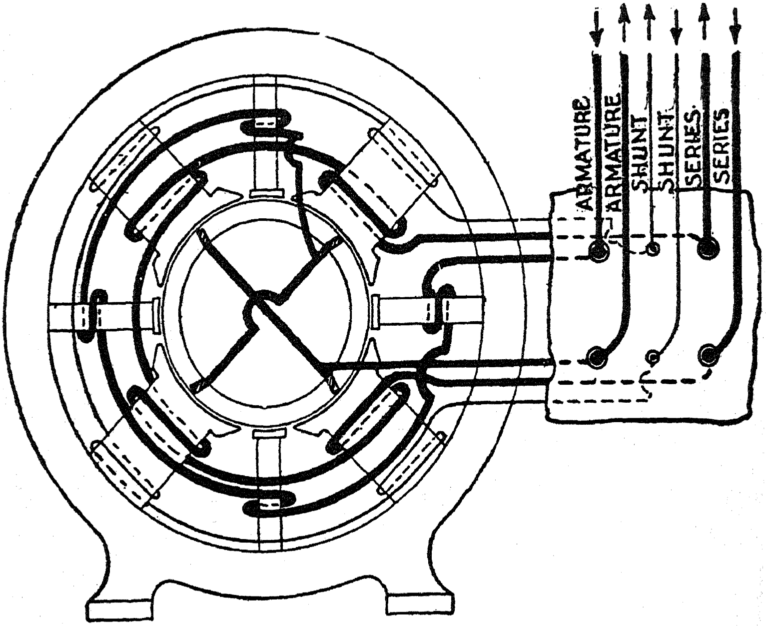

Arrangements of Leads on an Inter-Pole Motor

Connection diagram for variable speed compound inter-pole motor. Arrows indicate direction of current for accumulative compound right hand rotation. ***In case*** the direction of rotation is to be changed, reverse the armature connections at controller. In order to be sure that series and shunt windings are connected accumulatively, the following test may be made: Close the main line switch, momentarily, with machine connected as a series motor (that is, with the shunt circuit open). If the direction of rotation when running thus be the same as when running as a compound motor, it is connected accumulatively, if not, it is connected differentially, and in that case it will be necessary to reverse either the series or the shunt connections at the controller.

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FINDER

CHAPTER 22

Theory of the Armature

Current Distribution in Ring and Drum Armatures.—In studying the actions and reactions which take place in the armature, the student should be able to determine the directions of the induced currents. The basic principles of electromagnetic induction were given in Chapter X, from which, for instance, the distribution of current in the gramme ring armature, shown on fig. 701, is easily determined by the application of Fleming's rule.

Ques. In the Gramme ring armature (fig. 701) what is the distribution of armature currents?

Tracing the current from the negative to the positive brush, it will be seen that it divides, half going through coils **L,A,R,F** and half through coils *l,a,r,f*, these two currents ascend to the top of the ring, uniting at the positive brush.

Ans. There are two paths in parallel as indicated in fig. 701.

Ques. How does the voltage vary in the coils?

Ans. It varies according to the position of the coils, being least when vertical and greatest when horizontal in a two pole machine arranged as in fig. 701.

The upper and lower coils in the right hand half of the ring armature, fig. 701, will have about the same electromotive force induced in them, say 2 volts each, while the two coils between them will have a higher electromotive force, at the same instant, say 4 volts each, since they occupy nearly the positions of the maximum rate of change of the magnetic lines threading through them. These eight coils may be represented by two batteries connected in parallel, each battery consisting of two 2 volt cells

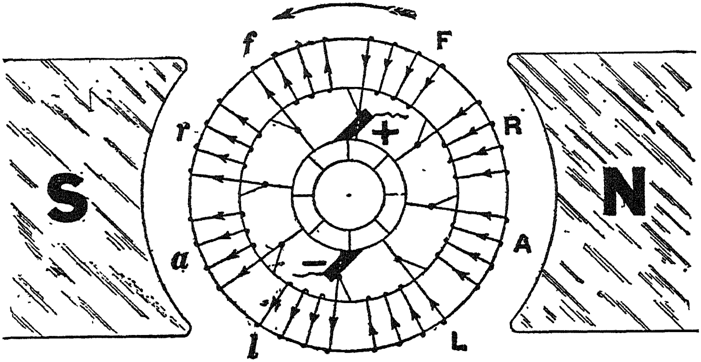

Fig. 701.—Current distribution in a gramme ring armature. There are two paths for the current between the brushes, half going up each side of the ring as indicated by the arrows, thus giving two paths in parallel as indicated in fig. 702.

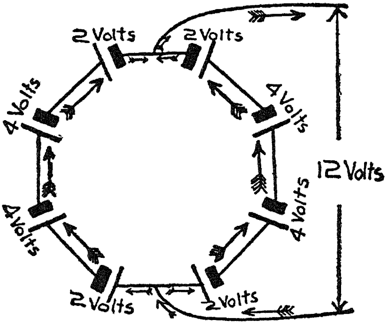

Fig. 702.—Battery analogy illustrating current distribution in a ring armature. The eight coils of the armature, fig. 701, are represented by two batteries of four cells each. The action of the two units thus connected is indicated by the arrows. In the external circuit the voltage is equal to that of one battery and the current is equal to the sum of the currents in each battery.

and two 4 volt cells as shown in fig. 702. The voltage of each battery then will be

$$2+4+4+2=12 \text{ volts}$$

The two batteries being connected in parallel, the voltage at the terminals will be the same, but the current will be the sum of the currents in each battery.

Ques. How may the number of paths in parallel be increased?

Ans. By increasing the number of poles.

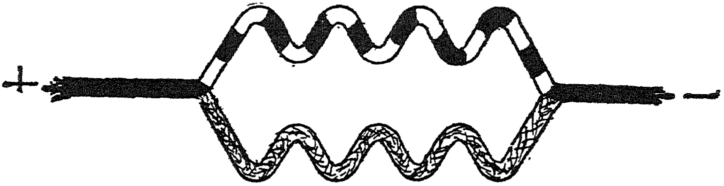

Fig. 703.—Diagram showing distribution of current in the gramme ring armature of fig. 701. The current flows in two parallel paths as indicated.

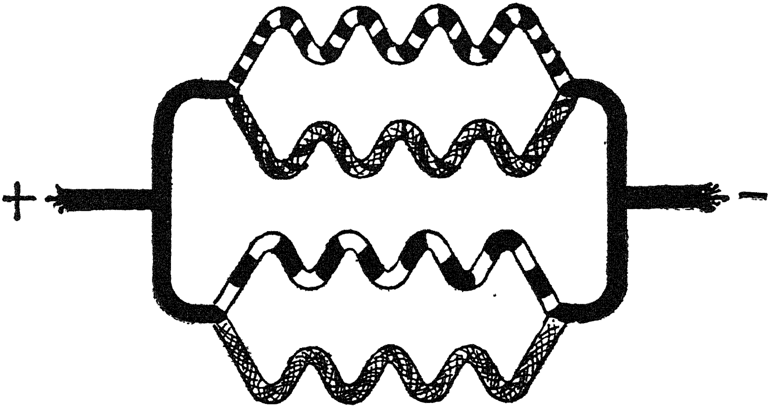

Fig. 704.—Diagram showing current distribution through armature of a four pole machine with like brushes connected. There are four paths in parallel, hence the induced voltage will equal that of one set of coils, and the current will be four times that flowing in one set of coils.

For instance, in a four pole machine, as in fig. 704, there are four paths in parallel. In this case the armature may be used to furnish two separate currents, though this is not desirable.

Ques. How are the brushes connected?

Ans. Usually all the positive brushes are connected together, and all the negative brushes as in fig. 705, giving four paths in parallel through the armature as indicated in fig. 704.

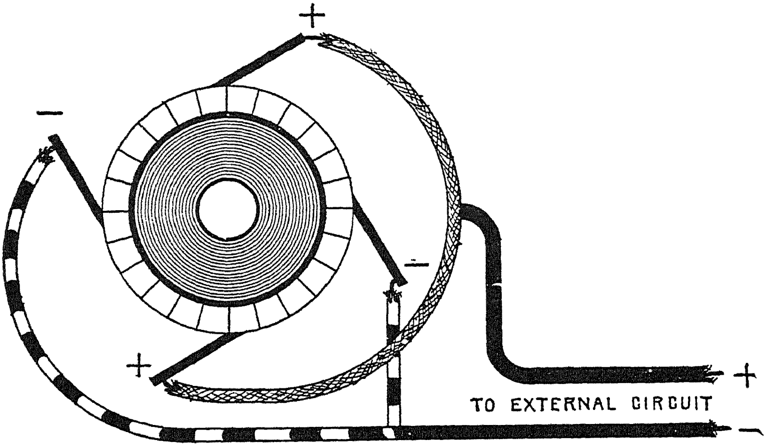

FIG. 705.—Brush connections for four pole dynamo. ***It is usual*** to connect all the positive brushes to one terminal and all the negative brushes to the other which gives four parallel paths as shown in the diagram, fig. 704. In a four pole machine, two separate currents can be obtained by omitting the parallel brush connections.

Ques. How does this method of brush connection affect the voltage?

Ans. The voltage at the terminals is equal to that of any of the sets of coils between one positive brush and the adjacent negative brush.

Thus in the four pole machine, fig. 704, the coils of the four quadrants are in four parallels, which gives an internal resistance equal to one-sixteenth that of the total resistance of the entire ring.

When the coils are connected in two circuits or series parallel, it requires only two brushes at two neutral points on the commutator, for any number of poles; this arrangement is shown in fig. 567.

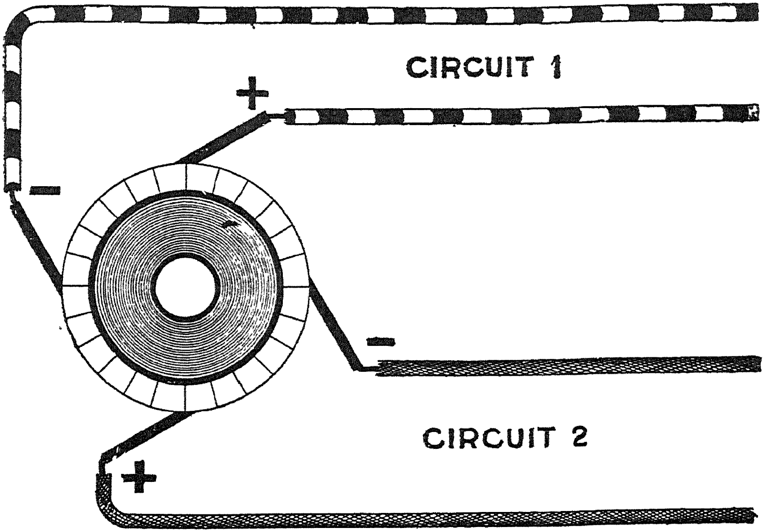

FIG. 706.—Brush connections for four pole dynamo arranged to obtain two separate currents by omitting the parallel brush connection shown in fig. 705.

Ques. In general what may be said about the current paths through an armature?

Ans. The paths may be in parallel or series parallel according as the winding is of the lap or wave type.

Variation of Voltage Around the Commutator.—There are numerous ways of determining the value of the induced voltage in an armature at various points around the commutator. In the method suggested by Morday, it can be measured by the use of a single exploring brush and a volt meter as shown in fig. 707.

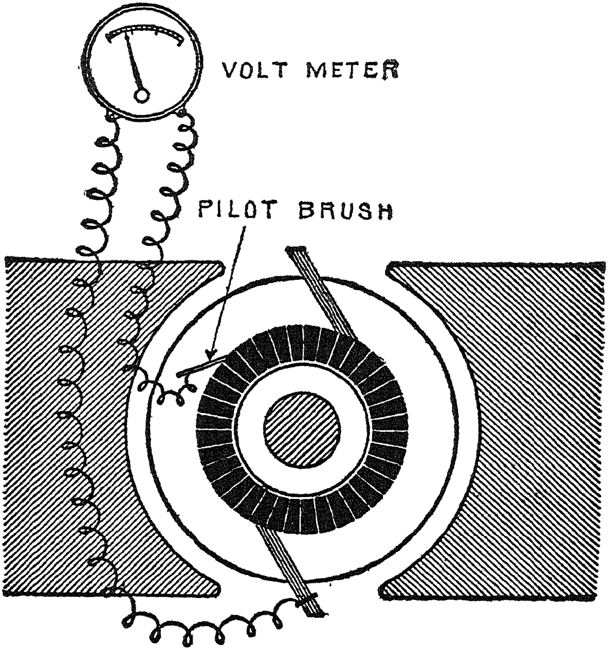

FIG. 707.—Morday's method of measuring the variation of voltage around the commutator by use of a single exploring brush and volt meter. *It consists* in connecting one terminal of the volt meter (preferably an electrostatic one) to one brush of the machine, and the other terminal to the exploring brush, which can be moved from point to point, readings being taken at each point.

In this method, one terminal of the volt meter is connected to one of the brushes of the dynamo, and the other terminal is joined by a wire to a small pilot brush which can be pressed against the commutator at any desired part of its circumference. With the machine running at its rated speed, the exploring brush is placed in successive positions between the two brushes of the machine. In each position a reading of the volt meter is taken and the angular position of the exploring brush noted.

Ques. How does the voltage vary between successive pairs of commutator segments?

Ans. The variation is not constant.

Cross Magnetization; Field Distortion.—In the operation of a dynamo with load, *the induced current flowing in the armature winding, converts the armature into an electromagnet setting up a field across or at right angles to the field of the machine.*

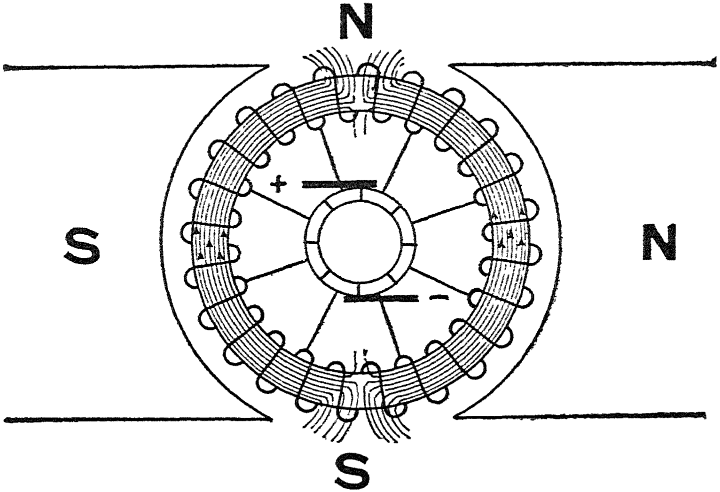

FIG. 708.—Cross magnetization. ***This is defined*** as lines of magnetic force set up in the windings of a dynamo armature which oppose at right angles the lines of force created between the poles of the field magnet. The figure shows this cross flux which is due to the armature current alone.

This cross magnetization of the armature tends to distort the field produced by the field magnets, the effect being known as *armature reaction.*

To understand the nature of this reaction it is best to first consider the effect of the field current and the armature current separately.

Fig. 708 represents the magnetic flux through an armature at rest, where the field magnets are separately excited. If the armature be rotated clockwise, induced currents will flow upward through the two halves of the winding between the brushes, making the lower brush negative and the upper brush positive.

Ques. If, in fig. 708, the current in the field magnet be shut off, and a current be passed through the armature entering at the lower brush, what is the effect?

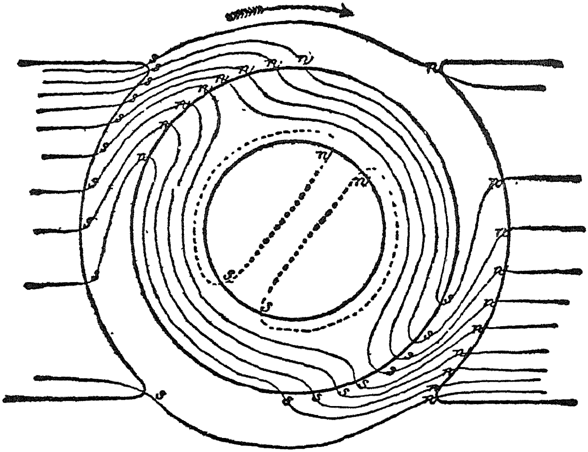

Fig. 709.—Distortion of magnetic field due to cross magnetization. *For clearness,* the effect is shown somewhat exaggerated. A drag or resistance to the movement of the armature is caused by the attraction of the north and south poles on the armature and pole pieces respectively.

Ans. The current will divide at the lower brush, flowing up each side to the top brush.

These currents tend to produce north and south poles on each half of the core at the points where the current enters and leaves the armature.

Hence, there will be two north poles at the top of the ring and two south poles at the bottom.

Ques. What effect is produced by the like poles at the top and bottom of the ring?

Ans. The external effect will be the same as though there were a single north and south pole situated respectively at the top and bottom of the ring.

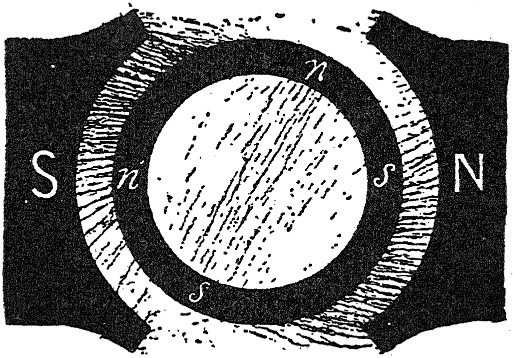

Fig. 710.—Actual distortion of field resulting from cross magnetization, as shown by iron filings.

Ques. In the operation of a dynamo, how do the poles induced in the armature affect the magnetic field of the machine?

Ans. They distort the lines of force into an oblique direction as shown exaggerated in the diagram fig. 709.

Ques. What effect has the presence of poles in the armature on the operation of the machine?

Ans. In fig. 709, the resultant north pole *n,n,n,* where the lines emerge from the ring, attracts the south pole *s,s,s,* where the lines enter the field magnet, hence a load is brought upon the engine, which drives the dynamo, in dragging the armature around against these attractions.

The stronger the current induced in the armature, the greater will be the power necessary to turn it.

Ques. Why does this reaction in the armature require more power to drive the machine?

Ans. The effect produced by the armature reaction is in accordance with Lenz's law which states that: *In electromagnetic induction, the direction of the induced current is such as to oppose the motion producing it.*

Remedies for Field Distortion.—Since the distortion of the magnetic field of a dynamo causes unsatisfactory operation, numerous attempts have been made to overcome this defect, as for instance, by:

1. Experimenting with different forms of pole piece;

The reluctance of the pole piece should be increased in the region where the magnetic flux tends to become most dense. The trailing horn of the pole piece may be made longer than the advancing horn and cut farther from the surface of the armature, so as to equalize the distribution of the magnetic flux.

2. Lengthening the air gap;

This increases the reluctance, and also necessitates more ampere turns in the field winding. The field distortion, however, will not be so great, as it would be if the magnetic field of the machine were weaker.

3. Slotting the pole pieces;

Both longitudinal gaps and oblique slots have been tried. The reduction of cross section of the pole piece causes it to become highly saturated and to offer large reluctance to the cross field.

4. The use of auxiliary poles.

These are small poles placed between the main poles and so wound and connected that their action opposes that of the cross field.

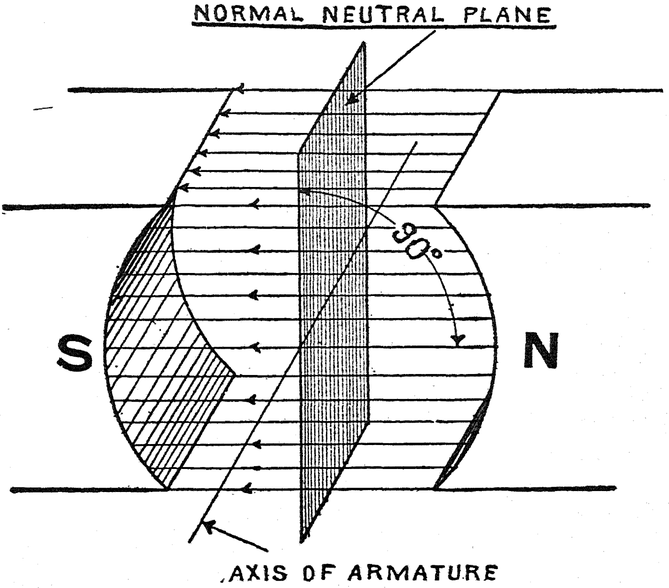

FIG. 711.—Normal neutral plane. This is a reference plane from which the lead is measured. As shown, the normal neutral plane lies at right angles to the lines of force of an undistorted field.

Normal Neutral Plane.—This may be defined as *a plane passing through the axis of the armature perpendicular to the magnetic field of the machine when there is no flow of current in the armature,* as shown in fig. 711.

It is the plane in which the brushes would be placed to prevent sparking when the machine is in operation were the field not distorted by armature reaction, and there were no self-induction in the coils.

Commutating Plane; Lead of the Brushes.—It has been found that *in order to reduce sparking to a minimum,* the brushes must be placed *in certain positions found by trial and designated as being located in the neutral plane.*

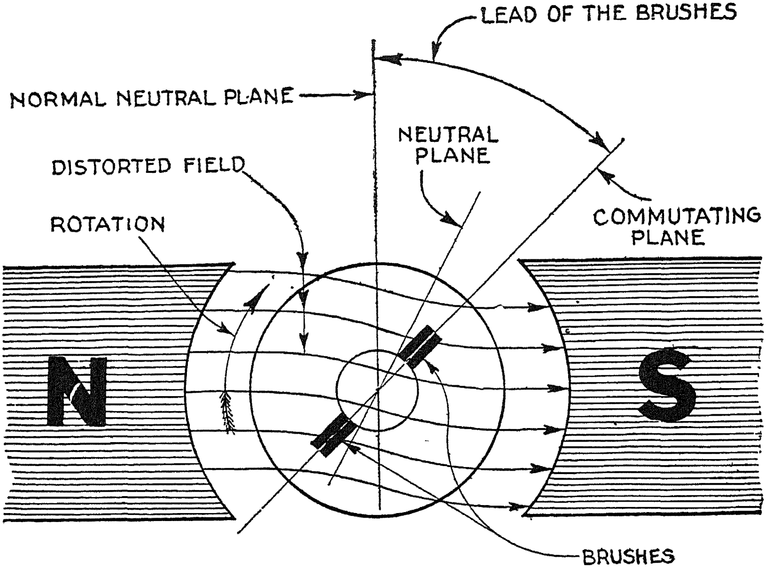

FIG. 712.—Lead of the brushes, or advance beyond the normal neutral plane in the direction of rotation of the armature which is necessary to prevent sparking due to field distortion and self induction in the coils.

When the brushes are in the neutral plane, they are in contact with commutator segments connecting with coils that are cutting the lines of force at the minimum rate.

Ques.—Define the term "commutating plane."

Ans. This is a plane passing through the axis of the armature and through the center of contact of the brushes as shown in figs. 715 and 727.

Ques. What is the angle of lead?

Ans. The angle between the normal neutral plane and the commutating plane.

In the operation of a dynamo since the field, on account of armature reaction, is twisted around in the direction of rotation, the proper position for the brushes is no longer in the normal neutral plane, but lies obliquely across, a few degrees in advance. Hence, for sparkless commutation, the commutating plane is a little in advance of the normal neutral plane, the lead being measured by the angle between these planes, as stated in the definition.

Ques. What may be said with respect to the angle of lead?

Ans. *For sparkless commutation, the angle of lead varies with the load.*

If the field be much altered at full load, it is evident that at half or quarter load it will not be nearly so much twisted, hence the necessity for mounting the brushes on some kind of rocking device which will allow them to be shifted in different positions for different loads. A desirable point, then, in dynamo design is to make the angle of lead at full load so small that it will not be necessary to shift the brushes much for variation of load. This can be accomplished by making the field magnet field considerably more powerful than the armature field.

Demagnetizing Effect of Armature Reaction.—In the operation of a dynamo, as previously explained, the position of the brushes for sparkless commutation must be varied with the load; that is, for light load they should occupy a position practically midway between the poles and for a heavy load they must be moved a few degrees in the direction of rotation. In other words, the commutating plane must be more or less in advance of the normal neutral plane as shown in fig. 730.

Ques. What is the effect of lead?

Ans. It produces a demagnetizing effect which tends to weaken the field magnets.

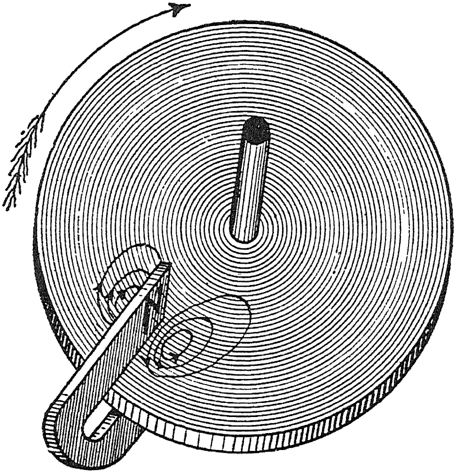

FIG. 713.—Arago's experiment illustrating eddy currents. Arago found that if a copper disc be rotated in its own plane underneath a compass needle, the needle was dragged around as by some invisible friction. The explanation of this phenomenon, known as *Arago's rotations*, is due to Faraday, who discovered that it was caused by induction. That is, a magnet moved near a solid mass of metal, induces in it currents, which in flowing from one point to another, have their energy converted into heat, and which, while they last, produce (in accordance with Lenz's law) electric pressures tending to stop the motion. Thus, in the figure, there are a pair of eddies in the part passing between the poles, and these currents oppose the motion of the disc. Foucault showed by experiment the heating effect of eddy currents, but such currents were known years before Foucault's experiments, hence they are incorrectly called Foucault currents.

Ques. Describe the demagnetizing effect in detail.

Ans. Tracing the armature currents, in fig. 715 according to Fleming's rule, it will be seen that current in inductors 1 to 18 flow *from* the observer indicated by crosses representing the tails of retreating arrows and in inductors 19 to 36, *toward* the observer from the back of armature, indicated by dots representing the points of approaching arrows.

In determining these current directions the inductors to the right of the neutral line are considered as moving downward, and those to the left as moving upward. The current in inductors 1 to 15 and 19 to 33, tends to cross magnetize the magnetic field of the machine, but the current in inductors 34 to 36 and 16 to 18 tends to produce north and south poles as indicated. These poles are in opposition to the field poles and tend to demagnetize them. Hence, the inductors lying outside the two upright lines are known as *cross magnetizing turns*, and those lying inside, as *demagnetizing turns*.

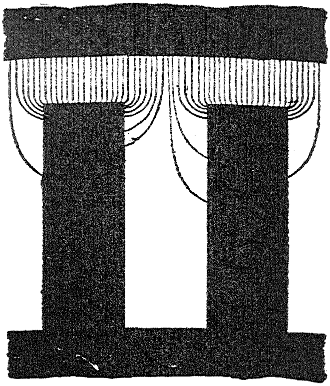

FIG. 714.—Distribution of lines of force for a toothed armature with a gap approximately equal to the breadth of a tooth and with slot slightly wider. In the gap the density of the lines shows alternate maxima and minima, the lines being very slightly curved at the level of the teeth; but below this level those that enter the slot swerve sharply round to enter the flanks of the teeth. Except in the case of very highly saturated teeth, there is no field in the slot at any greater depth than about equal to the slot width. The ratio of the density of the field in the slot to the density of the field in the tooth is roughly the same as the ratio of the gap length (from iron to iron) to the sum of gap length and tooth length. This distribution of lines of force as shown by Professors Hele-Shaw and Hay with the aid of a hydraulic model in which the stream lines in glycerine imitate the forms of the magnetic lines under varying conditions.

The breadth of the belt of demagnetizing turns included between the two upright lines is clearly proportional to the angle of lead; therefore the demagnetizing effect increases with the lead.

Eddy Currents; Lamination.—Induced electric currents, known as eddy currents, occur *when a solid metallic mass is rotated in a magnetic field*.

They consume considerable energy and often occasion harmful rise in temperature. Armature cores, pole pieces, and field magnet cores are specially subject to these currents.

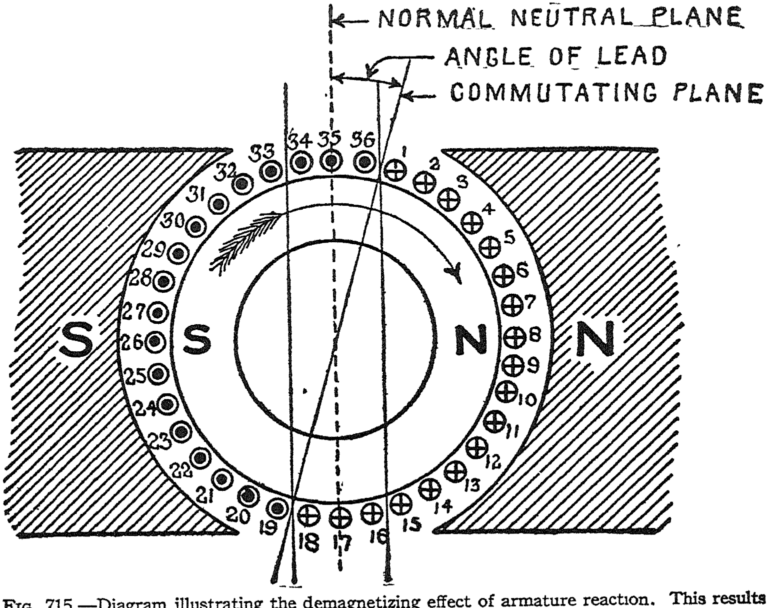

FIG. 715.—Diagram illustrating the demagnetizing effect of armature reaction. This results from the forward lead given the brushes in order to secure sparkless commutation.

Ques. Describe the formation of eddy currents.

Ans. In fig. 716, a bar inductor is seen just passing from under the tip of the pole piece N, of the field magnet. Noting the distribution of the lines of force, it will be seen that the edge *cd*, is in a weaker field than the edge *ab*, hence, since the two edges move with the same velocity, the pressure induced along *cd*, will be less than that induced along *ab*. This gives rise to whirls or current eddies in the copper bar as shown.

Ques. What should be noted in seeking a remedy for eddy currents?

Ans. It should be noted that eddy currents are due to very small differences of pressure and that the currents are large only because of the very low resistance of their circuits.

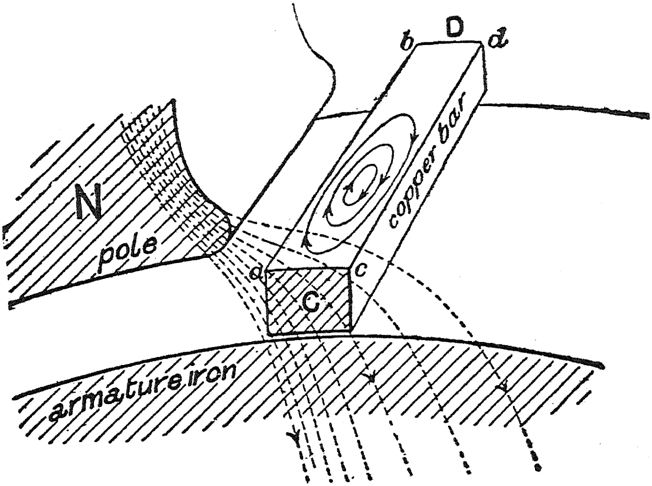

FIG. 716.—Formation of eddy currents in a solid bar inductor. On account of the appreciable size of the inductor, the field is sometimes weaker at one point than another, hence the unequal electric pressures thus produced will induce eddy currents.

Ques. What is the best means of reducing eddy currents?

Ans. Lamination.

Ques. Explain this mode of construction with respect to the bar inductor fig. 716.

Ans. In the case of a large bar inductor such as shown in fig. 716, it could be replaced by a number of small wires soldered together only at the ends. The layer of dirt or oxide on the outside of the wires will furnish sufficient resistance to practically prevent the eddy currents passing from wire to wire.

Ques. How should an armature core be laminated to avoid eddy currents?

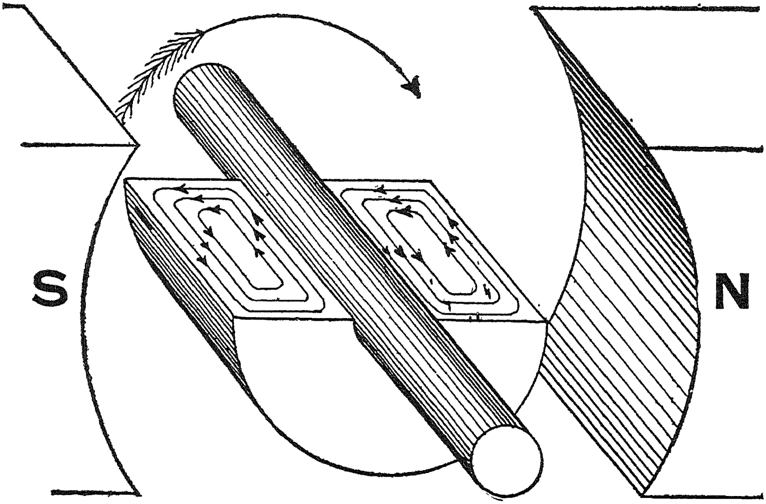

FIG. 717.—Eddy currents induced in a solid armature core. *Eddy currents* always occur when a solid metallic mass is rotated in a magnetic field, because the outer portion of the metal cuts more lines of force than the inner portion, hence the induced electric pressure not being uniform, tends to set up currents between the points of greatest and least pressure. Eddy currents consume a considerable amount of energy and often occasion harmful rise in temperature.

Ans. It should be laminated at right angles to its axis.

Fig. 717 shows the induced eddy currents in a solid armature core, and fig. 718 shows the manner in which the paths of these currents are interrupted and the losses due to their effect diminished by the use of laminated cores.

In fig. 718, only five laminations or plates are indicated, so as to show the sub-division of the eddy currents, but in practical armatures, the number of laminations or punchings ranges from 40 to 66 to an inch, and brings the eddy current loss down to about one per cent. A greater increase in the number of laminations per inch is not economical, however, owing to the difficulties encountered in the punching and handling of extremely thin sheets of iron, and the loss of space between the plates.

Armature cores constructed of the number of plates stated, and forced together by means of screws and heavy hydraulic pressure, contain from 80 to 90 per cent. of iron, and have a magnetic flux carrying capacity only fron 5 to 15 per cent. less than when they are made of an equal volume of solid iron.

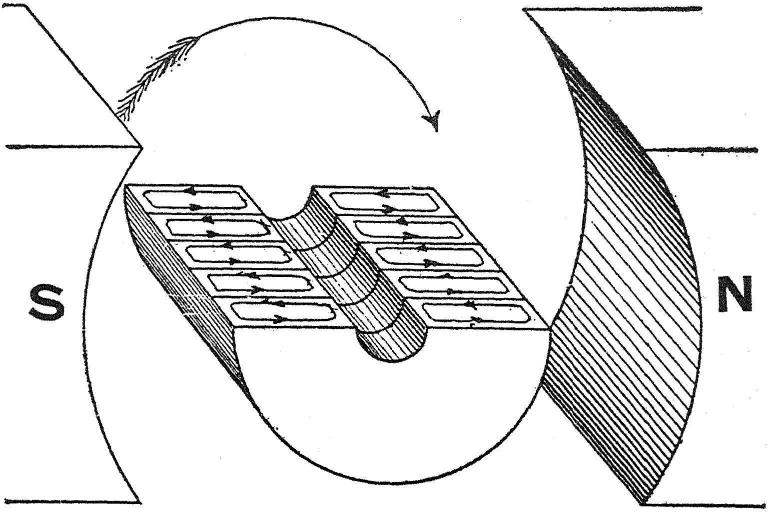

FIG. 718.—Armature core with a few laminations showing effect on eddy currents. ***In practice,*** the core is made up of a great number of thin sheet metal discs, about 18 gauge, which introduces so much resistance between the discs that the formation of eddy currents is almost entirely prevented.

Magnetic Drag on the Armature.—Whenever a current is induced in an armature coil by moving it in the magnetic field so as to cut lines of force, *the direction of the induced current is such as to oppose the motion producing it.* Hence, in the operation of a dynamo, considerable driving power is required to overcome this magnetic drag on the armature.

A conductor carrying a current is surrounded by a circular concentric magnetic field. If now such a conductor, with current flowing toward the observer as in fig. 719, be placed in a uniform magnetic field, a distortion of the magnetic lines will occur as shown in fig. 720. The resulting mechanical actions are easily determined by remembering that *the magnetic lines act like elastic cords tending to shorten themselves.* There is in fact a tension along the magnetic lines and a pressure at right angles to both, proportional at every point to the square of their density.

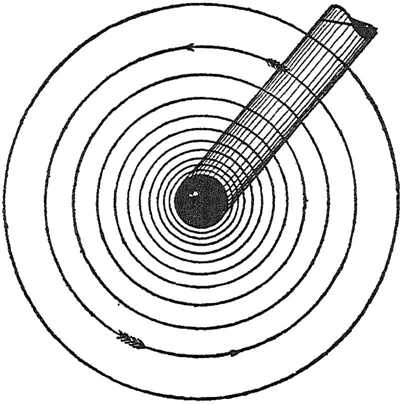

FIG. 719.—Circular concentric magnetic field surrounding a conductor carrying a current. If this conductor be moved across a magnetic field, as between the poles of a magnet, the lines of force will be distorted as in fig. 720, which will oppose the motion of the conductor.

It is evident by inspection of the lines in fig. 720, that there is a drag upon the conductor in the direction shown by the arrow.

Smooth and Slotted Armatures.—The inductors of an armature may be placed on a smooth drum or in slots cut in the surface parallel to the axis.

In the first instance, the magnetic drag comes on the inductors, and in the case of slots, upon the teeth.

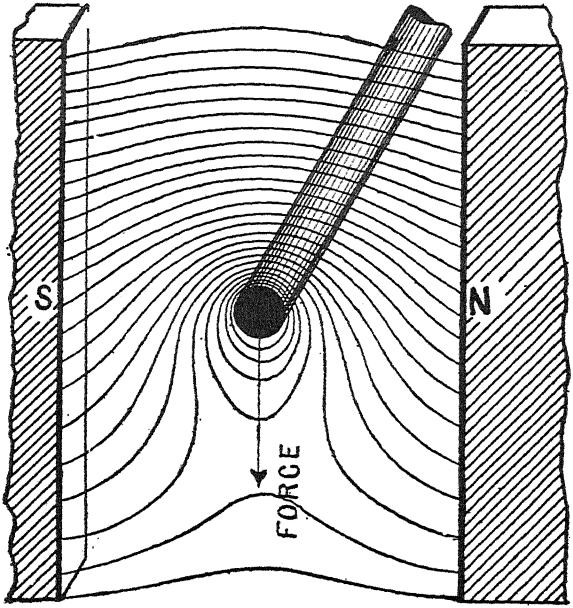

FIG. 720.—Illustrating drag on armature inductors. *In moving a wire,* carrying a current through a magnetic field, the lines of force are distorted, and the effect on the wire is the same as though the magnetic lines were elastic cords tending to shorten themselves. They therefore, oppose the motion of the wire; hence, *in dynamo operation,* more or less power is absorbed in overcoming this drag on the numerous inductors. In the figure the inductor is being moved upward against the "drag" due to the magnetic field.

The effect of embedding the armature inductors in slots is to distort the magnetic field as shown in fig. 721. Most of the lines of force pass through the teeth, thus, not only are the inductors better placed for driving purposes, but, being screened magnetically by the teeth, the forces acting on them are reduced, the greater part of the magnetic drag being taken up by the core.

