 or 50 H.P. induction motor, the instrument losses may be neglected. A careful study of the above will show when it becomes necessary to correct for instrument losses and the method of making these corrections. Connections are seldom used which make it necessary to correct for the losses in the current coils of either ammeter or wattmeter, as the losses vary with the change in the current. On the other hand, the voltages generally used are fairly constant at 110 or 220, and when the losses of the pressure coils at these voltages have once been calculated, the necessary instrument correction can be readily made.

the connection in circuit of the high tension switching devices, from which the conductors are led to bus bars, and thence to the step down transformers.

On a three phase system the transformers should be joined in delta connection, as a considerable advantage is thereby gained over the star connection, in that should one of the transformers become defective, the remaining two will carry the load without change except more or less additional heating. Between the transformers and rotary converter the circuits should be as short and simple as possible, switches, fuses, and other instruments being entirely excluded. The direct current from the converter is led to the direct current switchboard, and from there distributed to the feeder circuits.

WATTMETER ERROR FOR A LOAD OF 1,000 VOLT-AMPERES

(For a lag of 1 degree in the pressure coil)

Power factor	True watts	Error	Error of indication in per cent. of true value
1.	1,000	.3	0.03
.9	900	7.6	0.85
.8	800	10.5	1.31
.7	700	12.5	1.78
.6	600	13.9	2.32
.5	500	15.1	3.02
.4	400	15.9	3.98
.3	300	16.6	5.54
.2	200	17.1	8.55
.1	100	17.3	1.73

NOTE.—In the iron vane type instrument when used as a wattmeter, the current of the series coil always remains in perfect phase with the current ot the circuit, provided series transformers are not introduced. The error, then, is entirely due to the lag of the current in the pressure coil, and this error in high power factor is exceedingly small, increasing as the power factor decreases. In the above table it should be noted that the value of the error as distinguished from the per cent. of error, instead of indefinitely increasing as the power factor diminishes, rapidly attains a maximum value which is less than 2 per cent. of the power delivered under *the same current* and without inductance. It should also be noted that the above *tabulation is on the assumption* of a lag of 1 degree in the pressure coil. The actual lag in *Wagner instruments for instance*, is approximately .085 of a degree, and the error due to the lag *of the pressure coil in* Wagner instruments is, therefore, proportionally reduced from *figures shown in the above* tabulation.

Ques. In large sub-stations containing several rotary converters how are they operated?

Ans. Frequently they are installed to receive their respective currents from the same set of bus bars; that is, they may be operated as alternating current motors in parallel. They are also frequently operated independently from single bus bars, but very seldom in series with each other.

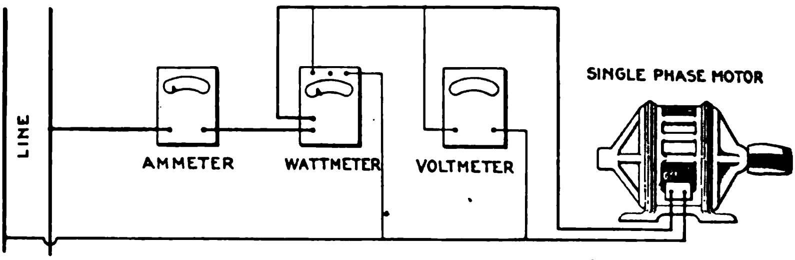


FIG. 2,880.—Single phase motor test. In this method of measuring the input of a single phase motor of any type, the ammeter, voltmeter and wattmeter are connected as shown in the illustration. The ammeter measures the current flowing through the motor, the voltmeter, the pressure across the terminals of the motor, and the wattmeter the total power which flows through the motor circuit. With the connections as shown, the wattmeter would also measure the slight losses in the voltmeter and the pressure coil of the wattmeter, but for motors of ¼ H.P. and larger, this loss is so small that it may be neglected. The power factor may be calculated by dividing the true watts as indicated by the wattmeter, by the product of the volts and amperes.

Ques. How may the direct current circuit be connected?

Ans. In parallel.

NOTE.—In motor testing, by the methods illustrated in the accompanying cuts, it is assumed that the motor is loaded in the ordinary way by belting or direct connecting the motor to some form of load, and that the object is to determine whether the motor is over or under loaded, and approximately what per cent. of full load it is carrying. All commercial motors have name plates, giving the rating of the motor and the full load current in amperes. Hence the per cent. of load carried can be determined approximately by measuring the current input and the voltage. If an efficiency test of the apparatus be required, it becomes necessary to use some form of absorption by dynamometer, such as a Prony or other form of brake. The output of the motor can then be determined from the brake readings. The scope of the present treatment is, however, too limited to go into the subject of different methods of measuring the output of the apparatus, and is confined rather to methods of measuring current input, voltage, and watts. The accuracy of all tests is obviously dependent upon the accuracy of the instruments employed. Before accepting the result obtained by any test, especially under light or no load, correction should be made for wattmeter error. See table of wattmeter error on page 2,075.

Ques. What provision should be made against interruption of service in sub-stations?

Ans. There should be one reserve rotary converter to every three or four converters actually required.

Ques. Why does a rotary converter operate with greater efficiency, and require less attention than does a dynamo of the same output?

Ans. There is less friction, and less armature resistance,

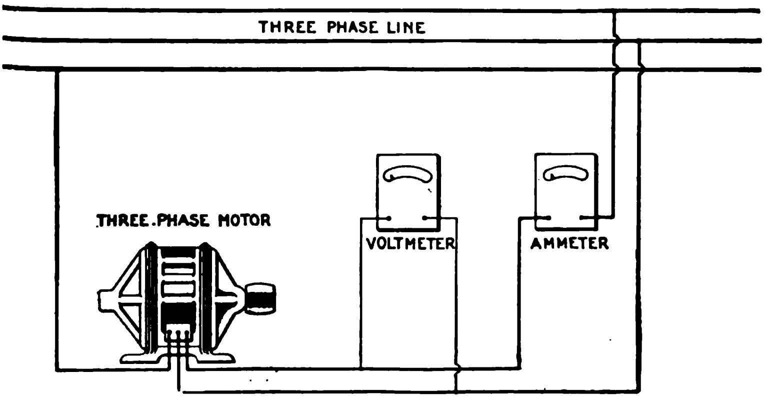


FIG. 2,881.—Three phase motor test; voltmeter and ammeter method. If it be desired to determine the approximate load on a three phase motor, this may be done by means of the connections as shown in the figure, and the current through one of the three lines and the voltage across the phase measured. If the voltage be approximately the rated voltage of the motor and the amperes the rated current of the motor (as noted on the name plate) it may be assumed that the motor is carrying approximately full load. If, on the other hand, the amperes show much in excess of full load rating, the motor is carrying an overload. The heat generated in the copper varies as the square of the current. That generated in the iron varies anywhere from the 1.6 power, to the square. This method is very convenient if a wattmeter be not available, although, it is, of course, of no value for the determination of the efficiency or power factor of the apparatus. This method gives fairly accurate results, providing the load on the three phases of the motor be fairly well balanced. If there be much difference, however, in the voltage of the three phases, the ammeter should be switched from one circuit to another, and the current measured in each phase. If the motor be very lightly loaded and the voltage of the different phases vary by 2 or 3 per cent., the current in the three legs of the circuit will vary 20 to 30 per cent.

the *latter because* the alternating current at certain portions of each *revolution* passes directly to the commutator bars witho

traversing the entire armature winding as it does in a dynamo; there is no distortion of the field and consequently no sparking, or shifting of the brushes, since the armature reaction resulting from the current fed into the machine and that due to the current generated in the armature completely neutralizes each other.

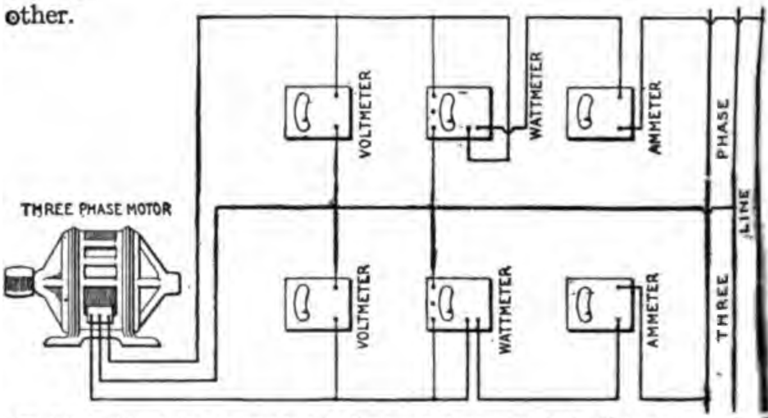


FIG. 2,882.—Three phase motor test by the two wattmeter method. If an accurate test of a three phase motor be required, it is necessary to use the method here indicated. Assume the motor to be loaded with a brake so that its output can be determined. This method gives correct results even with considerable unbalancing in the voltages of the three phases. With the connections as shown, the sum of the two wattmeter readings gives the total power in the circuit. Neither meter by itself measures the power in any one of the three phases. In fact, with light load one of the meters will probably give a negative reading, and it will then be necessary to either reverse its current or pressure leads in order that the deflection may be noted. In such cases the algebraic sums of the two readings must be taken. In other words, if one read plus 500 watts and the other, minus 300 watts, the total power in the circuit will be 500 minus 300, or 200 watts. As the load comes on, the readings of the instrument which gave the negative deflection will decrease until the reading drops to zero, and it will then be necessary to again reverse the pressure leads on this wattmeter. Thereafter the readings of both instruments will be positive, and the numerical sum of the two should be taken as the measurement of the load. If one set of the instruments be removed from the circuit, the reading of the remaining wattmeter will have no meaning. As stated above, it will not indicate the power under these conditions in any one phase of the circuit. The power factor is obtained by dividing the actual watts input by the product of the average of the voltmeter readings × the average of the ampere readings × 1.73.

Ques. What electrical difficulty is experienced with a rotary converter?

Ans. Regulation of the direct current voltage.

Ques. How is this done?

Ans. It can be maintained constant only by preserving uniform conditions of inductance in the alternating current circuit, and uniform conditions in the alternator.

While changes in either of these may be compensated to a certain extent by adjustment of the field strength of the converter, they cannot be entirely neutralized in this manner; it is therefore necessary that both the line circuit and the alternator be given attention if the best results are to be obtained from the converter.

Ques. What mechanical difficulty is experienced with rotary converters?

Ans. Hunting.

Ques. What is the cause of this?

Ans. It is due to a variation in frequency.

The inertia of the converter armature tends to maintain a constant speed; variations in the frequency of the supply circuit will cause a displacement of phase between the current in the armature and that in the line wires, which displacement, however, the synchronizing current strives to decrease. The synchronizing current, although beneficial in remedying the trouble after it occurs, exerts but little effort in preventing it, and many attempts have been made to devise a plan to eliminate this trouble.

NOTE.—Three phase motor test; polyphase wattmeter method. This is identical with the test of fig. 2,882, except that the wattmeter itself combines the movement of the two wattmeters. Otherwise the method of making the measurements is identical. If the power factor be known to be less than 50 per cent., connect one movement so as to give a positive deflection; then disconnect movement one and connect movement two so as to give a positive deflection. Then reverse either the pressure or current leads of the movement, giving the smaller deflection, leaving the remaining movement with the original connections. The readings now obtained will be the correct total watts delivered to the motor. If the power factor be known to be over 50 per cent., the same methods should be employed, except that both movements should be independently connected to give positive readings. An unloaded induction motor has a power factor of less than 50 per cent., and may, therefore, be used as above for determining the correct connections. For a better understanding of the reasons for the above method of procedure, the explanation of the two wattmeter method, fig. 2,882, should be read. The power factor may be calculated as explained under fig. 2,882. Connect as shown in fig. 2,882. The following check on connection may be made. Let the polyphase induction motor run idle, that is, with no load. The motor will then operate with a power *factor less than 50 per cent.* The polyphase meter should give a positive indication, but if *each movement be tried separately* one will be found to give a negative reading, the other *movement will give a positive reading*. This can be done by disconnecting one of the pressure *leads from the binding post* of one movement. When the power factor is above 50 per c[ent.] as *both movements* will give positive deflection.

Ques. What are the methods employed to prev hunting?

Ans. 1, the employment of a strongly magnetized f relative to that developed by the armature; 2, a heavy wheel effect in the converter; 3, the increasing of the inducta of the armature by sinking the windings thereon in deep s in the core, the slots being provided with extended heads; 4, the employment of damping devices or amortisseur wind on the pole pieces of the converter.