It should be noted that, although screened from the field, the inductors in a slotted armature cut magnetic lines precisely as if they were not protected. The effect is as though the magnetic lines flashed across the slots from tooth to tooth, instead of passing across the intermediate slot at the ordinary angular velocity.

Comparison of Smooth and Slotted Armatures.—The slotted armature has the following advantages over the smooth type:

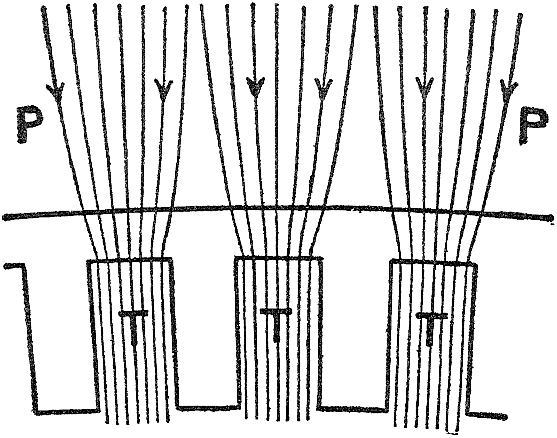

FIG. 721.—Effect of slotted armature. The teeth, as they sweep past the pole face, cause oscillations of the magnetic flux in the iron near the surface because the lines in the pole piece PP, tend to crowd toward the nearest teeth, and will be less dense opposite the slots. This fluctuation of the magnetic lines produces eddy currents in the pole faces unless laminated. The armature inductors, being screened from the field, are relieved of the drag which is taken by the teeth.

1. Reduced reluctance of the air gap;
2. Better protection for the winding;
3. Inductors held firmly in place preventing slippage;
4. No magnetic drag on inductors;
5. No eddy currents in inductors;

6. Better ventilation;
7. Opposition to armature reaction.

Due to increased density of flux through the teeth.

The disadvantages of slotted armatures may be stated as follows:

1. Tendency of the teeth to induce eddy currents in the pole pieces;

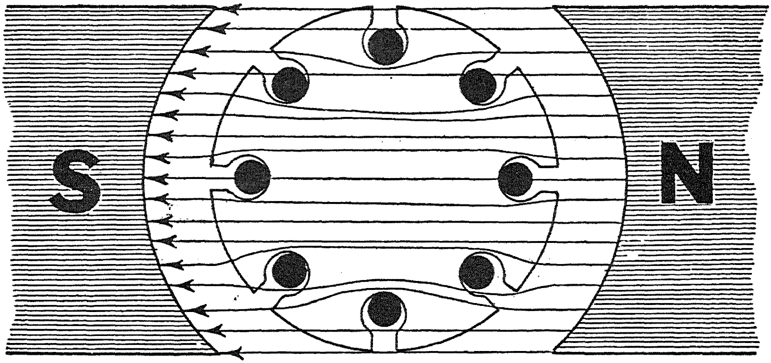

FIG. 722.—Leakage of lines of force through the core of a slotted armature especially in the case of partially enclosed slots.

2. Increased self-induction of the armature coils;
3. Greater hysteresis loss on account of denser flux in the teeth;
4. Leakage of lines of force through the core, especially in the case of partially enclosed slots.

Magnetic Hysteresis in Armature Cores.—When the direction or density of magnetic flux in a mass of iron is rapidly changed *a considerable expenditure of energy is required which does not appear as useful work.*

For instance, when an armature rotates in a bipolar field, the armature core is subjected to two opposite magnetic inductions in each revolution; that is, at any one instant a north pole is induced in the core opposite the south pole of the magnet, and a south pole in the core opposite the north pole of the magnet as indicated in fig. 723 by *n* and *s*. Accordingly, if the armature rotate at a speed of 1,000 revolutions per minute, the polarity of the armature will be changed 2,000 times per minute, and result in the generation of heat at the expense of a portion of the energy required to drive the armature. This loss of energy is due to the work required to change the position of the molecules of the iron, and takes place both in the process of magnetizing and demagnetizing; the magnetism in each case lagging behind the force.

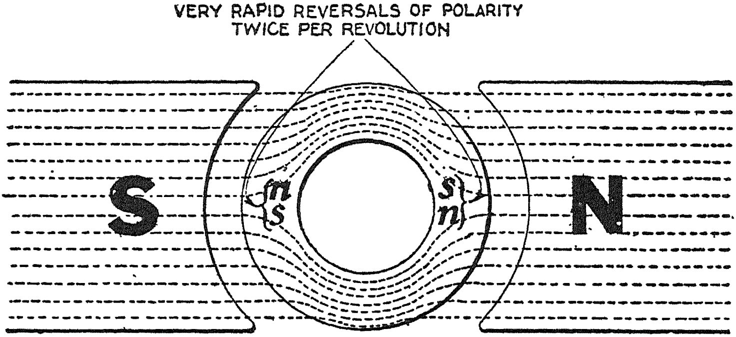

FIG. 723.—Magnetic hysteresis in armature core. Unlike poles are induced in the core opposite the poles of the field magnet. Since on account of the rotation of the core the induced poles are reversed a thousand or more times a minute, considerable energy is required to change the positions of the molecules of the iron for each reversal, resulting in the generation of heat at the expense of a portion of the energy required to drive the armature.

Core Loss or Iron Loss.—These terms are often employed to designate *the total internal loss of a dynamo due to the combined effect of eddy currents and hysteresis*, but as the losses due to the former are governed by laws totally different from those applicable to the latter, special analysis is required to separate them.

The eddy current loss per pound of iron in the armature core diminishes with the thinness of the laminated sheets, and may be made indefinitely small by the use of indefinitely thin iron plates, were it not for certain mechanical and economical reasons.

The loss due to hysteresis per pound of iron in the core, does not vary with the thinness of the core plates; it can be reduced only by the use of a material having a low hysteresis coefficient.

Dead Turns.—The voltage generated in a dynamo with a given degree of field excitation is not strictly proportional to the speed, but somewhat below on account of the various reactions. That is, the machine acts as though some of its revolutions were not effective in inducing voltage.

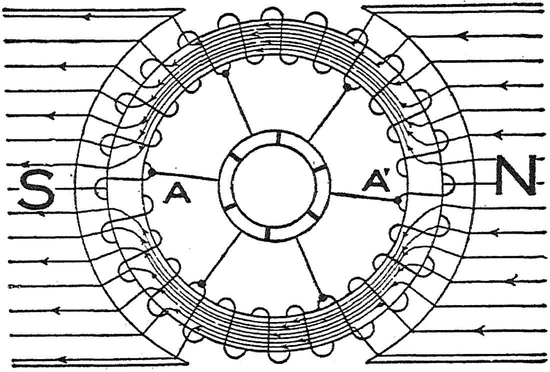

FIG. 724.—Distribution of magnetic lines through a ring armature. Since the lines follow the metal of the ring instead of penetrating the interior, no electric pressure is induced in that portion of the winding lying on the interior surface of the ring. There is, therefore, a large amount of dead wire or wire that is ineffective in inducing voltage; this is the chief objection to this ring type of armature.

The name *dead turns* is given to the number of revolutions by which the actual speed exceeds the theoretical speed for any output.

Again, this term is sometimes used to denote that portion of the wire on an armature which comes outside the magnetic field and is therefore rendered ineffective in inducing electric pressure. The number of dead turns is about 20% of the total number of turns.

Self-Induction in the Coils; Spurious Resistance.—Self-induction *opposes a rapid rise or fall of an electric current* in just the same way that the inertia of matter prevents any instantaneous change in its motion. This effect is produced by the action of the current upon itself during variations in its strength.

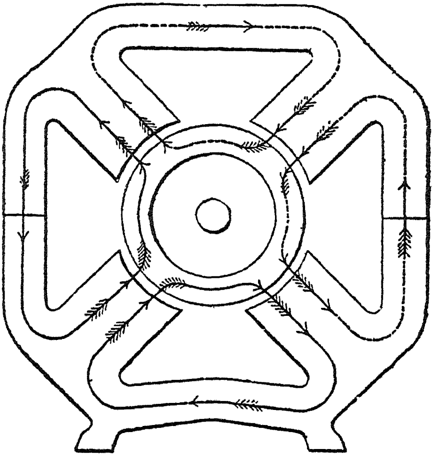

FIG. 725.—Distribution of magnetic lines through solid drum armature of a four pole machine

In the case of a simple straight wire, the phenomenon is almost imperceptible, but if the wire be in the form of a coil, the adjacent turns act inductively upon each other upon the principle of the mutual induction arising between two separate adjacent circuits.

Ques. What effect has self-induction on the operation of a dynamo?

Ans. It prevents the instantaneous reversal of the current in the armature coils. That is, the current tends to go on, and in fact does actually continue for a brief time after the brush has been reached.

Ques. What becomes of the energy of the current at reversal?

Ans. The energy of the current in the section of the winding undergoing commutation is wasted in heating the wire during the interval when it is short circuited, and as it passes on, energy must again be spent in starting a current in it in the reverse direction. There is, then, a lagging of the current in the armature coils due to self-induction.

Ques. What is spurious resistance?

Ans. This is an apparent increase of resistance in the armature winding, which is proportional to the speed of the armature, and due to the lagging of the current.

Armature Losses.—The mechanical power delivered to the pulley of a dynamo is *always in excess of its electrical output on account of numerous mechanical and electrical losses.*

Mechanical losses result from:

1. Friction of bearings;
2. Friction of commutator brushes;
3. Air friction.

The electrical losses may be classified as those due to:

1. Armature resistance;
2. Hysteresis;
3. Eddy currents.

Ques. How do the mechanical and electrical losses compare?

Ans. The mechanical losses are small in comparison with the electrical losses.

Ques. What may be said with respect to friction?

Ans. The bearing friction varies with the load. In calculating this loss not only must the weight of the armature be considered but also the belt tension and magnetic attraction in order to get the resultant thrust on the bearing.

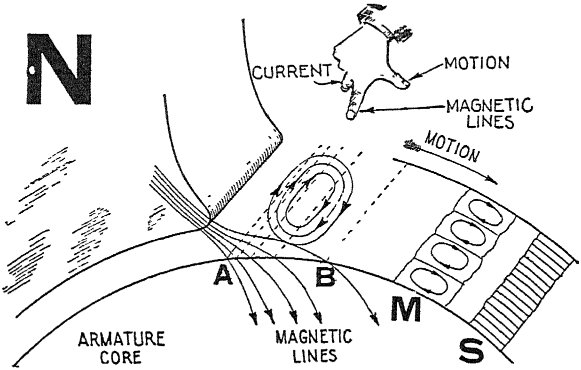

FIG. 726.—Foucault or "eddy" currents in solid armature core. Since the magnetic field is more dense at A, near the pole tip than at B, remote from the pole tip, the *rate* at which an element of the core in passing from A to B, cuts magnetic lines is *altered*, hence eddy currents are set up as shown. To break up the path of these eddy currents the core is laminated or built up of thin steel stampings as indicated at S, which interposes resistance between each stamping, thus opposing the formation of these currents. If the laminations were few and thick as at M, currents would be set up in each lamination as indicated. ***In practice***, the thin metal discs at S, are usually about No. 18 gauge thick.

Friction of the brushes is very small and may be neglected. A small loss of power is caused by the friction of the air on the armature. The latter, since it revolves rapidly, acts to some extent as a fan, and in some machines this fan action is made use of for ventilation and cooling.

Ques. How are the other losses determined?

Ans. The loss of power due to armature resistance is easily found by Ohm's law, but the hysteresis and eddy current losses, known collectively as *iron losses*, are not so easily determined. If the magnetization curve of the particular quality of iron used for armature plates be known, the hysteresis loss may be calculated approximately. Eddy current losses are the more important, especially in large machines. As previously explained, in all the moving metal masses unless laminated, there will be eddy currents set up if they cut magnetic lines. Power may be lost from this cause even in the metal of the shaft if there be leakage of magnetic lines into it.

TEST QUESTIONS

1. *What is the distribution of current in the ring armature?*
2. *How does the voltage vary in the coil?*
3. *How many paths in parallel?*
4. *How are the brushes connected?*
5. *How does the voltage vary around the commutator; between consecutive pairs of segments?*
6. *What is cross magnetization?*
7. *Describe armature reaction.*
8. *What are the remedies for field distortion?*
9. *Define the normal neutral plane; neutral plane; commutating plane.*

NOTE.—***Jean Bernard Leon Foucault,*** born 1819, died 1868, was a French scientist and inventor, noted for his optical researches and his investigations in connection with eddy currents, these being called Foucault currents after him.

10. *What is the angle of lead?*
11. *What is the effect of lead?*
12. *Describe the demagnetizing effect of armature reaction.*
13. *What causes a demagnetizing effect?*
14. *Describe the demagnetizing effect in detail.*
15. *What are eddy currents and why are they objectionable?*
16. *How are eddy currents best reduced?*
17. *How is an armature core laminated?*
18. *What is magnetic drag?*
19. *Describe the difference between a smooth and slotted armature.*
20. *Give comparison of smooth and slotted armatures.*
21. *What is magnetic hysteresis?*
22. *How does magnetic hysteresis affect an armature core?*
23. *Describe core loss or iron loss.*
24. *What are dead turns?*
25. *What percentage of the winding consists of dead turns?*
26. *What is spurious resistance?*
27. *What effect has self induction on the operation of a dynamo?*
28. *What are the various armature losses?*
29. *How do the mechanical and electrical losses compare?*

CHAPTER 23

Commutation and the Commutator

The act of commutation needs special study. If it be incorrectly performed, the imperfection at once manifests itself by sparks which appear at the brushes.

In the study of this chapter on commutation it would be advisable for the student to first review the basic principles of commutation as given in Chapter XIV, which contains a brief and simple explanation of how the alternating current in the armature is converted into direct current by the action of the commutator.

Ques. What is the period of commutation?

Ans. The time required for commutation, or the angle through which the armature must turn to commute the current in one coil.

Ques. Upon what does the period of commutation depend?

Ans. Upon the width of the brushes as shown in fig. 727.

This fixes the angle through which the armature must revolve to commute the current in one coil. This angle is formed, as shown in the figure, by two intersecting planes, M and S, which pass through the axis of the armature and the two edges of the brush. Commutation then, begins at M, and ends at S.

Ques. What is the position of the commutating plane with respect to M and S, in fig. 727?

Ans. It bisects the angle formed by the planes M and S.

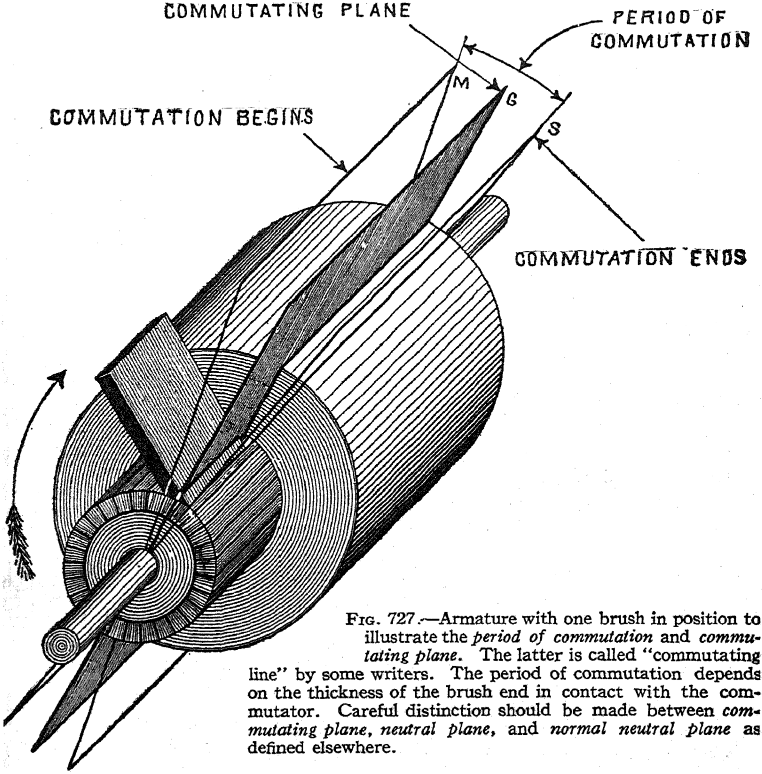

FIG. 727.—Armature with one brush in position to illustrate the *period of commutation* and *commutating plane*. The latter is called "commutating line" by some writers. The period of commutation depends on the thickness of the brush end in contact with the commutator. Careful distinction should be made between *commutating plane, neutral plane,* and *normal neutral plane* as defined elsewhere.

Ques. What is the commutating plane?

Ans. An imaginary plane passing through the axis of the rmature and the center of contact of the brush.

Ques. What two planes are referred to in stating the position of the brushes?

Ans. The normal neutral plane and the commutating plane.

The angle intercepted by these two planes represents the *lead*, thus in stating that the brushes have a lead of 6°, means that the angle intercepted by the normal neutral plane and the commutating plane is 6°.

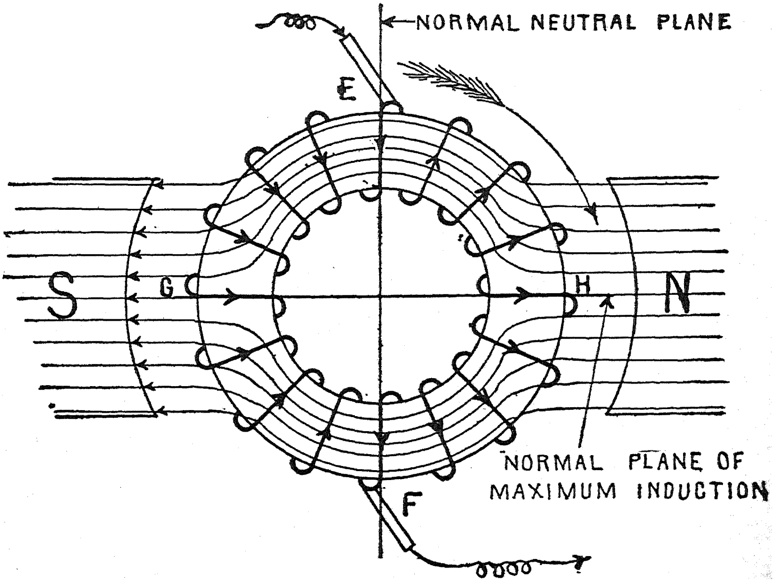

FIG. 728.—The proper position of the brushes, if there were no field distortion and self-induction in the armature coils, would be in the normal neutral plane. *In the actual dynamo* these two disturbing effects are present which makes it necessary to advance the brushes as shown in figs. 729 and 730 to secure sparkless commutation.

Ques. What is the difference between the normal neutral plane and the neutral plane?

Ans. This is illustrated in figs. 728 and 729. *The normal* *neutral plane is the position of zero induction assuming no distortion of the field* as in fig. 728. *The neutral plane is the position of zero induction with distorted field* as in fig. 729 and as is found in the actual machine; the distortion is exaggerated in the figure for clearness.

Ques. What is the normal plane of maximum induction?

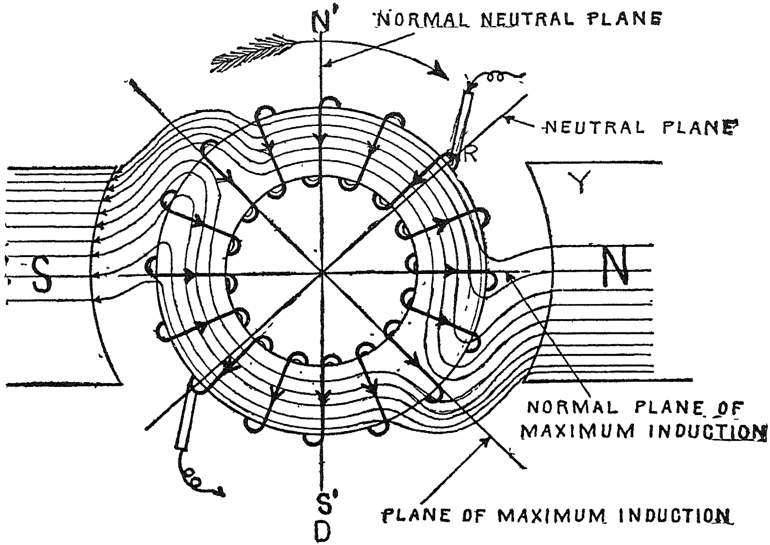

FIG. 729.—Brush adjustment for field distortion. The effect of the latter is to twist the lines of force around in the direction of rotation, thus maximum induction takes place in an inclined plane. The brushes then must be advanced to the *neutral plane* which is at right angles to the plane of maximum induction. This gives the proper position of the brushes *neglecting self-induction.*

Ans. *A plane* 90° *in advance of the normal neutral plane,* being the position of maximum induction with no distortion of field, as in fig. 728.

Ques. What is the plane of maximum induction?

Ans. *A plane* 90° *in advance of the neutral plane,** being the position of maximum induction in a distorted field, as in fig.729.

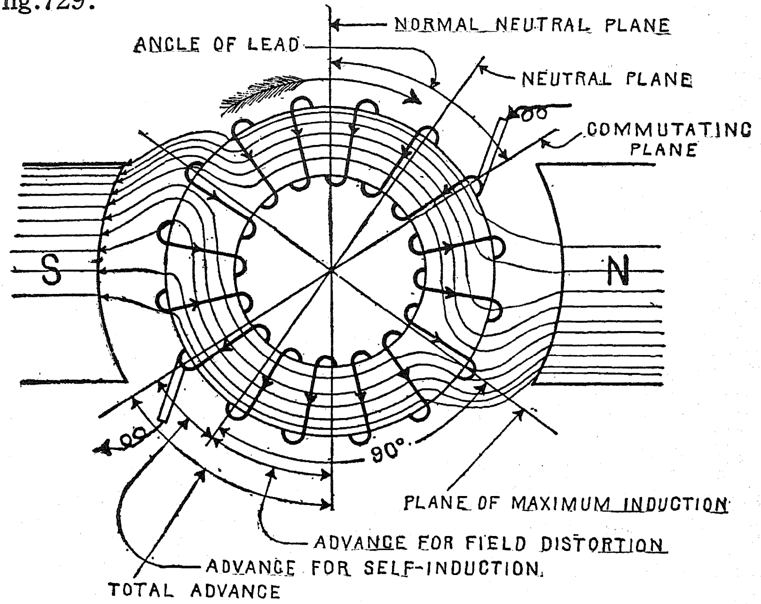

FIG. 730.—Brush adjustment for self-induction. For convenience an electric current is regarded as having weight and hence possessing the property of inertia. The current then during commutation cannot be instantly brought to rest and started in the reverse direction but these changes must be brought about gradually by an opposing force. Hence by advancing the brushes beyond the neutral plane as illustrated, commutation takes place with the short circuited coil cutting the lines of force so as to induce a current in the opposite direction; this opposes the motion of the current in the short circuited coil, brings it to rest and starts it in the opposite direction, thus preventing sparks. Figs. 728 to 730 should be carefully compared and thoroughly understood.

Ques. What should be noted with respect to the different planes?

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*NOTE.—The definition refers to a bi-polar machine. Of course the angle of advance depends upon the number of poles.

Ans. The commutating plane should be carefully distinguished from the normal neutral plane and from the neutral plane, as shown in fig. 730.

Commutation.—In order to understand just what happens during commutation, a section of a ring armature may be used for illustration, such as shown in fig. 731. Here the coils A, B,C,D,E, are connected to commutator segments 1,2,3,4, and the positive brush is shown in contact with two segments 2 and 3, the brush being in the neutral position. Currents in the coils on each side of the neutral line flow to the brush through segments 2 and 3; the brush then is positive.

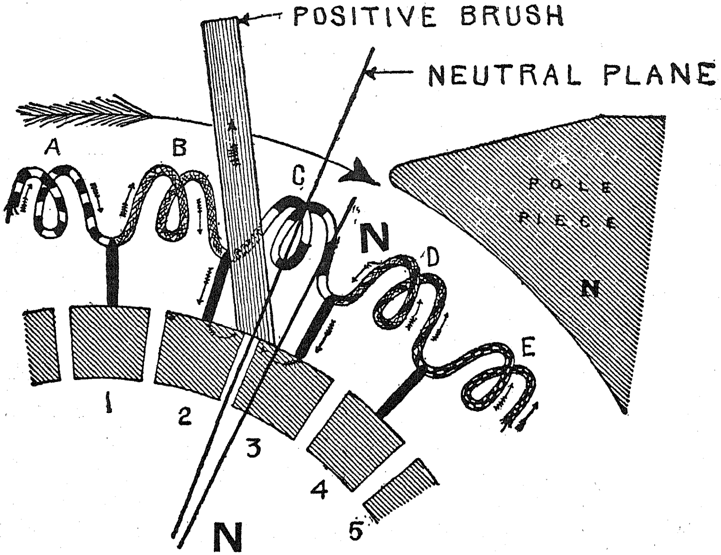


FIG. 731.—Commutation. This takes place during the brief interval in which any two segments of the commutator are bridged by the brush. The coil connecting with the two segments under the brush is thus short circuited. *During commutation* the current in the short circuited coil is brought to rest and started again in the reverse direction against the opposition offered by its so called inertia, or effect produced by self-induction.

Now, as the armature turns, the commutator segments come successively into contact with the brush. In the figure, segment 3, is just leaving the brush and 2, is beginning to pass under it, hence, for an instant the coil C, is short circuited.

Ques. In fig. 731, what are the current conditions?

Ans. Previous to contact with segment 2, current flowed in coil C, in the same direction as in coil B.

Ques. What occurs while the brush is in contact with segments 2 and 3?

Ans. During this brief interval, the current in C, is stopped and started again in the opposite direction.

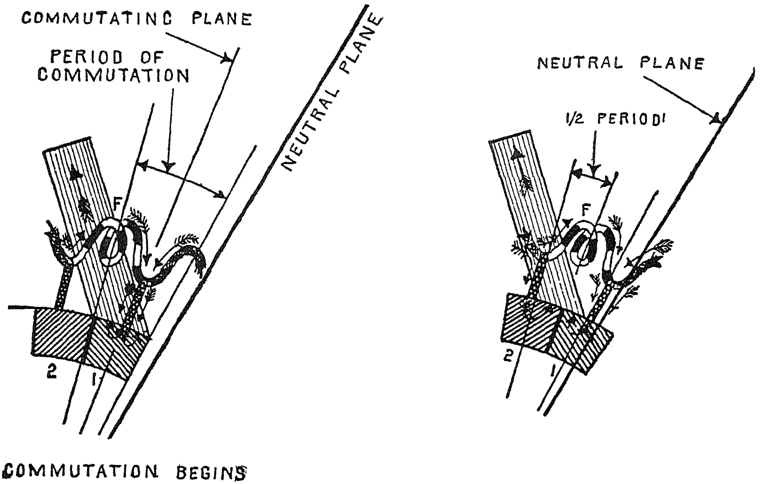
Similarly each coil of the armature as it passes the brush will be short circuited and have its current reversed. This is known as *commutation.*

Ques. What is the effect of field distortion with respect to commutation?

Ans. The neutral plane no longer coincides with the normal neutral plane but is advanced in the direction of rotation of the armature as shown in fig. 729.

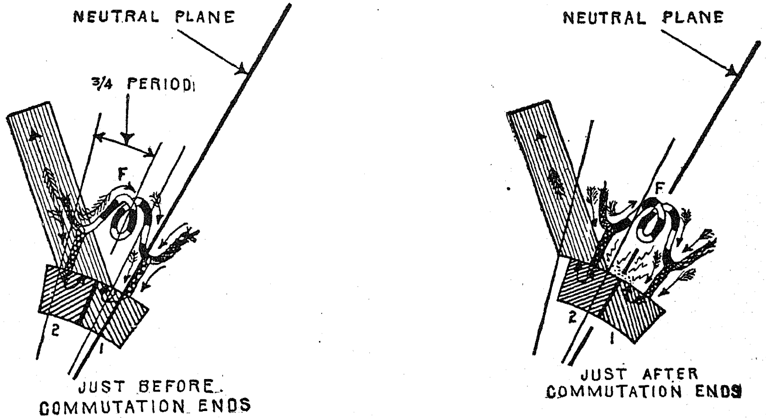
The reaction of the poles N′ and S′, of the armature field on the poles S and N of the main magnetic field tends to crowd the lines of force into the upper pole face of the south pole of the magnet, and into the lower pole face of the north pole. This effect is due to the strong magnetic attraction between the opposite poles S and N′, and N and S′, and the equally strong repulsion between like poles N and N′ and S and S′. Hence, the plane of maximum induction no longer coincides with the normal plane of maximum induction, but is advanced in the direction of rotation, depending upon the strength of the armature current, being shifted forward for an increase of current, and backward for a decrease of current. This distortion of the field and the consequent shifting of the plane of maximum induction naturally results in the shifting of the neutral plane from the vertical position to the inclined position as shown.

Position of the Brushes; Sparking.—In accordance with the laws of electromagnetic induction, if the bipolar ring armature shown in fig. 728 be rotated in the direction indicated by the arrow the armature current entering at the brush E, will divide, one part passing through the coils on the right half of the ring, and the other part through the coils on the left half of the ring, to the brush F, from which the total current will pass out, urged by the full value of the voltage induced in all the coils on both halves of the ring.



Figs. 732 to 735.—Improper brush adjustment resulting in excessive sparking. When the brushes are not advanced far enough, commutation takes place before the short circuited coil reaches the neutral plane, hence, its motion is not changed with respect to the magnetic field so as to induce a reverse current till after commutation. There is then no opposing

Again, if the brushes be placed at the points G and H, each half of a current entering at G, will pass through one-half of the coils on the left side and one-half of the coils on the right side of the ring, so that each half of the current will be urged forward by a pressure equal to the pressure tending to force it back, and therefore, no current will pass in or out through the brushes. From these considerations it is obvious that the proper position for the brushes would be in the normal neutral plane, *were it not for the disturbing effects of armature reaction and self induction of the current.*



Figs. 732 to 735—*Continued.*

force, during commutation, to stop and reverse the current in the short circuited coil, and when the brush breaks contact with segment 1, as in fig. 735, the "*momentum*" of the current in coil F, causes it to jump the air gap from segment 1 to segment 2 and the brush, against the enormous resistance of the air, thus producing a spark whose intensity depends on the momentum of the current in coil F. Sparking, if allowed to continue, will injure the brushes and commutator segments.

Ques. Should the brushes of a dynamo be placed in the neutral plane?

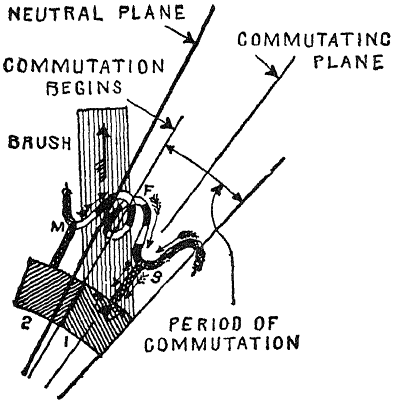
Ans. No.

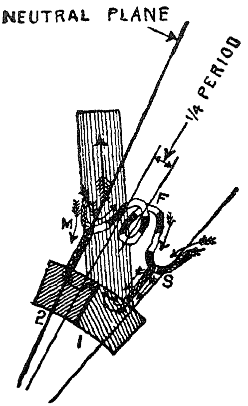
Ques. Why not?

Ans. The brushes must be advanced beyond the neutral plane to prevent sparking.

Ques. What is the cause of sparking at the brushes?

Ans. It is due to *self-induction* in the coil undergoing commutation.





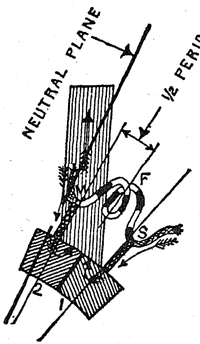
Figs. 736 to 740.—How sparkless commutation is obtained by advancing the brushes beyond the neutral plane; commutation progressively shown.

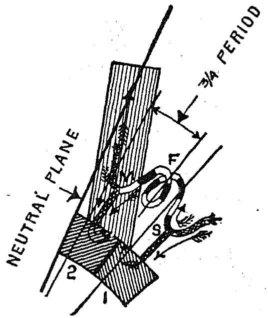
Fig. 736.—Commutation begins; current flows up both sides of the armature, uniting at S, and flowing to the brush through commutator segment 1 as indicated by the arrow.

Fig. 737.—Segment 2 has come into contact with the brush and coil F, in which commutator is taking place, is now short circuited. The current now divides at M, part passing to the brush through segment 2, and part through coil F, and segment 1. Although coil F, is short circuited and having passed the neutral plane, is cutting the lines of force so as to induce a current in the opposite direction, it still continues to flow with unchanged direction against these opposing conditions. This is due to *self-induction* in the coil which resists any change just as the momentum of a heavy moving body, such as a train of cars, offers resistance to the action of the brakes in retarding and stopping its motion.

Ques. Explain the effect of self-induction in detail.

Ans. When commutation takes place with the brushes in the neutral plane as in fig. 731, there will be no voltage induced in the short circuited coil C. The current, therefore, which flowed in coil C, before it was short circuited will cease, and as segment 3 breaks contact with the brush, it will be thrown as a perfectly idle coil upon the right hand half of the ring in which a current is flowing toward the brush. Moreover, the current which was flowing through D and 3, directly to the brush, must





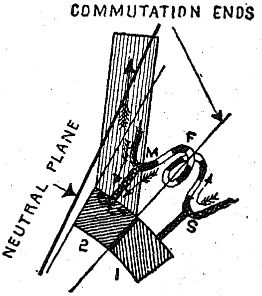
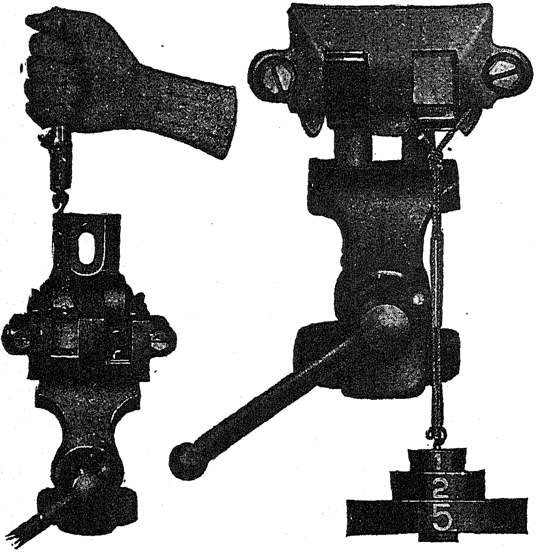


FIG. 738.—Segment 2 has moved further under the brush, and the opposition offered to the forward flow of the current in the short circuited coil F, by the reverse induction in the magnetic field to the right of the neutral plane has finally brought the current in F, to rest. The currents from each side of the armature now flow direct to the brush through their respective end segments 1 and 2.

FIG. 739.—Segment 1 is now almost out of contact with the brush. A current has now been started in the coil F, in the reverse direction due to induction in the magnetic field to the right of the neutral plane; it flows to the brush through segment 2. The current has not yet reached its full strength in F, accordingly, part of the current coming up from the right divides at S, and flows to the brush through segment 1.

FIG. 740.—Completion of commutation in segments 1 and 2; the brush is now in full contact with segment 2, the current in coil F, has now reached its full value, hence the current flowing up from the right no longer divides at S, but flows through F, and segment 2, to the brush. If the current in F, had not reached its full value, at the instant segment 1, left contact with the brush, it could not immediately be made to flow at full speed any more than could a locomotive have its speed instantly changed. This, as previously explained, is due to self-induction in the coil or the so called "inertia" of the current which opposes any sudden change in its rate of flow or direction. Accordingly that portion of the current which was flowing up from the right and passing off at S, to the brush through segment 1 as in fig. 739, would, when this path is suddenly cut off as in fig. 740, encounter enormous opposition in coil F. Hence, it would momentarily continue to flow through segment 1, and jump the air gap between this segment and the brush, resulting in a more or less intense spark depending on the current conditions in coil F.

suddenly traverse the longer path through the idle coil C. Now on account of self-induction, *the current acts in precisely the same manner as though it had weight;* that is, *it* ***cannot*** *be instantly stopped or started.* Therefore, when segment 3, leaves the brush, the current will not instantly change its path and flow through C, but will be urged by its "*momentum,*" and jump the air gap between the brush and segment 3, thus producing a spark.



Figs. 741 and 742.—Methods of measuring brush pressure (General Electric). **Fig. 741, spring** balance method; fig. 742, weight method. ***In either method*** a wooden block of the same size as the brush is used. This should be grooved lengthwise to hold the cord. If the wooden block be omitted, care must be taken to place the cord around the finger at the center of the carbonway, otherwise an incorrect reading will be taken. There are few motors which allow sufficient space within the motor to measure pressure on both brush holders with the spring balance. However, it is always desirable and generally necessary to remove the brush holder from the motor in taking measurements of brush pressure In the weight method, a weight equal to the proper pressure is applied as shown in figure 742. If the weight do not just balance the pressure of the finger, the ratchet adjustment on the brush holder should be changed. This operation should be repeated until proper adjustment be made.

Ques. How may this sparking be prevented?

Ans. If the brushes be given additional lead, that is, shifted further to the right to some position as NN, fig. 731, coil C, will not remain idle during the interval it is short circuited, *but will cut the magnetic lines in such a way as to induce a current in the reverse direction through it.*

Under these conditions, when segment 3, breaks contact with the brush, the current flowing through D, does not encounter an idle coil, but one in which a current is flowing in the same direction, hence, the tendency to jump the air gap and produce a spark is reduced; with proper adjustment of the brushes, there will be no sparking.

Ques. What is the objection to very thin brushes?

Ans. Time must be allowed for reversal of the current, hence the brushes must not be so thin as merely to bridge the insulation between segments.

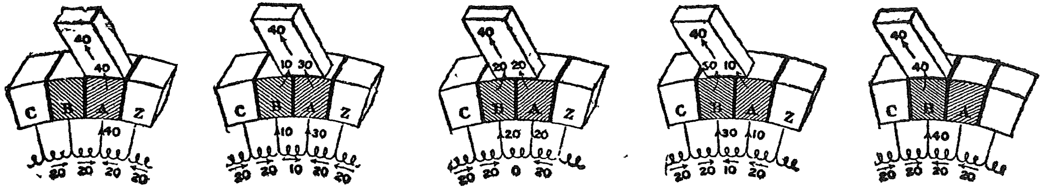
Ques. What is the effect of lead?

Ans. There is usually much sparking when the lead is too small; a little sparking when too great, and no sparking when just right.

If the lead be excessive, there is a waste of energy due to the generation of a larger reverse current in the short circuited coil than is necessary.

Fixed Position of Brushes.—The condition for sparkless commutation is that the current in the short circuited coil be reduced to zero, and increased in the opposite direction up to the same value as that in the next coil leading.

If the brushes are to remain in a fixed position, this condition will only be realized at the particular load for which the brushes are set. Thus, if the brushes be set for the average load, the reversing field will not be correct for either a weaker or stronger load. Hence, sparkless commutation with fixed brushes must be due to some other factor.



Figs. 743 to 747.—Brush contact resistance theory of commutation, neglecting self-induction and resistance in the coils. The total current is assumed to be 40 amperes made up of 20 amperes flowing toward the brush from the coils on the right and 20 amperes from the coils on the left. ***During commutation,*** that is, the interval during which the brush contacts with any two adjacent segments of the commutator, the current is assumed to vary directly as the contact area.

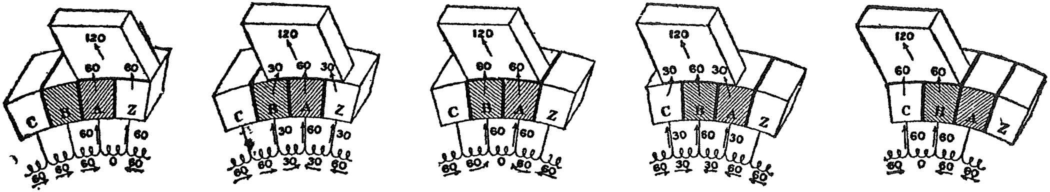
Fig. 743.—Beginning of commutation; segment A, is entirely under the brush, and B, is at the initial point of contact. For this position the currents from both sides flow to the brush through segment A.

Fig. 744.—One-quarter period of commutation. One quarter of the brush area is in contact with B, and three quarters in contact with A; hence, 10 amperes will flow through B, and 30 amperes through A.

Fig. 745.—Second quarter of commutation period. The brush now contacts equally with both segments, hence 20 amperes will flow through each segment.

Fig. 746.—Third quarter of commutation period. Three quarters of the brush area is in contact with segment B, and one quarter with segment A, accordingly, 30 amperes will flow through B, and 10 amperes through A.

Fig. 747.—Completion of commutation. The brush is in full contact with segment B, and at the point of breaking contact with A, hence the entire current from both sides or 40 amperes will flow through B.



Figs. 748 to 752.—Brush contact theory of commutation for case in which the brush covers two segments of the commutator. Fig. 748 beginning of commutation; fig. 749 one-quarter period; fig. 750 one-half period; fig. 751 three-quarter period; fig. 752 completion of commutation.

Ques. What may be said with respect to carbon brushes?

Ans. Since carbon possesses a high resistance, the drop will vary greatly with the contact area, thus affecting a difference of pressure in the two segments passing under the brush and it is largely to this that sparkless commutation is due.

Ques. What is the effect of resistance on commutation?

Ans. In fig. 731 during commutation, that is, while the brush contacts with any two segments, as 2 and 3, the currents coming up through the winding on either side of the neutral plane are offered two paths to the brush: 1, direct to brush through the connecting segment, or 2, across the short circuited coil and adjacent segment. Thus, on the right side: to brush through segment 3, or across coil C, and adjacent segment 2. *The current will take the path of least resistance.*

At the beginning of commutation, almost the entire brush area being in contact with segment 3, the contact resistance of this segment will be much less than for segment 2; hence, not only will the current at the right flow through 3, but also the current at the left after first traversing the short circuited coil. As commutation progresses, the area of contact of 3, decreases while that of 2, increases, and the respective resistances vary in inverse proportion.

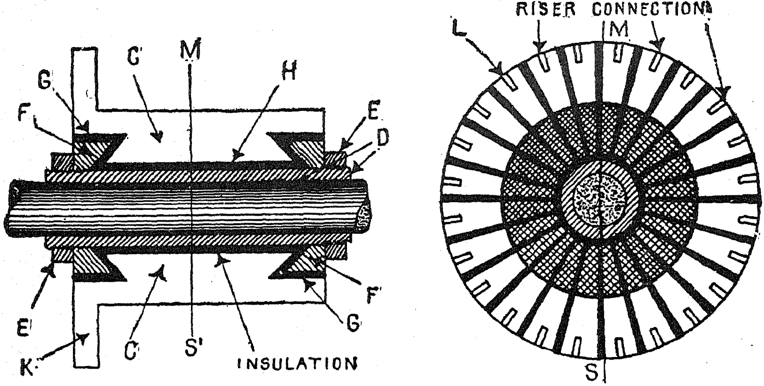
Likewise the tendency of the current in the left half of the winding to take the longer path through coil C, and segment 3, to the brush gradually decreases, becoming zero when the two contact areas become equal.

During the second half of the period of commutation, the contact area of segment 2, becomes greater and of 3, less; thus the resistance of 2, is lowered, and that of 3, increased. Accordingly, all of the current at the left will flow through segment 2, and the current at the right will flow through C and 2, rather than through 3. In this way the current is reversed in C, and, if the brush be broad enough to allow a sufficient time interval, the current in C, is built up to its full value before segment 3, leaves the brush, thus securing sparkless commutation.

This contact resistance factor in sparkless commutation is illustrated in figs. 743 to 747, it being assumed that during commutation, the brush contact resistance is inversely proportional to the area of contact, and that the winding is free of resistance and inductance. The current is taken as 40 amperes, in which case 20 amperes will flow from each side of the winding to the brush.

In fig. 743 the instant before commutation begins all the current will flow through segment A. At the end of the first quarter of the period of commutation, fig. 744, 30 amperes will flow from the right to brush through A, and from the left, 10 amperes through the short circuited coil via A and 10 amperes through B.

At the end of the second quarter or half period, fig. 745, the current through each half of the winding will flow to the brush through these respective segments.



SECTION ON LINE MS

SECTION ON LINE M'S''

FIGS. 753 and 754.—Side and end sectional views of commutator showing construction. The parts are: C, segments; D, tubular iron hub; E, end nuts; F, clamps; G, insulation; L, riser connection.

At the end of the third quarter, fig. 746, the current from the right will divide, 10 amperes going through A, and 30 amperes traversing the short circuited coil and out through B. The entire current from the left will flow through segment B.

At the end of the fourth quarter, fig. 747, or completion of the period the current from each half of the winding will flow to the brush through B.

Ques. What is the effect of increasing the degree of contact of the brushes?

Ans. It lengthens the period of commutation, and permits it to start in one coil before the preceding coil has entirely passed through this stage.

The effect of changing the degree of contact is shown in figs. 748 to 752, in which the width of the brush is made equal to that of two segments.

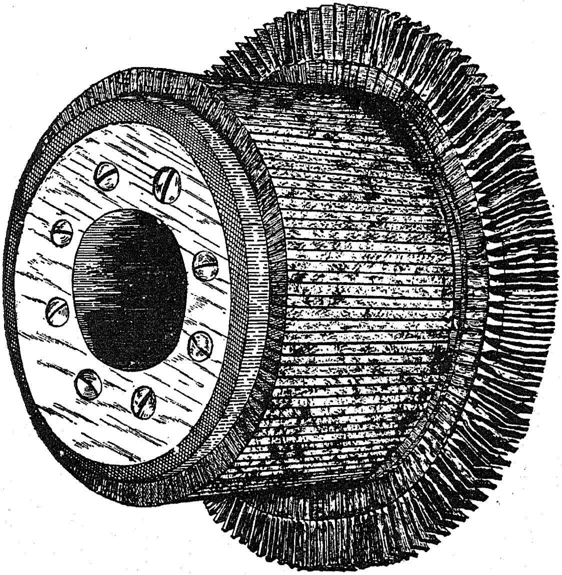


Fig. 755.—Front view of Western Electric Commutator for bar wound armature. This commutator is made of hard drawn copper and insulated throughout, ventilating spaces being provided near the shaft.

Construction of Commutators.—The commutator for a closed coil armature consists of a number of segments or L shaped bars C, of drop forged hard drawn copper assembled around a tubular iron hub as shown in figs. 753 and 754. The bars are held in position by the nuts E, and washers F, screwed on the ends of the tube D.

The bars are insulated from each other and from the washers by mica as shown by the heavy lines G, and they are also insulated from the tube either by a tube of mica H, or by a sufficient air space. The ends of the sections of winding are connected to the vertical portions of the bars K, by insertion in the slots L, where they are securely held in place by means of the binding screws, which for greater security are soldered together, and may be released from the slots, whenever necessary, by the application of a hot soldering iron.

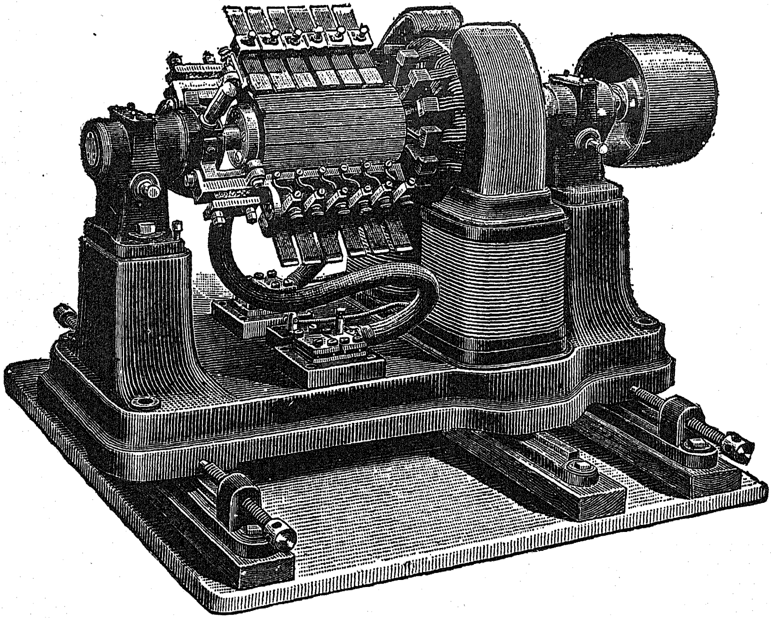


FIG. 756.—A large current low voltage bipolar dynamo built for electrolytic work and here shown to illustrate the large size commutator and brushes necessary to collect the large current. Carbon brushes would not be suitable for this class of machine because even with copper brushes, whose conductivity is much higher than carbon, the commutator must be of considerable size to give the required brush contact area. The contrast between the axial lengths of the armature and the commutator is very marked. The rocker construction is of the ordinary type, and heavy flexible cables conduct the current from the brush holders to the fixed terminals. The machine here illustrated gives 310 amperes at 7 volts when running at a speed of 1,400 R. P. M., corresponding to an output of 2.17 kilowatts.

It is very important that all the parts of the commutator should be fitted together perfectly and screwed up tightly, in order to prevent looseness.

Commutator segments are often made with the washers E, projecting beyond the ends, but such construction reduces the effective length of the commutator, therefore the under cut form of bar is preferable.

In the construction of commutators, the conditions of operation require that there be:

1. Adequate insulation;

It is necessary to have good insulation between each segment, and a specially good insulation between the segments and the hub or sleeve on which they are mounted; also between the segments and end clamps. The insulating material must not absorb moisture, hence asbestos, plaster, or vulcanized fibre are not used. The end insulating rings are usually built up of mica and shellac, moulded while hot under pressure to the correct shape.

2. Rigidity against centrifugal force;

Since the segments are subject to centrifugal force, they must be securely clamped in place. Screws cannot be used, for that would destroy the insulation. They are therefore held in place by insulated clamps as shown in fig. 753. These clamps should be strong and capable of holding the segments firmly in position, for if a segment should rise out of its place through centrifugal force, it would disturb the action of the brush and cause sparking.

3. Provision for wear;

The segments should be of considerable radial depth, so that the commutator may be turned down from time to time to preserve its circular form.

Points Relating to Commutators.—1. The number of commutator segments *depends on the scheme of winding and on the number of sections in the armature winding.*

2. Increasing the number of bars diminishes the tendency to spark, and lessens the fluctuations of the current.

There are two practical reasons for not using a very great number of segments: it increases the cost, and in small machines the segments would be too thin for proper commutation.

Types of Commutator.—Commutators are made in various forms, but they may be grouped into two general types:

1. Commutators for closed coil armatures;

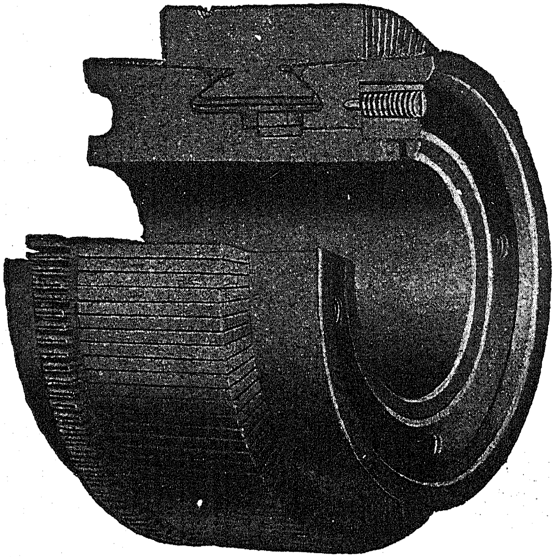


FIG. 757.—General Electric ring nut type commutator, with cap in front and shell in back, the two members being held together by a ring nut threading on the shell which extends through to the front end of the commutator. The commutator ring nut is locked in place by a set screw. *Replacement of segments.* Remove the thrust collar, band some wire around the segments to be replaced. Take out the set screw and unscrew the commutator nut. Remove the cap and mica cone. Next replace the copper segments; reassemble the mica cone and cap, and thread in the nut as far as possible while the commutator is cold. Heat the commutator and tighten the ring nut. Turn the face and regroove if necessary.

These consist of a large number of segments or bars, insulated from each other and varying in number according to the scheme of armature winding, and the number of sections into which that winding is grouped.

2. Commutators for open coil armatures;

This form of commutator was used on some early machines designed especially for arc lighting, such as the Brush and Thompson-Houston machines.

They consisted of a comparatively small number of segments each of which covered a wide angle; they were separated from each other by air gaps.

3. The segments should be of considerable depth to permit returning occasionally so that their circular form may be preserved;

4. The insulating material must be such that it will not absorb oil or moisture;

Mica is best adapted for insulation, but as there are a great many varieties, differing greatly in hardness and other equalities, it is important to select the kind that wears at the same rate as the segments. If the mica be too hard, the wearing of the segments will leave it projecting and prevent proper contact with the brushes; again, if the mica be too soft, it will result in furrows or depressions between the segments into which copper dust will collect, causing short circuits.

TEST QUESTIONS

1. *What is commutation?*
2. *Upon what does the theory of commutation depend?*
3. *What is the difference between;* ***a,*** *normal neutral plane;* ***b,*** *neutral plane;* ***c,*** *commutating plane?*
4. *What is the plane of maximum induction?*
5. *Describe at length the process of commutation.*
6. *What causes sparking?*
7. *Explain the effect of self induction in detail*
8. *Why are very thin brushes not used?*
9. *Why should a proper lead be given to brushes?*

11. *How does resistance affect commutation?*
12. *Describe in detail the construction of commutators.*
13. *What are the requirements for commutators.*
14. *Give some points relating to commutators.*
10. *What may be said with respect to fixed position of brushes?*

CHAPTER 24

Brushes and the Brush Gear

With respect to construction, brushes may be broadly classified as:

1. Metal, and
2. Carbon.

There are several varieties of metal brush, such as:

1. Gauze brushes;
2. Wire brushes;
3. Laminated or strip brushes.

Gauze Brushes.—These are very flexible and yielding, their use being attended with little wear of the commutator.

Ques. What is the construction of a gauze brush?

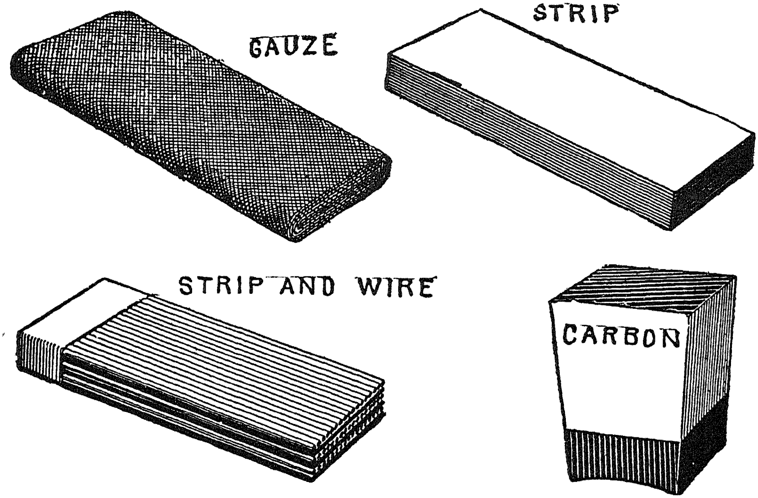
Ans. A gauze brush is made up of a sheet of copper gauze, folded several times, with the wires running in an oblique direction, so as to form a solid flat strip of from ¼ to ½ inch in thickness, increasing with the volume of the current to be collected.

Ques. What is the object of folding the gauze with the wires running in oblique directions?

Ans. It is to prevent the ends of the brush fraying or threading out, which would be the case if the gauze were folded up in any other manner.

Ques. What are the features of gauze brushes?

Ans. They make good contact, but are quite expensive.



FIGS. 758 to 761.—Various forms of brush. Fig. 758 gauze brush; fig. 759 laminated or strip brush; fig. 760 strip and wire brush as used on the early Edison machines; fig. 761 carbon brush. Carbon is preferred to copper for brushes on account of the reduction of sparking secured by its use and is now the prevailing type.

They may be set either tangentially or radially, the latter preferably, since the point of contact remains the same as the brushes wear away.

Wire Brushes.—This class of brush, which was extensively used before the invention of the gauze brush, is made up of a bundle of brass or copper wires, laid side by side and soldered together at one end.

Since wire brushes are harder than the gauze brush, they are more liable to cut or score the commutator, and are also more troublesome to trim.

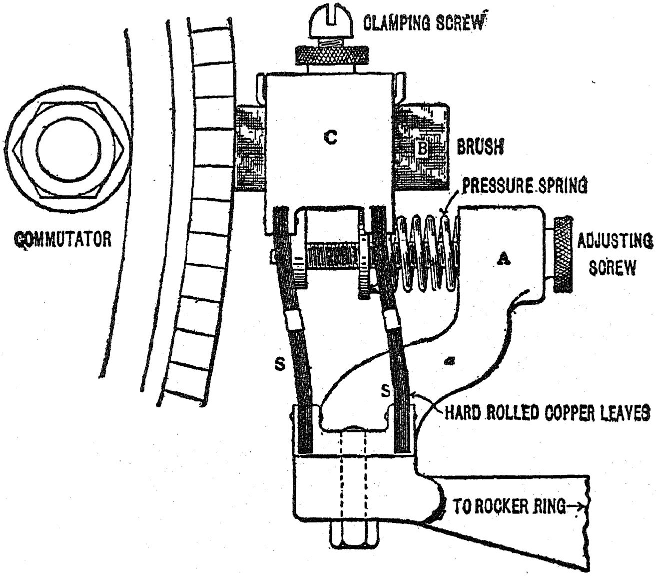


FIG. 762.—Multi-spring arm brush holder. The carbon brush B, is firmly clamped in the "box" C, by two screws which bear on a sheet of brass to protect the carbon from being broken by the ends of the screws. The box C, is carried by four flexible springs SS, one at each corner and formed of hard copper leaves. These are fixed at one end to the box and at the other to the solid base which is in one piece with the spoke attached to the rocker ring. An adjusting screw passes through appropriate lugs on the box C, and loosely through the head A, of a fixed arm *a*. Between the lower surface of *a*, and the upper lug on the box C, is placed the pressure spring.

Laminated or Strip Brushes.—These probably represent the simplest form of brush, but are not extensively used owing to the lack of flexibility. They consist of a number of strips of copper or brass, laid one upon the other and soldered at one end, as in fig. 759.

Ques. What name is generally given to strip brushes?

Ans. They are commonly and erroneously called *tangential brushes*, but they are really beveled at the end and set inclined to the line of tangency so that the ends of all the sheets will make contact.

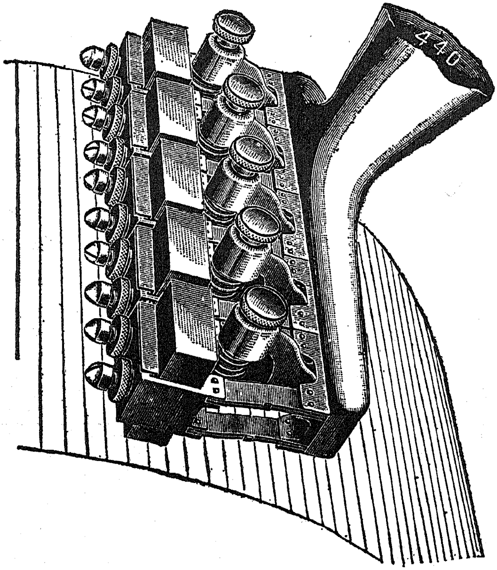


FIG. 763.—Perspective views of multi-spring arm brush holder. This holder is of the parallel type in which the brushes may be adjusted without affecting the lead. Each brush is held rigidly in its box and there are no sliding contacts in the path of the current. The holder is further described under fig. 762.

Carbon Brushes.—When metallic brushes are used upon the commutators of high tension machines, they frequently give rise to excessive sparking and also heating of the armature, the metallic dust given off appearing to lodge between the segments of the commutator, thus partially short circuiting the armature. To obviate this, carbon brushes are now used, this material being found very effectual in the prevention of sparking.

Ques. What is the usual form of carbon brushes?

Ans. They are usually in the form of oblong blocks.

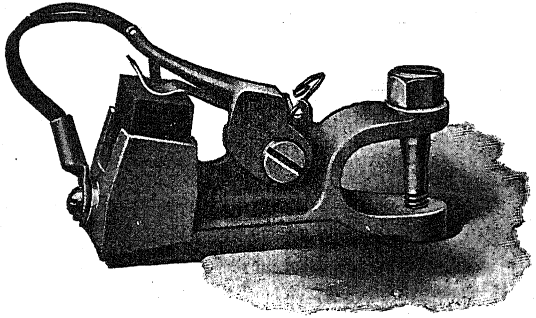


FIG. 764.—General Electric box type brush holder. The box which holds the brush is broached to allow the brush to slide freely, but not loosely, to and from the commutator against which it is normally held by a lever acting directly upon the brush head. This avoids the possibility of uneven bearing on the commutator, as the brushes are allowed very slight lateral or angular motion. The adjustment of a brush is also simplified after it has been removed and then replaced. Tension on the brush head is obtained by a special spring which maintains any given tension for which it may be set. An auxiliary flat steel spring on the lower side of the lever acts as a shock absorber between the lever and the brush head, absorbing all minor vibrations caused by a worn commutator. Side contact between brush and brush holder is not relied upon to carry the current, flexible copper pig tails performing this function to the exclusion of sliding contacts or tension springs, in order to reduce the brush loss. It is not necessary to take the brush rigging apart or loosen cable connections when it is desired either to remove or reverse the brushes to change the direction of armature rotation.

Ques. How are they adjusted on the commutator?

Ans. They are set "butt" end on the commutator, and fed forward as they wear away by means of a spring holder.

Ques. Why are carbon brushes so extensively used?

Ans. Because they are the only form of brush that will give good commutation with fixed lead.

Ques. What may be said of the different grades of carbon in use for brushes?

Ans. The very soft carbon leaves a layer of graphitic matter on the commutator, and at high voltages, this may cause sparking; such grade of carbon should only be used on low voltage machines.

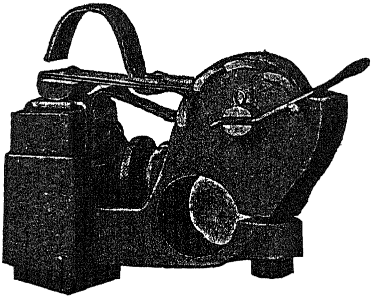


FIG. 765.—Westinghouse brush holder. It is made of brass, cast in one piece, and of standard sliding type with a shunt of braided copper wire directly connected to a clamp on each brush and to the solid portion of the holder, where it is held by a screw. This shunt relieves the spring of heavy currents. The holder is so arranged as to be easily accessible for adjustment, cleaning and renewal of carbons. Proper tension is provided by spiral strap springs so mounted as to eliminate friction and give uniform pressure over a wide working range. The spring tension is readily adjusted by a simple ratchet arrangement.

Ques. How are the ends of carbon brushes treated, and why?

Ans. They are usually covered at their upper part with a coating of electro-deposited copper to insure good contact with the holder.

Comparison of Copper and Carbon Brushes.—Copper brushes *tend to tear and roughen the surface of the commutator, while carbon brushes tend to keep the surface smooth.*

With carbon brushes, the armature may be run in either direction. The resistance of carbon being greater than copper, there is less short circuiting caused by carbon particles than by those of copper.

Ques. What is the chief merit of carbon brushes?

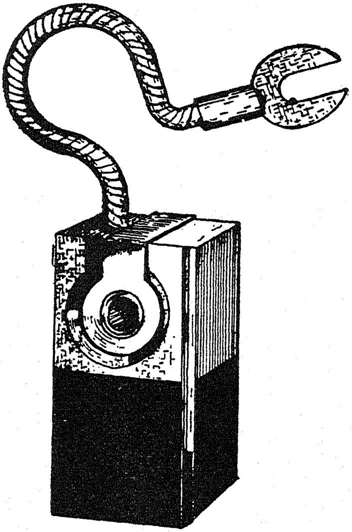


FIG. 766—Carbon brush and connecting lead or "pig tail."

Ans. They give less sparking than other types.

Ques. How has the construction of carbon brushes been varied?

Ans. Since, for minimum sparking, it is only necessary that the brush have high resistance in the region near its edge, attempts have been made to increase the conductivity of the other portions by combining with the carbon, copper sheets or wires.

Ques. What are the objections to carbon brushes?

Ans. They are easily broken and not being flexible, vibration, or any roughness of the commutator will cause bad contact.

Ques. For what class of machine are carbon brushes especially adapted?

Ans. For machines furnishing a small current at high pressure.

When carbon brushes are used, it is desirable that the current be small, because, on account of the low conductivity of the carbon, more contact area is necessary than with copper for equal current transmission. For fixed lead and fluctuating currents, carbon brushes should be used.

Ques. For what class of machine are copper brushes especially adapted?

Ans. For machines furnishing large current at low pressure, as in fig. 756.

Size of Brushes.—The number of brush sets *depends upon the number of poles of the machine, but there may be several brushes in each set.*

It is usual, except in the smallest machines, to place at least two brushes exactly similar side by side instead of one broad brush, thus allowing one brush to be removed for trimming or renewal while the machine is running.

Moreover, better contact is secured by this sub-division, because a slight elevation in the commutator surface at one point may slightly raise

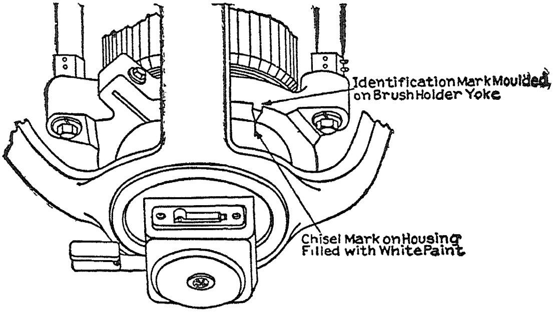


FIG. 767.—Method of indicating full load neutral on General Electric types BD and CD dynamos and motors (frames 23 to 95 inclusive). ***Brush setting,*** correct operating position is indicated by the projection on the brush holder yoke which should line up with a chisel mark on the bearing housing. Compound wound dynamo will have the brushes slightly in advance of the true neutral point. This brush setting will represent on all motors and shunt dynamos the full load neutral. On compound dynamos the difference between the marks will represent a slight forward lead of the brushes beyond the neutral point. On compound dynamos this is done to provide the proper brush location for satisfactory compounding or parallel operation.

NOTE.—When for any reason it becomes necessary to remove the brush holders from the studs, in reassembling, the bodies should be carefully set so that they are 3/32 in. distance from the surface of the commutator. Increasing this distance will cause commutation trouble.

NOTE.—***As the commutator is turned or worn down,*** the brush holder bodies should be loosened on the studs and turned toward the commutator surface until the distance between the bodies and the surface of the commutator is again 3/32 in. In all cases the toes of the brushes must be in alignment across the commutator surface, also brushes should be staggered so that commutator will wear evenly. When making these adjustments on the brush holders, it is necessary that the clamping bolts be tightened sufficiently to prevent the brush holder turning on the stud.

NOTE.—***When replacing*** the copper segments in bolted type commutators, operations should proceed as follows: Remove thrust collar from shaft and draw a few turns of wire tightly around the commutator to prevent the segments separating during the removal of the shell which frequently entails more or less pounding and jarring. Remove the leads directly connected to the segments to be replaced; remove all of the bolts and pull out the shell; next remove the mica cone; then take off the wire band, drive forward and take out one of the segments to be replaced; a new segment should be made using the old one as a template. This should be cut from solid copper since commutator segments are not interchangeable and must be of the same bar gauge or taper as the old segment. Place the two segments together with the bottom edges or thin side even, then lay out and form the new segment from the old one, taking care that the 30° and 3° angles are exact. Insert new side mica and place the new segment in the commutator. If necessary to replace several segments, proceed, one segment at a time, as described above. The mica cone, if not damaged while being removed, should be put back. If it be damaged, insert a new cone. Then press the shell back on the shaft until it is approximately one in. from its original position. Insert the bolts and take them up all around a little at a time to insure that the cap at the back of the commutator is drawn up evenly as the shell is being pressed home. The commutator should next be heated with a gas ring to approximately 115° Cen. and the bolts tightened while it is still hot.

one brush of a set at each revolution without much harm, while with one broad brush, the entire brush would be lifted, causing bad sparking.

Ques. What determines the number of brushes in each set?

Ans. It depends upon the current capacity, size of machine, and judgment of the designer.

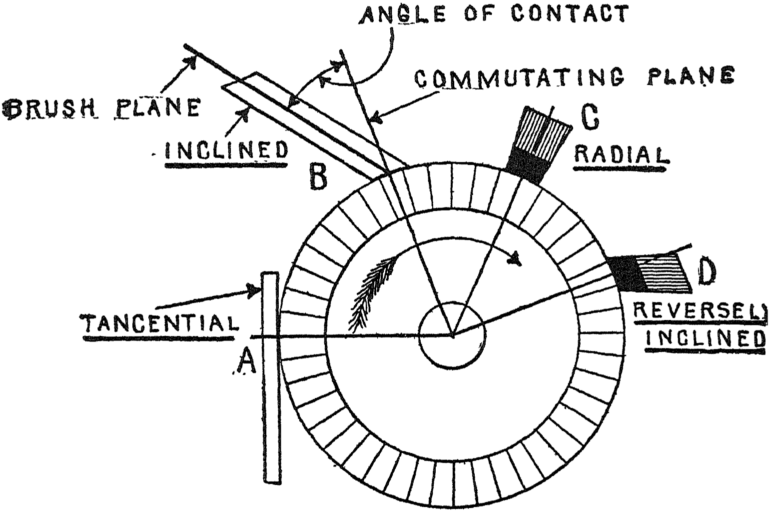


Fig. 768.—Contact angle for the different types of brush. At A, is shown a brush with tangential contact, and at B, a so called tangent brush; the latter is properly called an inclined brush. Sheet copper brushes are set tangentially as at A, and gauze brushes inclined as at B. Carbon brushes are placed radially as at C, when mounted in box holders, and inclined opposite to the direction of rotation when used with reaction holders.

Ques. What may be said with respect to the dimensions of the brushes?

Ans. No general rule can be given for breadth and thickness of brush.

The contact face must clearly be wider than the thickness of the insulation between commutator segments, since the period of commutation must last an appreciable interval of time on account of self-induction.

Ques. What should be the minimum width of the brush contact face?

Ans. It may be taken as one and one-half times the thickness of the commutator segments.

Ques. How wide should a carbon brush contact be?

Ans. The brush should be thick enough to cover two and one-half commutator segments.

The thickness should in no case be excessive on account of the loss due to heating, which results from the difference of pressure at the forward and rear edge of the brush.

Contact Angle of Brush.—This may be defined as *the angle which the brushes make with the commutating plane* as shown in fig. 768.

The several kinds of brush, together with the varied conditions of operation require different contact angles ranging from zero to 90°. Thus in the figure, a copper strip brush may lie at 90° or tangentially as at A.

Wire or gauze brushes should make a more or less acute angle as at B, in order to present the end and not the side of the brush to the commutator.

Carbon brushes may be placed end on or radially as at C, which is the position almost universally used in the case of traction or other reversing motors.

Sometimes the carbon brush is inclined as at D, in order that the revolving commutator may tend to push the brush against its supports and thus ensure better contact.

Brush Contact.—The relation between *contact pressure, contact resistance*, and *friction of brushes varies greatly for different kinds of brush.*

Copper brushes will carry from 150 to 200 amperes per sq. in. of contact surface; and carbon brushes from 40 to 70 amperes per sq. in. The usual contact pressure is 1.25 to 1.5 lbs. per sq. in. for copper brushes, and 1.5 to 2 lbs. per sq. in. for carbon brushes. The rim velocities of commutators vary from 1,500 to 2,500 feet per minute, the velocity usually increasing with the size of the machine.

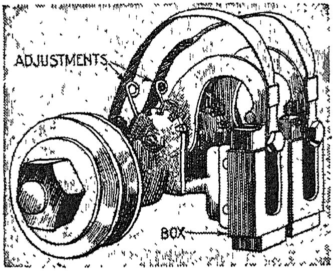


FIG. 769.—Bissell double brush holder. Flexible cables carry the current between the brushes and holders. This holder works equally well for forward or reverse rotation. Two or more holders are used on each stud except for the two smallest frames. The construction permits of adjustment or renewal of brush while the machine is in operation. Sufficient contact area of brush is provided to permit running on one carbon at ordinary loads in case the other becomes worn or inoperative.

Ques. What is the drop in voltage at the brushes?

Ans. For carbon brushes it is about .8 to 1 volt at each contact, or 1.6 to 2 volts for the two, positive and negative, contacts of a machine.

This value is not materially affected by placing a number of brushes in parallel or by using several sets, as in the case of multipolar machines, as such arrangement merely reduces the current density, and since the contact resistance varies in the inverse ratio, their product remains nearly constant.

Ques. What may be said of the friction of the brushes?

Ans. The coefficient of friction of brushes is about .2 to .25 for copper and .3 for carbon.

Ques. How many watts are lost at the brushes?

Ans. The watt loss is equal to 1.6 to 2 volts for carbon multiplied by the total current carried.

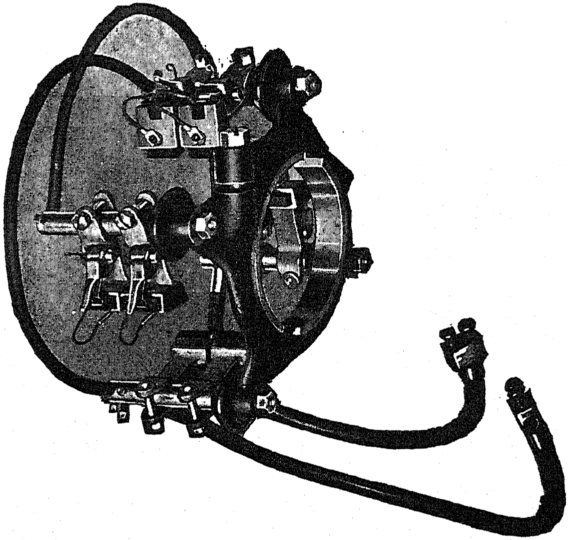


Fig. 770.—Western Electric brush gear. The brush holders carry carbon brushes and are so designed that the brushes may be firmly clamped in position and also be capable of independent adjustment. Any brush can be removed while the machine is in operation without disturbing the others and without moving the holder on the stud.

The watt loss on account of friction may be calculated by the formula: $\frac{.3 \times 746}{33,000}(P \times S)$ = watts lost by carbon friction, in which P, is the total pressure in pounds on the commutator, and S, the rim velocity of the commutator in feet per minute.

The losses due to contact resistance and brush friction are very liable to be greatly increased above the values that may be obtained by the preceding methods, if the commutator and brushes be dirty and rough, or not in good condition.

Brush Holders.—These are devices *employed to hold the brushes against the commutator with the proper pressure.*

They differ considerably in various types of machine, hence, no general rules can be given with respect to their construction or use, but any brush holder must fulfill the following requirements:

1. It must hold the brush securely and at the same time feed it forward as it wears away so as to maintain a proper contact;
2. It must hold the brush at the proper contact angle.
3. It must be capable of being raised from the commutator, and held out of contact by some form of catch;
4. It must be so constructed that the brush can be easily removed for cleaning or renewal;
5. The spring pressure must be adjustable;
6. The brush holders themselves must be carried on a rocker arm, or rocker ring.

It is desirable that brush holders be capable of individual adjustment, so that each may be set at its own point of minimum sparking. A few forms of brush holder are illustrated in figs. 771 to 774.

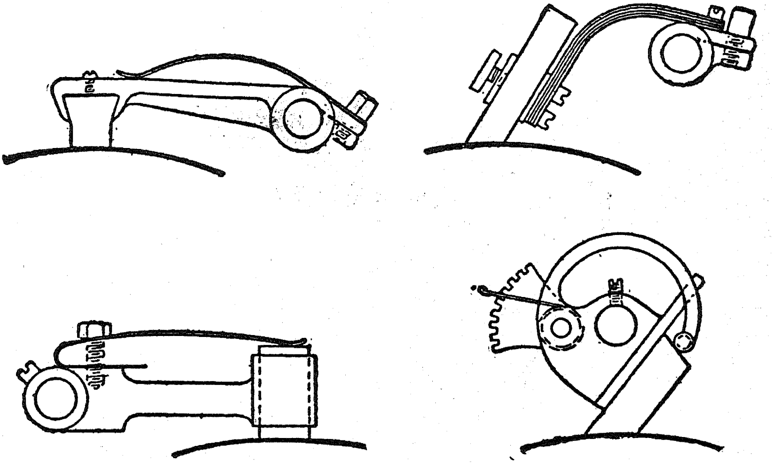
The various kinds of brush holder may be divided into four types:

1. Arm or lever type;
2. Spring arm type;

3. Box type;
4. Reaction type.

In the arm or lever type the brush is firmly attached to the extremity of a rigid arm capable of movement about the brush spindle, except in so far as it is restrained by a spring as in fig. 771.

Fig. 772 shows a brush holder of the spring arm type. The brush is firmly attached to the extremity of a spring arm, the other end of which is secured to the brush spindle, and when once adjusted is not capable of movement about the brush spindle.



Figs. 771 to 774.—Various types of brush holder. Fig. 771, arm or lever type; fig. 772, spring arm type; fig. 773, box type; fig. 774, reaction type.

In the box type of brush holder as illustrated in fig. 773, the brush is free to move up and down in the brush box, so far as it is not restrained by a spring rigidly secured to the arm which carries the brush box at its extremity.

Fig. 774 shows the reaction type of brush holder, in which the movement of the brush is constrained in one direction by the surface of a part rigidly secured to the brush spindle, and is further constrained by a spring controlled arm, the pressure of which is capable of ready adjustment.

Among the special forms of brush holder may be mentioned:

1. Scissors type of brush holder;

This is used for slip rings, and consisting of two arms pivoted together like a pair of scissors. The lower ends of the arms carry the brushes, suitably mounted, and the upper ends are drawn together by a spring, which thus exerts pressure on the brushes.

2. Clock spring type of brush holder;

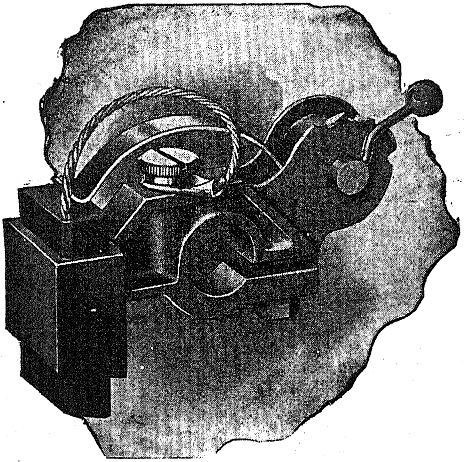


Fig. 775.—General Electric brush holder. This holder consists of a rugged iron casting, elliptical in section, and supported from the commutator end bearing bracket in such a manner as to provide for the shifting of the brushes. A handle attached to the yoke aids in this shifting and a thumb nut on the outside holds the whole brush gear in the desired position. The brush is fed through an accurately broached slot by a spring which maintains uniform pressure against the commutator throughout the wearing length of the brush. The long lever arm of the spring is sufficiently flexible to take up any minor vibrations of the brush. The tension of the brush may be adjusted without lifting it from the commutator or disturbing any of the other holders. The brush may be removed for inspection by throwing the spring out of notch. The brush is connected to the holder by flexible copper pig tails of ample current carrying capacity.