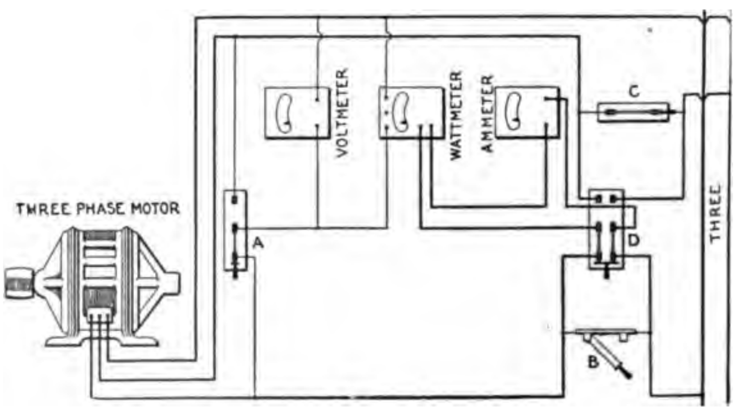


FIG. 2,883.—Three phase motor test; one wattmeter method. This method is equivalen the two wattmeter method with the following difference. A single voltmeter (as sh above) with a switch, A, can be used to connect the voltmeter across either one of two phases. Three switches, B, C and D, are employed for changing the connectio the ammeter and wattmeter in either one of the two lines. With the switches B an in the position shown, the ammeter and wattmeter series coils are connected in the hand line. The switch C must be closed under these conditions in order to have the dle line closed. Another reading should then be taken before any change of load occurred, with switch A thrown to the right, switch B closed, switch D thrown to right and switch C opened. The ammeter and the current coil of the wattmeter then be connected to the middle line of the motor. In order to prevent any interrup of the circuit, the switches B, D and C should be operated in the order given ab *With very light load on the motor the wattmeter will probably give a negative deflec in one phase or the other, and it will be necessary to reverse its connections before ta the readings. For this purpose a double pole, double throw switch is sometimes inse in the circuit of the pressure coil of the wattmeter so that the indications can be rev without disturbing any of the connections. It is suggested, before undertaking th that the instructions for test by the two wattmeter and by the polyphase w methods be read.*

Ques. What method is the best?

Ans. The damping method.

The devices employed for the purpose are usually copper shields placed between or around the pole pieces, although in some converters the copper is embedded in the poles, and in others it is made simply to surround a portion of the pole tips.

In any case its action is as follows: The armature rotating at a variable speed has a field developed therein which is assumed to be also rotating at a variable speed; the magnetism of this rotary field induces currents in the copper which, however, react on the armature and oppose any

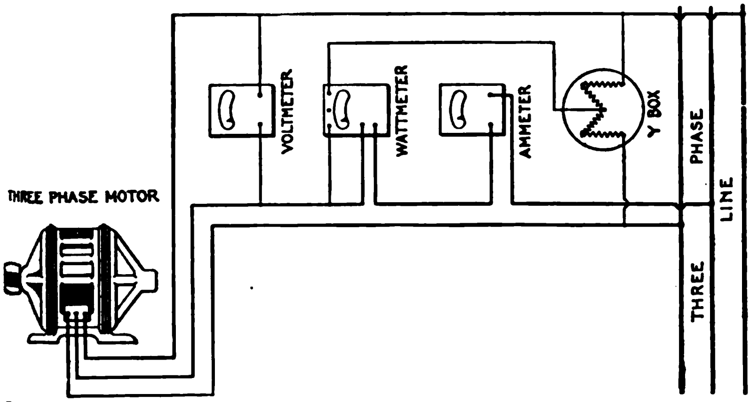


FIG. 2,884.—Three phase motor, one wattmeter and Y box method. This method is of service, only, provided the voltages of the three phases are the same. A slight variation of the voltage of the different phases may cause a very large error in the readings of the wattmeter, and inasmuch as the voltage of all commercial three phase circuits is more or less unbalanced, this method is not to be recommended for motor testing. With balanced voltage in all three phases, the power is that indicated by the wattmeter, multiplied by three. Power factor may be calculated as before.

tendency toward a further shifting of the magnetism in the armature and therefore prevent the development of additional currents in the copper. Since copper is of low resistance, the induced currents are sufficient in strength to thus dampen any tendency toward phase displacement, and so exert a steadying influence upon the installation as a whole.

Electrical Measuring Instruments.—In the manufacture of *most measuring* instruments, the graduations of the scal *are made at the factory*, by comparing the deflections of pointer with voltages as measured on standard apparatus. T voltmeters in most common use have capacities of 5, 15, : 150, 300, 500 and 750 volts each, although in the measureme of very low resistances such as those of armatures, heavy cabl or bus bars, voltmeters having capacities as low as .02 volt a employed.

The difference between the design of direct current vo meters of different capacities lies simply in the high resistan

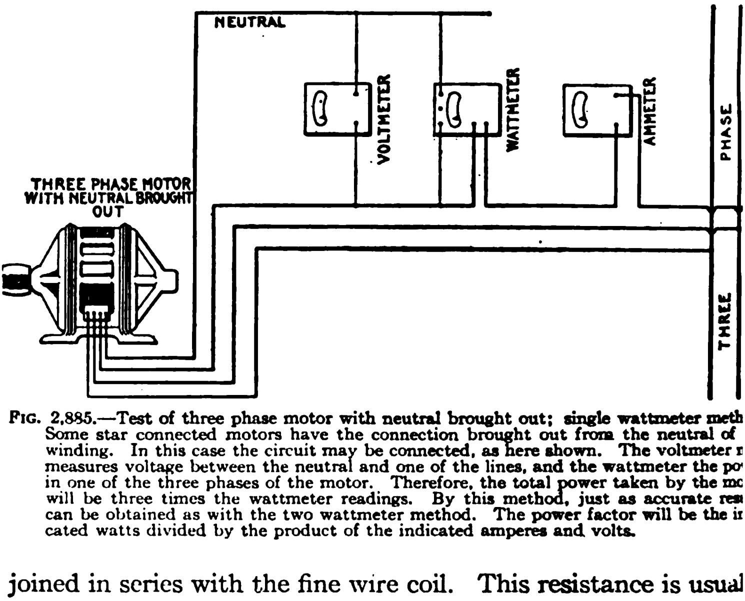


FIG. 2,885.—Test of three phase motor with neutral brought out; single wattmeter meth Some star connected motors have the connection brought out from the neutral of winding. In this case the circuit may be connected, as here shown. The voltmeter r measures voltage between the neutral and one of the lines, and the wattmeter the po in one of the three phases of the motor. Therefore, the total power taken by the mo will be three times the wattmeter readings. By this method, just as accurate res can be obtained as with the two wattmeter method. The power factor will be the ir cated watts divided by the product of the indicated amperes and volts.

joined in series with the fine wire coil. This resistance is usual about 100 ohms per volt capacity of the meter, and is compos of fine silk covered copper wire wound non-inductively on wooden spool.

In the operation of an instrument, if the pointer when d flected do not readily come to a position of rest owing friction in the moving parts, it may be aided in this respe gently tapping the case of the instrument with the hand; this will often enable the obstruction, if not of a serious nature, to be overcome and an accurate reading to be obtained.

Ques. Describe a two scale voltmeter.

Ans. In this type of instrument, one scale is for low voltage

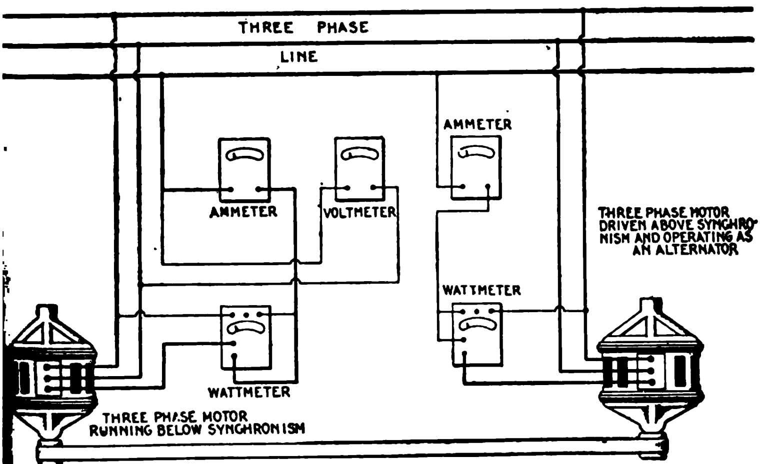


FIG. 2,886.—Temperature test of a large three phase induction motor. Temperature tests are usually made on small induction motors by belting the motor to a generator and loading the generator with a lamp bank or resistance until the motor input is equal to the full load. If, however, the motor be of considerable size, such that the cost of power becomes a considerable item in the cost of testing, the method here shown may be employed. For this purpose, however, two motors, preferably of the same size and type, are required. One is driven as a motor and runs slightly below synchronism, due to its slip when operating with load. This motor is belted to a second machine. If the pulley of the second machine be smaller than the pulley of the first machine, the second machine will then operate as an induction generator, and will return to the line as much power as the first motor draws from the line, less the losses of the second machine. By properly selecting the ratio of pulleys, the first machine can be caused to draw full load current and full load energy from the line. In this way, the total energy consumed is equivalent to the total of the losses of both machines, which is approximately twice the losses of a single machine. The figure shows the connection of the wattmeters, without necessary switches, for reading the total energy by two wattmeter method. Detailed connection of the wattmeter is shown in fig. 2,883. It is usual, in making temperature tests, to insert one or more thermometers in what is supposed to be the hottest part of the winding, one on the surface of the laminae and one in the air duct between the iron laminae. The test should be continued until *the difference in temperature between any part of the motor and the air reaches a steady value.* The motor should then be stopped and the temperature of the *armature also measured. For* the method of testing wound armature type induction *motors of very large size, see fig. 2,890.* For the approved way of taking temperature *readings and interpreting* results, see the "Standardization Rules of the A. I. E. E."

readings and the other for high voltage readings; on scales the values of the graduations for low voltages are u marked with red figures, while those for high voltages are n with black figures. A voltmeter carrying two scales mus contain two resistances in place of one; a terminal fron of these coils must be connected with a separate binding but the remaining terminal of each resistance is joined to

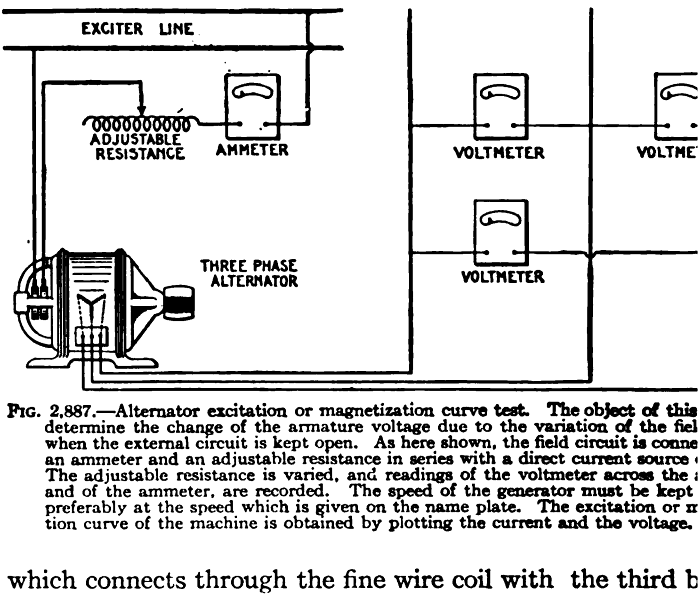


FIG. 2,887.—Alternator excitation or magnetization curve test. The object of this determine the change of the armature voltage due to the variation of the fiel when the external circuit is kept open. As here shown, the field circuit is conne an ammeter and an adjustable resistance in series with a direct current source The adjustable resistance is varied, and readings of the voltmeter across the and of the ammeter, are recorded. The speed of the generator must be kept preferably at the speed which is given on the name plate. The excitation or n tion curve of the machine is obtained by plotting the current and the voltage.

which connects through the fine wire coil with the third b post of the meter. The two first mentioned binding po usually mounted at the left hand side of the meter a last mentioned binding post and key at the right hand sid

The resistance corresponding to the high reading scale is co of copper wire having the same diameter as that constitut resistance for the low reading scale, but as the capacity of the scale is generally a whole number of times greater than th latter scale, the resistances for the two must bear the same pr

Ques. How is a two scale voltmeter connected?

Ans. In the connection of a two scale voltmeter in circuit, the single binding post is always employed regardless of which scale is desired. If, then, the voltage be such that it may be measured on the low reading scale, the other binding post employed is that connected to the lower of the two resistances

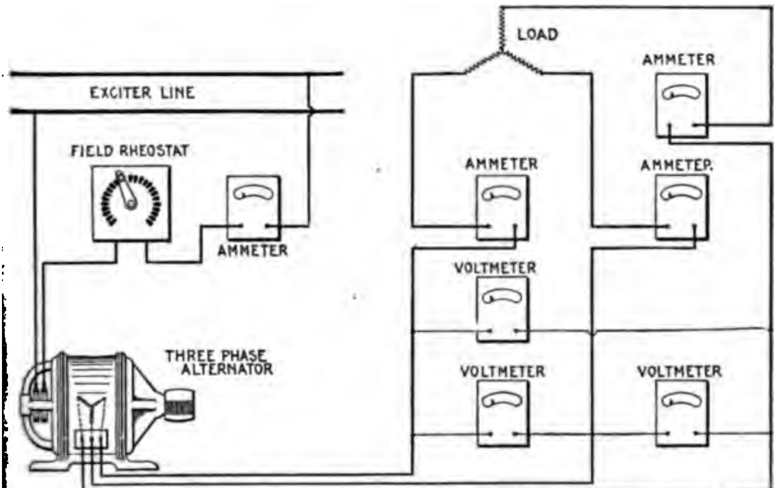


FIG. 2,888.—Three phase alternator synchronous impedance test. In determining the regulation of an alternator, it is necessary to obtain what is called the *synchronous impedance* of the machine. To obtain this, the field is connected, as shown above. Voltmeters are removed and the armature short circuited with the ammeters in circuit. The field current is then varied, the armature driven at synchronous speed, and the armature current measured by the ammeters in circuit. The relation between field and armature amperes are then plotted. The combination of the results of this test, with those obtained from the test shown in fig. 2,887, are used in the determination of the regulation of an alternator. Engineers differ widely in the application of the above to the determination of regulation, and employ many empirical formulae and constants for different lines of design.

NOTE.—Three phase alternator load test. By means of the connection shown in fig. 2,888, readings of armature current and field amperes can be obtained with any desired load. The field current can be varied also so as to maintain constant armature voltage irrespective of load; or the field current may be kept constant and the armature voltage allowed to vary as the *load increases. The* connections may also be used to make a temperature test on the *alternator by loading it* with an artificial load. In some cases after the alternator is installe[d] *the connection may be* used *to* make a temperature test, using the actual commercial load [the] *alternator is furnishing.*

contained within; if, however, the pressure be higher than thc recorded on the low reading scale, the binding post connect to the higher of the two resistances contained within is used.

Inasmuch as the capacities of the scales are usually marked on near the corresponding binding posts, there will generally be no difficu in selecting the proper one of the two left hand binding posts.

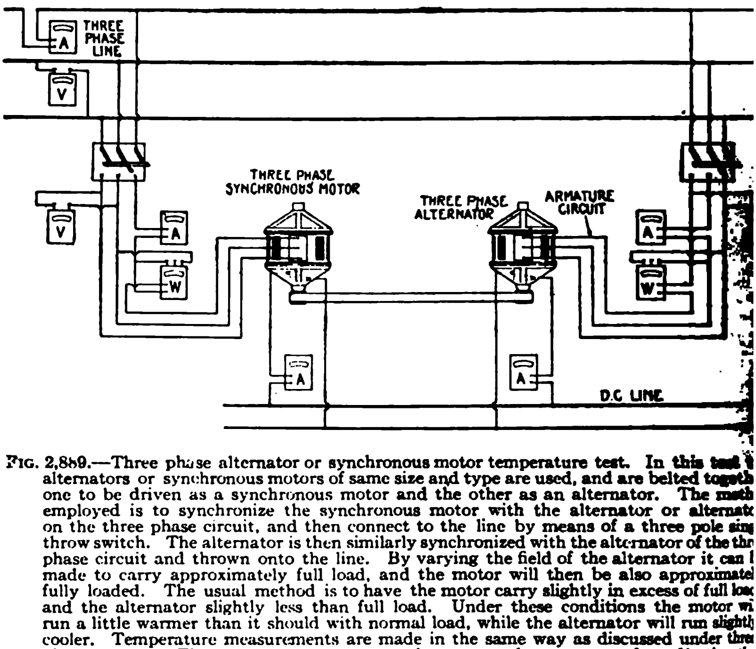


FIG. 2,889.—Three phase alternator or synchronous motor temperature test. In this test alternators or synchronous motors of same size and type are used, and are belted togeth one to be driven as a synchronous motor and the other as an alternator. The meth employed is to synchronize the synchronous motor with the alternator or alternatc on the three phase circuit, and then connect to the line by means of a three pole sing throw switch. The alternator is then similarly synchronized with the alternator of the thr phase circuit and thrown onto the line. By varying the field of the alternator it can l made to carry approximately full load, and the motor will then be also approximatel fully loaded. The usual method is to have the motor carry slightly in excess of full loa and the alternator slightly less than full load. Under these conditions the motor wi run a little warmer than it should with normal load, while the alternator will run slightl cooler. Temperature measurements are made in the same way as discussed under thre phase motors. The necessary ammeters, voltmeters and wattmeters for adjusting the loads on the motors and generator are shown in above figure. If pulleys be of sufficient size to transmit the full load, with, say one per cent. slip, the pulley on the motor should be one per cent. larger in diameter than the pulley on the alternator, so as to enable the alternator to remain in synchronism and at the same time deliver power to the circuit. With very large machines under test, it is inadvisable to use the above method as it is sometimes difficult to so adjust the pulleys and belt tension that the belt slip will be just right to make up for the difference in diameter of the pulleys, and very violent flap ping of the belt results. To meet such cases, various other methods have been devis One which gives consistent results is shown in fig. 2,890.

Ques. How is a two scale voltmeter connected when ıe binding posts are not marked?

Ans. If only an approximate idea is possessed of the voltage › be measured, it is always advisable to connect to the binding ɔst corresponding to the high reading scale of the meter in ·der to determine if the measurement may not be made safely ɑd more accurately on the low reading scale. In any case, ɔme knowledge must be had of the voltage at hand, else the igh reading portion of the instrument may be endangered.

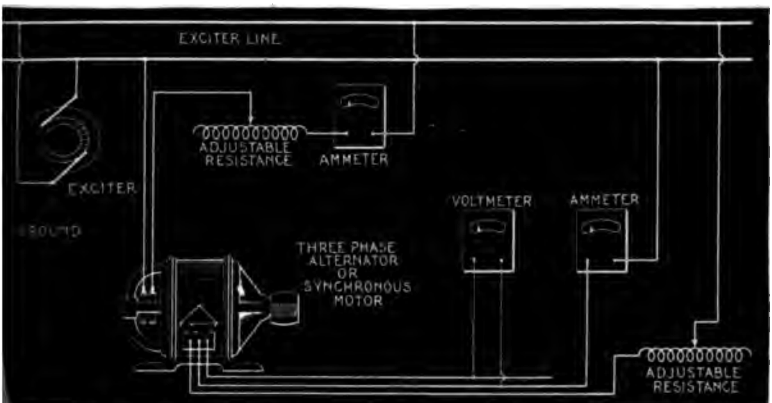


Fig. 2,890.—Three phase alternator or synchronous motor temperature test. Supply the field with normal field current. The armature is connected in open delta as illustrated, and full load current sent through it from an external source of direct current, care being taken to ground one terminal of the dynamo so as to avoid danger of shock due to the voltage on the armature winding. The field is then driven at synchronous speed. If the armature be designed to be connected star for 2,300 volts, the voltage generated in each leg of the delta will be 1,330 volts, and unless one leg of the dynamo were grounded, the tester might receive a severe shock by coming in contact with the direct current circuit. The insulation of the dynamo would also be subjected to abnormal strain unless one terminal were grounded. By the above method the field is subjected to its full copper loss and the armature to full copper loss and core loss. Temperature readings are taken as per standardization rules of the A. I. E. E. This method may also be used with satisfactory results on large three phase motors of the wound rotor type. If the alternator pressure be above 600 volts, a pressure transformer should be used in connection with the voltmeter.

Too much care cannot be taken to observe these precautions whenever the voltmeter is used, for the burning out or charring of the insulation either in the fine wire coil or in the high resistance of the meter by

excessive current, is one of the most serious accidents that can befall t instrument.

If a voltmeter has been subjected to a voltage higher than that for whi it was designed, yet not sufficiently high to injure the insulation, but hi enough to cause the pointer to pass rapidly over the entire scale, dama has been done in another way. The pointer being forced against the side the case in this manner, bends it more or less and so introduces an error the readings that are afterward taken.

The same damage will be done if the meter be connected in circuit s that the current does not pass through it in the proper direction, althoug

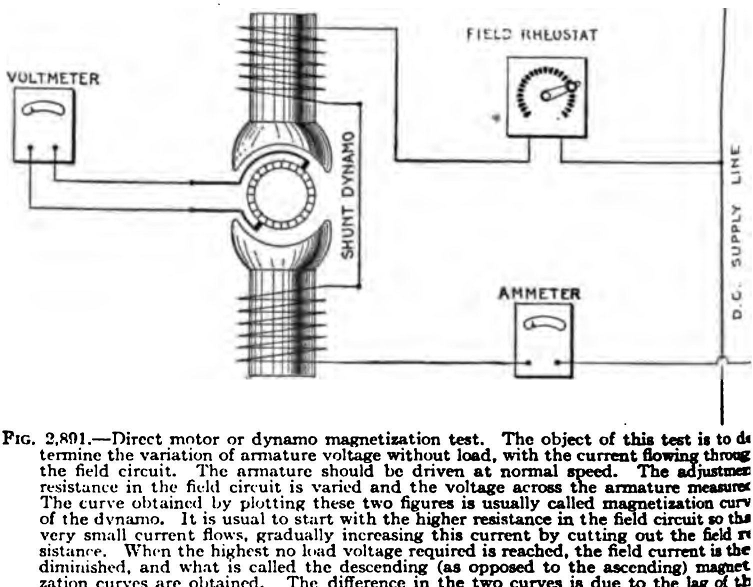


FIG. 2,801.—Direct motor or dynamo magnetization test. The object of this test is to de termine the variation of armature voltage without load, with the current flowing throug the field circuit. The armature should be driven at normal speed. The adjustmer resistance in the field circuit is varied and the voltage across the armature measure The curve obtained by plotting these two figures is usually called magnetization curv of the dynamo. It is usual to start with the higher resistance in the field circuit so tha very small current flows, gradually increasing this current by cutting out the field re sistance. When the highest no load voltage required is reached, the field current is the diminished, and what is called the descending (as opposed to the ascending) magnet zation curves are obtained. The difference in the two curves is due to the lag of th magnetization behind the magnetizing current, and is caused by the hysteresis of th iron of the armature core.

in this case the pointer is not liable to be bent so much as when it is force to the opposite side of the meter by an abnormal current, since then it ha gained considerable momentum which causes a severer impact. The exten of the damage may be ascertained by noting how far away from the zer mark the pointer lies when no current is passing through the instrument If this distance be more than two-tenths of a division, the metal case enclo ing the working part should be removed and the pointer straightened by careful use of a pair of pinchers.

Ques. What should be noted with respect to location of instruments?

Ans. If they be placed near conductors carrying large currents, the magnetic field developed thereby will produce a change in the magnetism of the instruments and so introduce an error in the readings.