In this type the necessary contact pressure is applied to the brush by means of a clock spring, which, with the aid of a ratchet may be wound up and adjusted to any desired pressure.

Ques. How are brush holders carried?

Ans. They are carried by a *rocker arm* for bipolar, and by a *rocker ring* for multipolar machines, which is mounted upon one of the main bearings, or upon a support specially provided for it, being pivoted to revolve from the same center as the shaft, to permit shifting the brushes.

Ques. Mention one trouble sometimes encountered with brush holders.

Ans. There is sometimes trouble resulting from the current passing through the spring which heats it and destroys its elasticity.

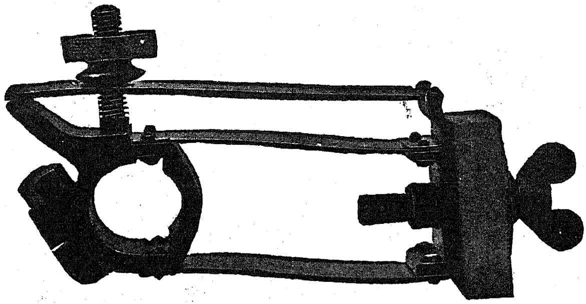


FIG. 776.—Parallel spring brush holder. This is an unsatisfactory type of holder, the box holder being much more desirable.

Ques. How may this be avoided?

Ans. By insulating one end of the spring, and carrying the entire current directly from the brush itself to the main conductors by a flexible copper strip or cable firmly connected to both.

Ques. What may be said with respect to brush construction on machines for electrolytic work?

Ans. The collection of large currents at low voltage, generated by comparatively small machines, requires careful design of brushes and brush holders. The commutator is longer than the commutators on machines of equal capacity at higher voltages, and as a rule the commutator segments are thicker and fewer in number. Each brush set is made up of numerous narrow brushes rather than two abnormally wide ones.

An example of brush and brush gear designed to meet such conditions is shown in fig. 756.

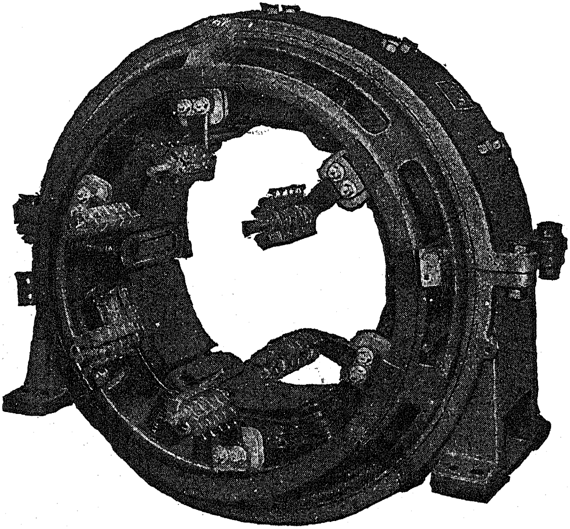


FIG. 777.—General Electric assembled frame multipolar brush gear engine type dynamo.

In large machines for electrolytic work, it is not unusual to find the current divided between two wide commutators, one at each end of the armature, thus giving a longer axial bearing surface for the brushes without inconveniently lengthening the pins upon which the separate brushes are threaded.

Multipolar Brush Gear.—The brush gear which includes the holders and carrier arm or ring, becomes more complicated as the number of poles and magnitude of the current is increased.

In the early days of multipolar machines, schemes of armature winding were devised such that all the necessary cross connections were made inside the machine, and the number of brush holders reduced to two and placed at an angular distance apart depending upon the number of poles.

Such windings, though possible, are not used much, chiefly on account of their complexity, which not only increases the danger of error in construction, but also makes repairs costly. In modern multipolar machines, such complicated windings are avoided, and the several sets of brushes are connected together in two groups, positive and negative. These connections are carefully designed as part of the brush gear.

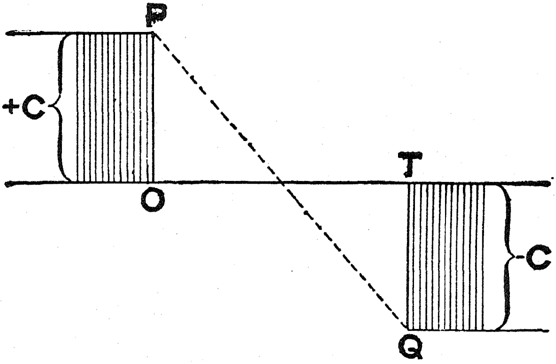


Fig. 778.—Curve of commutation, ideal case. Assume during commutation that there is a contact resistance inversely proportional to the area of contact between the brush and commutator. In the diagram let abscissæ measure time and the ordinates, current in the coil that is to be commutated. Taking zero as the instant when commutation begins and T, the time when it ends, and the initial value of the current in the coil as C, then the problem is how to convert the value +C, into the value −C, during the time T. The ideal case should be that this reversal should take place by a uniform change: or graphically, that the current curve should slope uniformly from beginning to end, the current having its value reduced to zero at a time ½ T, this was seldom the case.

Ques. How are the brushes held in large multipolar dynamos?

Ans. They are held at the proper points of commutation by arms offset from a cast iron rocker ring, which is itself supported by brackets projecting from the magnet yoke as shown in fig. 777.

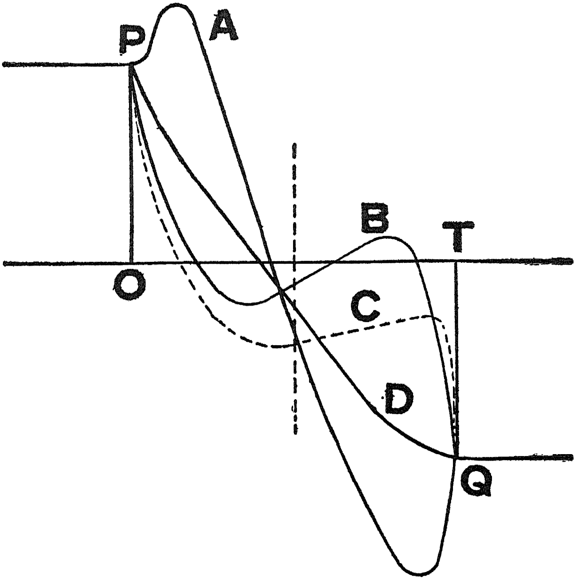


FIG. 779.—Curve of commutation as observed by Everett and Peake. They found in a particular machine that the curve had the forms here shown. The curve marked A, shows an initial increase (as may happen at light loads) with an oval reversal at the end. Curve B, shows an under commutation with an insufficient lead. Curve C, with an increased load, shows a rapid reversal at first, but an under-commutation towards the end of the period. Curve D, shows a gradual fall, which slackens toward the end of commutation. If there were no self induction to delay the change of current, a straight line might be obtained.

Ques. What provision is made for shifting the ring to adjust the lead?

Ans. The ring is rotated by means of a worm gear and hand wheel.

TEST QUESTIONS

1. *Name two general types of brushes.*
2. *Describe a gauze brush.*
3. *What are the features of carbon brushes?*
4. *How are carbon brushes adjusted on the commutator?*
5. *Why are carbon brushes so extensively used?*
6. *What is the comparison between copper and carbon brushes?*
7. *What is the chief merit and objections to carbon brushes?*
8. *For what type of machine are:* ***a,*** *carbon;* ***b,*** *copper brushes adapted?*
9. *How is the size and number of brushes determined?*
10. *What may be said with respect to the dimensions of the brushes?*
11. *What should be the minimum width?*
12. *Find the contact angle of brush.*
13. *What are the proper conditions of brush contact?*
14. *Does the voltage drop at the brushes?*
15. *How many watts are lost at the brushes?*
16. *Describe and name some requirements of brush holders.*
17. *Name the various types of brush holders.*
18. *What are some special forms?*
19. *How is the arm lever type attached?*
20. *Describe the spring arm type.*

21. *How does the brush move in the box type?*
22. *What trouble is sometimes encountered with brush holders, and how avoided?*
23. *How are brushes arranged to collect large currents at low voltage as on electroplating dynamos?*
24. *Describe the multipolar brush gear.*
25. *What provision is made for shifting the ring to adjust the lead?*

CHAPTER 25

Armature Construction

The armature of a dynamo has been defined as: *a collection of coils of wire wound around an iron core, and so arranged that electric currents are induced in the wire when the armature is rotated in a magnetic field.*

From the mechanical point of view the armature may be said to be made up of the following parts:

1. Shaft;
2. Core;
2. Spider (in large machines);
4. Winding;
5. Commutator

Of the two types of armature, ring and drum, the latter is almost universally used, hence the examples of construction which follow will be confined chiefly to this type.

Shaft.—A typical armature shaft is shown in fig. 780. It is made of steel and, except in the smaller machines, is thicker in the middle than at the ends for stiffness to withstand the strong magnetic side pull on the core when the latter is slightly nearer one pole piece than the other.

Ques. What is the object of providing shoulders on the shaft as in fig. 780?

Ans. They serve to keep the armature in the proper position with respect to the bearings.

Ques. How is the shaft proportioned?

Ans. If it be proportioned to secure the proper stiffness, it will be found of ample size to resist the twisting strain.

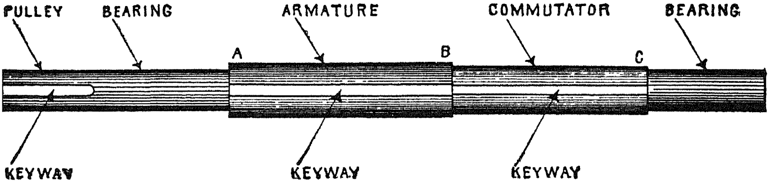


FIG. 780.—Typical shaft for an armature. The illustration shows the keyways for pulley, armature and commutator. In the smaller sizes, there is usually a flange at A, and threads at B and C, for retaining nuts.

The shaft is subject also to bending by the weight of the armature, by the magnetic drag on its core, and in belt driven machines, by the lateral drag of the pulley. When running, it is also subjected to bending stresses if the armature be not properly balanced. If the bearings do not give, it is evident that all such actions tend to bend the shaft at definite points.

Core.—In the small and medium size dynamos, the core is attached direct to the shaft. There are two kinds of core.

1. Smooth;
2. Slotted.

Ques. What may be said of the smooth type of core?

Ans. It has become obsolete, except in special cases, as for machines used for electrolytic work where a large current at low voltage is required.

Ques. What is necessary with a smooth core?

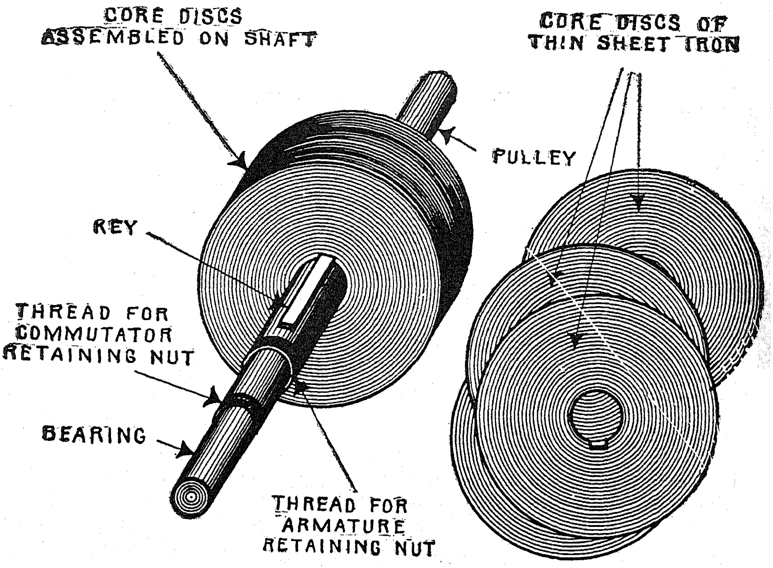


FIG. 781 and 782.—Laminated smooth core armature partly assembled. *It consists of* numerous discs of thin sheet iron threaded on the shaft and pressed together by end plates. The object of this construction is to prevent eddy currents.

Ans. Driving horns as later described.

Ques. What is a slotted core?

Ans. One having a series of parallel slots, similar to the spaces between the teeth of a gear wheel, and in which the inductors are laid.

Ques. What provision is made to avoid eddy currents in cores?

Ans. They are laminated.

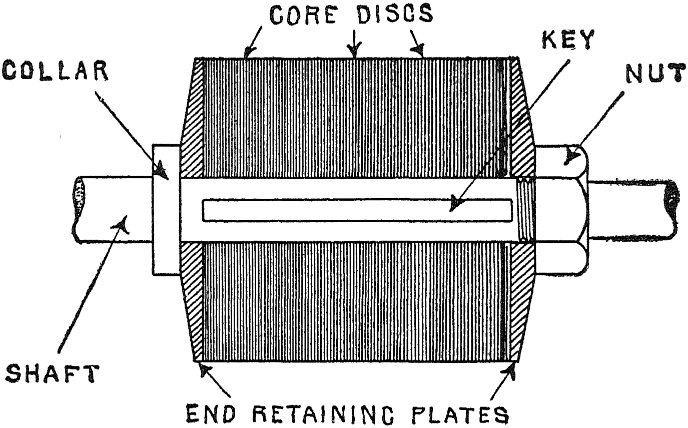


FIG. 783.—Sectional view of laminated smooth core armature showing end plates, flange and retaining nut. A key is provided to prevent rotation of the core with respect to the shaft.

Ques. Describe this method of construction.

Ans. The core is made of stampings of thin wrought iron or mild steel. The numerous discs stamped from the sheet metal are threaded on the shaft as in fig. 781, forming a practically solid metal mass.

Ques. How thick are the discs?

Ans. The thickness ranges from .014 inch to .025 inch, corresponding to 27 and 22, B and S, gauge respectively, 27 gauge being mostly used.

Ques. How are the discs held in place?

Ans. By two end plates pressed together either by large nuts screwed directly on the shaft as in fig. 783, or by bolts passing through the core from end to end, as in fig. 784, holes being punched in the discs for the purpose.

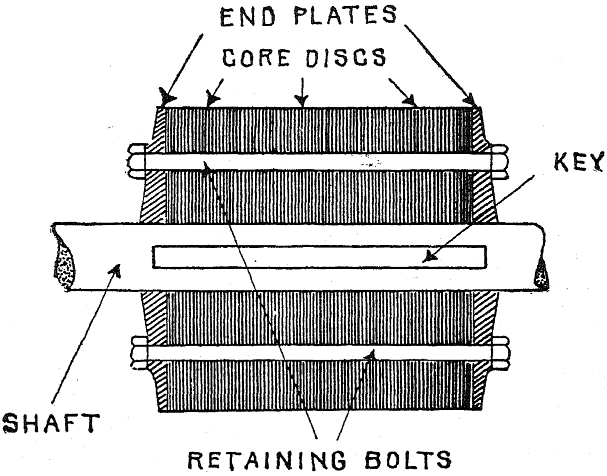


FIG. 784.—Laminated armature core with through retaining bolts. In the larger sizes, these bolts are used instead of nuts threaded on the shaft on account of the large size of the latter.

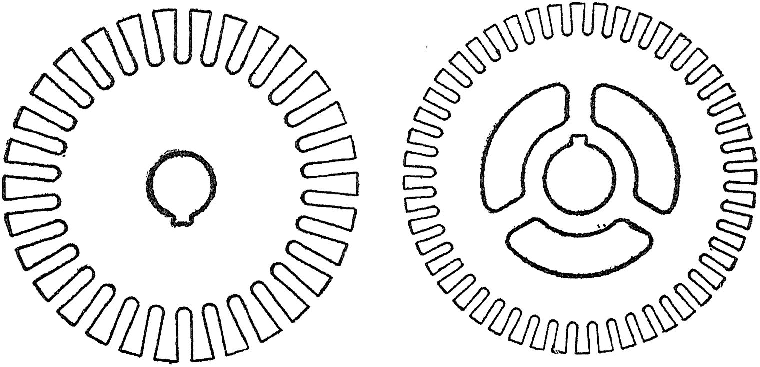
Ques. What precaution is taken with respect to the core bolts?

Ans. They are insulated from the core by tubes and washers of mica or other insulating material.

Core discs are stamped in one piece up to about 30 inches in diameter, and for larger sizes they are built up from sections as later described.

Figs. 785 and 786 show two forms of disc stamped in one piece. The first illustrates a solid disc, and the second a *ventilated* disc in which more or less of the metal is cut away near the center, thus providing passages for the circulation of air which carries away some of the heat generated in the armature.

Insulation of Core Discs.—When the discs are stamped from very thin metal, *the mere existence of a* ***film of oxide*** *is sufficient insulation.*



Figs. 785 and 786.—Solid and ventilated core discs. In fig. 785, the metal cut away near the center reduces the weight and provides passages for air circulation. ***In some instances*** a forced circulation is secured by means of a fan attached to the armature, as shown in fig. 798.

It is usual, however, to apply a quick drying varnish that will give a hard tough coat and not soften with heat or become brittle and crumble under vibration. The varnish may be applied either by dipping or with a japanning machine; it must be very thin, and the solvent employed should be a very volatile spirit.

Ques. What is the construction of the core end plates, and why?

Ans. The rims are beveled quite thin to avoid eddy currents.

Ques. How is the core connected to the shaft?

Ans. Since the core has the full torque exerted upon it by the drag of the inductors, it must be firmly connected to the shaft by means of a key, as shown, so that it may be positively driven.

Forms of Armature Teeth.—The teeth stamped in the core discs are made in various shapes, depending largely on the method of securing the inductors in the slots against electromagnetic drag and centrifugal force. The teeth may be cut with their sides:

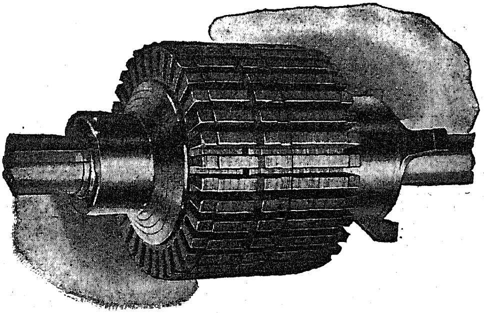


Fig. 787.—General Electric slotted armature core. ***The laminations*** are of sheet steel, annealed and japanned. They are mounted directly on the shaft (except in the large sizes), and held in place by substantial end plates.

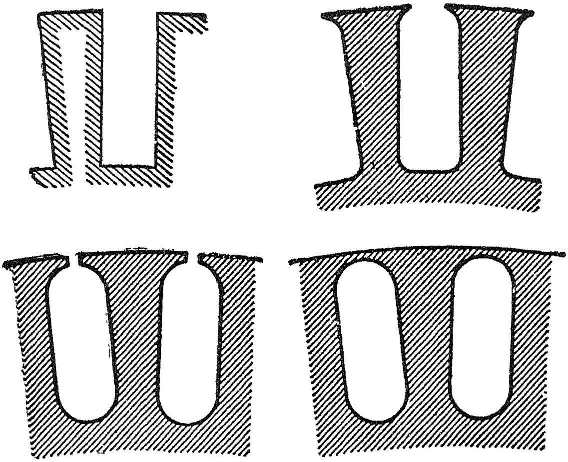
1. Inclined;
2. Projecting;
3. Notched.

Ques. What may be said of teeth with inclined sides?

Ans. A tooth of this type is shown in fig. 788, being slightly narrower at the root than at the top, the resulting slot having parallel sides.

Ques. What are the features of the projecting type of tooth?

Ans. The projecting type is shown in figs. 789 and 790, in which the tops project; this gives a larger core area around the circumference of the armature which reduces the reluctance of the air gap, and provides projecting surfaces for retaining the inductors in the slots by the insertion of wedges.



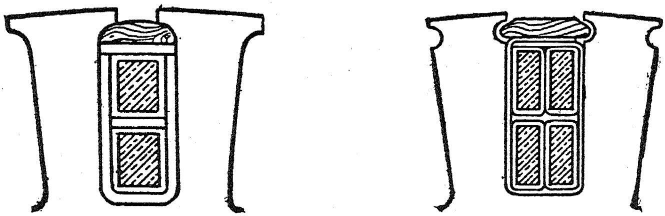
Figs. 788 to 791.—Various forms of armature teeth, fig. 788 inclined type forming a slot with parallel sides; figs. 789 and 790 protecting type which provides a support for the retaining wedges; fig. 791 enclosed type which forms "tunnels" for the inductors.

Ques. What is the object of cutting notches in teeth?

Ans. They are provided for the insertion of retaining wedges, as in fig. 793; this results in less area at the top of the teeth.

Ques. How should teeth be proportioned to secure most efficient operation?

Ans. The width of the tooth should be about equal to the width of the slot minus twice the thickness of the slot insulation; that is, the cross sectional area of the teeth should be equal to that of the slots.



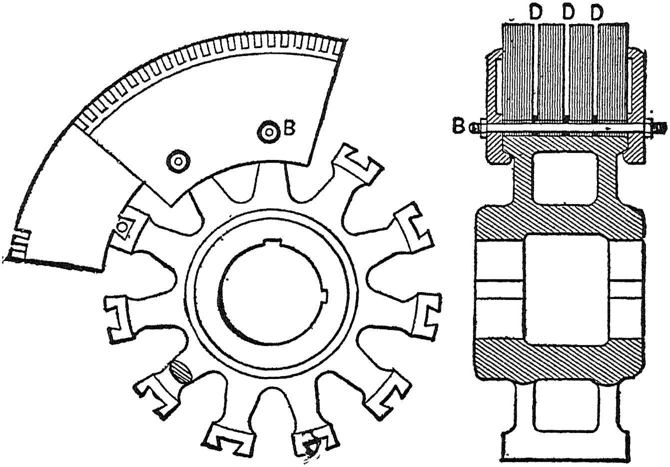
Figs. 792 and 793.—Projecting and notched teeth; cross sections showing inductors and retaining wedges in place.

Advantages and Defects of Slotted Armatures.—The slotted armature, sometimes called the Pacinotti armature, after its inventor, has the following advantages over the smooth type:

1. The inductors are held more firmly in place to resist stresses due to electro-magnetic drag and centrifugal force;
2. The inductors are protected by the teeth against mechanical injury;
3. Less reluctance of the air gap;
4. The intermittent induction due to the presence of the teeth prevents the formation of eddy currents;
5. When the teeth are saturated they oppose the shifting of the lines due to armature reaction.

The disadvantages of slotted armatures compared with the smooth type are:

1. Greater hysteresis loss, caused by denser flux in the teeth;
2. Generation of eddy currents in the polar faces when the latter are not of laminated construction;
3. Greater self-induction in the armature coils;
4. Construction more expensive;
5. Leakage of magnetic lines through core exterior to winding.



FIGS. 794 and 795.—Side and end view of built up armature cores. ***The sheet metal ring*** sections containing the teeth are fastened into dovetail notches in the spider as shown. The layers of ring sections are placed so as to break joints and are held by end clamps and through bolts B. Distance pieces are inserted at intervals to provide ventilating spaces D D D.

The generation of eddy currents in the polar faces may be overcome by making the air gap at least 50 per cent. of the distance between the teeth, so that the magnetic lines can spread from the corners of the teeth, and become nearly uniformly distributed over the polar faces. Magnetic leakage through the core may be reduced by making the amount of metal above the inductors very small.

Slotted Cores, Built Up Construction.—In the case of large dynamos, the core discs are built up in order to reduce the cost of construction; the following parts are used:

1. Spider;
2. Core rings split into sections.

Ques. What is the approved method of core construction in large armatures?

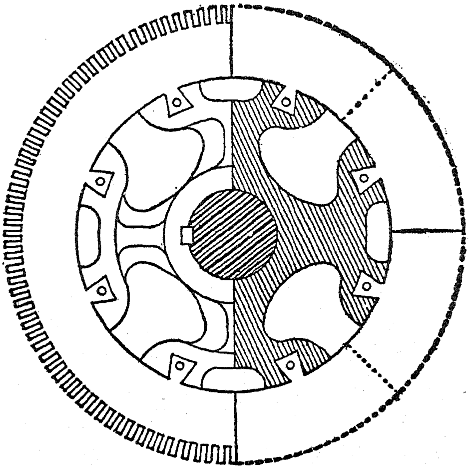


Fig. 796.—Built up core with four spoke spider, each spoke carrying two dovetail notches. *In this construction* a little more air space obtained for ventilation than where a separate spoke is provided for each notch.

Ans. The core should be of the built up construction to avoid waste of material in the stampings.

Ques. Describe the construction of a built up core.

Ans. Ring sections stamped from sheet metal are fastened to a central support or *spider,* which consists of an iron hub with radiating spokes and a rim with provision for fastening the rings. The rim of the spider is provided with dovetail notches into which fit similarly shaped internal projections on the core segments.

These features are shown in figs. 794 and 795.

Each layer of core sections is placed on the spider so as to break joints and the core thus formed is firmly held in place by end clamps as shown.

The manner of fastening the rings to the spider is an important point, for it must be done without reducing the effective cross section of the core in order not to choke the magnetic flux.

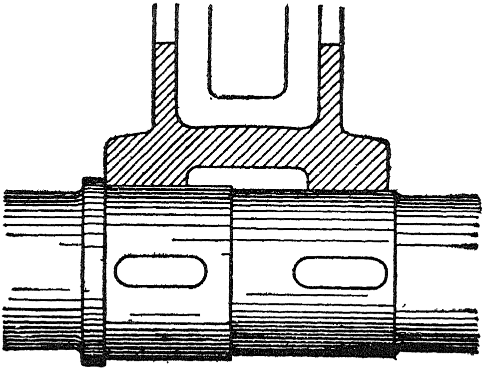


FIG. 797.—Hub and shaft design on large machines to reduce the machine work and facilitate erecting.

In order to secure a better fit and reduce the machine work, the spider hub in large machines is sometimes cored with enlarged section between the outer bearing surfaces, and it is not unusual to find these surfaces turned to two different sizes as in fig. 797, to admit of easier erecting.

To avoid any trouble that may arise by unequal expansion, the rim of the spider is not made continuous, but in several sections as shown in fig. 796. The rim here consists of four sections each of which has two dovetail notches. By thus dividing the rim into sections, its weight is somewhat reduced and the ventilating spaces between the sections increased.

Ventilation.—In the operation of a dynamo more or less heat is generated, depending on the load; hence it is desirable that *provision be made to carry off some of this heat to prevent excessive rise of temperature.*

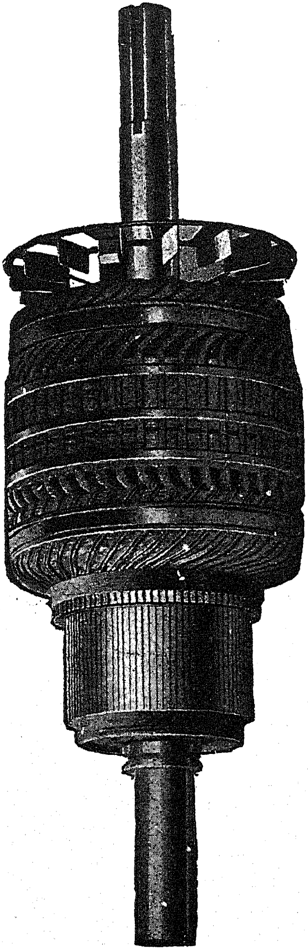


FIG. 798.—General Electric barrel wound armature, having a fan attached at one end to induce a circulation of air for ventilation.

Ques. Why do armature cores heat?

Ans. They heat from these causes: eddy currents, hysteresis, and heat generated in the inductors.

Ques. How is adequate ventilation secured?

Ans. The spider is constructed with as much open space as possible through which air currents may circulate. The core is divided into several sections with intervening air spaces D, as shown in fig. 795, the discs being kept apart at these points by distance pieces. These openings between the discs are called *ventilating ducts;* they are usually spaced from 2 to 4 inches apart.

Ques. What other provision is sometimes made to secure ventilation?

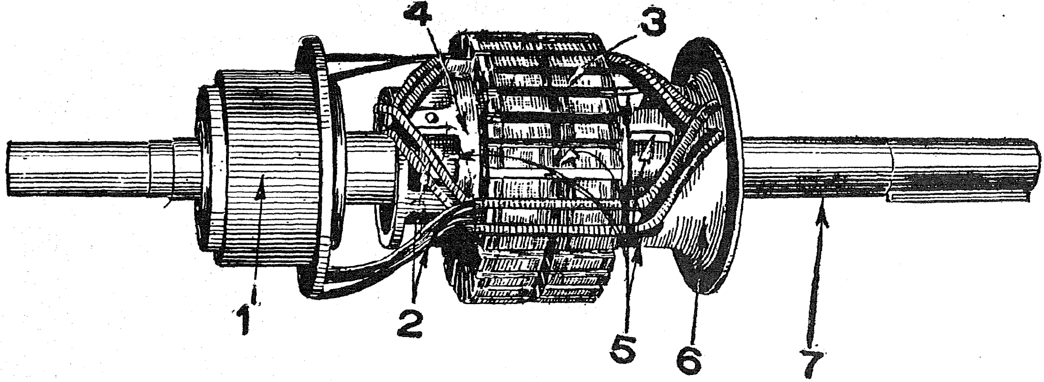


FIG. 799.—Allis Chalmers armature core and commutator assembled, showing two coils in position. 1, ***commutator*** is assembled complete and pressed on shaft. Hard drawn copper bars insulated with mica. Mica undercut between bars; 2, ***armature coils*** form wound, interchangeable, heavily insulated and treated to resist oil and moisture; 3, ***armature laminations*** punched with combination dies. Thick brass tooth supports prevent vibration and flanging; 4, ***core*** with lamination riveted together permits removal of shaft without dismantling the core or commutator. Frames E-120 and larger have core and commutator built on a steel sleeve so that shaft can be pressed out of finished armature without disturbing windings; 5, ***air passages*** through coil supports, core and commutator insure thorough ventilation, low operating temperatures and long life to insulation; 6, ***end head,*** support coils and ventilating fan; 7, ***shaft.***

Ans.—In some machines a forced circulation of air is secured by means of a fan attached to one end of the armature as shown in fig. 798.

Insulation of Core.—Before the winding is assembled on the core, the latter should be thoroughly insulated.

Japan or enamel insulation is not sufficient because it is liable to have bubbles or minute holes in it, or be pierced by particles of metal or by the rough edges of the core discs. Two or more layers of strong paper, fibre, canvas or mica, should be applied to the core before placing the inductors in position.

The ends of the core should be insulated with thicker material, since the strain upon it is greater, especially at the edges.

Armature Windings.—The subject of windings has been fully treated from the theoretical point of view in Chapter 19. It remains then to explain the different methods employed in the shop and the mechanical devices used to construct the scheme of winding adopted.

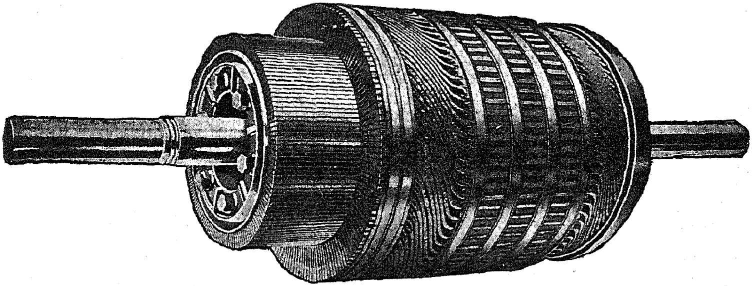


Fig. 800.—Typical iron clad barrel wound armature complete; view showing the openings for ventilation. ***The advantage*** of the form of winding adopted, is the ease with which a coil may be replaced in case of injury and the additional cooling surface. The coils are held in place by maple wedges secured by binding wires which are soldered throughout their length.

Ques. What is the construction of the inductors?

Ans. They are made of copper; the ordinary form consists of simple copper wire, insulated with enameled, single or double covering of cotton or silk, and in some cases copper bars are used for large current machines.

Ques. What is the objection to copper bars?

Ans. They are liable to have eddy currents set up in them as illustrated in fig. 716.

Ques. What may be said with respect to the size of wire used for inductors?

Ans. Wire larger than about number 8 B and S, gauge (.1285 inch diameter) is not easily handled, hence for large inductors, two or more wires may be wound together in parallel.

According to the mechanical features and manner of assembling on the core, drum windings may be divided into several classes, as follows:

1. Hand winding;
2. Evolute or butterfly winding;
3. Barrel winding;
4. Short or bastard winding;
5. **Former** winding.

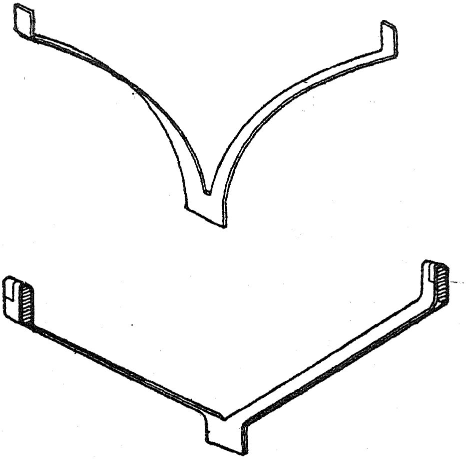
Hand Winding.—The first windings were put on by hand, and proved objectionable on account of the clumsy overlapping of the wires at the ends of the armature, which stops ventilation and hinders repairs, while the outer layers overlying those first wound, bring into close proximity inductors of widely varying voltage. The method is still used in special cases and for small machines.

Evolute or Butterfly Winding.—This mode of winding was *introduced by Siemens for electroplating dynamos to overcome the objections to hand winding*.

It takes its name from the method of uniting the inductors by means of spiral end connectors as shown in fig. 806, also in figs. 801 and 802, which show more modern forms.

Ques. What are evolute connectors?

Ans. The fork shaped strips used to connect bars at different positions on the armature, as shown in fig. 801.



Figs. 801 and 802.—Evolute and "straight out" connectors. ***In small machines*** the connectors must be curved as in fig. 801, but in large machines, especially where the teeth are wide, they may be straight as in fig. 802. These connectors may take either of the following forms: 1, *involute or evolute connectors*—An involute is the curve drawn by the extremity of a piece of string which is unwound from a cylinder; 2, *spiral connectors*—These consist of double spirals, the commutator being usually connected to the junction of the two spirals. These connectors are also known as "butterfly" connectors.

In large machines, especially where the teeth are wide, these connectors may be straight, as in fig. 802, but in small machines they must be curved in the manner shown in fig. 801, as the room available may diminish by as much as half, as the lowest point is reached, and the room occupied by the strip is the width of a horizontal section at various points. This width, in the case of the straight connectors, is constant.

In place of the wooden block, used in early machines, for fastening the middle part of the connectors, they may be anchored to an insulated clamping device built up like a commutator and for that reason called a *false commutator*.

Ques. How are the inductors arranged in evolute winding?

Ans. In fig. 805, it will be seen that the ends of the evolute connectors lie in two planes, hence the connectors must project to different distances beyond the core.

Accordingly, one long and one short bar may be conveniently placed in each slot, side by side. In large machines, especially where the teeth are wide, the connectors may be straight as in fig. 802. Evolute connectors may be used for either lap or wave windings.

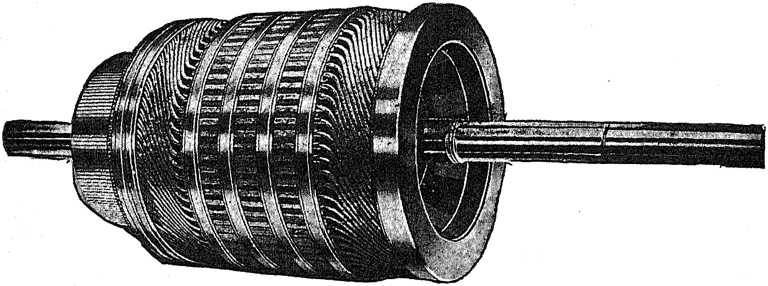
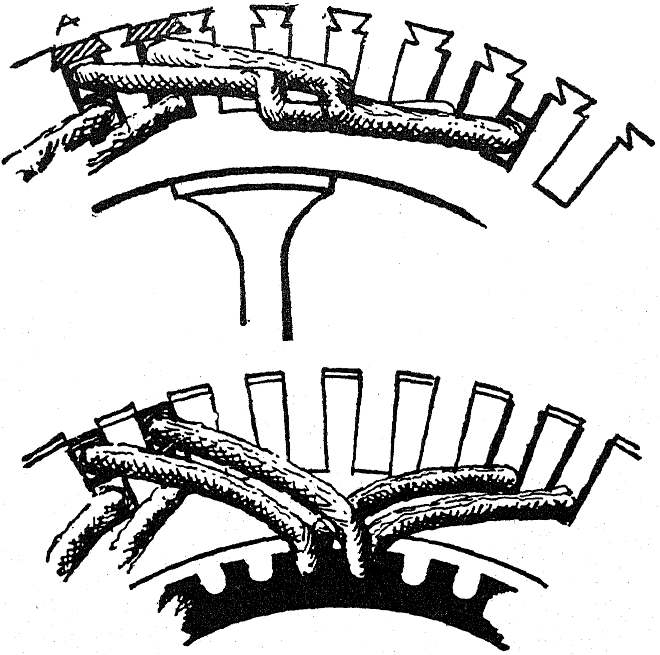


FIG. 803.—Barrel wound armature; rear view showing back head and coil guard. The construction of core and winding is described in fig. 625. The shaft is of crucible steel ground to gauge. The commutator segments are of drop forged copper in the smaller and hard-drawn copper in the larger sizes. The insulating material between the segments is mica. On the larger sizes, the commutator shell is fitted with a thread and mounted on a spider. This construction provides openings between the commutator and shaft for ventilation.

Barrel Winding.—This is a form of drum winding *in which the inductors are arranged in two layers and carried out obliquely on an extension of the cylindrical surface of the drum to meet and connect with radial risers.*

Barrel winding has been very widely adopted. Although it involves an increased length of armature, this gives additional cooling surface and provides for good ventilation.

In barrel winding, the coil ends must of necessity be arranged in two layers but the method may be used for either one or two coils per slot, the difference in arrangement for these two cases being shown in figs. 807 and 808. In the single layer barrel winding, fig. 807, each slot is occupied by but one side of one coil. In the double layer barrel winding, fig. 808, the opposite sides of two separate coils occupy space in the same slot. The coils, on emerging from the slots bend in opposite directions, and if one side of a coil occupy the bottom portion of a slot, its other side usually occupies the top portion of a slot distant from the first slot by the polar pitch.



Figs. 804 and 805.—*Barrel* and *evolute* windings; end views showing placement of coils. When all the coils are wound on the former, the placing of them on the armature is a simple matter. After insulating the slots, the winder begins at any convenient slot, and inserts the coils as shown. Before he can fill all the slots, some of the first coils must be raised and the last ones inserted underneath. There is not much difference between barrel and evolute winding and one style may be used at one end of the armature and the other at the opposite end.