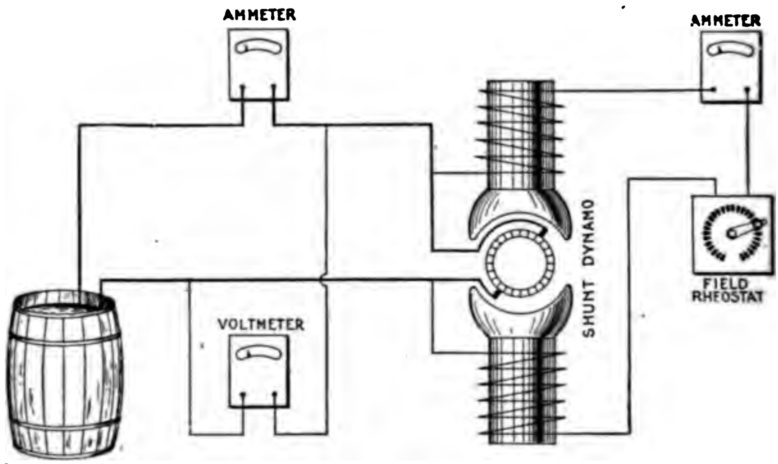


FIG. 2,892.—Shunt dynamo, external characteristic test. The external characteristic of a shunt dynamo is a curve showing the relation between the current and voltage of the external circuit. This is obtained by the connection as here shown. The shunt field is so adjusted that the machine gives normal voltage when the external circuit is open. The field current is then maintained constant and the external current varied by varying the resistance in the circuit. By plotting voltage along the vertical, against the corresponding amperes represented along the horizontal, the external characteristic is obtained.

Ques. How should portable instruments be wired?

Ans. The wires must be firmly secured to the supports on which they rest, so as to reduce the possibility of their being pulled by accident, and so causing the instruments to fall.

A fall or a rough handling of the meter at once shows its effect on the readings, for as much harm is done as would result from a similar treatment of a watch.

The hardened steel pivots used in all high grade voltmeters are gr and polished with extreme care so as to secure and maintain a degree of sensitiveness. The jewels on which the moving parts re are of sapphire, and they too must necessarily be made with skil carefulness; if, therefore, the jewels become cracked and the p dulled by careless handling, the meter at once becomes useless as a r uring instrument.

Ques. How should readings be taken?

Ans. The deflections of the pointer should be read to te

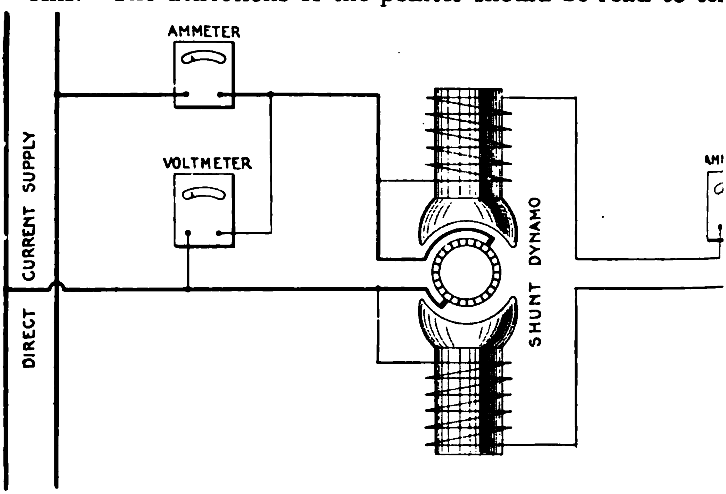


FIG. 2,893.—Load and speed test of direct current shunt motor. The object of this te to maintain the voltage applied to the motor constant, and to vary the load by m of a brake and find the corresponding variation in speed of the machine and the cur drawn from the circuit. If the motor be a constant speed motor, the field resistan maintained constant. The above indicates the method of connecting instruments the test alone; for starting the machine the ordinary starting box, should, of course inserted.

of a division; this can be done with considerable accura especially after a little practice.

For very accurate results, a temperature correction should be appl to compensate the effect which the temperature of the atmosphere upon the resistance of the meter when measurements are being t In ordinary station practice the temperature correction is ne being for resistance corresponding to the high scale in first class

less than one-quarter of 1 per cent. for a range of 35 degrees above or 35 degrees below 70 degrees Fahrenheit.

Ques. What attachment is sometimes provided on station voltmeters used for constant pressure service?

Ans. A normal index.

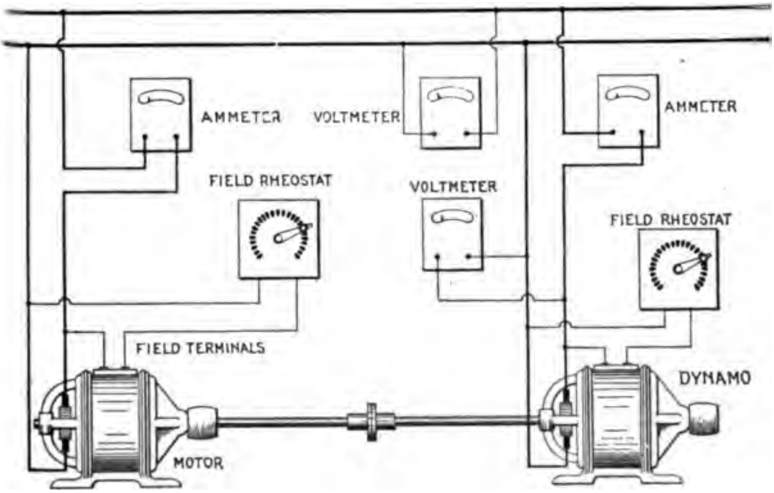


FIG. 2,894.—Temperature test of direct current motor or dynamo; loading back method. In making temperature tests on a small dynamo it is usual to drive the dynamo with a motor and load the dynamo by means of a lamp bank or resistance, the voltage across the dynamo being maintained constant, and the current through the external circuit adjusted to full load value. The temperatures are then recorded, and when they reach a constant value above the temperature of the atmosphere, the test is discontinued. Similarly, in making a test on a small motor, the motor is loaded with a dynamo and the load increased until the input current reaches the normal full load value of the motor, the test being conducted as for a small dynamo. When, however, the apparatus, either motor or dynamo, reaches a certain size, it becomes necessary, in order to economize energy, to use what is called the **loading back method**, as here illustrated. The motor is started in the usual way, with the dynamo belted to it, the circuit of the dynamo being open. The field of the dynamo is then adjusted so that the dynamo voltage is equal to that of the line. The dynamo is then connected to the circuit and its field resistance varied until it carries normal full load current. Under these conditions, if the motor and dynamo *be of the same size and type*, the motor will carry slightly in excess of full *load, the difference being* approximately twice the losses of the machines. Under these *conditions the total* power drawn from the line is equal to twice the loss of either machine. Temperature readings are taken as in other temperature tests.

Ques. What precaution must be taken in connecting station voltmeters?

Ans. Care must be taken to guard against any short circuiting of the voltmeter, which, would mean a short circuiting of the generator, and as a result the probable burning out of its armature.

The high resistance of the voltmeter prevents any such occurrence when it is connected in the proper way, but should one side of the circuit

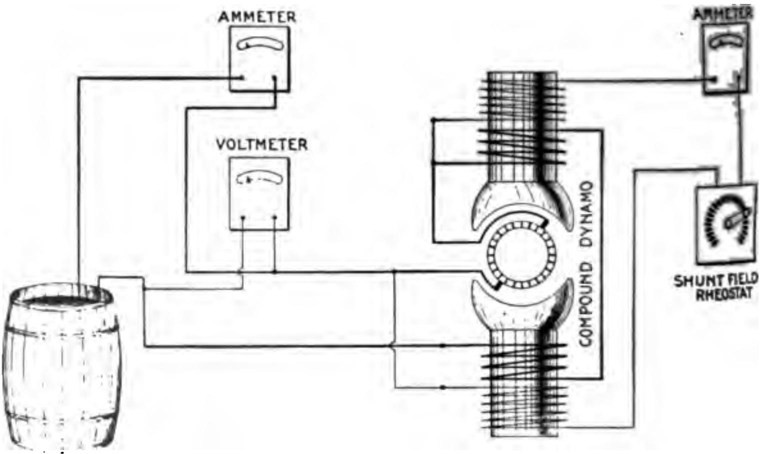
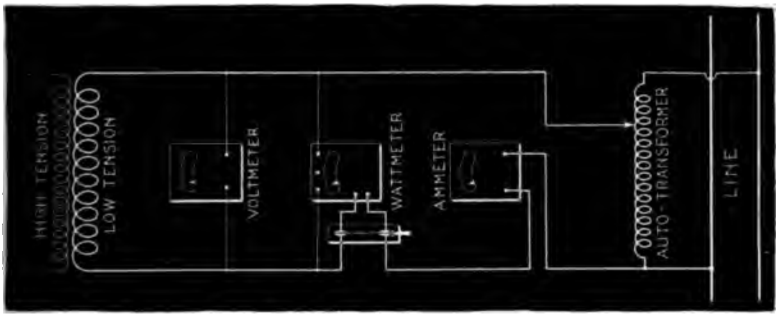


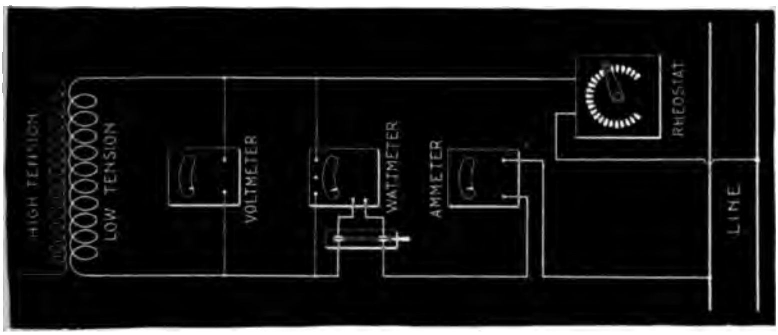
FIG. 2,895. Compound dynamo external characteristics test; adjustable load. The object of the test is to determine the relation between armature voltage and armature current. Shunt field is adjusted to give normal secondary voltage when the external circuit is open. The load is then applied by means of an adjustable resistance or lamp bank, and readings of external voltage and current recorded. If the machine be normally compounded the external voltage will remain practically constant throughout the load range. If the machine be under-compounded, the external voltage will drop with load and if over compounded, there will be a rise in voltage with increase in load.

be grounded to the metal case or frame of the meter, a careless handling of the lead connected with the other side of the circuit would produce the result just mentioned.

Ques. Why do station voltmeters indicate a voltage slightly lower than actually exists across the leads?

Ans. Since they are usually connected permanently in circuit; a certain amount of heat is developed in the wiring of the instrument.





Figs. 2,896 and 2,897.—Transformer core loss and leakage, or exciting current test. With the primary circuit open, the ammeter indicates the exciting or no load current. It should be noted that all instruments are inserted on the low voltage side, for both safety of the operator and because the measurements are more accurate. The no load primary current, if the ratio of transformation be 10 : 1, will be one-tenth of the measured secondary current. The wattmeter connected, as shown, measures the sum of the losses, in the transformer, in the pressure coil of the wattmeter, and in the voltmeter. On all standard makes of portable instruments, the resistance of the wattmeter pressure coil and of the voltmeter is given, and the loss in either instrument is the square of the voltage at its terminals, divided by its resistance. Subtracting these losses from the total indicated upon the wattmeter, gives the true core or iron loss. It should be noted that in this diagram is shown an auxiliary transformer with a number of taps for obtaining the exact rated voltage of the transformer under test. In fig. 2,897 is shown, in general, the same connections as in fig. 2,896, except that the auto-transformer has been replaced by a resistance. If the line voltage available be not much in excess of the rated voltage of the *transformer under test*, very little error is introduced by the use of the resistance method. *However, if the difference* be 10 per cent. or more the auxiliary transformer shown *fig. 2,896 should* be used. Measurements made under the resistance method alw *give lower results* than those obtained with the auxiliary transformer.

[redacted]

The effect of this heat increases the voltmeter resistance and consequently reduces the current below that which otherwise would pass through the meter; since the deflections of the pointer are governed by the strength of the current, station voltmeters invariably indicate a voltage slightly lower than that which actually exists across their leads.

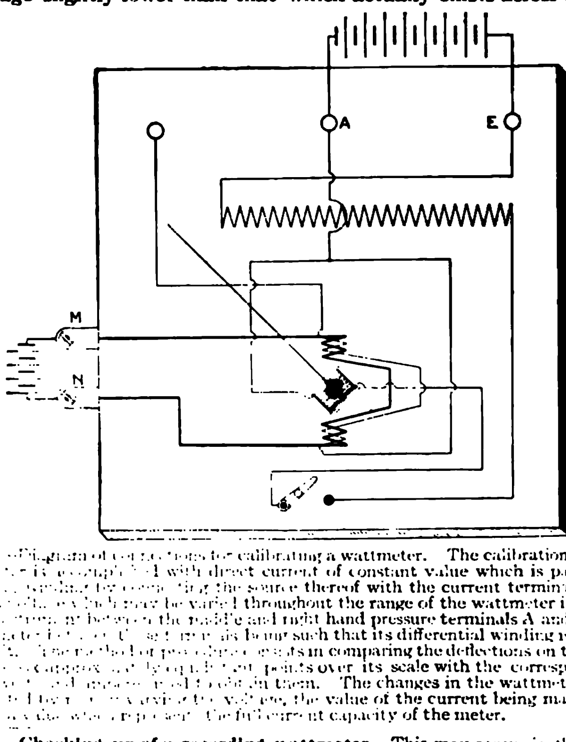


FIG. 2,898.—Diagram of connections for calibrating a wattmeter. The calibration of a portable wattmeter is accomplished with direct current of constant value which is passed through the [illegible] winding by connecting the source thereof with the current terminals. A direct current [illegible] which may be varied throughout the range of the wattmeter is also applied [illegible] between the middle and right hand pressure terminals A and E the winding [illegible] such that its differential winding is [illegible] in comparing the deflections on the wattmeter [illegible] points over its scale with the corresponding [illegible] The changes in the wattmeter deflections [illegible] the value of the current being maintained [illegible] the full current capacity of the meter.

NOTE.—**Checking up of a recording wattmeter.** This may conveniently be done [illegible] ammeter connected in circuit, and also the readings on the dial of the [illegible] wattmeter during this period. If this test be continued for an [illegible] the current in amperes, and the [illegible] recorded on the counters of the dial.

NOTE.—**Transformer testing.** In the early days of transformer building, before the [illegible] wattmeter had been perfected, leakage or exciting current was the criterion of good design. After the introduction of the wattmeter, core loss became the all important factor, and for a long time the question of leakage current was lost sight of. With the introduction of silicon steel, leakage or exciting current again assumed prominence. Keeping in mind the fact that all characteristics of a transformer are of more or less importance, it is essential that the users of such apparatus have at hand the necessary facilities for making all such variable quantities. The tests which all users of transformers should make, are [illegible] in this chapter.

Ques. Can direct current be measured by an alternating current voltmeter?

Ans. Yes.

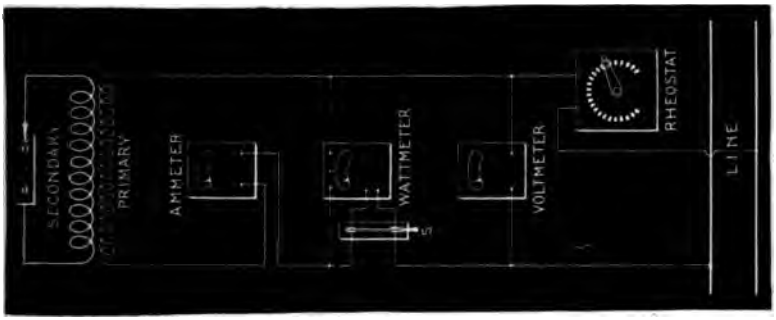


Fig. 2,899.—Transformer copper loss by wattmeter measurement and impedance. At first glance, this method would seem better than the calculation of loss after measurement of the resistance. However, it should be noted that the wattmeter is, in itself, subject to considerable error under the low power factor that will exist in this test. The secondary of the transformer is short circuited, and a voltage applied to the primary which is just sufficient to cause full load primary current. If full current pass through the primary of the transformer with the secondary short circuited, the secondary will also carry full load current. With connections as shown, and with the full load current, the voltmeter indicates the impedance volts of the transformer. This divided by the rated voltage gives what is called the *per cent. impedance of the transformer*. In a commercial transformer of 5 kw., this should be approximately 3 per cent. The iron loss of the transformer under approximately 3 per cent. of the normal voltage will be negligible, and the losses measured will be the sum of the primary and secondary copper losses. As in the discussion of the core loss measurements, the wattmeter readings must be corrected for the loss in its pressure coil, the method of correction being the same as that discussed under the core loss measurement. If the impedance volts, as measured, be divided by the primary current, the impedance of the transformer is obtained. The reciprocal of this quantity is known by the term "admittance." *When two or more transformers are connected in parallel they divide the load in proportion to their admittance.* It is, therefore, important that the users of transformers know the impedance of the apparatus used, in order to determine whether two or more transformers will operate satisfactorily in parallel. For discussion of wattmeter error on low power factor, see note on page 2,075. For accurate measurement of impedance, the voltmeter should be connected directly across the terminals of the transformer rather than as shown in the diagram.

NOTE.—**Transformer copper loss test.** The usual and best method of obtaining copper losses is to separately measure the primary and secondary resistance and calculate from these the primary and secondary copper losses. For general diagram of connections and discussion of the drop method, see fig. 2,875. The current should be kept well within the load current of the transformer to avoid temperature rise during the test. In other words, the resistance *of the coil is the voltage* across its terminals divided by the current. The resistance of the *primary coil can be measured* similarly. The copper loss in watts in each coil will then be the *product of the resistance* and the square of the rated current for that coil. The total copper *loss will be the sum.*

Ques. What would be the effect of placing a direct current voltmeter across an alternating current circuit, and why?

Ans. There would be no deflection of the pointer owing to the rapid reversals of the alternating current.

Ques. What are the usual capacities of alternating current voltmeters?

Ans. They are 3, 7.5, 10, 12, 15, 20, 60, 75, 120, 150, 300 and

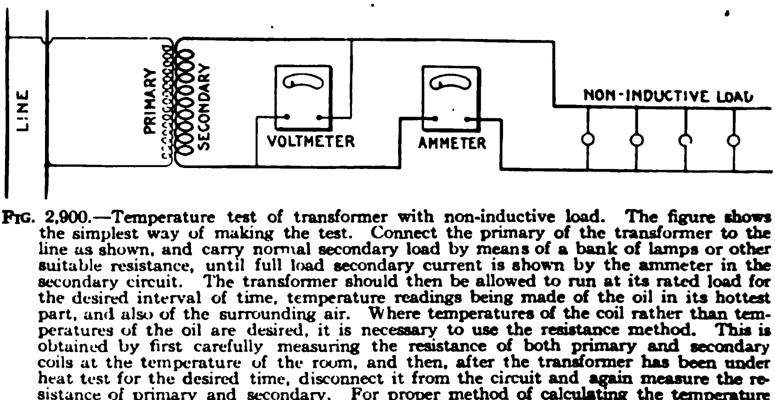


FIG. 2,900.—Temperature test of transformer with non-inductive load. The figure shows the simplest way of making the test. Connect the primary of the transformer to the line as shown, and carry normal secondary load by means of a bank of lamps or other suitable resistance, until full load secondary current is shown by the ammeter in the secondary circuit. The transformer should then be allowed to run at its rated load for the desired interval of time, temperature readings being made of the oil in its hottest part, and also of the surrounding air. Where temperatures of the coil rather than temperatures of the oil are desired, it is necessary to use the resistance method. This is obtained by first carefully measuring the resistance of both primary and secondary coils at the temperature of the room, and then, after the transformer has been under heat test for the desired time, disconnect it from the circuit and again measure the resistance of primary and secondary. For proper method of calculating the temperature rise from resistance measurements, the reader is referred to the standardization rules of the A. I. E. E. In making resistance measurements of large transformers by the drop method care should be taken to allow both ammeter and voltmeter indications to settle down to steady values before readings are taken. This may require several minutes. Each time the current is changed it is necessary in order to obtain check values on resistance measurements, to wait until the current is again settled to its permanent value before taking readings. All resistance measurements must be taken with great care, as small errors in the measurement of the resistance may make very large errors in the determination of the temperature rise. The method above described is satisfactory for small transformers. Where large units are to be tested, the cost of current for testing becomes an important item. The "bucking test" as in fig. 2,901, is more economical.

600 volts, but these capacities may each be increased by the use of a multiplier.

Ques. How are station voltmeters usually attached to the switchboard?

Ans. They are usually bolted to the switchboard by means of four iron supports mounted on the back of the instrument; two of these are fastened near each side of the case.

Under certain conditions, however, as in paralleling of alternators, it is convenient to have the alternating current voltmeter mounted on a swinging bracket at the side of the switchboard. The voltmeter may then be swung around in any desired direction so as to enable the attendant to keep informed of the voltage while switching in each additional alternator.

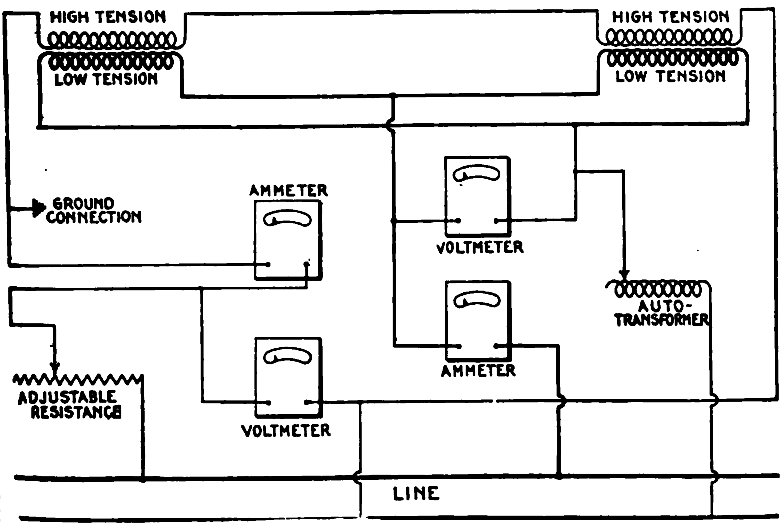


FIG. 2,901.—Transformer temperature "bucking test." For this purpose two transformers of the same size and ratio are required. The connections are as shown. Full secondary voltage is applied, and rheostats or auxiliary auto-transformers are inserted in the circuit to properly regulate the voltage. The primaries are connected with one bucking the other, and a voltage equal to twice the impedance voltage of either transformer inserted in the primary circuit. It should be noted that when the secondaries are subjected to the full secondary voltage, a full primary voltage exists across either primary, but with the primaries connected so that the voltage of one is bucked against the voltage of the other, the resultant voltage in the circuit will be zero. By applying to the primary circuit twice the impedance voltage of either transformer, full primary and secondary current will circulate through both transformers. On the other hand, by subjecting the secondaries to the full secondary voltage, the iron of the transformer will be magnetized as under its regular operating conditions, and the full iron loss of the transformer introduced. *This method permits the operation of two transformers under temperature test with their full losses,* without taking energy from the line equal to the rated capacity. *Measurements of temperature* are taken in exactly the same way as above. This method *is successfully employed* for making temperature tests on transformers of all sizes.

Ques. How should an ammeter be operated to get accurate readings, and why?

Ans. It should be cut out of circuit except while taking a reading, because of the error introduced by the heating effect of the current.

In an ammeter having a capacity of 50 amperes, the error thus introduced will be less than 1 per cent. if connected continuously in circuit with a current not exceeding three-quarters this capacity.

An ammeter of 100 amperes capacity may be used indefinitely in circuit with less than 1 per cent. error up to one-half its capacity, and

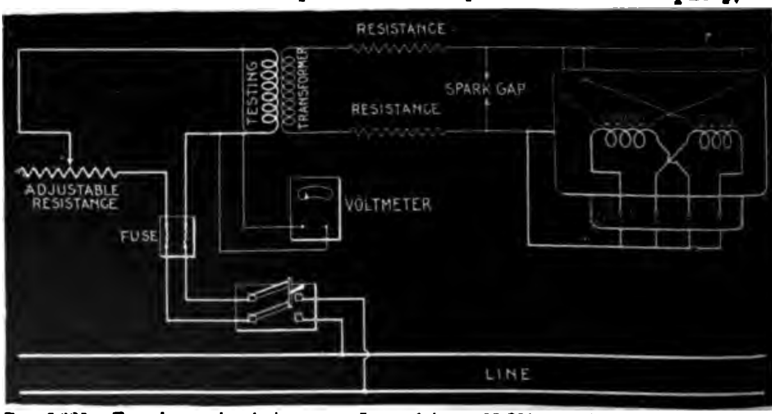


FIG. 2,902.—Transformer insulation test. In applying a 10,000 volt insulation test between the primary and secondary of a transformer, the testing leads should be disconnected from the transformer under test, and a spark gap introduced as shown, with the test needle set at a proper sparking distance for 10,000 volts. A high resistance should be connected in the secondary before closing its circuit, and the voltage gradually increased by cutting out this secondary resistance until a spark jumps across the spark gap. When the spark jumps across the spark gap, the voltmeter reading should be recorded and the testing transformer disconnected. The spark gap should then be increased about 10 per cent. and the high tension leads connected to the transformer under test as indicated in the diagram. In order to equalize the insulation strains, all primary leads should be connected together, all secondary leads not only connected together, but to the core as well. All resistance in the rheostat in the low tension circuit should then be inserted and the switch closed. Gradually cut out secondary resistance until the voltmeter shows the same voltage as was recorded previously when the spark jumped across the gap, and apply this voltage to the transformer for one minute. Insulation tests for a period of over one minute are very unadvisable, as transformers with excellent insulation may be seriously damaged by prolonged insulation tests. The longer the strain to which any insulation is subjected, the shorter the subsequent life of the insulation. Also the greater the applied voltage above the actual operating voltage of the apparatus, the shorter the subsequent life of the insulation. In testing small transformers, the spark gap may be omitted and the voltage of the low pressure coil of the testing transformer measured. This multiplied by the ratio of transformation gives the testing voltage.