Short or Bastard Winding.—In this type of winding, *the end connectors project from the inductors in straight lines parallel to the shaft and then are bent inward.*

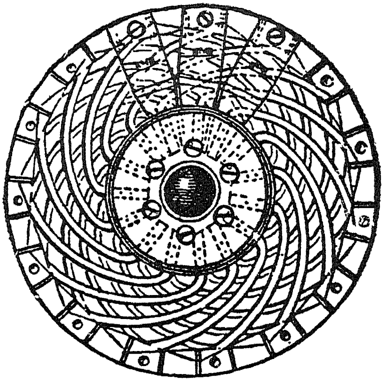
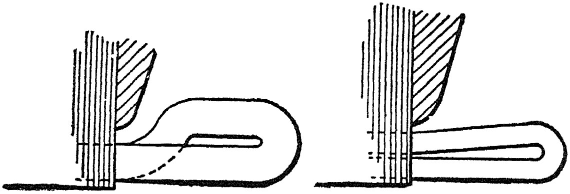


FIG. 806.—Siemens' bar armature; end view. ***Each inductor*** in the form of a bar is connected to the next by means of two evolute spiral copper strips, one bending inwardly, the other outwardly, their junction being in some cases secured to a block of wood upon the shaft. Their outer ends are attached to the bars by rivets or silver solder.



FIGS. 807 and 808.—Single layer and double layer barrel winding. Barrel winding is a method of arranging the ends of armature coils as they pass from one pole to the next, in which, instead of using *involute* or *butterfly* connections, V-shaped end connections are used which lie on a cylindrical surface, which is a continuation of the armature surface. The coil *ends* must of necessity be arranged in two layers, but the method may be used for either one or two coils per slot, the difference in arrangement for these is here illustrated.

It has the effect of being somewhat shorter than the barrel winding. In order to secure better ventilation, it is usual to combine a bastard winding at the rear end of the armature with a barrel winding at the commutator end. This class of winding is used only with bar armatures

Former Winding.—This relates to *a method of winding coils, and not to any particular type;* that is, mechanical winding as distinguished from hand winding.

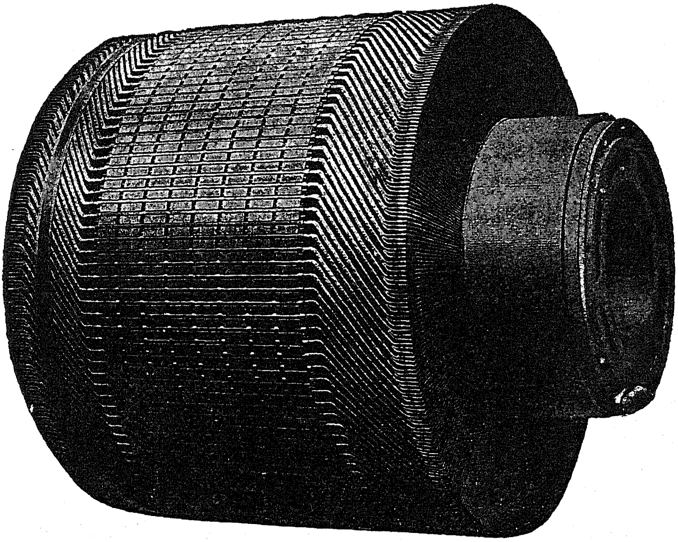


FIG. 809.—Westinghouse barrel wound armature. ***The coils*** are former wound from copper strap and are interchangeable. In the larger size machines they are of the single type. The illustration shows plainly the characteristic feature of barrel winding, namely the oblique end connectors carried out on the extended drum.

While hand winding is necessary for ring armatures, a drum armature is wound better and more easily by the aid of machinery.

Ques. What is a "former" coil?

Ans. A former coil, as its name suggests, is one that is

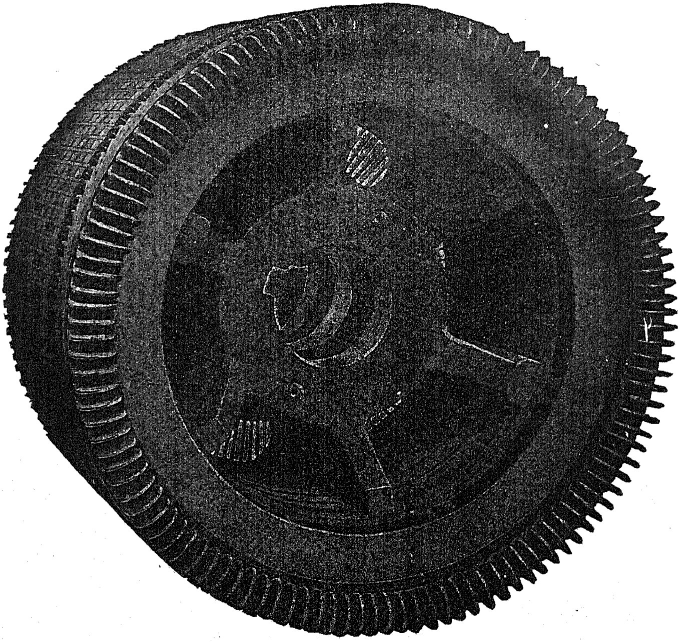
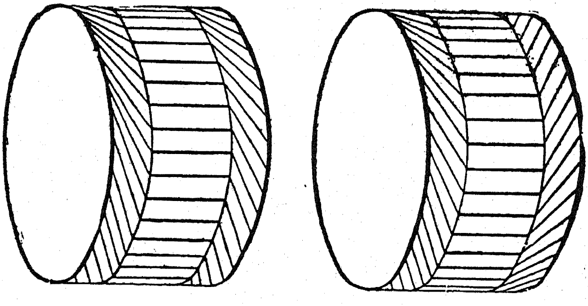


Fig. 810.—Rear end of Westinghouse wave-barrel wound armature; view showing ventilation.



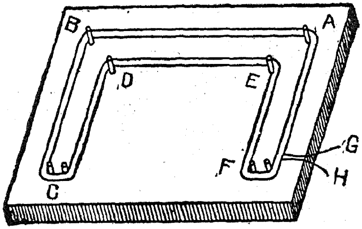
Figs. 811 and 812.—Diagrams illustrating wave and lap barrel windings.

wound complete upon a former before being placed upon the armature.

Ques. What is the advantage of this method of winding coils?

Ans. By the use of formers much time is saved, thus reducing the cost, and also by their use all the coils are symmetrical which improves the appearance of the finished winding.

Ques. How is the required shape of the template or former for winding the coils determined?



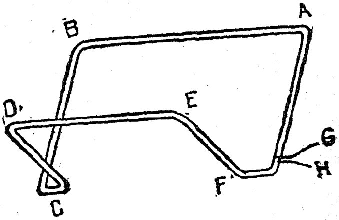


Fig. 813.—Method of winding evolute coils. ***In making the former,*** it is necessary to know the dimensions of the coil, hence, a pattern coil must first be made, from which the spacing of the pins can be taken so that the completed coil will fit into the slots for which it is intended. After the pins have been properly spaced on the board, the wire is wound around them as indicated, as many turns being taken as decided on for each coil. When the coil is thus completely wound, it is taken from the pins, and the lower ends, C and F, placed in a suitable clamp. The two halves of the coil are then spread apart, the coil assuming the shape illustrated in fig. 814.

Fig. 814.—Appearance of an evolute former wound coil opened out. The points A, B, C, etc., correspond to similar points in fig. 813.

Ans. By winding one coil on the armature in order to ascertain its dimensions and shape; it is then removed from the armature and used as a pattern in constructing the former.

Types of Former Coil.—Of the numerous shapes of former coil, mention should be made of:

1. Evolute coils;
2. Diamond or hair pin loop coils.

Ques. Describe the evolute type of former coil.

Ans. The evolute coil is wound around eight pins inserted in a board as shown in fig. 813.

The required number of turns are taken around these pins and their ends G and H, left projecting. The coil thus formed is now covered with tape and after removal from the board, is put into a clamp at C and F, and opened up as shown in fig. 814, which is the form required for insertion in the proper slots of the armature.

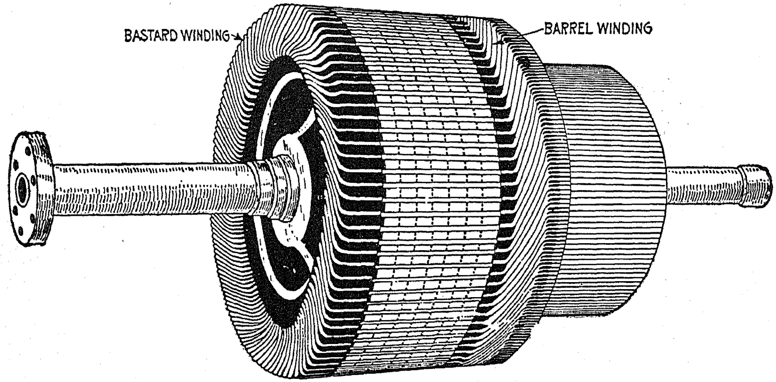


Fig. 815.—Westinghouse combination bastard and barrel winding. A bastard winding at the rear end is combined with a barrel winding at the commutator end, as shown in the illustration, to secure better ventilation.

Ques. What is the peculiarity of the evolute coil?

Ans. The two sides of the evolute coil have unequal dimensions.

The part marked AB, in fig. 813, which is an upper layer inductor is no longer than the part DE, which constitutes a lower layer inductor. The portions DC and EF, act as parts of an inner layer of evolutes, and the portions AF and BC, as parts of an outer layer of evolutes. These features are shown in fig. 814.

Ques. How are evolute coils placed on the core?

Ans. They are placed in position as shown in figs. 804 and 805, continuing around the core until all the slots are filled.

To complete the operation it is necessary to raise some of the first laid coils and insert the last ones below them. The winding is thus completed and is symmetrical.

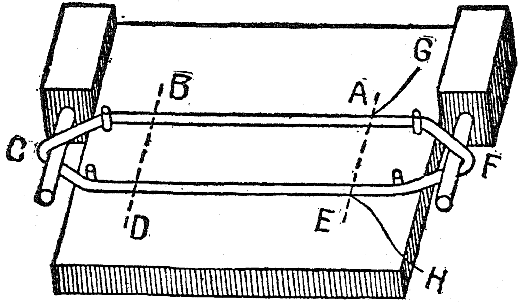


FIG. 816.—Method of winding diamond or hair pin loop coils. *There are several ways* of making these coils. A former may be prepared, as shown in the figure, with a board having four pins inserted, and having two blocks attached at the ends carrying horizontal pins as shown. Around the several pins, the coil is wound to the required number of turns and taped. This coil differs from the evolute coil in that the two halves are of equal size, the parts which act respectively as upper and under inductor being of equal length. The coil as shown is suitable for wave winding.

Ques. Describe the method of winding the diamond or hair pin loop type of former coil.

Ans. The diamond or hair pin loop coil may be wound on a former such as shown in fig. 816.

This consists of a board having four upright pins, A,B,D,E, properly spaced and two horizontal pins C,F, attached to extensions at each end of the board. A coil of the required number of turns is wound around these pins and then opened out as in fig. 816. After varnishing and baking it is ready to be placed on the armature.

Ques. For what class of winding are diamond or hair pin loop coils suitable?

Ans. For barrel winding.

Ques. How are straight out coils placed on the core?

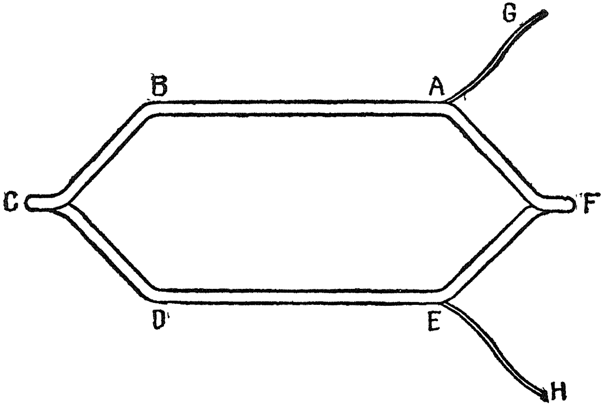


FIG. 817.—Appearance of diamond or hair pin loop coil after being opened out. ***In opening out*** the coil, the ends C and F, are put into a clamp and twisted at right angles to the plane of the coil. The letters correspond to the points indicated in fig. 816.

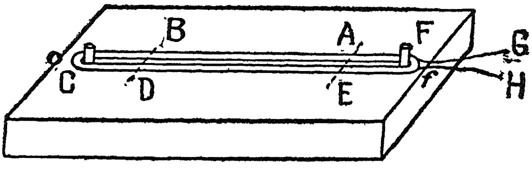


FIG. 818.—Another and simpler method of winding a diamond or hair pin loop coil. A board with only two pins is employed as shown; this plan, however, gives more trouble in the subsequent opening out of the coil.

Ans. In the same manner as described for evolute coils; when in position straight out coils appear as in fig. 804.

Ques. What is the approved method of putting tape on a coil?

Ans. Considerable time is saved by the use of a machine designed for the purpose, such as shown in fig. 819.

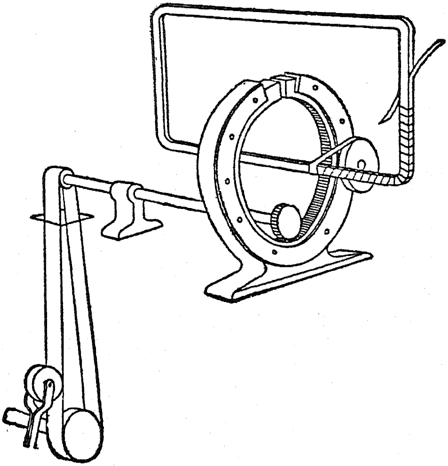


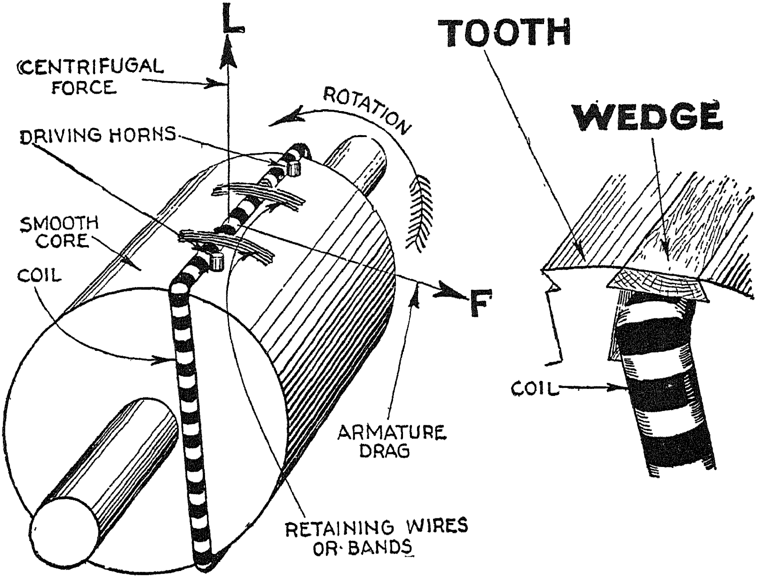
FIG. 819.—Armature coil taping machine. Numerous machines have been invented for taping armature coils. They consist essentially of a device which revolves a roll of tape around the coil, in such a direction that the tape is unwound from the roll and rewound on the coil. The speed at which the coil is fed through the machine will determine the overlapping of the tape.

The construction of these machines is such that a roll of tape placed on a split metal ring is revolved around the coil to be taped, the coil being gradually moved until it is entirely covered.

Coil Retaining Devices.—In the operation of a dynamo there are two forces which tend to throw the inductors out of position:

1. Armature drag;
2. Centrifugal force.

Both of these forces are present with smooth core armatures, but only centrifugal force with slotted armatures. The devices used to hold the inductors in position against these forces are:



FIGS. 820 and 821 —Smooth and slotted armatures showing devices used to retain coils in position against centrifugal force and armature drag. In fig. 820 the arrows **L** and **F**, show the directions in which these forces act from which it is seen that the force **L**, tends to pull the coil off the core radially (hence the binding ribbons, or wires) and the force **F**, acting tangentially against rotation tends to slide the coil around the core (hence the driving horns). In the slotted armature the teeth and wedges retain the coils in position.

1. Driving horns;
2. Binding ribbons;
3. Retaining wedges.

Ques. What are driving horns?

Ans. They are simply pins or strips projecting from the surface of a smooth core as shown in fig. 820.

Ques. What other kinds of retainer are used on smooth core armatures?

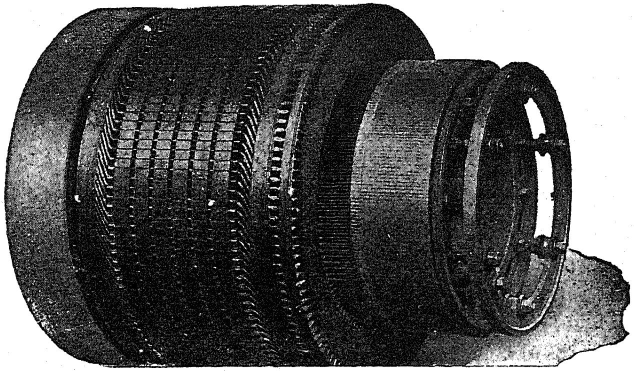


FIG. 822.—Armature of Ridgway three wire dynamo. ***It is built*** on a simple design and commonly referred to as that of Dobrowolsky. It contains a balance coil wound on a laminated core, bolted to the back of the armature spider and protected by a heavy cast iron shield. The slip ring is bolted to the commutator shell and the holder for the carbon brush is mounted on adjacent outboard bearing.

Ans. They require several binding wires or bands placed around the winding to prevent the inductors being thrown off the core by centrifugal force **L**, as shown in fig. 820.

Ques. With slotted armatures what provision must be made for retaining the inductors in position?

Ans. Retaining wedges must be inserted into the notches or between the projecting tops of the teeth.

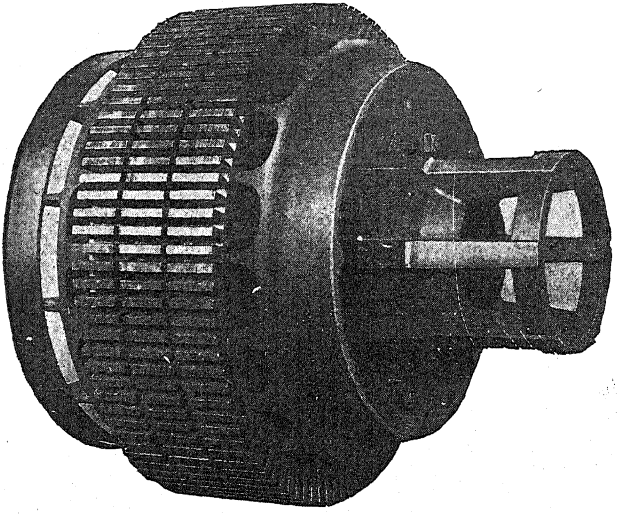


FIG. 823.—Crocker-Wheeler armature core, built up of steel discs. ***In construction,*** the discs are assembled in groups and mounted on a cast iron spider.

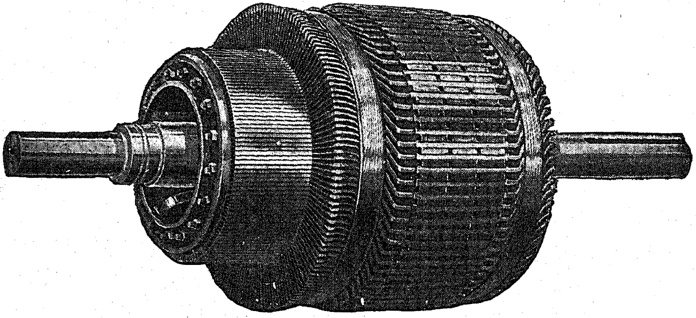


FIG. 824.—Crocker-Wheeler armature complete. The coils are form wound and insulation is reinforced by lining the slots with press boards. Wooden slot wedges, bands and wires retain the coils in the slots.

NOTE.—***Wedges*** are usually made of well baked hard wood, such as hornbeam, or hard white vulcanized fibre. Sometimes a springy strip of German silver is used.

TEST QUESTIONS

1. *Define the word armature.*
2. *What are the essential parts of an armature?*
3. *What is the prevailing type of armature?*
4. *What is the object of providing shoulders on the shaft?*
5. *Describe the core of an armature.*
6. *Name two types of core, and which is the prevailing type.*
7. *Describe a slotted core.*
8. *What provision is made to avoid eddy currents?*
9. *How thick are the discs and how are they held in place?*
10. *How are core discs insulated?*
11. *How are core end plates constructed and why?*
12. *Describe the method of connecting a core to a shaft.*
13. *Name three forms of armature teeth.*
14. *What are the features of projecting teeth?*
15. *Why are notches cut in teeth?*
16. *State the advantages and defects of slotted armatures.*
17. *How do slotted armatures compare with smooth?*
18. *Describe built up armature construction.*
19. *Why do armature cores heat?*
20. *How is ventilation secured?*
21. *Describe the methods of insulating cores.*
22. *What is the construction of the inductors?*
23. *What kind of inductors are liable to eddy currents?*
24. *Classify drum windings.*

25. *Why are hand windings objectionable?*
26. *What is an evolute or butterfly winding?*
27. *Describe evolute connections.*
28. *What is a barrel winding?*
29. *What is the advantage of former coil winding?*
30. *What is the difference between an evolute and a straight out coil?*
31. *Why are coil retaining devices used?*
32. *In what type of core are the coils naturally retained?*

CHAPTER 26

Operation of Dynamos

Before Starting a Dynamo or Motor.—When the machine has been securely fixed, it should be carefully examined to see that all parts are in good order.

The examination should be made as follows:

1. The field magnet circuit should first be inspected to see that none of the wires or connections have broken or have become loose, and that the coils are correctly connected;

2. The caps of the bearings should be taken off, and these and the journals carefully cleaned of all grit and dirt. They should then be oiled, and the caps replaced and screwed up by hand only;

3. The gaps between the outer surface of the armature and the polar faces should be examined in order to ascertain whether any foreign body, such as a small screw or nail has lodged therein. If such be the case, it should be carefully removed with a bit of wire;

4. The guard plates protecting the armature windings should be removed, and the windings carefully inspected by slowly rotating the armature, to see that they are not damaged, and that the insulation is perfect. The armature should then be finally rotated by hand to see that it revolves freely, and that the bearings are securely fixed;

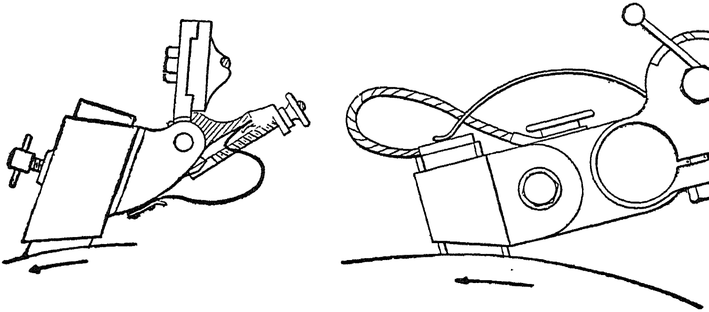
5. The commutator should be examined to see that it is not damaged in any way through one or more of the segments being knocked in, or the lugs being forced into contact with one another;

6. The brush holders and brushes should be inspected to see that the former work freely on the spindle, and that the hold off catches work properly, are clean and make good contact with the brush holders or flexible leads.

7. Having ascertained that the machine is not injured in any way, and that the armature revolves freely, the brushes should be adjusted.

In the subsequent working of the dynamo it will of course be unnecessary to follow the whole of these proceedings every time the machine is started, as it is extremely unlikely that the machine will be damaged from external causes while working without the attendant being aware of the fact.

Adjusting the Brushes.—The *adjustment of the brushes* upon the commutator requires careful attention if sparking is to be avoided. There are two adjustments to be made:



FIGS. 825 and 826.—Diagrams illustrating how to set brushes. ***Some brush holders*** require brushes set ***with*** the direction of rotation of the commutator, and others, set ***against*** the direction of rotation. In fig. 825, is shown a brush holder of the first class, which must always be set as indicated by the arrow. If set in the opposite direction, trouble will ensue, as an inspection of the figure will show, because the surface of the commutator and the brush would form a toggle joint, and the brush would tend to dig into the commutator and either break itself or bend the brush rigging. In fig. 826, is shown a brush holder of the second type. This brush is set against the direction of rotation, but an inspection of the cut will show that there is, in this case, no tendency for the brush to dig into the commutator surface. Each type of brush holder, of which there are several, should be adjusted as recommended by the manufacturer to secure proper working.

1. For pressure;

The brushes must bear against the commutator segments with sufficient pressure for proper contact.

2. For lead.

The brushes must have the proper angular advance (positive or negative, according as the machine is a dynamo or motor) to prevent sparking.

Ques. At what point on the commutator should the brushes bear?

Ans. The points upon the commutator at which the tips of the brushes (carried by opposite arms of the rocker) bear, should be, in bipolar dynamos, at opposite extremities of a diameter. In multipolar dynamos the positions vary with the number of poles and the nature of the armature winding.

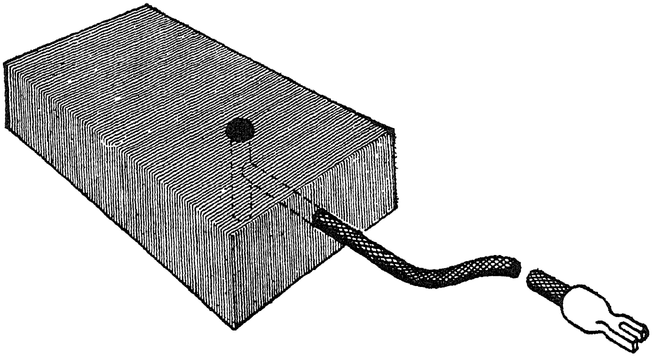


FIG. 827.—Method of soldering cable to carbon brush. ***Drill*** a hole in the end, also in the side of the brush, as shown in the sketch, and after thoroughly tinning the "pigtail," place it in the end hole and fill the holes up with solder through the side hole. ***Another method*** is to drill a hole through the carbon so that the cable will just slip through, countersink the edge of the hole a little, clean the cable thoroughly and pass it through the hole. Then with any good flux and solder, fill the countersunk part on both sides.

Ques. What provision is made to facilitate the correct setting of the brushes?

Ans. Setting marks are usually cut in the collar of the commutator next to the bearing.

Ques. How are the brushes set by these marks?

Ans. The tips of all the brushes carried by one arm of the rocker are set in correct line with the commutator segments marked out by one setting mark, and the tips of the brushes carried by the other arm or arms are set in correct line with the segments marked out by the other mark or marks.

If one or more of the brushes in a set be out of line with their setting mark, it will be necessary to adjust the brushes up to this mark by pushing them out or drawing them back, as may be required, afterwards clamping them in position.

When adjusting the brushes, the armature should always be rotated, so that the setting marks are horizontal. The rocker can then be rotated into position, and the tips of both sets of brushes conveniently adjusted to their marks. In those brush holders provided with an index or pointer for adjusting the brushes, the setting marks upon the commutator are absent, length of the pointer being so proportioned that when the tips of the brushes are in line with the extreme tips of the pointers, the brushes bear upon the correct positions on the commutator.

Ques. What should be done after adjusting the brushes to their correct positions upon the commutator?

Ans. Their tips or rubbing ends should be examined while in position to see that they bed accurately on the surface of the commutator.

In many instances it will be found that this is not the case, the brushes sometimes bearing upon the point or toe, and sometimes upon the heel, so that they do not make contact with the commutator throughout their entire thickness and width. The angle of the rubbing ends will therefore need to be altered by filing to make them lie flat.

Ques. How is the proper brush contact secured?

Ans. When the brushes do not bed properly they should be refitted to secure proper contact.

Ques. How is the pressure adjustment made?

Ans. This is effected by regulating the tension of the springs provided for the purpose upon the brush holders.

Ques. With what pressure should the brushes bear against the commutator?

Ans. The tension of the springs should be just sufficient to cause the brushes to make a light yet reliable contact with the commutator.

The contact must not be too light, otherwise the brushes will vibrate, and thus cause sparking; nor must it be too heavy, or they will press too hard upon the commutator, grinding, scoring and wearing away the latter and themselves to an undesirable extent, and moreover, giving rise to heating and sparking.

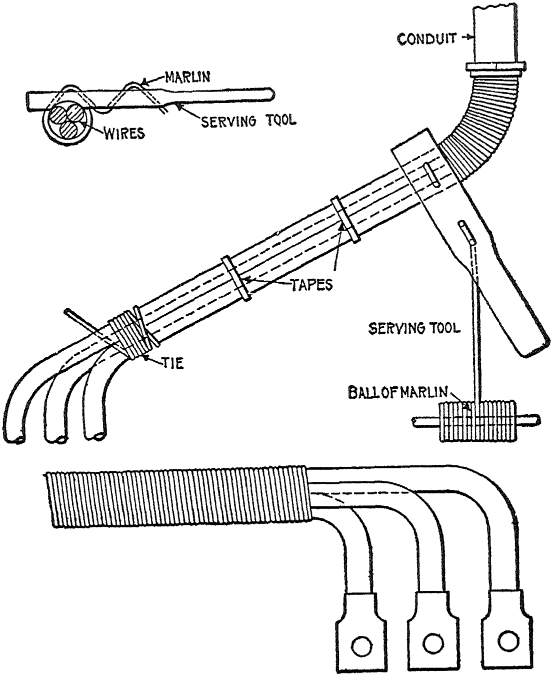
The correct pressure is attained when the brushes collect the full current without sparking, while their pressure upon the commutator is just sufficient to overcome ordinary vibration due to the rotation of the commutator.

Direction of Rotation.—This is sometimes a matter of doubt and often results in considerable trouble. As a general rule, a dynamo is intended to run in a certain direction; either right handed or left handed *according to whether the armature, when looked at from the pulley end, revolves with or against the direction of the hands of a clock.*

Dynamos are usually designed to run right handed, but the manufacturers will make them left handed if so desired.

It may be necessary to reverse the direction of rotation of a dynamo, of the driving pulley to which it has to be connected happen to revolve left handed, or if it be necessary to bring the loose side of the belt on top of the pulley, or to place the machine in a certain position on account of limited space.

The direction of rotation of ordinary series, shunt, or compound bipolar dynamos may be reversed by simply reversing the brushes without changing any of the connections, then changing the point of contact of the brush tips 180°.



Figs. 828 to 830.—Method of winding cables with marlin. ***When connecting*** the feeders and dynamo and service leads to a switchboard, the wires are often *served* with marlin. By serving is meant to tightly wrap the wires of each set together with marlin. A tool for serving may be made as in fig. 828, using a piece of oak 2 ins. wide, ⅞ in. thick and 14 ins. long, having four holes drilled through it, as shown. The marlin is passed through the holes commencing at the hole nearest the handle, the object being to cause a strain on the marlin at the point where it passes around the wire, so that the marlin may be wrapped tightly. It is necessary to serve the first four or five inches by hand, pushing the winding into the conduit as far as possible. This acts as an additional protection to the wires where they leave the conduit. The serving is continued, as in fig. 829, to within four or five inches of the first lug by means of the serving tool, passing the ball of marlin around the wires with the serving tool. The wires are then bent in shape, as in fig. 830. To serve the wires properly it is necessary to tie the ends of the wires taut. The wires should be straightened and run together so as to be parallel, being bound with tape at different points to keep them so. When the serving is complete the marlin should be thoroughly painted with a moisture resisting compound.

In multipolar dynamos, a similar change, amounting to 90° for a four pole machine, and 45° for an eight pole machine, will reverse their direction of rotation. It will be understood that under these conditions, the original direction of the current and the polarity of the field magnets will remain unchanged.

This rule does not apply to early arc dynamos and other machines, which have to be run in a certain direction only, in order to suit their regulating devices.

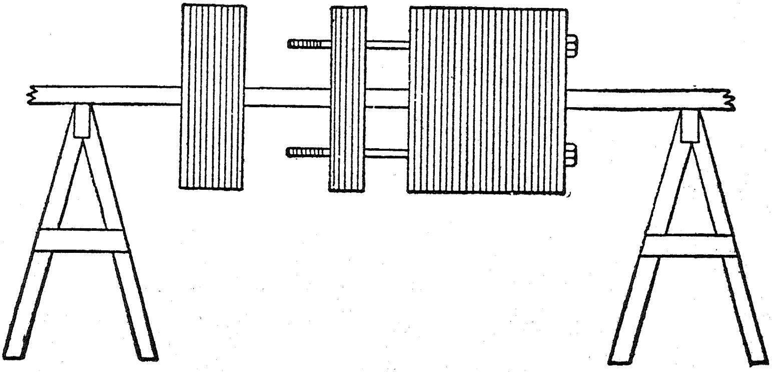
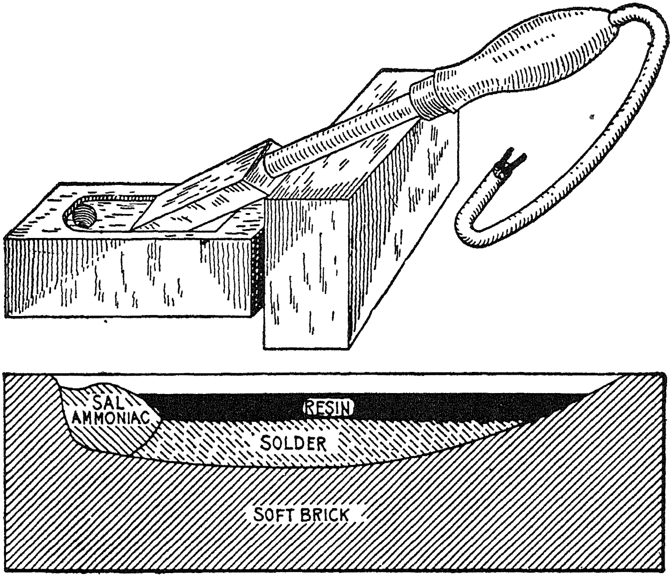


FIG. 831.—Method of assembling core discs. ***For this operation*** two wooden "horses" should be provided to support the core at a convenient height, as shown in the illustration.

If the direction of current generated by a dynamo be opposite to that desired, the two leads should be reversed in the terminals, or the residual magnetism should be reversed by a current from an outside source.

NOTE.—***The marlin serving*** will stiffen the wires and they can be bent very neatly to avoid touching the bus bars of the board. When painted the marlin hardens so that it is difficult to bend the wires after the paint has dried. It then requires a strong pressure to bend them. The marlin acts as an additional insulation and mechanical protection to the wires, and while no harm would result from the wires coming in contact with the bars while thus protected, it looks better to bend them so as to avoid touching the bars.

Starting a Dynamo.—Having followed the foregoing instructions, all keys, spanners, bolts, etc., should be removed from the immediate neighborhood of the machine, and the dynamo started.



Figs. 832 and 833.—Tinning block for electric soldering tool. ***It is made*** with two soft bricks One brick is used to support the soldering tool, and the other to contain the tinning material and to furnish a material which will keep the copper bit bright enough to receive its coating of "tin." Fig. 833 represents a section of the tinning brick, which is scooped out on top as shown by the lower line. Into one end of the hollow in the brick, some sal-ammoniac is placed to help tin the copper bit. Sal-ammoniac is a natural flux for copper and aids greatly in keeping the tool well tinned. Next, some melted solder is run into the hollow of the brick, and lastly enough resin to fill the cavity nearly to the top. When the tool is not in use, the electricity is switched off and the tool permitted to lie in the resin. If it be desired to repair the tin coating a little when the tool is in use, the latter is rubbed on the brick below the layer of solder, and the layer of resin. If the tool be in very bad condition, it may be pushed into the sal-ammoniac once or twice and then rubbed in the solder again. It requires but little heat to keep the brick and its contents ready for use. In fact, the brick is a fair insulator of heat and prevents the escape of heat from one side of the tool. When momentarily not in use, the tool remains in the solder which becomes melted underneath the layer of resin. When the copper bit becomes too hot, it will begin to volatilize the resin, thus calling attention to this fact, whereupon, the electricity should be turned off from the tool.

Ques. How should a dynamo be started?

Ans. A dynamo is usually brought up to speed either by starting the driving engine, or by connecting the dynamo to a source of power already in motion.

In the first case, it should be done by a competent engineer, and in the second case by a person experienced in putting on friction clutches to revolving shafts, or in slipping on belting to moving pulleys.

Ques. Should the brushes be raised out of contact in starting?

Ans. The brushes should not be in contact in starting if there be any danger of reverse rotation, as might happen when the dynamo is driven by a gas engine.

Aside from this, it is desirable that the brushes be in contact, because they are more easily and better adjusted, and the voltage will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped before any injury is done.

Ques. How should a series machine be started?

Ans. The external circuit should be closed, otherwise a closed circuit will not be formed through the field magnet winding and the machine will not build up.

Ques. What is understood by the term "build up"?

Ans. In starting, the gradual voltage increase to maximum.

Ques. How should a shunt or compound machine be started?

Ans. All switches controlling the external circuits should be opened, as the machine excites best when this is the case.

If the machine be provided with a rheostat or hand regulator and resistance coils, these latter should all be cut out of circuit, or short circuited, until the machine excites, when they can be gradually cut in as the voltage rises.

When the machine is giving the correct voltage, as indicated by the volt meter or pilot lamp, the machine may be switched into connection with the external or working circuits.

Ques. In starting a shunt dynamo, should the main line switch be closed before the machine is up to voltage or after?

Ans. If the machine be working on the same circuit with other machines, or with a storage battery, it is, of course, necessary to make the voltage of the machine equal to that on the line before connecting it in the circuit. If the machine work alone, the switch may be closed either before or after the voltage comes up.

The load will be thrown on suddenly if the switch be closed after the machine has built up its voltage, thus causing a strain on the belt, and possibly drawing water over the engine cylinder.

On the other hand, if the switch be closed before the voltage of the machine has come up, the load is picked up gradually, but the machine may be slow or may even refuse to pick up at all.

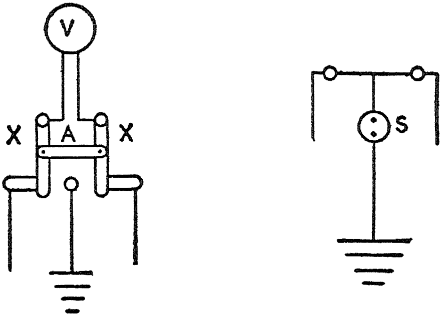
Ques. Why does a shunt machine pick up more slowly if the main switch be closed first?

Ans. Because the resistance of the main line is so much less than that of the field that the small initial voltage due to the residual magnetism causes a much larger current in the armature than in the shunt field.

If this be too large, the cross and back magnetizing force of the armature weakens the field more than the initial field current strengthens it, and so the machine cannot build up.

Ques. If a shunt dynamo will not pick up, what is likely to be the trouble?

Ans. The speed may be too slow; the resistance of the external circuit may be too small; the brushes may not be in proper position; some of the electrical connections in the dynamo may be loose, broken or improperly made; the field may have lost its residual magnetism.



FIGS. 834 and 835.—Diagrams of ground detectors. Fig. 834, a ground detector switch suitable for mounting on a switch board. The two arms pivoted at their upper ends are connected with an insulating bar A, and make contact at their lower ends with two brass strips and a contact button, which are connected to the bus bars and ground, respectively. When the arms are moved to the left, the positive bus bar is connected to the ground through the voltmeter V. In fig. 835 is another form of ground detector. This is known as a lamp ground detector. On a 110 volt system two ordinary lamps are connected in series, while the line connecting the lamps is connected to the ground through a snap switch S. When current is on, the two lamps will burn with equal brilliancy, but at a lower candle power. When the switch S is closed, if the two lines be clear, the brilliancy of the lamps will not be affected, but if there be a ground on the positive side, one lamp will burn brighter, the brightness depending on the resistance of the ground. If there be a dead ground, the lamp will burn to its full candle power.

Ques. What is the indication that the connections between the field coils and armature are reversed?

Ans. If the machine build up when brought to full speed, the connections are correct, but if it fail to build up, the field coils may be improperly connected.