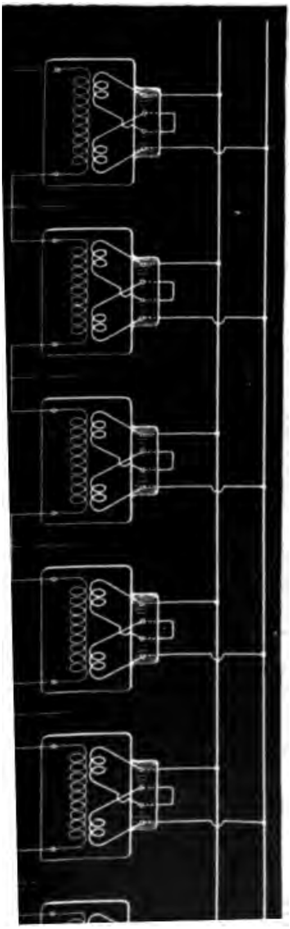


FIG. 2,903.—Transformer insulation test as made when a special high tension transformer be not available. In this method a number of standard transformers, connected as shown may be employed, but great care should be taken to have such transformer cases thoroughly insulated from the ground and from one another, in order to minimize the insulation strains in the testing transformers. Care should be taken to insert in the circuit of each testing transformer a fuse, not in excess of the transformer capacity, which will blow, in case of a break down in the apparatus under test. In testing insulation between secondary and core, disconnect the primary entirely, apply one terminal of the testing transformer to the secondary terminals of the transformer under test, and the other terminal of the testing transformer to the core of the transformer under test. This test should also not be in excess of one minute.

for five minutes at three-quarters capacity without exceeding the 1 per cent. limit.

The 150 scale ammeter may be left in circuit for an indefinite length of time at one-third its full capacity, and for three minutes at one-half its full capacity, with a negligible error.

Ammeters of 200 and of 300 ampere capacities must not continuously carry more than one-quarter of these loads respectively if the readings are to have an accuracy within 1 per cent. nor more than one-half these respective number of amperes for three minutes if the same degree of accuracy be desired.

In order to cut or shunt the ammeter out of circuit when not in use, it is customary when wiring the instrument in place, to introduce a switch as a shunt across it; this switch is kept closed except when a measurement is being taken.

When currents larger than 300 amperes have to be measured, ammeter shunts are generally

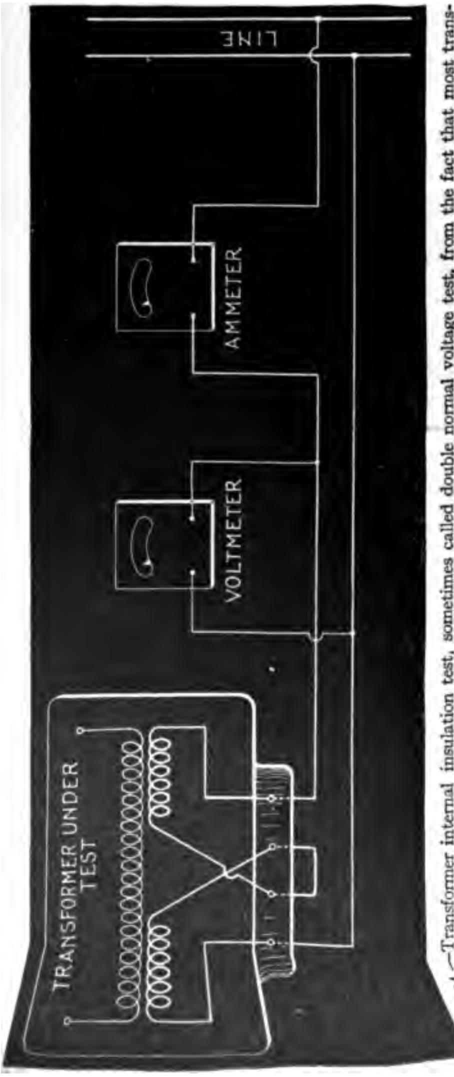


FIG. 2,904.—Transformer internal insulation test, sometimes called double normal voltage test, from the fact that most transformers are tested with double normal voltage across their terminals. If either the primary or secondary of the transformer be connected to some source of current with voltage double that of the voltage of the transformer under test, the insulation between adjacent turns, and also the insulation between adjacent layers will be subjected to twice the normal operating voltage. It is good practice to employ high frequency for this test in order to prevent an abnormal current from passing through the transformer. Sixty cycle transformers are usually tested on 133 cycle, and 25 cycle transformers on 60 cycle circuits for this double normal voltage test. It is necessary to insert the resistance in the circuit of the transformer and bring the voltage up gradually, the same as applying other high insulation tests in order to prevent abnormal rises in pressure at the instant of closing the circuit.

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Electrical measuring instruments, owing to the nature of their construction and the conditions under which they must necessarily be used, are subject to variations in accuracy. This feature is an annoying one on account of the difficulty of detecting it; a meter may, as far as appearances go, be in excellent working order and yet give readings which are not to be relied upon.

Ridiculous as it may appear, the average station attendant may frequently be seen straining his eyes to read to tenths of a division on the scale of a meter which, if subjected to test, would show an inaccuracy of over 2 per cent.

In testing a meter, by comparing it with a standard, in order to obtain the best results there should be one man at each meter so that simultaneous readings may be taken on both instruments, and the man at the standard meter should maintain the voltage constant while a

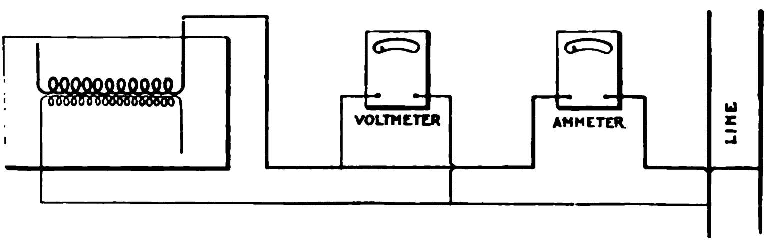


FIG. 2,905.—Transformer insulation resistance test. The insulation, besides being able to resist puncture, due to increased voltage, must also have sufficient resistance to prevent any appreciable amount of current flowing between primary and secondary coils. It is, therefore, sometimes important that the insulation resistance between primary and secondary be measured. This can be done, as here shown. Great care should be taken to have all wires thoroughly insulated from the ground, and to have an ammeter placed as near as possible to the terminals of the transformer under test, in order that current leaking from one side of the line to the other, external to the transformer, may not be measured. Great care is required in making this measurement, in order to obtain consistent results.

reading is being taken, by means of a rheostat in the field circuit of the generator supplying the current.

Each meter should be checked or calibrated at five or six approximately equidistant points over its scale; the adjustable resistance being varied each time to give a deflection on the standard meter of an even number of divisions and the deflection on the other meter recorded at whatever it may be. Having obtained the necessary readings, the calculation of the constant or multiplying factor of the meter undergoing test is next in order.

This may best be shown by taking an actual case in which a 150 scale *voltmeter is being* tested to determine its accuracy. The data and *calculations are as follows:*

Readings on standard meter	Readings on meter tested	Constant
150	149.2	150 ÷ 149.2 = 1.005
125	125.0	125 ÷ 125.0 = 1.000
100	98.9	100 ÷ 98.9 = 1.011
75	73.6	75 ÷ 73.6 = 1.019
50	50.0	50 ÷ 50.0 = 1.000
25	24.8	25 ÷ 24.8 = 1.008
		6.043

Average constant for six readings, 6.043 ÷ 6 = 1.007.

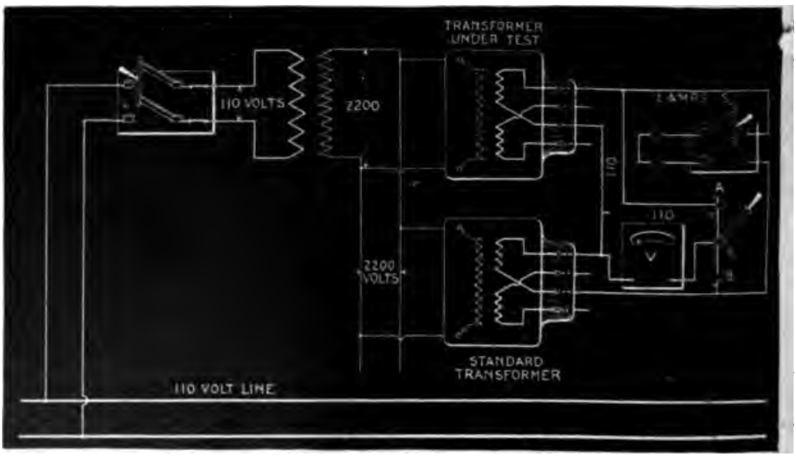


FIG. 2,906.—Transformer winding or ratio test. The object of this test is to check the ratio between the primary and the secondary windings. For this purpose a transformer of known ratio is used as a standard. Connect the transformer under test with a standard transformer as shown. Leave switch S_2 open. With the single pole double throw switch in position S_1B, the voltmeter is thrown across the terminals of the standard transformer. With the switch in position S_1A, the voltmeter is thrown across the terminals of the transformer under test. The voltmeter should be read with the switch in each position. If the winding ratio be the same as that of the standard transformer, the two voltmeter readings will be identical.

It may be stated in general that before taking the readings for this test, the zero position of the pointer on the meter tested should be noted, and if it be more than two-tenths of a division off the zero mark, the case of the meter should be removed and the pointer straightened.

Furthermore, it will be noticed from the readings here recorded that the test is started at the high reading end of the scale; this is done in order that the pointer may gradually be brought up to this spot, by slowly cutting out of circuit the adjustable resistance, and thus show whether or not the pointer has a tendency to stick at any part of the scale. If the meter seem to be defective in this respect, it should be remedied either by bending the pointer or scale, or by renewing one or both of the jewels, before the comparison with the standard is commenced.

It is obvious from the readings recorded for the 150 scale voltmeter, that as compared with the corresponding deflections of the standard, the former are a trifle low.

In order to determine for each observation how much too low they are, it is necessary to divide each reading on the standard by the corresponding reading on the meter tested. The result is the amount by which a deflection of this size on the meter tested must be multiplied in order to obtain the exact reading. This multiplier is called a constant, and as shown, a constant is determined for each of the six observations.

The average constant for the six readings is then found, and this is taken as the constant for the meter as a whole; that is, whenever this 150 scale voltmeter is used, each reading taken thereon must be multiplied by 1.007 in order to correct for its inaccuracy.

The most convenient and systematic way of registering the constant of a meter is to write it, together with the number of the meter and the date of its calibration, in ink on a cardboard tag and loop the same by means of a string to the handle or some other convenient part of the meter.