This can be tested by connecting a volt meter across the terminals of the armature, or by means of a magnetic needle placed at a short distance

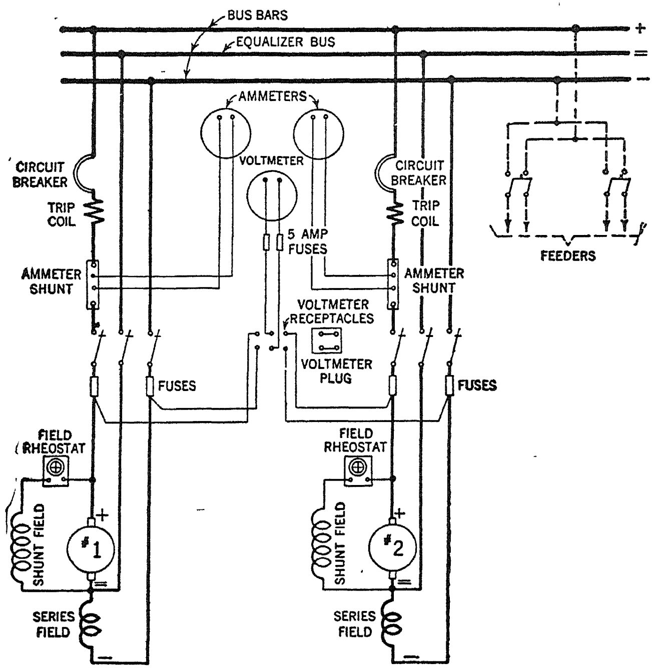


Fig. 836.—Method of correcting reversed polarity in compound wound dynamo. For instance, assume that No. 1 dynamo has had its polarity reversed and that No. 2 is running connected to the bus bar. To reverse No. 1, stop No. 1 and then make sure that the circuit breaker and negative switch are open and that any other special connections to other machine or station lighting circuits are open. Then close the positive and equalizer switches. If No. 1, machine be a large unit and No. 2, a small unit, it will be necessary to cut out the resistance of the shunt field circuits by means of the rheostat, if it be desired to maintain its bus bar voltage at its normal point. No. 1, machine is then brought up to full speed when it will be found to have recovered its correct polarity.

from one of the pole pieces in such a position that it does not point to the north pole. If the field coils be improperly connected, the current due to the initial voltage will weaken the field magnetism and thus prevent the machine building up, and when the field circuit is closed the volt meter reading will be reduced, or the magnetic needle will be less strongly attracted.

Ques. What will be the result if the connections of some of the field coils of a dynamo be reversed?

Ans. If one-half the number of coils oppose the other half, the field magnetism will be neutralized and the machine will not build up at all; but if one of the coils be opposed to the others, the machine might build up, but the generated voltage will be low, and there will be considerable sparking at some of the brushes.

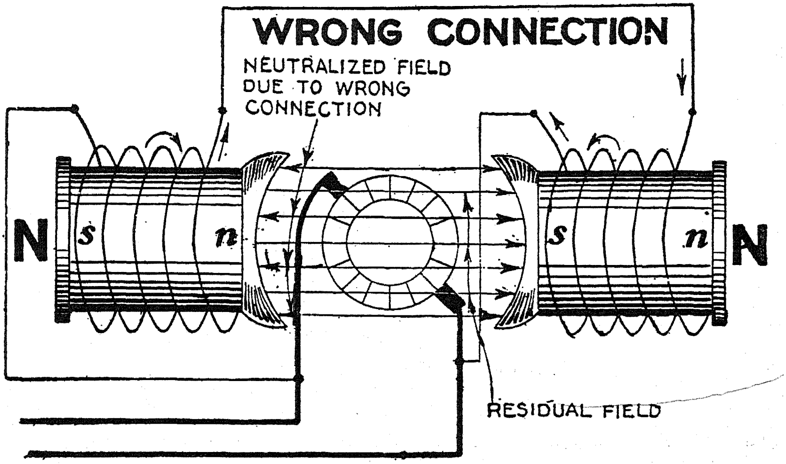


FIG. 837.—Wrongly connected shunt wound dynamo illustrating neutralized field magnetism due to opposing pressures in the field coils.

Ques. How may it be ascertained which coil is reversed?

Ans. In all dynamos there should be an equal number of positive and negative poles, and in almost all of them the poles should be alternately positive and negative. Therefore, if a pocket compass be brought near the pole pieces, and it show that there are more poles of one kind than the other, the indication is that one or more of the coils are reversed, and the improper sequence of alternation will determine which one is wrongly connected.

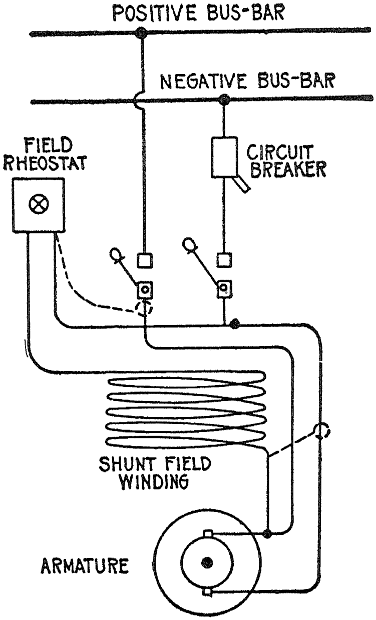


FIG. 838.—Method of correcting reversed polarity in large shunt dynamo by transposing the shunt field leads, and then starting up the machine. As soon as the volt meter registers any voltage, the dynamo may be stopped and the field leads restored to their original position, when it will be found that the residual magnetism in the pole pieces will usually bring the dynamo up to its polarity and proper voltage. This method has the disadvantages, of the uncertainty as to the machine building up, and that a temporary wire must probably be run from the switch board to one terminal of the field circuit, which is usually connected to a terminal back of the dynamo frame, so that the flow of current through the field coils may be reversed. With dynamos having laminated field magnet cores of comparatively low residual magnetism, this method may suffice, but in the case of solid field magnetic cores it is not practical. A better method is to disconnect the shunt field leads and temporarily extend them to some other source of direct current. If the current be of higher voltage than the coils are designed for, as for instance 110 volt dynamo and available current 500 volt, caution must be exercised and a suitable resistance be provided to protect the coils. A 500 volt coil, however, may be supplied from 110 volt circuit, providing the field winding to be energized is equipped with a cut off switch having a discharge resistance, so that it may be used to close and break the circuit when the temporary leads have been connected. If the field windings be not so provided, a bank of lamps or some other non-inductive resistance must be connected across the leads between the field magnet coils and the point at which the circuit is to be opened and closed. This is to provide a path for the discharge of the induced voltage. The circuit should not remain closed more than a few seconds if the full voltage can be applied.

Ques. When a dynamo loses its residual magnetism, how can it be made to build up?

Ans. By temporarily magnetizing the field.

To do this a current is passed through it from another dynamo, or from the cells of a small primary battery as in fig. 839. Usually, this will set up sufficient initial magnetism to allow the machine to build up. The battery circuit should be broken before the machine has built up to full voltage.

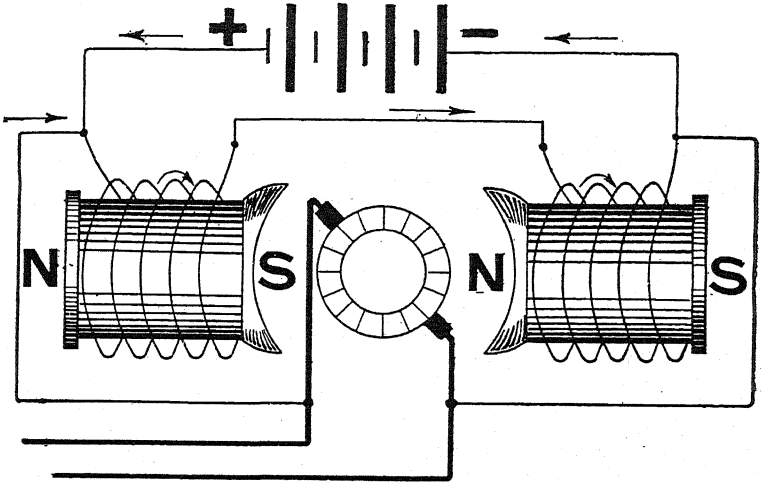


FIG. 839.—Method of making dynamo build up when it has lost its residual magnetism.

Ques. What should be done if a dynamo become reversed by a reversal of its field magnetism due to lightning, short circuit, or otherwise?

Ans. The residual magnetism should be reversed by a current from another dynamo, or from a battery; but if this be not convenient, the connections between the machine and the line should be crossed so that the original positive terminal of the dynamo will be connected to the negative terminal of the line and vice versa.

Ques. Can a dynamo be reversed by reversing the connections between the field coils and the armature?

Ans. No, for if these connections be reversed, the machine will not build up.

Ques. Will a dynamo build up if it become reversed?

Ans. Yes.

Ques. Then what is the objection to a reversed dynamo?

Ans. Since the direction of current of a reversed dynamo is also reversed, serious trouble may occur if it be attempted to connect it in parallel, with other machines not reversed.

Attention While Running.—When a dynamo is started and at work, *it will need a certain amount of attention to keep it running in a satisfactory and efficient manner.*

The first point to be considered is the adjustment of the brushes. If this be neglected, the machine will probably spark badly, and the commutator and brushes will frequently require refitting to secure good contact.

Ques. What may be said with respect to the lead of the brushes?

Ans. The lead in all good dynamos is very small, and varies with the load and class of machine.

The best lead to give to the brushes can in all cases be found by rotating the rocker and brushes in either direction to the right or left of the supposed commutating plane until sparking commences, increasing with the movement as in fig. 840.

The position midway between these two points is the correct position for the brushes, for at this position the least sparking occurs, and it is at this position that the brushes should be fixed by clamping the rocker.

Ques. How does the lead vary in the different types of dynamo?

Ans. In series dynamos giving a constant current, the brushes require practically no lead. In shunt and compound dynamos the lead varies with the load, and therefore the brushes must be rotated in the direction of rotation of the armature with an increase of load, and in the opposite direction with a decrease of load.

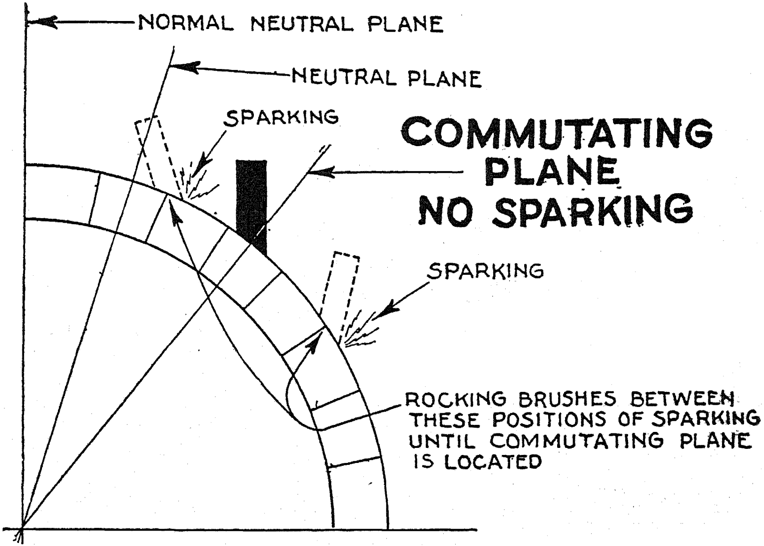


FIG. 840.—Method of finding the correct position of the brushes by rocking.

In cases where the dynamos are subjected to a rapidly varying or fluctuating load, it is of course not possible to constantly shift the brushes as the load varies, therefore the brushes should be fixed in the positions where the least sparking occurs at the moment of adjustment. If at any time violent sparking occur, which cannot be reduced or suppressed by varying the position of the brushes by rotating the rocker, the machine should be shut down at once, otherwise the commutator and brushes are liable to be destroyed, or the armature burnt up. This especially refers to high tension machines.

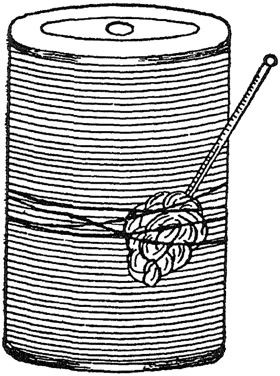


FIG. 841.—Method of taking temperature. ***In taking*** the temperature of a hot part, it is convenient to use a thermometer in which the scale of degrees has been etched on the stem. Bind this to the heated part, having first taken the precaution to cover the bulb with waste to prevent the radiation of heat and take the reading when the column of mercury has ceased to rise. The question which most often presents itself to the attendant is how hot can the various parts of a dynamo or motor become and yet be within the safe limit. The degree of heat can be determined by applying the hand to the various parts. If the heat be bearable it is entirely harmless, but if the heat become unbearable to the hand for more than a few seconds, the safety limit has been reached and the machine should be stopped and the fault located. Of course when the solder begins to melt at the commutator connections and shellac begins to "fry out" of the armature and an odor of burnt cotton begins to pervade the air, the safe limit has been far exceeded, and in most cases, as a matter of fact, serious damage is the result. To be more definite, *no part of the dynamo or motor should be allowed to rise in temperature more than* 80 *degrees* F. *above the temperature of the surrounding air*, excepting in the case of commutators where no solder has been used to connect the leads. These can be allowed to rise to a still higher temperature.

Ques. What should be done if the brushes begin to spark excessively?

Ans. First, look at the ammeter to see if an excessive amount of current is being delivered; second, see if the brushes make good contact with the commutator, and if the latter have a bar too high, or too low, and an open circuit.

Ques. What should be done if the current be excessive?

Ans. If the current exceed the rated capacity by more than 50 per cent., and continue for more than a few minutes, the main switch should be opened, otherwise the machine may be seriously injured.

Ques. How does an excessive current injure a dynamo?

Ans. By causing it to overheat which destroys the insulation of the armature, commutator, etc.

Lubrication.—The shaft bearings of dynamos may be lubricated by sight feed oilers or oil rings. The latter method is almost universally used. An oil well is provided in the hollow casting of the pedestals as shown in fig. 931.

Oil rings revolve with the shaft and feed the latter with oil, which is continuously brought up from the reservoir below. The dirt settles to the bottom and the upper portion of the oil remains clear for a long period, after which it is drawn off through the spigot and a fresh supply poured in through openings provided in the top. The latter are often located directly over the slots in which the rings are placed, so that the bearings can be lubricated directly by means of an oil cup, if the rings fail to act or the reservoir become exhausted.

Ques. What kind of oil can should be used in filling the reservoir, or oil cups?

Ans. One made of some non-magnetic material such as copper, brass, or zinc.

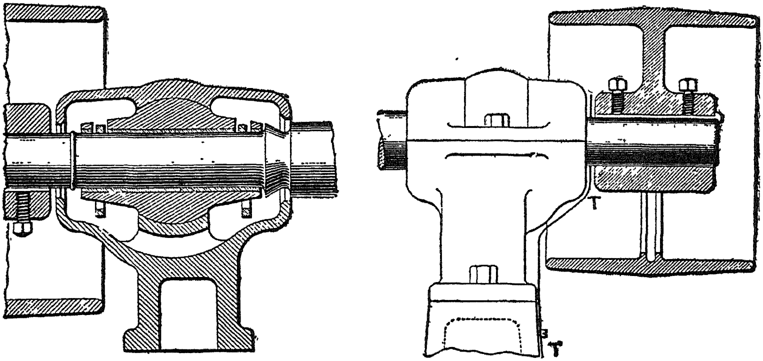
If iron cams be used, they are liable to be attracted by the field magnets, and thus possibly catch in the armature.

Ques. What is the indication of insufficient lubrication?

Ans. The bearings become unduly heated.

Ques. What precaution should be taken with new dynamos?

Ans. They are liable to heat abnormally and for the first few days they should be carefully watched and liberally supplied with oil.



FIGS. 842 and 843.—Remedies for leakage of oil from self-oiling bearings. If there be sufficient space, a metal ring may be attached to the shaft as in fig. 842. With this arrangement the high speed of the shaft will carry the oil outside of the ring and throw it off in the oil reservoir. Another way is to insert a tin apron, as shown in fig. 843 at T, which will serve to drain the oil which may creep along the shaft, and also cut off the draft from the pulley which may suck the oil out of the bearing. Sometimes a tin fan is attached to the pulley, which tends to drive the oil back into the bearing, and which also assists in keeping the box cool.

After a dynamo has been running for a short time under full load, its armature imparts a certain amount of heat to the bearings, a little more also to the bearing on the commutator end of shaft; beyond this there is no excuse for excessive heating. The latter may result from various causes, some of which are given with their remedies, as follows:

1. A poor quality of oil, dirty or gritty matter in the oil;
2. Journal boxes too tight;
3. Rough journals, badly scraped boxes;

4. Belt too tight;
5. Bearings out of line;
6. Overloaded dynamo;
7. Bent armature shaft.

Ques. What is the allowable degree of heating?

Ans. It may be taken as a safe rule that no part of a working dynamo should have a temperature of more than 80° Fahr. above that of the surrounding air.

Accordingly, if the temperature of the engine room be noted before applying the thermometer to the machine, it can at once be seen if the latter be working at a safe temperature. In taking the temperature, the bulb of the thermometer should be wrapped in a woolen rag. The screws and nuts securing the different connections and cables should be examined occasionally, as they frequently work loose through vibration.

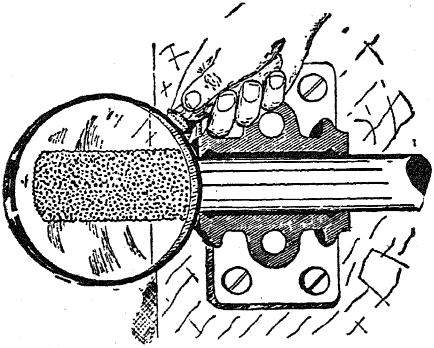


FIG. 844.—Imaginative view of a shaft showing its rough granular structure. *In operation*, these minute irregularities interlock and act as a retarding force, or frictional resistance. Hence, the necessity for lubrication—a lubricant presents a thin intervening film against which the surfaces rub.

Instructions for Stopping Dynamos.—When shutting down a machine, *the load should first be gradually reduced, if possible, by easing down the engine; then when the machine is supplying little or no current, the main switch should be opened.*

This reduces the arcing at the switch contacts, and prevents the engine racing.

When the volt meter almost indicates zero, the brushes should be raised from contact with the commutator.

This prevents the brushes being damaged in the event of the engine making a backward motion, which it often does, particularly in the case of a gas engine. *On no account should the brushes be raised from the commutator while the machine is generating any considerable voltage;* for not only is the insulation of the machine liable to be damaged, but in the case of large shunt dynamos, the person lifting the brushes is liable to receive a violent shock.

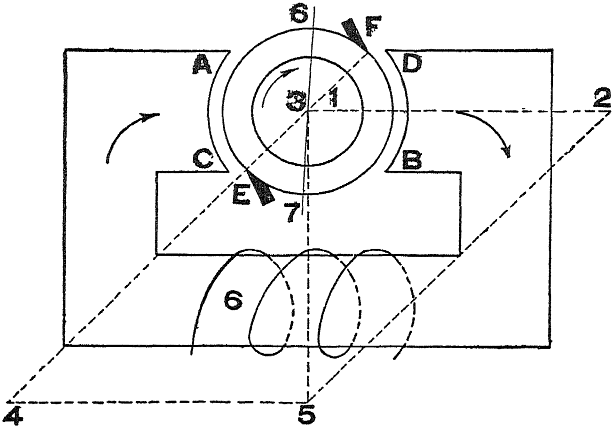


FIG. 845.—Diagram illustrating forces acting on a dynamo armature. In the figure the normal field magneto-motor force is in the direction of the line 1,2, produced by the field circuit G, if there be no current in the armature. Now as soon as the armature current flows, it produces the opposing force 3,4, which must be combined with 1,2 to give the resulting force to produce magnetism and hence voltage. The resultant 1,5, if 3,4 be large enough, does not differ much from the original force 1,2. Or, expressed in a more physical way, the brushes E,F, rest on the commutator and all the turns embraced by twice the angle 6,3,F, oppose the flow of flux through the armature core as well as all the turns embraced by twice the angle, 7,3,E. The remaining turns distort the flux, making the pole corners at A and B, denser, and at C and D, rarer, so that the entire effect is to kill an increase of flux, or voltage. This cross magnetism tends also to decrease the flow of flux, for the extra ampere turns required to force the flux through the dense pole tips are greater than the decreased ampere turns relieved by the reduction of flux at the other pole tips; this follows, since iron as it increases in magnetic density requires ampere turns greater in proportion than the increase of flux.

Ques. What attention should the machine receive after it has been shut down?

Ans. It should be thoroughly cleaned.

Any adhering copper dust, dirt, etc., should be removed from the armature by dusting with a stiff brush, and the other portions of the machine should be thoroughly cleaned with linen rags.

Waste should not be used, as it is liable to leave threads or fluff on the projecting parts of the machine, and on the windings of the armature, which is difficult to remove.

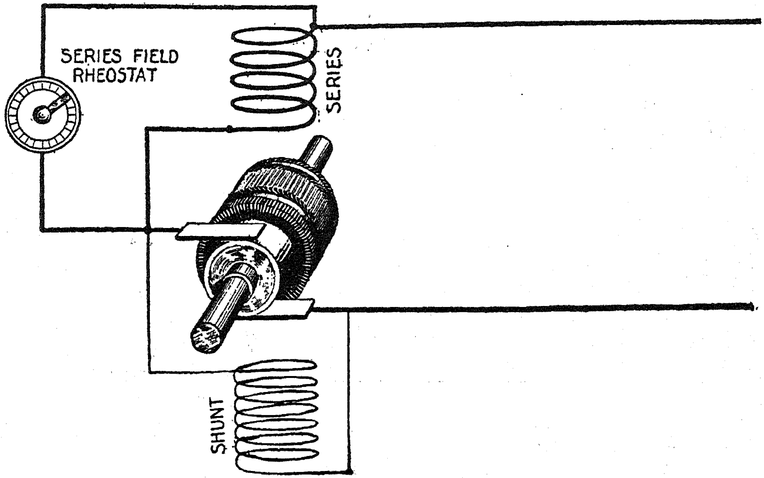


Fig. 846.—Resistance adjustment of compounding of dynamo. A series field rheostat is shunted across the series field as shown. In large machines the rheostat is usually composed of grids. In smaller machines it is in the form of resistance ribbon. For a test machine a piece of German silver wire is generally used, so arranged that any desired length of it may be connected across the series coil. If the machine be too highly over compounded, it is merely necessary to cut down the length of the shunt wire and so decrease its resistance. This allows a greater part of the load current to flow through the shunt and less through the series field. The series field, therefore, will be just so much weaker, and the voltage correspondingly lower.

Ques. What attention should be given to the brushes and brush gear?

Ans. They should be examined and thoroughly cleaned.

If necessary the brushes should be refitted and readjusted. All terminals, screws, bolts, etc., should be carefully cleaned and screwed up ready for the next run. The brush holders should receive special attention, as when dirty, they are liable to stick and cause sparking. All dirt and oil should be removed from the springs, contacts, pivots, and other working parts.

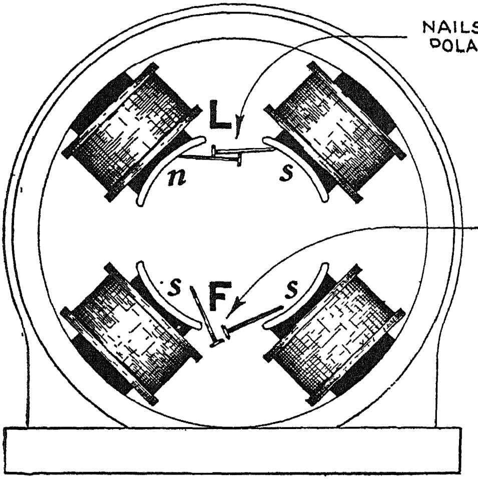


Fig. 847.—Nail method of testing correctness of polarity of poles.

It is advisable at stated intervals to entirely remove the brush holders from the rocker arms, and give them a thorough cleaning by taking them apart, and cleaning each part separately with emery cloth and benzoline or soda solution.

Another point to which particular attention should be given is the cleaning of the brush rocker. This being composed wholly of metal, and the two sets of positive and negative brushes being only separated from it by a few thin insulating washers, it follows that if any copper dust given off by the brushes be deposited in the neighborhood of these washers, there is considerable liability for a short circuit of the machine to occur by the dust bridging across the insulation.

NOTE.—When dynamos feeding current to motors are to be shut down, the switches on the motors should first be opened. Otherwise some of the motor fuses will blow. As the voltage goes down the motors will draw more current to do the work. If a plant be shut down with the motor switches "in" it will generally be found impossible to start a shunt dynamo, the low resistance in the mains not allowing enough current to flow around the shunt fields to energize them.

Ques. What further attention should be given?

Ans. It is a good plan, when the machine has been thoroughly cleaned and all connections made secure, to occasionally test the insulation of the different parts.

If a record be kept of these tests, any deterioration of the insulation can at once be detected, localized and remedied before it has become sufficiently bad to cause a breakdown.

As a means of protecting the machine from any moisture, dirt, etc., while standing idle, it is advisable to cover it with a suitable waterproof cover.

Overload of Dynamo.—It may happen, through some cause or other that a greater output is taken from the machine than it can safely carry. When this is the case, the fact is indicated by excessive sparking at the brushes, great heating of the armature and other parts of the dynamo, and possibly by the slipping of the belt (if it be a belt driven machine), resulting in a noise. The causes most likely to produce overload are:

1. Excessive voltage;
2. Excessive current;

NOTE.—*In operating dynamos* having metal brushes, it is of importance to keep the commutator smooth and glossy. To accomplish this, it is necessary to keep the commutator and brushes clean and free from grit, and to occasionally lubricate the commutator with some light oil, such as ordinary machine oil. This should be done daily if the machine be in constant use. Keep the brushes resting upon the commutator with just enough pressure to insure a good firm contact. This will be found to be much less than the springs are capable of exerting.

NOTE.—*A good method* to adopt in cleaning the machine is as follows· Loosen the brush holder thumb screws and tilt the brushes off the commutator (or, if box brush holders be used, take them out of their holders). Then run the machine and hold a clean cloth against the commutator. After the commutator is clean, hold against it a cloth or piece of waste moistened with machine oil and reset the brushes. If for any reason the brushes begin to cut or score the commutator, it may be readily detected by holding the finger against the commutator; the ridge may be easily felt by the finger. This should be attended to at once in the following manner: Tilt back the brushes (or if box brushes be used take them out of their holders), and hold lightly against the commutator a piece of No. 00 sand paper well moistened with oil, passing it back and forth until the surface is perfectly smooth. Then wipe off the commutator with a clean piece of cloth or waste and lubricate with another clean piece moistened with oil and reset the brushes.

3. Reversal of polarity of dynamo;
4. Short circuits or grounds in dynamo, or external circuits.

Ques. What is the indication of excessive voltage?

Ans. It is indicated by the voltmeter, or by the brilliancy of the pilot lamp.

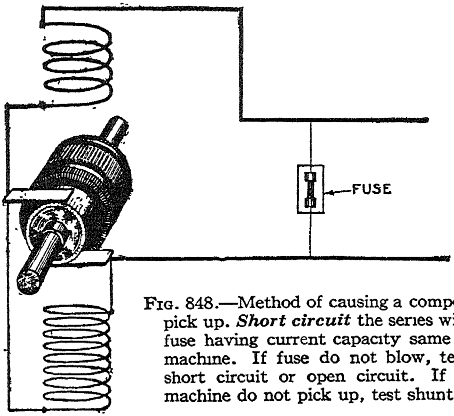


FIG. 848.—Method of causing a compound dynamo to pick up. ***Short circuit*** the series winding through a fuse having current capacity same as that of the machine. If fuse do not blow, test armature for short circuit or open circuit. If fuse blow, and machine do not pick up, test shunt winding.

Ques. What are the causes of excessive voltage?

Ans. Over excitation of the field magnet or too high speed.

In the former case, resistance should be introduced into the field circuit to diminish the current flowing therein if a shunt machine; or if a series

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NOTE.—***To shut down a compound wound dynamo*** operating in parallel with others: 1, Reduce the load as much as possible by throwing in resistance with the field rheostat; 2, throw off the load by opening the circuit-breaker, if one be used, otherwise open the main dynamo switches; 3, shut down the driving machine; 4, wipe off all oil and dirt, clean the machine and put it in good order for the next run. If the machine be operating independently and no motors are connected to the circuit, close the engine throttle valve and permit the engine and dynamo to come to rest. Turn all resistance in the field rheostat. Open the main switch. Where motors are served they must be disconnected first, otherwise a loaded motor may stop when the impressed voltage decreases somewhat below normal. Then, since its armature is not turning, it is in effect a short-circuit and may blow fuses or make other trouble.

machine, a portion of the current should be shunted across the field coils by means of a resistance arranged in parallel with the series coils; or the same effect may be produced in both cases by reducing the speed of the armature if this be possible.

If due to excessive speed, which will be indicated by a speed indicator, the natural remedy is to reduce the speed of the engine driving the dynamo, or, if this be not easily done, insert resistance into the dynamo circuit, as described above.

Ques. What are the causes of excessive current?

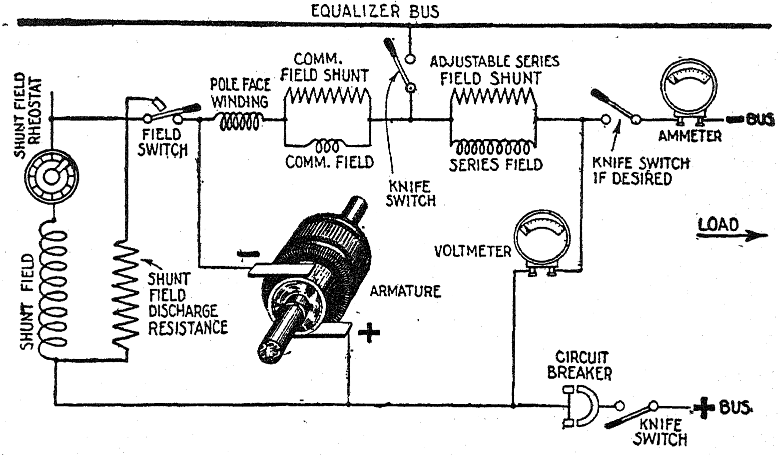

FIG. 849.—Connection diagram General Electric type LD dynamo.

Ans. If the dynamo be supplying arc lamps, the excessive current may possibly be caused by the bad feeding of the lamps If this be the case, the fact will be indicated by the oscillations of the ammeter needle, and the unsteadiness of the light.

If incandescent lamps be in the circuit, the fault may be caused by there being more lamps in circuit than the dynamo is designed to carry.

Under such circumstances, another dynamo should be switched into circuit in parallel, or, if this be not possible, lamps should be switched off until the defect is remedied.

When motors are in the circuit, sparking frequently results at the dynamo commutator, owing to the fluctuating load. In such cases the brushes should be adjusted to a position at which the least sparking occurs with the average load.

Ques. What may be said with respect to reversal of polarity of dynamos?

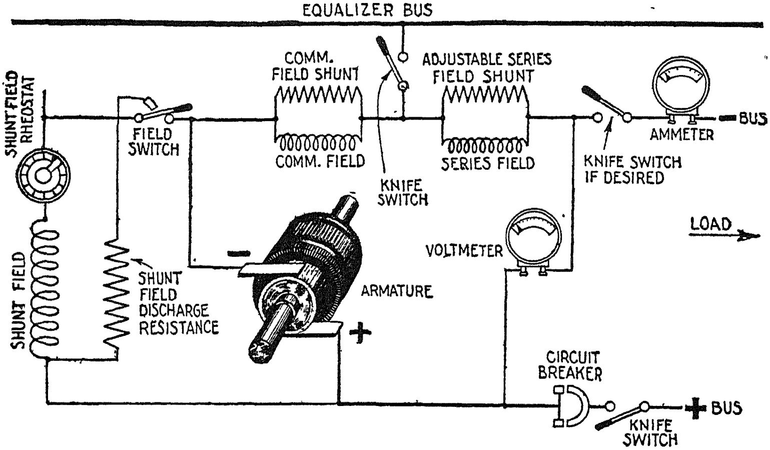

FIG. 850.—Connection diagram General Electric types MCF and MDF dynamos.

Ans. When compound or series wound dynamos are running in parallel, their polarity is occasionally reversed while stopping by the current from the machines at work.

Loose Connections, Terminals, etc.—When any of the connecting cables, terminal screws, etc., securing the different circuits are loose, sparking at the brushes, as a rule, results, for the reason that the vibration of the machine tends to continually alter the resistance of the various circuits to which they are connected.

When the connections are excessively loose, sparking also results at their points of contact, and by this indication the faulty connections may be readily detected. When this sparking at the contacts is absent, the whole of the connections should be carefully examined and tested.

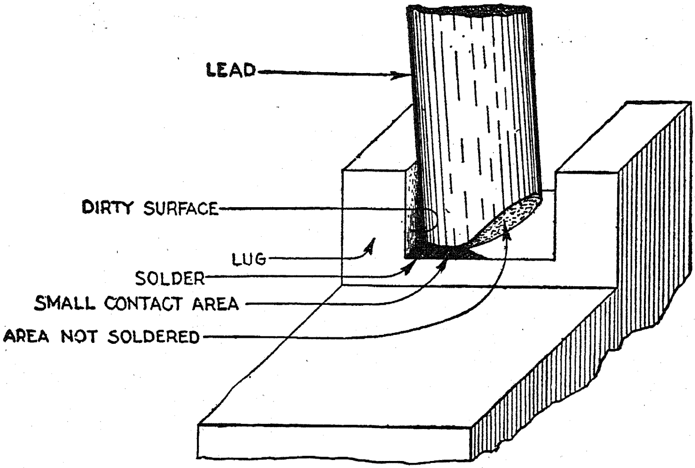

FIG. 851.—Break in armature circuit due to poor workmanship in soldering. If the lugs or risers be not perfectly tinned before attempting to solder the leads into them, the solder will not take hold over the entire area, and a lead may be held in place only by a thin film of solder on the outside surface. When the current through the armature is heavy, the contact area between the riser and the leads may not be sufficient to carry the necessary current without excessive heating. This will melt out what little solder there is, and an open circuit will result.

Breaks in Armature Circuit.—If there be a broken circuit in the armature, as sometimes happens through a fracture of the armature connections, etc., there will be serious flashing or sparking at the brushes, which cannot be suppressed by adjusting the rocker. As a rule it results in the production of "flats" upon one or more bars of the commutator.

Ques. How may such sparking be reduced without stopping the machine?

Ans. By placing one of the brushes of each set a little in advance of the others, so as to bridge the gap.

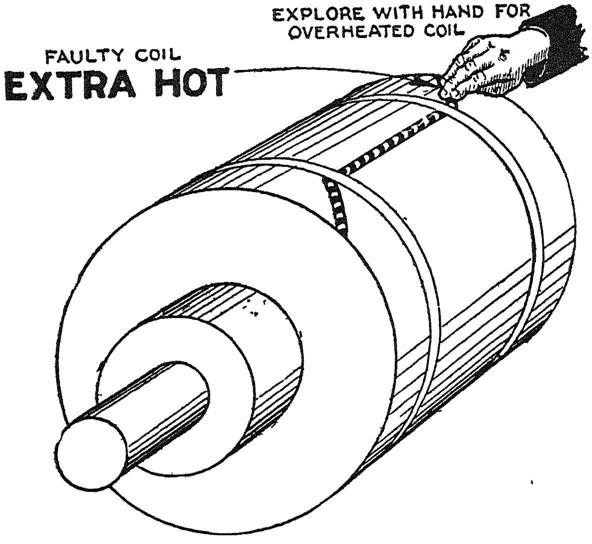

FIG. 852.—Thermal test for short circuit in armature. Run dynamo a short time or until its running temperature is reached. Stop machine and pass the hand over the end windings. The defective coil will heat much more than the other coils, and is detected by the excess temperature.

Short Circuits in Armature Circuit.—This fault is indicated by sparking at the commutator, and in bad cases by an excessive heating of the armature, dimming of the light and slipping of the belt, and in the case of a drum armature, by a sudden cessation of the current.

Short Circuits or Breaks in Field Magnet Circuit.—Either of these faults is liable to give rise to sparking at the commutator. If one of the coils be short circuited, the fact will be indicated by the faulty coil remaining cool while the perfect coil is overheated. The fault may arise through some of the connections to the coils making contact with the frame of the machine or with each other. To ascertain this, examine all the connections, and test with a battery and galvanometer. A total break in one or more of the field coils may readily be detected by means of the battery and galvanometer.

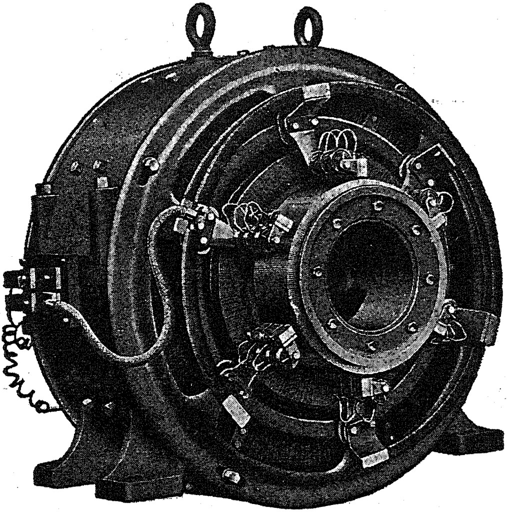

FIG. 853.—Diehl engine type dynamo 50 *k.w.* 250 volts.

NOTE.—*The reduction in size* of Diehl type K steel frames has reduced the height from center of shaft to ground to a minimum measurement. This is advantageous for wall and ceiling mounting and for direct coupling to and mounting on the same bed plate with machinery to be driven. It may be stated that it is usually a simple matter to raise the shaft height if necessary, but difficult and sometimes impossible to lower the shaft height without expensive construction.

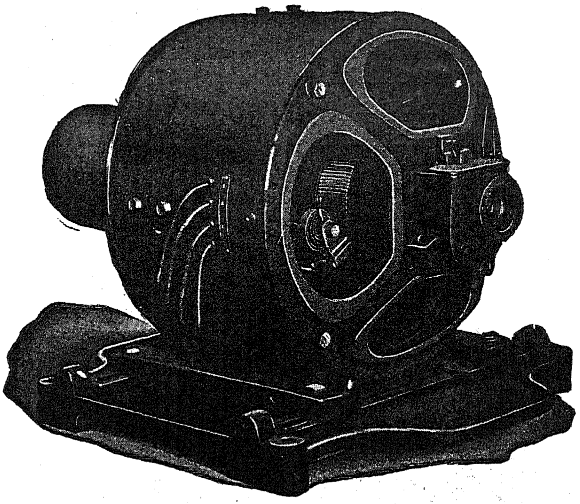

FIG. 854.—Diehl types LA and LB dynamo designed to meet conditions where the output is definitely known and which will not be subjected to any permanent increase. However, they may be subjected to momentary overloads as high as 50 per cent without injury to any part.

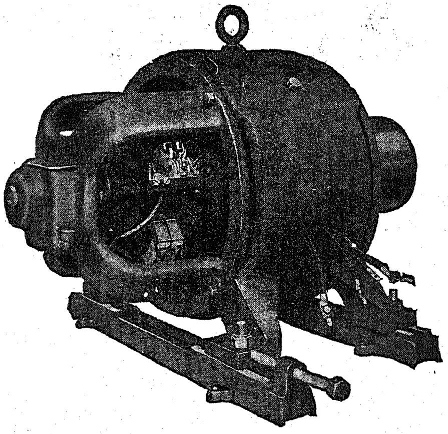

FIG. 855.—Burke type WA motor with rail and pulley.

TEST QUESTIONS

1. *What examination should be made before starting a dynamo (or motor)?*
2. *What two brush adjustments are necessary?*
3. *Where should the brushes bear?*
4. *How are the brushes set by these marks?*
5. *Describe the pressure adjustment.*
6. *Give rules for direction of rotation.*
7. *How should the dynamo be started?*
8. *Describe in detail how to start:* ***a,*** *series;* ***b,*** *shunt;* ***c,*** *compound dynamos.*
9. *Why does a shunt dynamo sometimes fail to pick up?*
10. *What should be done if the dynamo lose its residual magnetism?*
11. *How does the lead vary in the different types of dynamo?*
12. *What attention should be given while running?*
13. *What should be done if the brushes begin to spark excessively?*
14. *Describe in detail lubrication system, and method of lubricating dynamos?*
15. *What kind of oil should be used?*
16. *Give some causes of excessive heating.*
17. *Give at length instructions for stopping dynamos.*
18. *After shutting down a dynamo what attention should be given?*

19. *What further attention should be given?*
20. *What are the causes most likely to produce overload?*
21. *What may be said with respect to loose connections, terminals, etc.?*
22. *Describe the causes of various kinds of short circuits and remedy.*

CHAPTER 27

Coupling of Dynamos

Series and Parallel Connections.—When it is necessary to generate a large and variable amount of electrical energy, as must be done in central generating stations, apart from the question of liability to breakdown, it is neither economical nor desirable that the whole of the energy should be furnished from a single dynamo. Since the efficiency of a dynamo is dependent upon its output at any moment, or the load at which it is worked (the efficiency varying from about 95 per cent. at full load to 80 per cent. at half load), it is advisable in order to secure the greatest economy in working, to operate any dynamo as near full load as possible.

Under the above circumstances, when the whole of the output is generated by a single dynamo this can evidently not be effected, for the load will naturally fluctuate up and down during the working hours, as the lamps, motors, etc., are switched into and out of circuit; hence, although the dynamo may be working at full load during a certain portion of the day, at other times it may probably be working below half load, and therefore the efficiency and economy in working in such an arrangement is very low.

Ques. How is maximum efficiency secured with variable load?

Ans. It is usual to divide up the generating plant into a number of units, varying in size, so that as the load increases, it can either be shifted to machines of larger size, or when it exceeds the capacity of the largest dynamo, the output of one can be added to that of another, and thus the dynamos actually at work at any moment can be operated as nearly as possible at full load.

Ques. What should be noted with respect to connecting one dynamo to another?

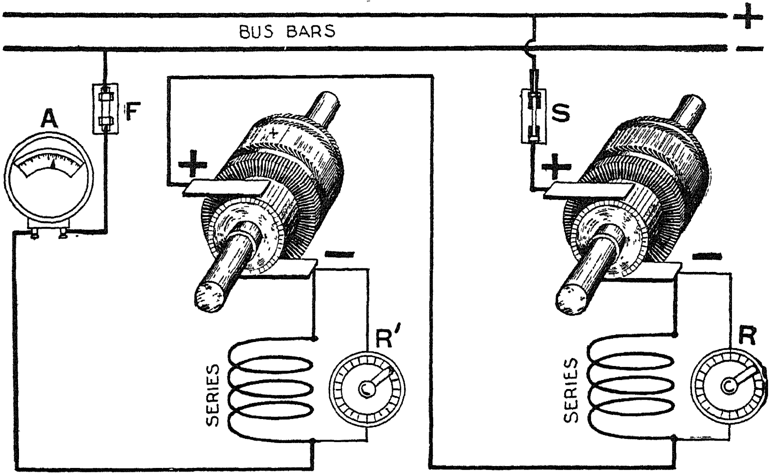

FIG. 856.—Diagram showing method of coupling series dynamos in series. R and R′, are two hand regulators which are placed in shunt across the coil terminals to regulate the pressure and output of the machine.

Ans. It is necessary to take certain precautions (as later explained) in order that the other dynamos may not be affected by the change, and that they may work satisfactorily together.

Ques. What are the two methods of coupling dynamos?

Ans. They are connected in series, or in parallel.

In coupling dynamos in series, the current capacity of the plant is kept at a constant value, while the output is increased in proportion to the pressures of the machines in circuit.

When connected in parallel, the pressures of all the machines are kept at a constant value, while the output of the plant is increased in proportion to the current capacities of the machines in circuit.

Coupling Series Dynamos in Series.—Series wound dynamos will run satisfactorily together without special precautions when coupled in series, if the connections be arranged as in fig. 856.

The positive terminal of one dynamo is connected to the negative terminal of the other, and the two outer terminals are connected directly to the two main conductors or bus bars through the ammeter A, fuse F, and switch S. If it be desired to regulate the pressure and output of the machines, variable resistances, or hand regulators R,R′, may be arranged as shunts to the series coils as shown, so as to divert a portion or the whole of the current therefrom.

Series Dynamos in Parallel.—Simple series wound dynamos not being well adapted for the purpose of maintaining a constant pressure, are in practice seldom coupled in parallel; the conditions or working, however, derive importance from the fact that compound dynamos, being provided with series coils, are subject to similar conditions when working in parallel, which is frequently the case.

Ques. What may be said with respect to coupling two or more plain series dynamos in parallel?

Ans. The same procedure cannot be followed as in the case of plain shunt dynamos, for the reason that if the voltage of the dynamo to be coupled be exactly equal to that of the bus bars when connected in parallel, the combination will be unstable.

Ques. Why is this?

Ans. If, from any cause, the pressure at the terminals of one of the dynamos fall below that of the others, it immediately takes a smaller proportion of the load.

As a consequence, the current in its field coils is reduced, and a further fall of pressure immediately takes place. This again causes the dynamo to relinquish a portion of its load, and a further fall of pressure again occurs. Thus the process goes on, until finally the dynamo ceases to supply current, and the current from the other dynamos flowing in its field coils in the reverse direction reverses its magnetism, and causes it to run as a motor against the driving power in the opposite direction to that in which it previously ran as a dynamo.

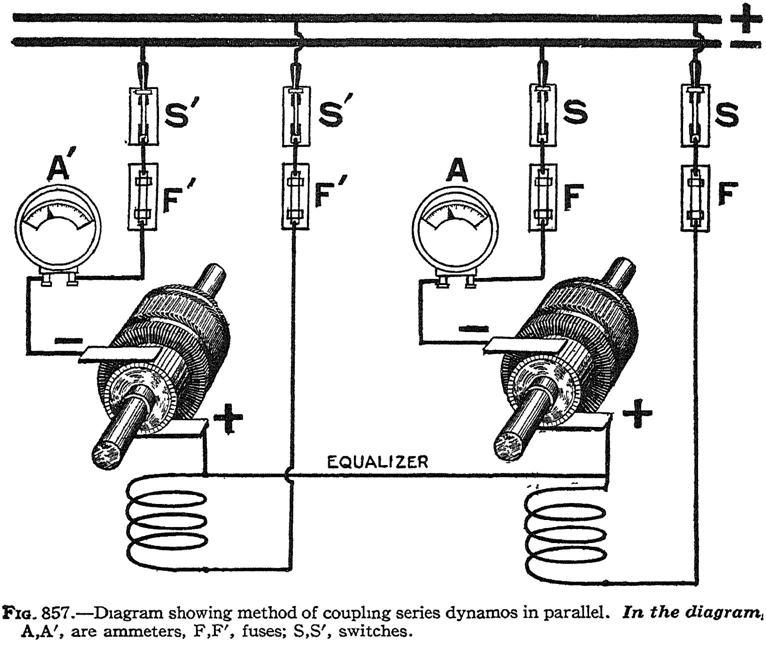

FIG. 857.—Diagram showing method of coupling series dynamos in parallel. *In the diagram,* A,A′, are ammeters, F,F′, fuses; S,S′, switches.

Under such circumstances the armature is liable to be destroyed if the fuse be not immediately blown, and in any case it is subjected to a very detrimental shock. This tendency to reverse in series dynamos can be effectually prevented by connecting the field coils of all the dynamos in parallel.

Ques. How are the field coils of all the dynamos connected in parallel?

Ans. This is effected in practice by connecting the ends of all the series coils where they join on to the armature circuit by a third connection, called the "equalizing connection" or "equalizer," as shown in fig. 857.

Ques. What is the effect of the equalizer?

Ans. The immediate effect is to cause the whole of the current generated by the plant to be divided among the series coils of the several dynamos in the inverse ratio of their resistance, without any regard as to whether this current comes from one armature, or is divided among the whole.

The fields of the several dynamos being thus maintained constant, or at any rate being caused to vary equally, the tendency for the pressure of one dynamo to fall below that of the others is diminished.

Shunt Dynamos in Series.—The simplest operation in connection with the coupling of dynamos, and the one used probably more frequently in practice than any other, is the coupling of two or more shunt dynamos to run either in series or in parallel.

When connected in series, *the positive terminal of one machine is joined to the negative of the other, and the two outer terminals are connected through the ammeter A, fuses F, F', and switch S, to the two main conductors or omnibus bars* as represented in fig. 858.

The machine will operate when the connections are arranged in this manner, if the ends of the shunt coils be connected to the terminals of their respective machines.

Shunt Dynamos in Parallel.—The coupling of two or more shunt dynamos to run in parallel is effected without any difficulty. This method of coupling dynamos is one that is very frequently used. Fig. 859 illustrates diagrammatically the method of arranging the connections.

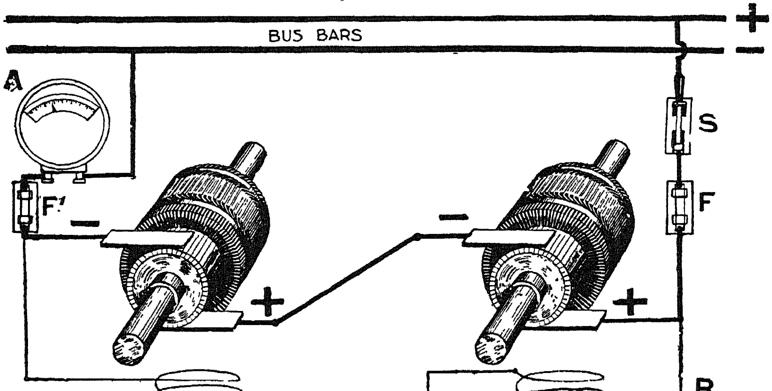

Fig. 858.—Diagram showing method of coupling shunt dynamos in series. The ends of the shunt coils may be connected to the terminals of their respective machine, or they may be connected in series as shown.

The positive and negative terminals of each machine are connected respectively to two massive insulated copper bars, shown at the top of the diagram, called *omnibus bars*, through the double pole switches S,S′, and the double pole fuses F,F′.

Ammeters A,A′, are inserted in the main circuit of each machine, and serve to indicate the amount of current generated by each. An automatic switch or cut out, AC, AC′, is also shown as being included in the main circuit of each of the machines, although this appliance is sometimes dispensed with.

The pressure of each of the machines is regulated independently by means of the hand regulators R,R′, inserted in series with the shunt circuit.

The shunt circuits are represented as being connected to the positive and negative terminals of the respective machines, but in many cases where the load is subjected to sudden variations, and when a large number of machines is connected to the bus bars, the shunt coils are frequently connected direct to these. In such circumstances this method is preferable, as by means of it the fields of the idle dynamos can be excited almost at once direct from the bus bars by the current from the working dynamos; hence, if a heavy load come on suddenly, no time need be lost in building up a new machine previous to switching it into parallel. The

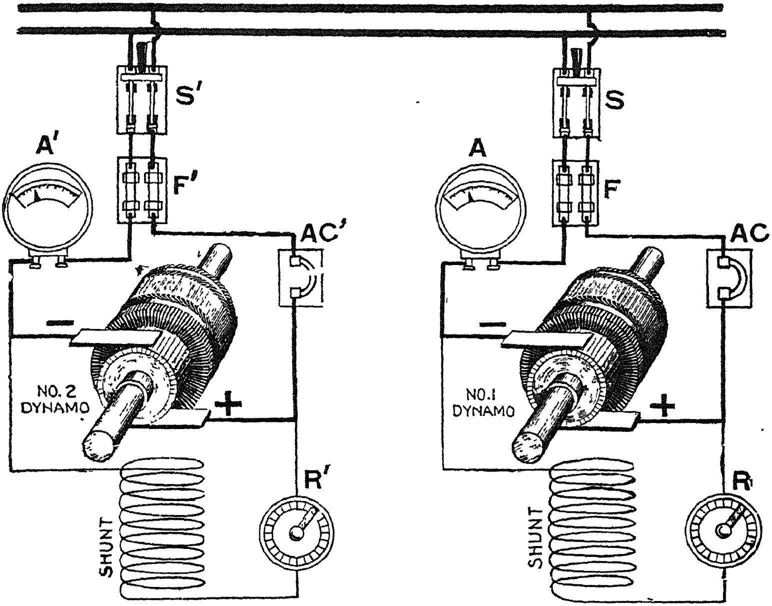

Fig. 859.—Diagram showing method of coupling shunt dynamos in parallel.

pressure of the lamp circuit is given by a volt meter, whose terminals are placed across the bus bars; and the pressure at the terminals of each of the machines is indicated by separate volt meters or pilot lamps, the terminals of which are connected to those of the respective machines.

Ques. Describe a better method of parallel connection.

Ans. Better results are obtained *by connecting both the shunt coils in series with one another,* so that they form one long shunt between the two main conductors, the same as in fig. 858.

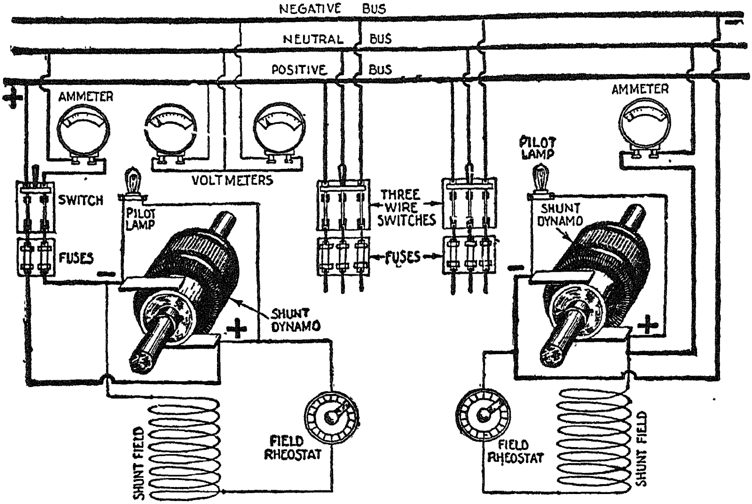

FIG. 860.—Connections for two shunt dynamos to run on the three wire system. The two machines are connected in series, three wires being carried from them one from the outside pole of each machine and one from the junction of the two machines. The voltage between the outside wires is equal to the combined voltage of the two machines and the voltage between the outside and the central or neutural wire is equal to the voltage of the corresponding machine. If the load on each side of the system be equal, there will be no current in the neutral wire, while if the loads be unequal, the neutral wire will have to carry the difference in current between the two outside wires.

When arranged in this way, the regulation of both machines may be effected simultaneously by inserting a hand regulator R, in series with the shunt circuit as represented.

Switching Dynamo Into and Out of Parallel.—In order to put an additional dynamo in parallel with those already working, it is necessary *to run the new dynamo up to full speed, and, when it excites, regulate the pressure by means of a hand regulator until the voltmeter connected to the terminals of the machines registers one or two volts more than the voltmeter connected to the lamp circuit, and then close the switch.* The load upon the machine can then be adjusted to correspond with that upon the other machines by means of the hand regulator.

Ques. In connecting a shunt dynamo to the bus bars must the voltage be carefully adjusted?

Ans. There is little danger in overloading the armature in making the connection, hence the pressure need not be accurately adjusted.

It is, in fact, common practice in central stations to judge the voltage of the new dynamo merely by the appearance of its pilot lamp.

Ques. How is a machine cut out of the circuit?

Ans. When shutting down a machine, the load or current must first be reduced, by gradually closing the stop valve of the engine, or inserting resistance into the shunt circuit by means of the hand regulator; then when the ammeter indicates nine or ten amperes, the main switch is opened, and the engine stopped.

By following this plan, the heavy sparking at the switch contacts is avoided, and the tendency for the engine to race, reduced.

Ques. What precaution must be taken in reducing the current?

Ans. Care must be taken not to reduce the current too much.

Ques. Why is this necessary?

Ans. There is danger that the machine may receive a reverse current from the other dynamos, resulting in heavy sparking at the commutator, and in the machine being driven as a motor.

Ques. What provision is made to obviate this danger?

Ans. Dynamos that are to be run in parallel are frequently provided with automatic cutouts, set so as to automatically switch out the machine when the current falls below a certain minimum value.

Dividing the Load.—If a plant, composed of shunt dynamos running in parallel, be subjected to variations of load, gradual or instantaneous, the dynamos will, if they all have similar characteristics, each take up an equal share of the load.

If, however, as is sometimes the case, the characteristics of the dynamos be dissimilar, the load will not be shared equally, the dynamos with the most drooping characteristics taking less than their share with an increase of load, and more than their share with a decrease of load.

If the difference be slight, it may be readily compensated *by means of the hand regulator increasing or decreasing the pressures of the machines, as the load varies.*

If, however, the difference be considerable, and the fluctuations of load rapid, it becomes practically impossible to evenly divide the load by this means.

Under such circumstances, the pressure at the bus bars is liable to great variations, and there is also liability of blowing the fuses of the overloaded dynamos, thus precipitating a general breakdown. To cause an equal division of the load among all the dynamos, under such circumstances, it is necessary *to insert a small resistance in the armature circuits of such dynamos as possess the straightest characteristics, or of such dynamos as take more than their share of an increase of load.*

By suitably adjusting or proportioning the resistances, the pressures at the terminals of all the machines may be made to vary equally under all variations of load, and each of the machines will then take up its proper share of the load.

Coupling Compound Dynamos in Series.—Since compound dynamos may be regarded as a combination of the shunt and series wound machines, and as no special difficulties are encountered in running these latter in series, analogy at once leads to the conclusion that compound dynamos under similar circumstances may be coupled together with equal facility.

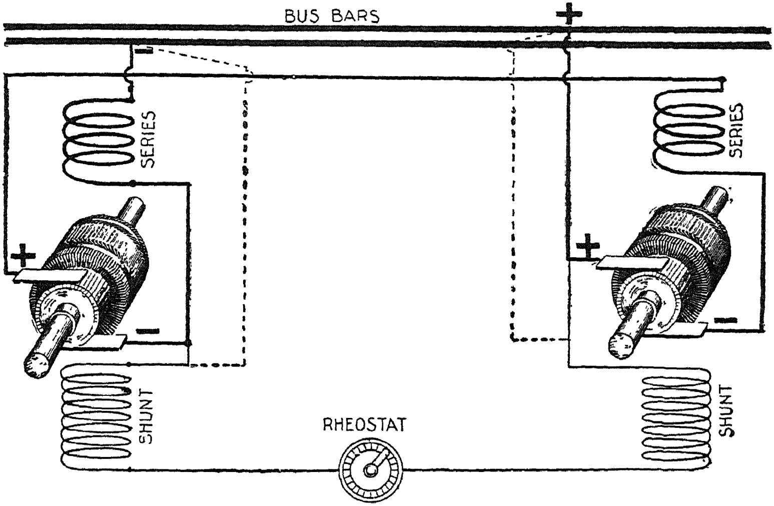

FIG. 861.—Coupling compound dynamos in series; short shunt connection. The dotted lines indicate the changes that would be made for long shunt connection.

Ques. How are compound dynamos connected to operate in series?

Ans. The series coils of each are connected as in fig. 856, and the shunt coils are connected as a single shunt as in fig. 858, which may either extend simply across the outer brushes of the machines, so as to form a double short shunt, or may be a shunt to the bus bars of external circuit, so as to form a double long shunt.

Compound Dynamos in Parallel.—Machines of this type will not run satisfactorily together in parallel unless all the series coils are connected together by an equalizing connection, as in series dynamos.

The method of arranging the connections as adopted in practice is illustrated in fig. 862. By means of it idle machines are completely disconnected from those at work.

Ques. How is the equalizer connected?

Ans. The equalizer is connected direct to the positive brushes of all the dynamos, a three pole switch being fitted for disconnecting it from the circuit when the machine to which it is connected is not working. The two contacts of the switch are respectively connected to the positive and negative conductors, while the central contact is connected to the equalizer.

Switching a Compound Dynamo Into and Out of Parallel.—If the characteristics of all the dynamos be similar, and the connections arranged as in figs. 862, or 863, the only precaution to be observed in switching a new machine into parallel is to have its voltage equal, or nearly equal to that of the bus bars previous to closing the switch. If this be the case, the new machine will take up its due share of the load without any shock.

Ques. How is a compound dynamo, running in parallel, cut out of circuit?

Ans. The load is first reduced to a few amperes, as in the case of shunt dynamos, either by easing down the engine, or by cutting resistance into the shunt circuit by means of the hand regulator, and then opening the switch.

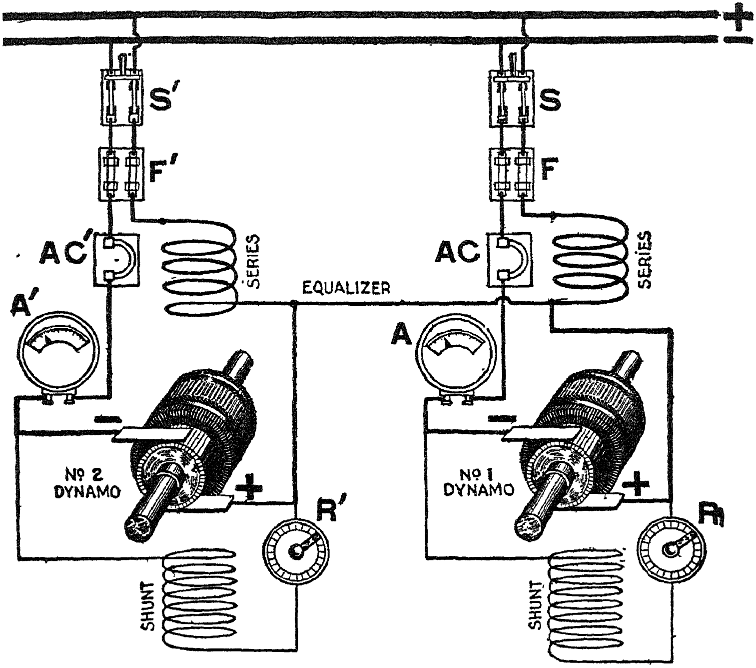

Fig. 862.—Diagram showing method of coupling compound dynamos in parallel.

Previous to this, however, it is advisable to increase the voltage at the bus bars to a slight extent, as while slowing down the engine the load upon the outgoing dynamo is transferred to the other dynamo armatures, and the current in their series coils not being increased in proportion, the voltage at the bus bars is consequently reduced somewhat.

Equalizing the Load.—When a number of compound dynamos of various output, size, or make, are running together in

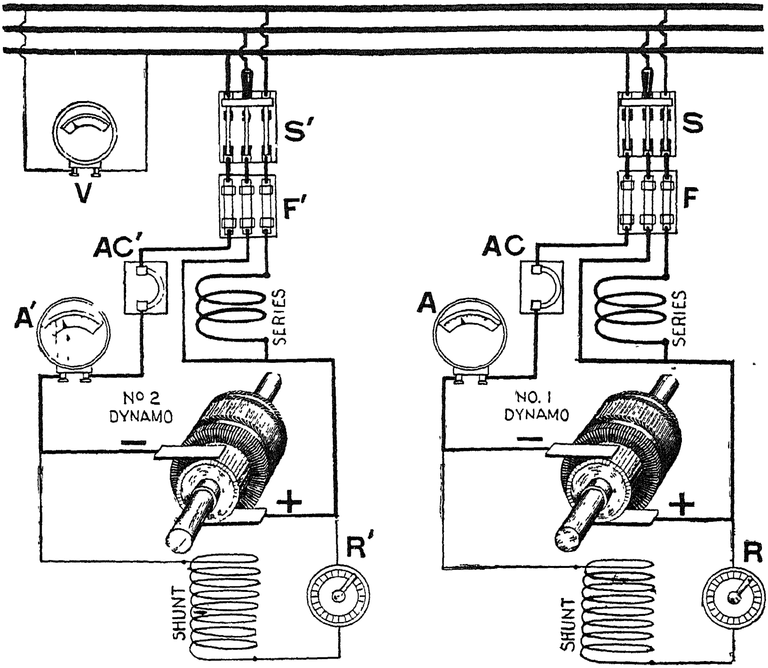

Fig. 863.—Diagram showing another and better method of coupling compound dynamos in parallel. *With this arrangement,* the idle machines are completely disconnected from those at work. The same reference letters are common in both diagrams. S,S', are switches; F,F', fuses; A,A' ammeters, which indicate the total amount of current generated by each of the machines; AC, AC', automatic switches, arranged for automatically switching out a machine in the event of the pressure at its terminals being reduced through any cause; R,R', are hand regulators; inserted in the shunt circuits of each of the machines, by means of which the pressures of the individual machines may be varied and the load upon each adjusted. The pressure at the bus bars is given by the voltmeter V, one terminal of which is connected to each of the bars; a second voltmeter may be used, to give the pressure of any individual machine, by connecting "voltmeter keys" to the terminals of each of the machines, or a separate voltmeter may be used for each individual machine. The only essential difference between figs. 862 and 863 is, that in fig. 862 the equalizer is connected direct to the positive brushes of all the dynamos, while in fig. 863 the equalizer is brought up to the switchboard and arranged between the two bus bars, a switch being fitted for disconnecting it from the circuit when the machine to which it is connected is not working.

parallel, it frequently happens that all their characteristics are not exactly similar, and therefore the load is unequally distributed, some being overloaded, while others do not take up their proper share of the work.

If the difference be small, it may be compensated *by means of the hand regulator;* if large, however, other means must be taken to cause the machines to take up their due proportion of the load.

If the series coils of the several dynamos be provided with small adjustable resistances, in the form of German silver or copper ribbon inserted in series with the coils, the distribution of the current in the latter may be altered *by varying the* resistance attached to the individual coils. The effect of the

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NOTE.—***The action of an equalizing bar*** in equalizing the load on compound dynamos run in parallel may be explained as follows: The compound winding of a dynamo raises the pressure in proportion to the current flowing through it, and if, in a system of parallel operated compound dynamos without the equalizing connection, the current given by one machine were slightly greater than the currents from the others, the pressure of that machine would increase. With this increase in pressure above the other machines, a still greater current would flow, and so raise the pressure further. The effect is therefore cumulative, and in time the one dynamo would be carrying too great a proportion of the whole current of the system. With the equalizing connection, whatever the current flowing from each machine, the currents in the various compound windings are all equal, and so the added pressure due the compound winding is practically the same in each machine. Any inequality in output from the machines is readily eliminated by adjusting the shunt currents by means of the shunt rheostats. When compound wound dynamos are operated in parallel, the equalizer bar insures uniform distribution among the series coils of the machines.

NOTE.—***To secure the best results in parallel operation,*** dynamos should be of the same design and construction and should possess as nearly as possible the same characteristics; that is, each should respond with the same readiness, and to the same extent, to any change in its field excitation. Any number of such machines may be operated in parallel.

NOTE.—***The usual practice*** is to connect the equalizer and the series field to the positive terminal, though if desired, they may be connected to the negative terminal; both however, must be connected to the same terminal. The resistance of the equalizer should be as low as possible, and it must never be greater than the resistance of any of the leads from the dynamos to the bus bar. Sometimes a third wire is run to the switchboard from each dynamo and there connected to an equalizer bar, but the usual practice is to run the equalizer directly between the dynamos and to place the equalizer switches on pedestals near the machines. This shortens the connections and leads to better regulation. The positive and equalizer switches of each machine differ in pressure only by the slight drop in the series coil, and in some large stations these two switches are placed side by side on a pedestal near the machine. In such cases, the equalizer and positive bus bars are often placed under the floor near the machines, so that all leads may be as short as possible. If all the dynamos be of equal capacity, all the leads to bus bars should be of the same length, and it is sometimes necessary to loop some of them.

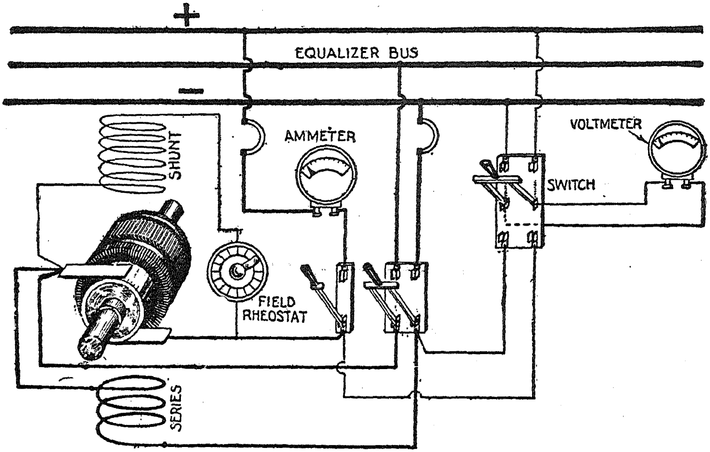


FIG. 864.—Diagram showing method of coupling a compound dynamo with one or more machines using a single pole and a two pole switch.

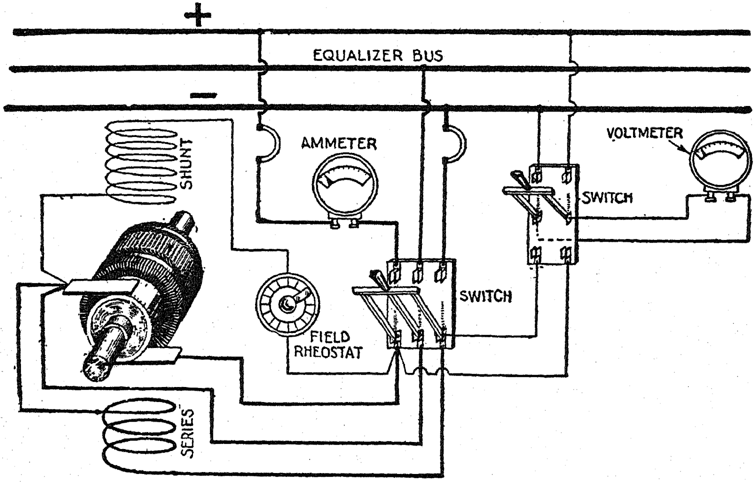


FIG. 865.—Diagram showing method of coupling a compound dynamo with one or more machines using a three pole switch.

series coils upon the individual armatures in raising the pressure may be adjusted, and the load thus evenly divided among the machines.

Shunt and Compound Dynamos in Parallel.—It is not practicable to run a compound dynamo and a shunt dynamo in parallel, for, unless the field rheostat of the shunt machine be adjusted continually, the compound dynamo will take more than its share of the load.

TEST QUESTIONS

1. *Name two methods of connecting dynamos.*
2. *Describe at length:* ***a,*** *series;* ***b,*** *parallel methods of connecting dynamos.*
3. *How is maximum efficiency secured with variable load?*
4. *What results are obtained with:* ***a,*** *series;* ***b,*** *parallel connections?*
5. *What can be said about coupling series dynamos in series?*
6. *How are series dynamos coupled in parallel?*
7. *Explain the application of an equalizer.*
8. *Explain in detail how shunt dynamos are connected:* ***a,*** *in series;* ***b,*** *in parallel.*
9. *Describe the approved parallel connection.*
10. *Describe the method of switching the dynamo into and out of parallel.*
11. *How is the load divided?*

12. *How are compound dynamos coupled in:* ***a,*** *series;* ***b,*** *parallel?*
13. *How is the equalizer connected?*
14. *Describe the method of switching compound dynamos into and out of parallel.*
15. *How is the load equalized in compound dynamos connected in parallel?*
16. *How are best results secured in parallel operation?*

CHAPTER 28

Dynamo Fails to Excite

This trouble is of frequent occurrence in both old and new machines. If a dynamo fail to excite, the operator *should first see that the brushes are in the proper position and making good contact, and that the external circuit is* ***open*** *if the machine be shunt wound, and* ***closed,*** *if series wound.*

In starting a dynamo it should be remembered that shunt and compound machines require an appreciable time to build up, hence, it is best not to be too hasty in hunting for faults.

The principal causes which prevent a dynamo building up are:

1. Brushes not properly adjusted;
2. Defective contacts;
3. Incorrect adjustment of regulators;
4. Speed too low;
5. Insufficient residual magnetism;
6. Open circuits;
7. Short circuits;

    a. In external circuits;
    b. In dynamo.

8. Wrong connections;
9. Reversed field magnetism.

Brushes Not Properly Adjusted.—If the brushes be not in or near their correct positions, the whole of the voltage of the armature will not be utilized, and will probably be insufficient to excite the machine.

If in doubt as to the correct positions, the brushes should be rotated by means of the rocker into various points on the commutator, sufficient time being given the machine to excite before moving them into a new position.

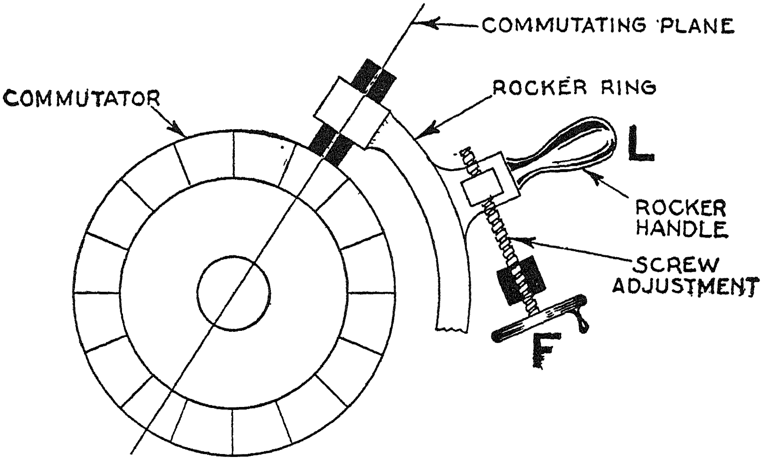


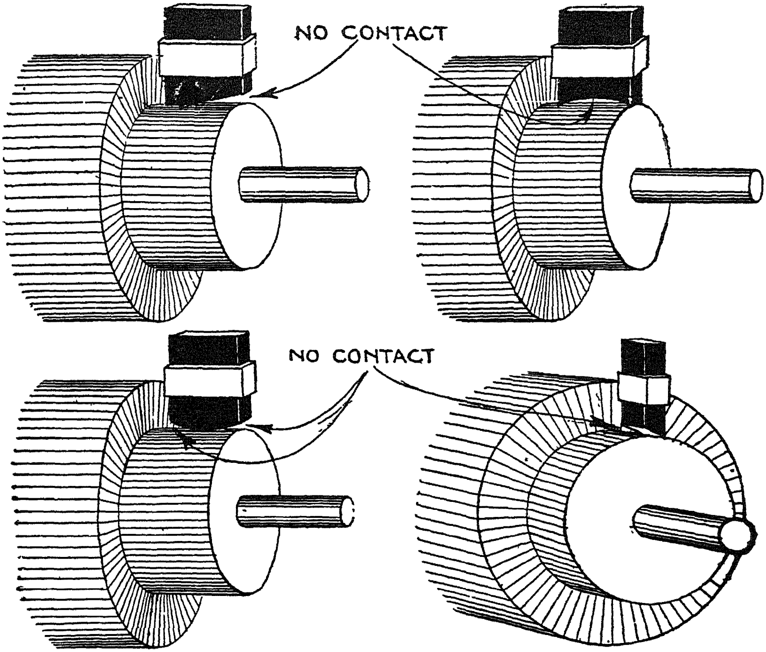
FIG. 866.—Brush adjustment for proper commutation. The brushes are usually attached to a rocker ring so that they may be brought into the correct radial position or commutating plane by means of handle L, in small machines, or by screw gear F, in large machines.

Defective Contacts.—If the different points of contact of the connections of the machine be not kept thoroughly clean and free from oil, etc., it is probable that enough resistance will be interposed in the path of the exciting current to prevent the machine building or exciting. Each of the contacts should, therefore, be examined, cleaned, and screwed up tight.

Ques. Which of the contacts should receive special attention?

Ans. The contact faces of the brushes and surface of the commutator.

These are very frequently covered with a slimy coating of oil and dirt, which is quite sufficient to prevent the machine exciting.



Figs. 867 to 870.—Defective contact of brushes due to face not being true.

Incorrect Adjustment of Regulators.—When shunt and compound machines are provided with field regulators, it is possible that the resistance in circuit may be too great to permit the necessary strength of exciting current passing through the field windings. Accordingly, the fault is corrected by cutting out more or less of the resistance.

The field coils of series machines are sometimes provided with short circuiting switches or resistances arranged to shunt the current across the field coils.

If too much of the current be shunted across, the switch should be opened, or if there be a regulator, it should be so adjusted that it will pass enough current through the field windings to excite the machine.

Speed Too Low.—In shunt and compound dynamos there is ***a certain critical speed*** *below which they will not excite.*

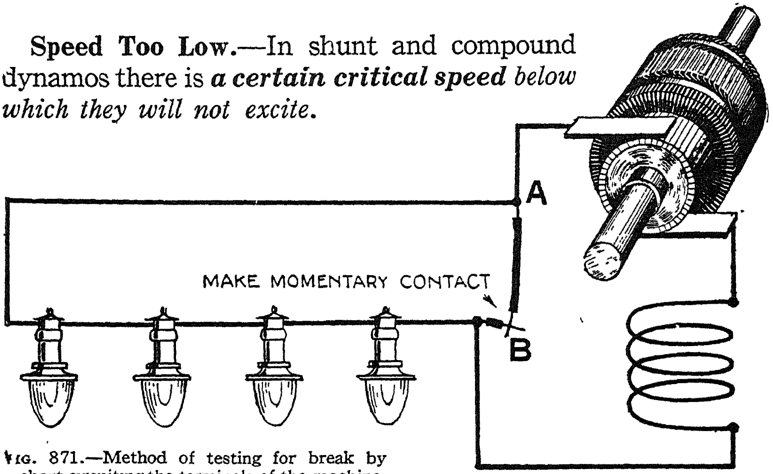


Fig. 871.—Method of testing for break by short circuiting the terminals of the machine.

If the external circuit test out apparently all right, and there be no defective contacts in any part of the machine, and all short circuiting switches, etc., be cut out of circuit, the machine still refusing to excite, short circuiting the terminals of the machine should be tried. This should be done very cautiously, especially in case of a high tension machine. It is advisable to have, if possible, only a portion of the load in circuit, and the short circuit should be effected as shown in the figure. The short circuit may be made by momentarily bridging across the two terminals of the machine with a single piece of wire. As this, however, is liable to burn the terminals, a better plan is to fix a short piece of scrap wire in one terminal, and then with another piece of insulated wire make momentary contacts with the other terminal and the short piece of wire. If the machine excite, it will be at once evident by the arc which occurs between the two pieces of wire. As the voltage of a series machine when induced to build in this manner generally rises very rapidly, great care should be taken that the contact is at first only momentary, merely a rubbing or scraping touch of the wires. The contact may be prolonged if the machine do not excite at the first contact. Compound wound machines can often be made to excite quickly by short circuiting their terminals in this manner.

If the normal speed of the machine be known, it can be seen whether the failure to excite arises from this cause, by measuring the speed of the armature with a speed indicator. In all cases it is advisable, if the machine do not excite in the course of a few minutes, to slightly increase the speed. As soon as the voltage rises, the speed may be reduced to its regular rate.