NOTE.—**Transformer polarity test.** A test of importance in the manufacture of transformers, and sometimes necessary for the user, is the so called *banking* or *polarity* test. The transformers from any particular manufacturer have the leads brought out in such a manner that a transformer of any size can be connected to primary and secondary lines in a given order without danger of blowing the fuses due to incorrect connections. All manufacturers of transformers, however, do not bank transformers in the same way, so that it is necessary in placing transformers of different makes to test for polarity. This is done as shown in fig. 2,906. One transformer is selected as a standard and the leads of the second transformer connected as indicated in the diagram. If the transformers be 1,100-2,200 volts to 110-220, two 110 volt lamps are connected in the secondaries of the transformers as indicated, while the primary of the transformer is connected across the line. In transformers built for two primary and two secondary voltages, it is necessary to test each primary and each secondary. The diagram shows the method of connecting one 2,200 volt coil and one 110 volt coil to the transformer to be tested. When the primary circuit of the transformer under test is closed, and if the secondary leads of the 110 volt coil under test be brought out of the case properly, the two 110 volt lamps should be brightly illuminated. If, on the other hand, the two 110 volt terminals have been reversed, no current will flow through the lamps. If these two terminals be found to be brought out correctly, transfer the secondary leads of the transformer under test to the second 110 volt coil. Upon closing the primary circuit, the lamp should again be brightly illuminated. Repeat this process with each of the secondary coils and the other *primary coil, and if the* lamps show up brightly in every case on closing the primary *circuit, all leads have been* properly brought out. If on any tests the lamps do not light up *brightly, the leads on the* transformer must be so changed as to produce the proper banking

[redacted]

Ques. What are the usual remedies applied to a voltmeter to correct a 3 or 4 per cent. error?

Ans. They consist of straightening the pointer, varying the tension of the spiral springs, renewing the jewels in the bearings, altering the value of the high resistance, and, in the case of a direct current instrument, strengthening the permanent magnet.

Ques. How is the permanent magnet strengthened?

Ans. After detaching it from the instrument, wrap around several turns of insulated wire, and pass through this wire for a short time 3 or 4 amperes of direct current in such a direction as to reinforce the magnet magnetism.

Ques. How may the value of the high resistance of a voltmeter be altered?

Ans. Determine the resistance of the voltmeter and add or subtract, according as the reading is high or low, a certain length of wire whose resistance is in per cent. of the voltmeter resistance the same as the per cent. of error.

NOTE.—The complete calibration of a two scale voltmeter does not, as might be supposed, necessitate that the readings on both scales be checked with standards, for since the resistance corresponding to the one scale is always some multiple of the resistance of the other, the constants of the two scales are proportional. For instance, if S = the reading at the end of the high scale of the voltmeter; S^1 = the reading at the end of the low scale of the voltmeter; R = the resistance in the meter corresponding to the high scale; R = the resistance in the meter corresponding to the low scale; K = the constant for the high scale, and K^1 = the constant for the low scale. Then

$$SK + R = S^1K^1 + R^1$$

from which

$$K^1 = SKR + S^1R$$

That is to say, if the respective resistances corresponding to the two scales be known, and the constant of the high scale be determined by comparison with a standard, then by aid of these known values and the maximum readings on the two scales, the constant of the low scale may be calculated. It is also possible to calculate the constant of the high scale if the constant of the low scale be known, together with the values of the resistances corresponding to the two scales; for from the equation previously given.

$$K = RS^1K^1 + R^1S$$

Ques. What is a frequent cause of error in an alternating current meter, and why?

Ans. The deterioration of its insulation, which permits the working parts of the instrument coming in contact with the surrounding metal case.

A convenient method of testing for deterioration of insulation is shown in fig. 2,905.

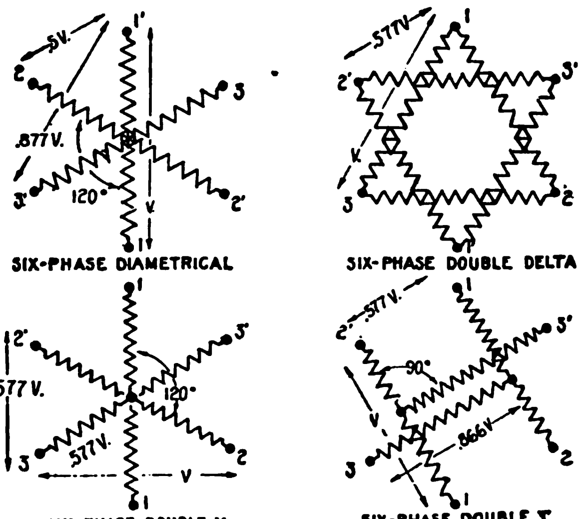


FIG. 2,907.—Diagrams showing various synchronous converter transformer connections. The diametrical connection is used most frequently as it requires only one secondary coil on each transformer, this being connected to diametrically opposite points on the armature winding. The middle points can be connected together and a neutral obtained the unbalanced three wire direct current having no distorting effect. With diametrical secondaries, the primaries should preferably be connected delta, except with regulating pole converters where they must be connected Y. Diametrical secondaries with delta primaries should not be used with regulating pole converters. Double star connection of secondaries may, however, be used with delta primaries, and is free from the trouble of the triple harmonic of the transformer appearing in the primary. In this case, however, the two secondary neutrals must not be connected with each other.

How to Test Generators.—In the operation of electrical *stations,* many problems dealing with the generators installed *therein* can be readily solved by the aid of characteristic curv

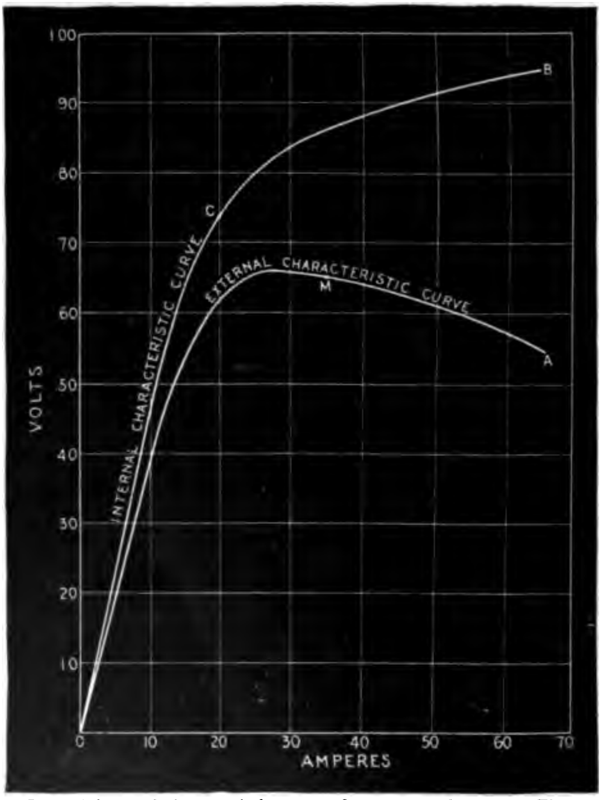


FIG. 2,908.—General form of characteristic curves for a series dynamo. The general curve that may be expected is OA. It is obtained practically in the same manner as for the shunt characteristic curve, except that no field rheostat is employed. Commencing with no load or amperes, there will probably be a small deflection noticeable on the voltmeter, due to the residual magnetism. The other readings are taken with successive reductions of main current resistance. The curve OA thus obtained for a certain series generator is practically a straight line at the beginning, representing thereby a proportional increase of voltage with increase of current, but after a certain current is reached (about 20 amperes in this case) the curve flattens and takes a downward direction. The turning point occurs in the characteristic curves of all series generators, and it denotes the stage at which the iron magnet cores become so saturated with lines of magnetic force that they will not readily allow more to pass through them; this turning point is technically known as the point of saturation, and the current corresponding (20 amperes in this case) is called the critical current of the dynamo. The point of saturation in any given series machine is governed by the amount of iron in the magnetic circuit; its position in the curve therefore var according to the design of the generator as does also the critical current. The valu the latter is important inasmuch as the valuable features of a series generator which bear a relation to the generators similarly as do indicator diagrams to steam engines.

In steam engineering, a man who did not fully understand the method of taking an indicator diagram would be considered not in touch with his profession, and in electrical engineering the same would be true of one ignorant of the method of obtaining characteristic curves.

The necessary arrangement or connection of the generator from which it is desired to obtain a characteristic curve, consists in providing a constant motive power so that the machine may be run at a uniform speed, and when the field magnets of the generator are separately excited the field current from the outside source must also be maintained constant, preferably by a rheostat connected in the field of the auxiliary exciting machine. It is also necessary in every case that means be provided for varying the main current of the generator step by step from zero to maximum. This may best be done by employing a water rheostat, as shown in fig. 2,909.

Ques. What instruments are needed in making a test of dynamo characteristics?

Ans. A voltmeter, ammeter, speed indicator, the usual switches and rheostats.

Ques. How is the apparatus connected?

Ans. It is connected as shown in fig. 2,910.

Ques. Describe the test.

Ans. Having completed the preliminaries as in fig. 2,910, the test should be started with the main circuit of the generator

FIG. 2,908.—*Text continued.*

selves only when the machine is supplying a greater number of amperes than that of the critical current, for if the series generator be worked along that part M A of the curve to the right of the point of saturation it becomes nearly self-regulating as regards current, because as the current increases the voltage drops. In the diagram in addition to the characteristic curve O A, which may more definitely be called an external characteristic curve on account of representing the conditions external to the generator, there is shown a total characteristic curve, O C B. The latter curve represents the relation between the current and the total voltage developed in the armature, and may be plotted from the external characteristic curve if the resistance of the armature between brushes and the resistance of the series field winding be known. For example, assume these combined resistances amount to .6 ohm. At 30 amperes there would be required 30 × .6 = 18 volts to force this current through the armature and field windings. At 30 amperes the external pressure is *65 volts, as shown by* the curve O A; the total voltage developed for 30 amperes is, therefore, the external voltage plus the internal voltage or 65 + 18 = 83 volts. Plotting 83 volts *for 30 amperes will give* one point for the external characteristic curve of this machine, and *by determining in like manner the total voltages developed for six or eight different currents over the scale, sufficient data will be at hand for plotting and drawing in the curve.*

open. Then, in the case of the shunt machine, the speed should be made normal and the field rheostat adjusted until the voltmeter reading indicates the rated voltage of the machine at no load and readings taken. The electrodes of the water rheostat should be adjusted for maximum resistance and main circuit closed, and a second set of readings taken. Several sets of

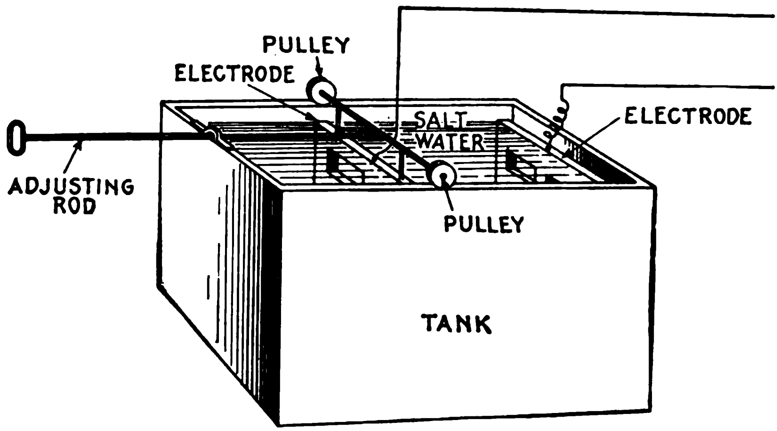


FIG. 2,909.—Water rheostat. It consists essentially of a tank of suitable size containing salt water into which are placed two electrodes having means of adjustment of the distance separating them. The solution depends on the voltage. Pure water is seldom used for pressures under 1,000 volts. The size of the tank is determined by the size of the electrodes, and roughly the size of the latter equal the number of amperes. With a current density of one ampere per square inch, a water solution gives a drop of 2,500 to 3,000 volts per inch distance between the plates. Where high voltage is used, the water must be circulated through and from the tank by rubber hose allowing for 2,500 volts, a length of 15 to 20 feet of 1 inch hose to prevent grounding. In place of the arrangement shown above, a barrel may be used for the tank, and for the electrodes, coils of galvanized iron wire. This is the simplest form and is satisfactory.

readings are taken, with successive reductions of water rheostat resistance. The results are then plotted on coordinate paper giving the characteristic curve shown in fig. 2,908.

Ques. What does the characteristic curve (fig. 2,911) show?

Ans. An examination of the curve shows that the highest point of the curve occurs at no load or 0 amperes; that as the current is increased, the voltage drops, first slightly to the point B and then rapidly until the point E is reached, when any further lowering of resistance in the main circuit to increase the current causes not only a rapid decline in the voltage but also of the current until both voltage and current become approximately zero.

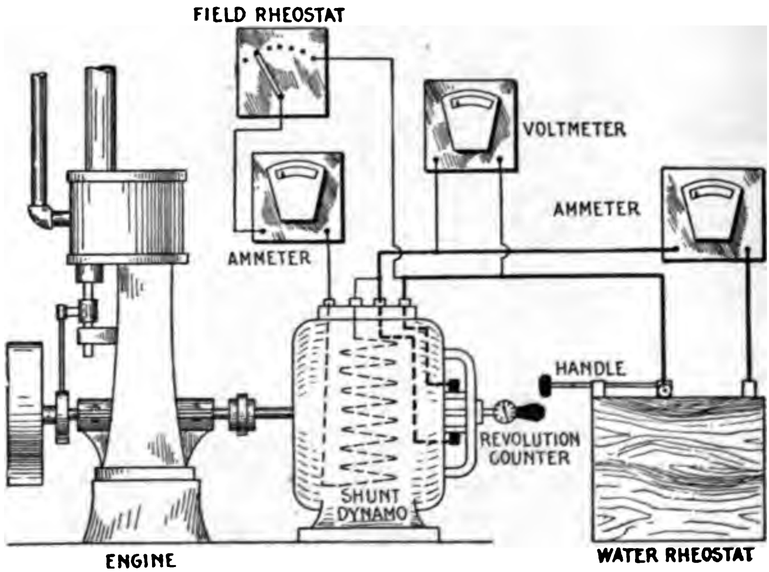


FIG. 2,910.—Connections for test of dynamo. During the test, one man should be assigned to the tachometer, another man to the water rheostat, and there should preferably be one man at each of the electrical measuring instruments. In order to enable the man at the tachometer to keep the speed constant, he should be in communication either directly or indirectly with the source of the driving power, and the man at the water rheostat should be in plain view of the man reading the ammeter so that the latter party may signal him for the proper adjustment of the rheostat in order that the desired increase of current be obtained for each set of readings.

In some generators, a very slight current results even when the terminals of the machine are actually short circuited; that is, due to residual *magnetism* in the pole pieces, the lower portion of the curve often *terminates*, not exactly at zero, but at a point some distance along the *current line*.

[redacted]

The working portion of the curve is from A to C, at which time the machine is supplying a fairly constant voltage. From C to E shows a critical condition of affairs, while the straight portion D O represents the unstable part of the curve caused by the field current being below its proper value.

The position of the point C determines the maximum power the machine is capable of developing, being in this case $(47.5 \times 25) \div 746 =$ 1.59 horse power.

Ques. How may the commercial efficiency of a generator be determined?

Ans. To obtain the commercial efficiency, the *input* and *output* must be found for different loads.

The input may be found by running the generator as a motor at its rated speed, loading it by means of a Prony brake. The generator must be stripped of all belting or other mechanical connections, supplied with its normal voltage and full load current, and the pressure of the Prony brake upon its armature shaft or pulley adjusted until the rated speed of the armature is obtained. The data thus obtained is substituted in the formula

$$\text{input in brake horse power} = \frac{2\pi L W R}{33{,}000} \quad . \quad . \quad . \quad . \quad (1)$$

in which

L = length of Prony brake lever;
W = pounds pull at end of lever;
R = revolutions per minute.

The output or electrical horse power for the same load is easily calculated from the formula

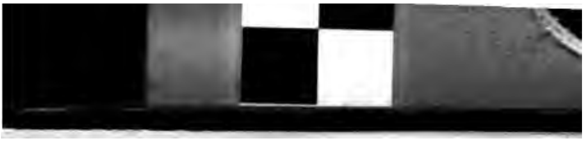
$$\text{output in electrical horse power} = \frac{\text{amperes} \times \text{volts}}{746} \quad . \quad . \quad (2)$$

After obtaining value for (1) and (2) the commercial efficiency for the load taken is obtained from the formula

$$\text{commercial efficiency} = \frac{\text{output}}{\text{input}} \quad . \quad . \quad . \quad . \quad (3)$$

Having obtained the commercial efficiency, the difference between the ideal 100 per cent. and the efficiency found will be due to certain losses in the generator. These losses may be classified as

1. Mechanical;
2. Electrical.



The mechanical losses are the friction of the bearings and brushes, and air friction. The electrical losses consist of the eddy current loss, hysteresis loss, armature resistance loss, and field resistance loss.

In testing for these losses, the generator to be tested should be belted to a calibrated motor which latter machine should preferably be of the constant pressure, shunt wound type.

The friction of the bearings and belt of the generator are determined together by raising the brushes off its commutator and running it at the rated speed by means of the calibrated motor.

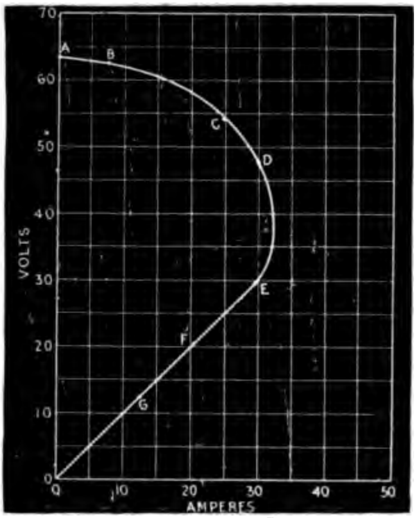


FIG. 2,911.—Characteristic curve of shunt dynamo. Suppose in making the test, the deflections on the meters for the first readings be 63 volts and 0 amperes, the plotting of these values will give the first point on the curve. Similarly, the second readings with main circuit closed and maximum resistance in the water rheostat may be assumed to be 62.5 volts and 7.5 amperes, which plotted gives the second point B. A still further lowering of the plate will permit a stronger current in the main circuit, and the value of this together with its corresponding voltage will give a third point for the curve. Neither for this reading, however, nor for the following readings of the test should the field rheostat be altered. When six or eight points ranging from zero to a maximum current have been obtained and plotted, a curved line should be drawn through them such as shown through ABCDEFGO, the *characteristic curve* of the dynamo. While the curve may be sketched in free hand, it should preferably be drawn by the aid of French curves. In case the French curve cannot be exactly made to coincide with all the points as for instance C and D, it should be run in between giving an average result, and smoothing out irregularities, or small errors due to the "personal equation." The meter of course must be correct or calibrated and the readings corrected by the calibration coefficient.

The amount of power as ascertained from the calibration curve of th motor for the voltage and current used therein when driving the g erator as just explained, is a measure of these two losses. The p thus used is practically constant at all loads and is about 2 per cent. of that necessary to drive the generator at full load.

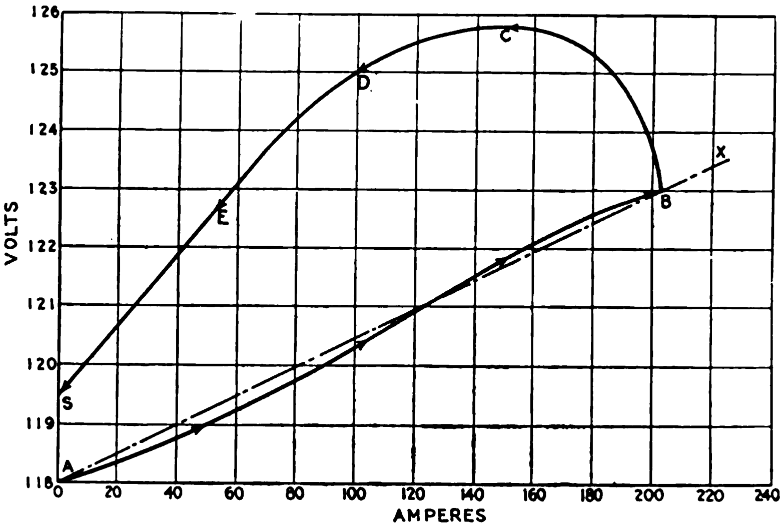


FIG. 2,912.—Characteristic curves for a compound dynamo. If the machine be over compounded, the characteristic curve has the form of the curve A B, which curve was obtained from a machine overcompounded from 118 to 123 volts, and designed to give 203 amperes at full load. The preliminary arrangements for testing a compound dynamo are similar to those for a shunt generator, and if the shunt across the series field winding be already made up and in position, the readings are taken precisely in the same manner. It is generally considered sufficient if observations be recorded at zero, ¼, ½, ¾ and full load. If it be desired to ascertain the effect which residual magnetism has upon the field magnets the current is decreased after the full load point is reached without opening the circuit, and readings are taken in succession at ¾, ½, ¼ and zero load giving in this case the curve B C D E S. It is thus seen that residual magnetism exerts no small effect upon the voltage obtained at the different loads, for had there been no residual magnetism in the field magnets the curve B C D E S would have coincided with the curve A B. The curve A B, and the straight line A X drawn through the points A and B, are almost identical, and as A X represents the theoretical characteristic curve for the machine, it is seen that compounding is practically perfect. In order to insure such accurate results being obtained, providing the machinery be correctly designed, requires considerable care in taking the readings; for example, each step or load on the ascending curve should not be exceeded before the corresponding deflection is taken, else the residual magnetism will cause the pressure reading to be higher than it actually should be, and the following pressure readings will also be affected in the same manner. In case the shunt to be employed across the series field has not been made up, it is advisable to perform a trial test before taking the readings for the curve as previously described. The trial test consists in taking two readings,—one at no load and the other at full load, the shunt being so adjusted as to length and section that the desired amount of compounding will be obtained in the latter reading with normal voltage at no load. If the first trial fail to produce the desired result by giving too low a voltage at full load, the length of the shunt across the series field should be increased, or its section should be reduced by employing a less number of strips in its makeup; again, if the voltage at full load be higher than that desired, there must be made a decrease in length or an increase of section in the shunt employed.

The friction of the brushes can very conveniently be determined next by lowering them on the commutator and giving them the proper tension.

The increase in power resulting from the greater current that will now be taken by the motor to run the dynamo at its rated speed, will be a measure of this loss. In general, its value will be about .5 per cent. of the total power required to drive the dynamo at full load, and this also will remain constant at all loads.

The friction of the air upon the moving armature of the dynamo cannot be determined experimentally, but theoretically this loss is small and may be estimated as .5 per cent.; it is also constant at all loads.

The core loss may be determined experimentally by exciting the field magnets of the dynamo with the normal full load field current through the magnet coils, and noting the increase of power required by the motor to maintain the rated speed of the dynamo thus excited under no load, over that necessary under the same conditions with no field excitation. This increase of power will be the value of the core loss. The core loss is approximately 3 per cent. of the power required to operate the dynamo at full load, and it is constant at varying loads. If it be desired to divide the core loss into its component parts, it is necessary also to run the dynamo under the same conditions as before with field excitation but at half its rated speed. If, then,

H = the power lost in hysteresis at rated speed,
E = the power lost in eddy currents at rated speed,
T = the power lost in hysteresis and eddy currents at rated speed,
S = the power lost in hysteresis and eddy currents at half speed,

there may be formed the two following equations:

$$T = H + E, \text{ and } S = \frac{H}{2} + \frac{E}{2},$$

from which the elimination of H will give $E = 2T - 4S$.

The value of the eddy current loss thus found will be about 1½ per cent., and constant at all loads.

Having previously ascertained the power lost in both eddy currents and hysteresis, and knowing now the power lost in eddy currents alone, it is easy to find that lost in hysteresis by simply subtracting the latter known value from the former. The value of the hysteresis loss is therefore approximately 1½ per cent., and it is constant at different loads.

There yet remains to be determined the armature resistance loss and the field resistance loss. As for the calibrated motor, this may be disconnected from the dynamo, as it need not be used further in the test.

The armature resistance is the resistance of the armature winding of the dynamo, between the commutator bars upon which press the positive and negative brushes. Assume that the value of the armaresistance be known, call this value R ohms, together with that of the full load armature current, which is also known and which call I amperes, this is sufficient data for calculating the armature resistance loss at full load. It is evident that to force the full load current I through the armature resistance R will require a pressure of R volts, and that the watts lost in doing so will be the voltage multiplied by the current. The armature resistance is consequently

$$I R \times I = I^2 R \text{ watts}$$

or, expressed in horse power it is

$$I^2 R \div 746$$

At full load it is usually about 2 per cent. of the total power required to drive the generator fully loaded. The armature resistance loss varies in proportion to the load, in fact, as the last expression shows, it increases as the square of the armature current.

The field resistance loss is calculated in the same manner as just explained for the armature resistance loss, it being equal in horse power to the square of the full load field current multiplied by the resistance of the field winding and divided by 746. In a shunt dynamo it is practically constant at 2 per cent. of the total power at full load, but in a series or in a compound generator it will vary in proportion to the load.

[redacted]