Insufficient Residual Magnetism.—This fault is not of frequent occurrence; it takes place chiefly when the dynamo is new, and may be remedied by passing the current from a few

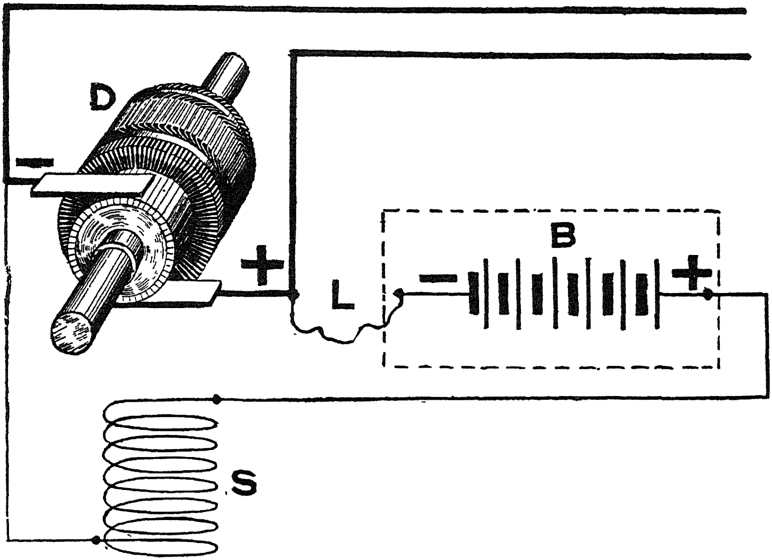


Fig. 872.—Method of overcoming insufficient residual magnetism. The flexible "lead" L of the dynamo D, is disconnected from the positive terminal of the machine, and is connected to the negative or zinc pole of the battery B, the other or positive carbon pole being connected to the terminal, from which the lead was removed, and shunt circuit S. As thus arranged, it will be seen that the battery B, is in series with the armature and shunt circuit, and therefore its voltage will be added to any small voltage generated in the armature. When the machine is started, the combined voltages will probably be able to send sufficient current through the shunt to excite the machine. As the voltage rises and the strength of the current in the shunt windings increases, the flexible lead may be again inserted into the terminal from which it was removed. The battery will thus be short circuited, and may be cut out of circuit without any danger of breaking the shunt circuit, and thus causing the machine to demagnetize.

storage cells, or from another dynamo, for some time in the proper direction through the field coils. If a heavy current, such as is obtainable from a storage battery, be not available, and the machine be shunt or compound wound, a few primary cells arranged as in fig. 872 will generally suffice.

Open Circuits.—Dynamos are affected by open circuits in different ways, depending upon the type. Series machines require closed circuit to build up, while an open circuit is necessary with the shunt machine.

An open circuit may be due to:

1. Broken wire or faulty connection in the machine;
2. Brushes not in contact with commutator;
3. Safety fuse blown or removed;
4. Circuit breaker open;
5. Switch open;
6. External circuit open.

If the trouble be due merely to the switch or external circuit being open, the magnetism of a shunt machine may be at full strength, and the machine itself may be working perfectly, but if the trouble be in the machine, the field magnetism will probably be very weak.

Open circuits are most likely to occur in:

1. The armature circuit;
2. The field circuit;
3. The external circuit.

When the open circuit is due to the brushes not making good contact, simple examination generally reveals the fact.

Ques. What causes breaks in the field circuit?

Ans. Bad contacts at the terminals, broken connections, or fracture of the coil windings.

Ques. How is the field circuit tested for breaks?

Ans. The flexible leads attached to the brushes are removed from their connections with the field circuit, and the latter is then tested for conductivity with a galvanometer.

Ques. Where is a break likely to occur in a shunt machine?

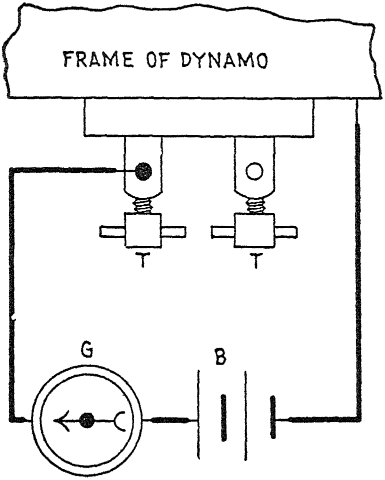


FIG. 873.—Method of testing dynamo for short circuits. *In the figure*, one pole of the battery B, is placed in contact with the frame of the machine at a point which has previously been well scraped and cleaned; the other pole is connected to one of the galvanometer terminals as shown. The other terminal of the galvanometer is connected to each of the dynamo terminals TT, under test in turn. If a deflection of the needle be produced when the galvanometer terminal is in contact with either, the terminals are in contact with the frame, and they should then be removed, and the fault repaired by additional insulation or by reinsulating.

Ans. In the hand regulator through a broken resistance coil or bad contact.

Very frequently the fault occurs in the connecting wires leading from the machine to the hand regulator fixed upon the switchboard, or in the short wires connecting the field coils to the terminals or brushes.

The insulation of a broken wire will sometimes hold the two ends together so as to defy any but the most careful inspection or examination; therefore, in order to avoid loss of time, it is advisable to disconnect the wires if possible, and test each separately for conductivity with a battery and electric bell connected as in fig. 874. If the fault be not located in the various connections, the magnet coils should be tested with a galvanometer, battery and resistance box coupled up as in fig. 882, care being first taken to disconnect the ends of each of the coils.

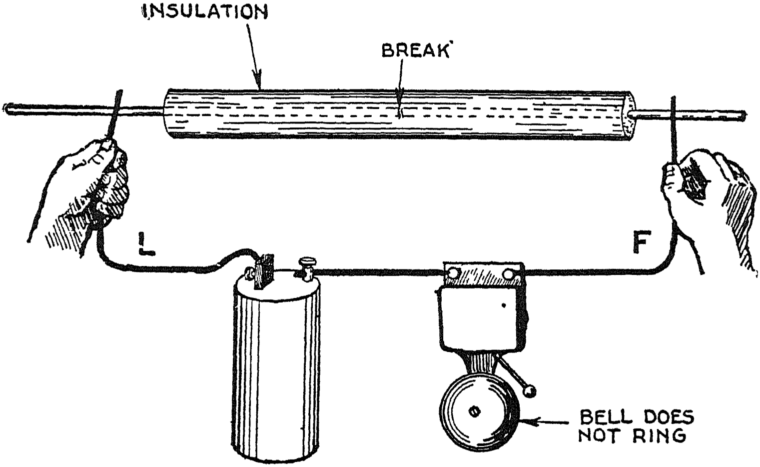


FIG. 874.—Test for break in insulated wire with bell and dry cell. Connect bell and dry cell in series and to ends of the wire to be tested by leads **L** and **F**. If the bell do not ring there is a break in the wire.

Ques. At what point of a shunt coil does a break usually occur?

Ans. At the point where the wire passes through the flanges of the spool or bobbin.

Ques. How should the coil be repaired?

Ans. In most cases a little of the wood or metal of which the flange is made can be gouged or chipped out, and a new connecting wire soldered on to the broken end of the coil without much difficulty.

If it be necessary to take the magnets apart at any time, care should be taken in putting them together again to wipe all faces perfectly clean, and screw up firmly into contact, and to see that the connections of the coils are made as they were before being taken apart.

If the faulty coil cannot be repaired quickly, and the machine is urgently required, the coil may be cut out of circuit entirely, or short circuited, and the remaining coils coupled up so as to produce the correct polarity in the pole pieces.

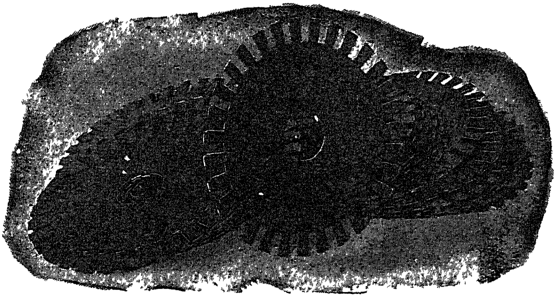


Fig. 875.—Watson armature discs. Each lamination is made from low carbon electrical steel of high magnetic permeability. Each disc is annealed and afterwards varnished.

Ques. What trouble is liable to be encountered in operating after cutting out a coil?

Ans. The remaining coils are liable to heat up to a greater extent than formerly, owing to the increased current.

It is advisable to proceed cautiously in starting the dynamo, since the temperature may exceed a safe limit. If this occur, a resistance may be put in circuit with the field coils, or the speed of the dynamo reduced.

Ques. What kind of dynamo is affected by breaks in the external circuit?

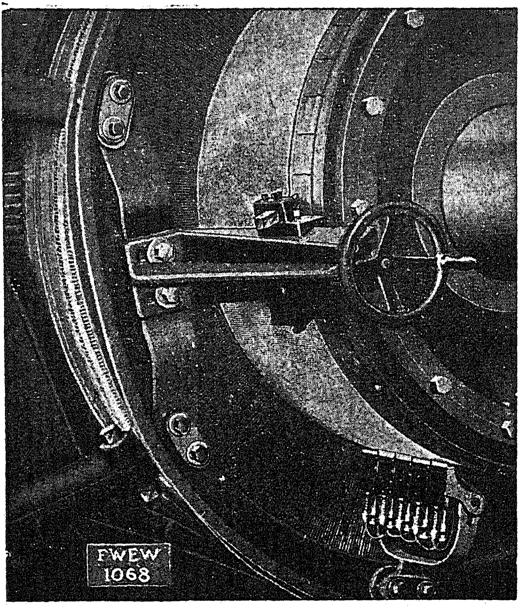


FIG. 876.—General Electric yoke type commutator truing device for machines having brush mechanism mounted on a yoke carried by the field frame. ***It consists of*** a carriage for the tool holder having a screw feed and a bracket for attaching to the brush yoke. The bracket replaces two brush holder brackets on the brush yoke, and is made to fit the yoke of the particular machine on which it is to be used.

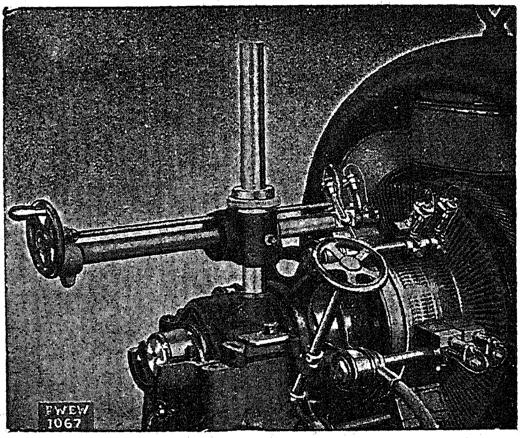


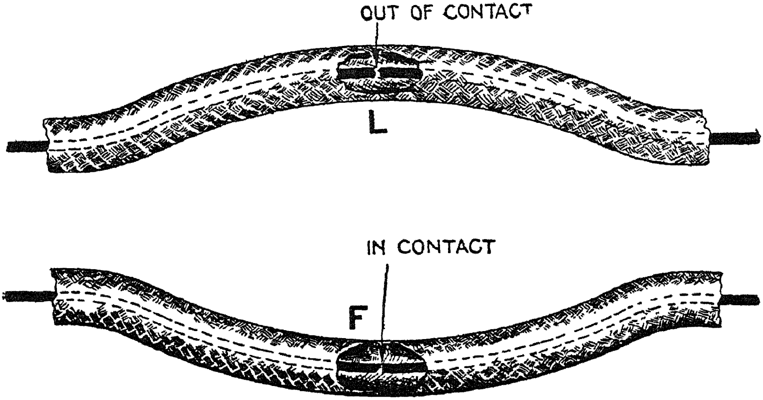
FIG. 877.—General Electric pedestal type commutator truing device. When this device is used, the armature is revolved in its own bearings by means of a handle clamped to the pulley. The tool has a horizontal travel of 21 ins. (being 3 ins. wide inside the fastening bolt in the base), and a vertical adjustment of 12 ins., adapting it to machines with commutators up to 36 ins. in diameter.

Ans. A series dynamo.

Ques. Name the kind of break that is difficult to locate.

Ans. A partial break.

Short Circuits.—In a series or compound dynamo *a short circuit or heavy load will overload the machine and cause the fuses to blow.*



Figs. 878 and 879.—Partial break. An insulated conductor which is broken at some point, may, due to vibration or other cause, frequently change its position with result that the current will be broken when in some position as at L, or in contact when in some other position as at F. In the illustrations the insulation is cut away at L and F to show more clearly the *partial break*.

A shunt machine will not excite under these circumstances, for the reason that practically the whole of the current generated in the armature passes direct to the external circuit, and the difference of pressure between the shunt terminals is practically nil.

Ques. What should be done if it should be suspected that the failure to excite arises from the cause just mentioned?

Ans. The main leads should be taken out of the dynamo terminals, then, if due to this cause, the machine will excite.

Ques. What parts of a dynamo are specially liable to be short circuited?

Ans. The terminals, brush holders, commutator, armature coils and field coils.

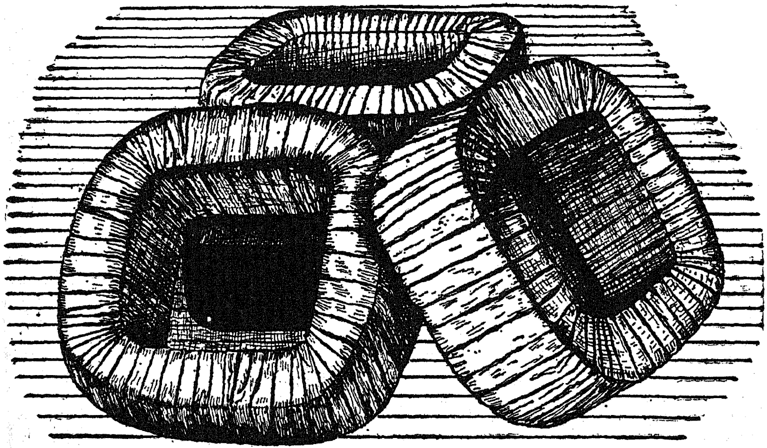


FIG. 880.—Watson field coils. Automatic machinery is employed to wind these coils; after winding, they are bound with tape, then baked to expel all moisture, and while hot, are saturated with an insulating compound and again baked for twelve hours to make them practically oil and water proof. Heavy flexible leads are brought out to avoid danger of breaking or other damage.

Ques. How are the terminals liable to be short circuited?

Ans. The terminals of the various circuits of the machine are liable to be short circuited, either through metallic dust bridging across the insulation, or through the terminals making direct contact with the frame of the machine.

Ques. What precaution should be taken with the brush holders?

Ans. Since they are liable to be short circuited through the rocker by metallic dust lodging in the insulating washers, they should be kept clean.

Ques. How are the brush holders tested?

Ans. A galvanometer and battery are connected in series with one terminal of the galvanometer connected to one set of brushes; the unconnected terminal of the battery is then connected with the other set of brushes. A deflection of the needle will indicate a short circuit.

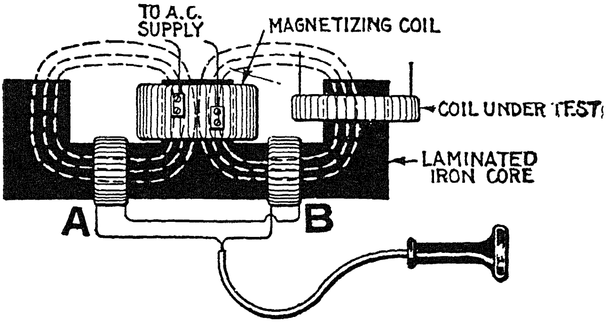


FIG. 881.—Field coil testing with telephone receiver. In the method here shown, a telephone receiver is connected in series with two symmetrically placed coils A and B. Very little sound will be heard when the flux through the two coils AB, is the same; but if a short-circuited coil is being tested, the fluxes through the coils A,B, will not be equal and a noise can be heard in the receiver.

Ques. What is the effect of a short circuit in the field coils or field circuit?

Ans. The machine generally refuses to excite.

Ques. How are the field coils tested for short circuit?

Ans. By measuring the resistance of each coil with an ohmmeter or Wheatstone bridge.

The faulty coils will show a much less resistance than the perfect coils. The fault may also be discovered and located by passing a strong current from a battery or another dynamo through each of the coils in turn, and observing the relative magnetic effects produced by each upon a bar of iron held in their vicinity.

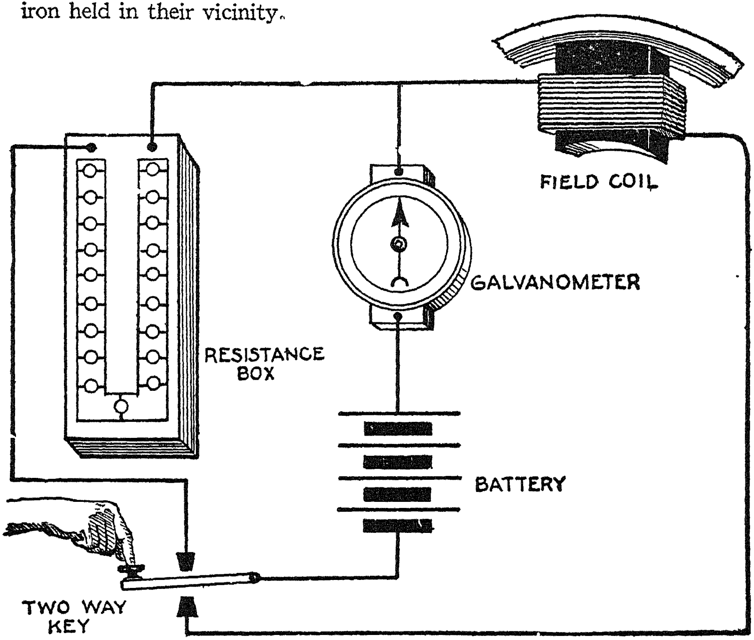


FIG. 882.—Method of testing field coils for short circuit with galvanometer and resistance box. Connect as shown. ***In testing,*** first note deflection with field coil in circuit, then press key so that the current will pass through the resistance box, and adjust the resistance in the box so that the deflection of the galvanometer is about the same as with the field coil. Now switch from one circuit to the other, changing the resistance in the box until equal deflections are obtained. When this obtains, the resistance in the box is the same as the resistance of the field coil.

The short circuit may be in the terminals or connections, and these should first be examined and tested.

Some series dynamos are provided with a resistance, arranged in parallel

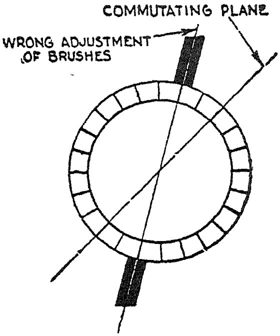


Fig. 883.—Dynamo fails to excite due to wrong adjustment of brushes. If in doubt as to the correct positions, the brushes should be rotated by means of the rocker into various points on the commutator, sufficient time being given the machine to excite before moving them into a new position.

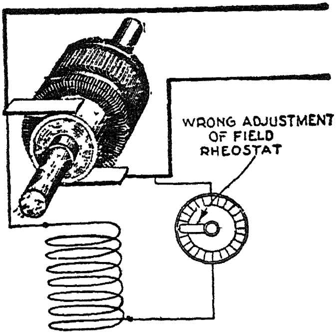
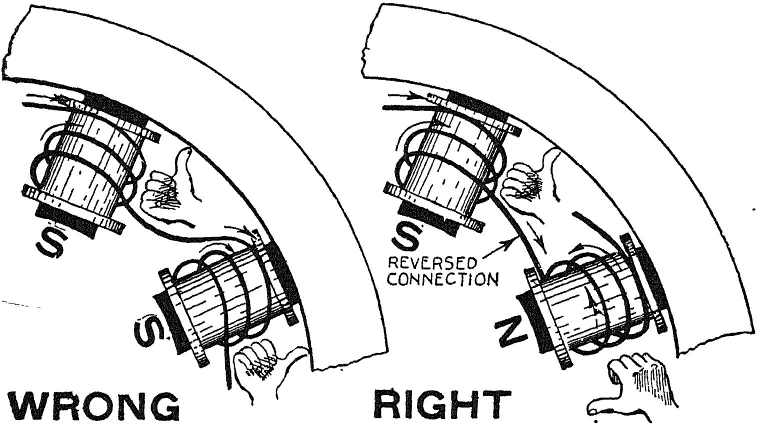


Fig. 884.—Dynamo fails to excite due to wrong adjustment of the field rheostat. The resistance in circuit may be too great to allow of the necessary strength of exciting current passing through the field windings. Therefore, before starting, remove by cutting out or short circuiting the whole of the resistance coils from circuit.

or shunt with the field coils, to divert a portion of the current therefrom, and thus regulate the output.

When making a series dynamo excite, all resistances and controlling devices should be temporarily cut out of circuit by opening the shunt circuit. Series machines frequently have a switch which short circuits the field coils. Care should be taken that this is open, or otherwise the machine will not excite.

Wrong Connections.—When a machine is first erected, the failure to build up may be due to incorrect connections. The whole of these latter should therefore be traced or followed out, and connected properly in the case of wrong connections.



FIGS. 885 and 886.—Method of connecting polarity of field coils by reversing connections.

Sometimes errors are made in connecting the field coils, causing them to act in opposition. This may occur when the dynamo is a new one or the coils have been removed for repairs. It may be caused either through the coils having been put on the field cores the wrong way, or through incorrect coupling up. Under these circumstances, the dynamo, if bipolar, will fail to excite; and if multipolar, poles will be produced in the yokes, etc. It may be remedied by removing one of the coils from the core and putting it on the reverse way, or by reversing its connections. The correctness of connections of all the coils should be verified.

In compound dynamos it sometimes happens that the machine will excite properly, but that the series coils tend to reverse the polarity of the dynamo, thus reducing the voltage as the load upon the machine increases. This may be detected when the machine is loaded by short circuiting the *series coils*, not the *terminals*. If the voltage rise in doing this, the series coils are acting in opposition to the shunt coils, and the connections of the *series coils* must be reversed.

Reversed Field Magnetism.—This is sometimes caused by the nearness of other dynamos, but is generally due to reversed connections of the field coils. Under such conditions the field coils tend to produce a polarity opposed to the magnetization to which they owe their current, and therefore the machine will refuse to excite until the field connections are reversed, or a current is sent from another dynamo or a battery through the field coils in a direction to produce the correct polarity in the pole pieces.

TEST QUESTIONS

1. *Give numerous reasons why dynamo fails to excite.*
2. *Why should the brushes be properly adjusted?*
3. *What is the effect of defective contacts?*
4. *Why should the brushes be given special attention?*
5. *What attention should be given to regulators?*
6. *Why should the speed not be too low in shunt and compound dynamos?*
7. *What is the effect of insufficient residual magnetism?*

8. *How are dynamos affected by open circuits?*
9. *What are the usual causes of open circuit?*
10. *Where are open circuits most liable to occur?*
11. *What causes breaks in the field circuit?*
12. *How are coils prepared?*
13. *What trouble is encountered with partial breaks?*
14. *What kind of dynamo is affected by breaks in the external circuit?*
15. *How are brush holders tested?*
16. *What may be said with respect to wrong connections?*
17. *What sometimes causes reversed field magnetism?*

CHAPTER 29

Armature Troubles

Faults and Their Causes.—A large proportion of the mishaps and breakdowns which occur with dynamos and motors arise from causes more strictly within the province of the man in charge than in that of the designer. The armature, being a complex and delicately built structure, is subject in operation to various detrimental influences giving rise to faults.

Many of the faults which occur are avoided by operators better informed as to the electric and magnetic conditions which obtain in the running of the machine, especially the mechanical stresses on the copper inductors due to the magnetic field and the necessity of preserving proper insulation.

The chief mishaps to which armatures are subject are as follows:

1. Short circuits;
    - *a.* In individual coils;
    - *b.* Between adjacent coils;
    - *c.* Through frame or core;
    - *d.* Between sections of armature;
    - *e.* Partial short circuits.
2. Grounds;
3. Breaks in armature circuit.

Short Circuit in Individual Coils.—This is a common fault, which makes its presence known by excessive heating of the armature, flashing at the commutator, flickering of the light on lighting circuits, and by a smell of burning varnish or overheated insulation. When these indications are present, the machine should be stopped at once, otherwise the armature is liable to be burnt out.

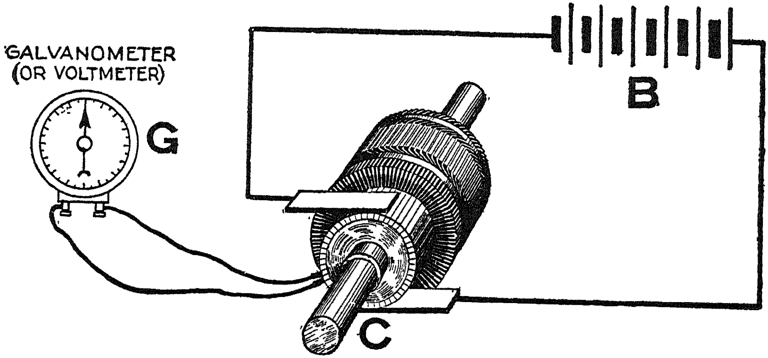


Fig. 887.—Method of locating short circuited armature coil. Disconnect the external and field circuits from the armature, and pass a large current—say from 20 to 100 amperes—from a battery B, or another dynamo through the whole armature by means of the brushes. Then, having previously well cleaned the commutator, measure the difference of pressure between adjacent segments all round the commutator C, by means of a voltmeter or galvanometer G, the terminals of which are connected to adjacent segments, as shown. The short circuited coil or coils will be located by the difference of pressure between the corresponding segments being little or nothing. It may be remarked, however, that this is not always a decisive test. In some cases the short circuit may be intermittent, or may disappear as soon as the armature ceases to rotate. In such cases, the short circuit is caused by the wire coming into contact through the action of the centrifugal forces developed by the rotation of the armature.

The fault is due either to metallic dust lodging in the insulation between adjacent bars of the commutator, or to one or more convolutions of the coils coming into contact with each other, either through a metallic filing becoming embedded in the insulation or damage to the insulation.

Ques. How is the faulty coil located?

Ans. When the machine is stopped, the faulty coil, if not burnt out, can generally be located by the baked appearance of the varnish or insulation, and by its excessive temperature over the rest of the coils.

Ques. What should be done if the machine do not build, and it be suspected that the fault is due to short circuited armature coils?

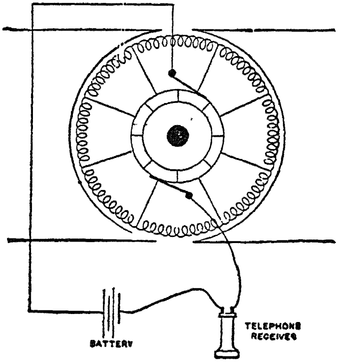


FIG. 888.—Test for break in armature lead. Clean the brushes and commutator, and apply current from a few cells of battery having a telephone receiver in circuit as shown in the figure. If the machine have more than two brushes, connect the leads to two adjoining brushes and raise the others. Now rotate the armature slowly by hand and there will be a distinct click in the receiver as each segment passes under the brushes until one brush bears on the segment at fault, when the clicking will cease. In making this test, the brushes must not cover more than a single segment.

Ans. The field magnets should be excited by the current from a storage battery or another dynamo, and, having raised the brushes from contact with the commutator, the armature should be run for a short time. In stopping, the faulty coil or coils may be located by the heat generated by the short circuit.

When the dynamo is started for the purpose of localizing a short circuit, precautions should be taken, and the machine only run for a few minutes at a time until the faulty coil is detected.

When the faulty coil has been located, the insulation between the segments of the commutator to which its ends are connected should be carefully examined for anything that may bridge across from segment to segment, and scraped clean. If the commutator be apparently all right, the fault probably lies in the winding. The insulation of the winding should be carefully examined, and any metallic filings or other particles discovered therein carefully removed, and a little shellac varnish applied to the faulty part.

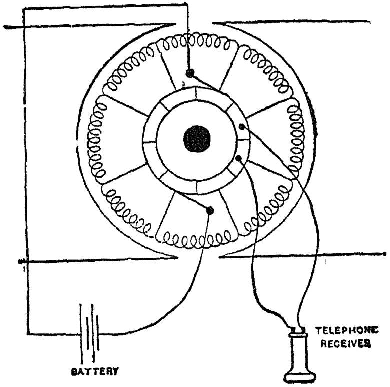


FIG. 889.—Bar to bar test for open circuit in coil or short circuit in one coil, between segments. If, in testing as in fig. 888, on rotating the armature completely around, the receiver indicate no break in the leads, connect the battery leads directly to the brushes, as shown in the above figure, and touch the connections from the receiver to two adjacent bars, working from bar to bar. The clicking should be substantially the same between any two commutator bars; if the clicking suddenly rise in tone between two bars, it indicates a high resistance in the coil or a break (open circuit).

Ques. If the insulation on adjacent conductors has been abraded, how should it be repaired?

Ans. A small boxwood or other hardwood wedge, coated with shellac varnish should be driven in tightly between the wire; this will generally be sufficient.

Ques. If a faulty coil cannot be quickly repaired and the dynamo be needed, what should be done?

Ans. The coil may be cut out of circuit, and the corresponding commutator segments connected together with a piece of wire (of a size proportionate to the amount of current to be carried), soldered to each. It will not be necessary to cut out and remove the entire coil.

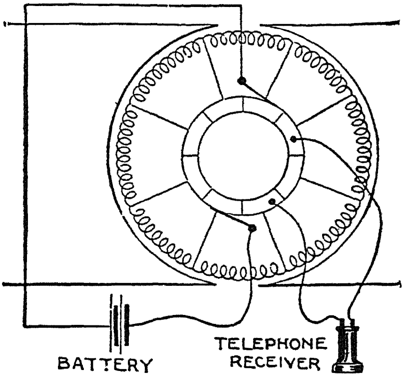


FIG. 890.—Alternate bar test for short circuit between sections. Where two adjacent commutator bars are in contact, or a coil between two segments becomes short circuited, the bar to bar test described in fig. 889 will detect the fault by the telephone receiver remaining silent. If a short circuit be found, the leads from the receiver should then include or straddle three commutator bars, as here shown. The normal click will then be twice that between two segments until the faulty coils are reached, when the clicking will be less. When this happens, test each coil for trouble and, if individually they be all right, the trouble is between the two. To test for a ground, place one terminal of the receiver on the shaft or frame of the machine, and the other on the commutator. If there be a click it indicates a ground. Move the terminal about the commutator until the least clicking is heard and at or near that point will be found the contact. Grounds in field coils can be located in the same manner.

If the active portions only be separated so that they do not form a closed circuit, it will answer the purpose. If the wires be cut with a chisel at the point where they pass over the ends of the core, and the ends separated, it will be quite as effective as removing the entire coil. It is wise, of course, to rewind the coil at the first opportunity.

Short Circuits between Adjacent Coils.—In ring armatures the presence of this fault does not necessarily imply that the machine will not build; in drum armatures, wound into a single layer of inductors, it entirely prevents this occurring.

Reference to a winding diagram will show that adjacent coils are during a certain period of the revolution at the full difference of pressure generated by the machine. Hence, if any two adjacent coils be connected

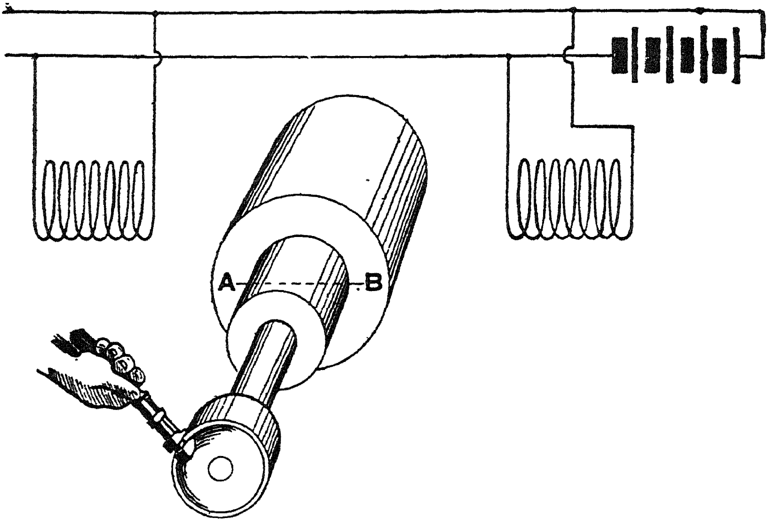


FIG. 891.—Method of locating short circuits between adjacent armature coils. Fasten a monkey wrench to the rim of the pulley, or a crank to the shaft. Now, excite the fields, and, to make the effect more marked, connect the coils in parallel. When this has been done it will require considerable force to rotate the armature, and then it will move quite slowly, except at one position. When this position has been found, mark the armature at points in the center of the pole pieces at points A and B, and at both ends of the armature. The explanation is that both halves of the armature oppose one another at this position; but when not at these points a continuous circuit is formed, and the resultant magnetic effect is considerable. The "cross" or "short" circuit is nearly always found on the commutator end in the last half of the winding, where the wires pass down through the first half terminals. This applies to an unequal winding In armatures where the windings are equal, it is as liable to occur at one point as at another. With this method a defect can be found and remedied in a few moments, for it has always been a simple matter to repair it when discovered. These results can be observed in a perfect armature by connecting the opposite sections of the commutator.

together or short circuited, the whole of the armature will be practically closed on itself, any current generated flowing within the armature only.

Large drum armatures wound with compressed and stranded bars and connectors are particularly susceptible to this fault, a slight blow generally forcing one or more of the strands into contact with the adjacent bars, thus short circuiting the armature, and rendering it practically useless so far as the generation of current is concerned.

In this class of short circuit in drum armatures, the method of locating the faulty coil by exciting the field, and running the armature on open circuit, does not apply, for the reason that the whole armature will be heated equally.

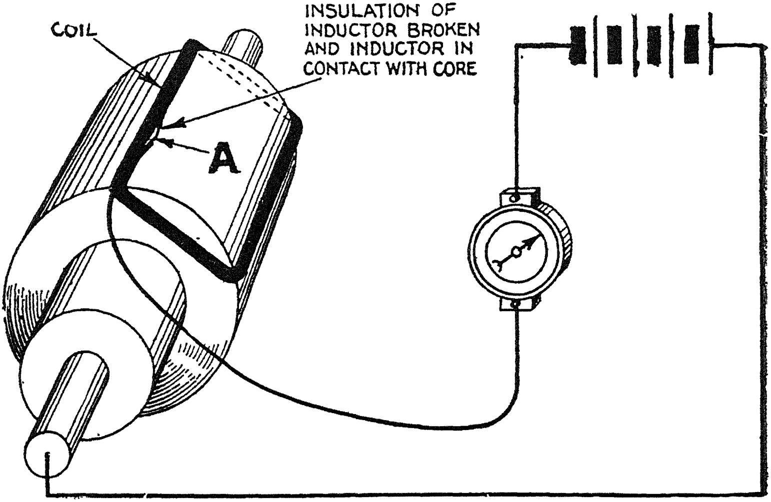


FIG. 892.—Method of locating short circuits between inductor and armature core. The galvanometer, battery and coil to be tested are connected in series as shown, and then the unconnected terminal of the galvanometer is brought into contact with the shaft. If then some portion of the insulation of the wire has been abraded or destroyed, thus bringing the bare wire into contact with the metal core, as at **A**, in the figure, the needle of the galvanometer will be deflected since a closed circuit is formed through the core and wire. If the insulation be perfect, the needle will not be deflected. It will thus be seen that in the conductivity test (fig. 887) it is necessary that the needle should be deflected, or turned, to prove that all is right, while in the insulation test the converse holds good; if the needle be deflected, it proves that the insulation is broken down.

A method of locating such fault is illustrated in fig. 891. This applies to drum wound armatures. Faults of this description can frequently be discovered by a careful inspection of the windings of the armature without recourse to testing.

When located, the fault can usually be repaired with a hardwood wedge, or a piece of mica or vulcanized fibre cemented in place with shellac varnish.

Short Circuits between Inductor and Core of the Armature. —Detection of this fault can be effected by the methods just described above, and by disconnecting the whole of

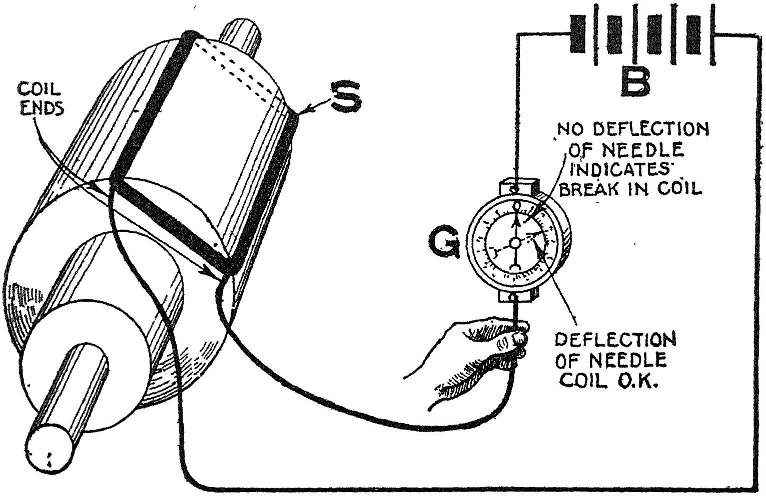


FIG. 893.—Method of testing for breaks. The instruments are connected as shown. B, is the battery, G, the galvanometer, and S, the coil of wire being tested. One terminal of the battery is connected to a terminal of the galvanometer, and the other to one of the ends of the coil under test. The other terminal of the galvanometer is connected to the other end of the coil. If the connecting wires be making good electrical contact with the respective terminals, and the wire of coil being tested be unbroken, the needle of the galvanometer will be deflected as soon as a closed circuit is made by the end of the coil coming into contact with the galvanometer terminal. If the wire of the coil be broken in some part or the ends of the connecting wires do not make good electrical contact with the terminals the needle will not be deflected. In order to prevent mistakes, it is advisable to test the battery and galvanometer connections and contacts by short circuiting or bringing the ends of the wire connecting the terminal of the galvanometer and negative pole or the battery together before starting to test the circuit or coil. If the needle be deflected, the connections are all right; if not deflected, there is a bad contact somewhere, which must be made good before the test can proceed.

the armature coils from the commutator and from each other, and testing each separately with a battery and galvanometer coupled up as in fig. 892, one wire being connected to the shaft and the other to the end of the coil under test. As a rule, there is no way of remedying this fault other than unwinding the defective coils, reinsulating the core, and rewinding new coils.

Short Circuits between Sections through Binding Wires.—This fault is the result of a loose winding, and is caused by the insulation upon which the binding wires are wound giving way, thus bringing coils at different pressures together. As a consequence of the heavy current which flows, the binding wires are as a rule unsoldered or burned.

The location of the fault can therefore be effected by simple inspection. To remedy, it will be necessary to unwind and rewind on new binding wires, on bands of mica or vulcanized fibre, soldering at intervals to obviate flying asunder.

Partial Short Circuits in Armatures.—This is usually due to the presence of moisture in the windings. To remedy the fault, the armature should be taken out and exposed to a moderate heat, or subjected to a current equal to that ordinarily given by the dynamo.

Under the action of heat or of this current the moisture will be gradually dispersed. When thoroughly dry, and while still warm, a coat of shellac should be applied to the whole of the windings.

Burning of Armature Coils.—The reason for the burning of an armature coil may be explained as follows: The coil, segments, and the short circuit between the segments form a closed circuit of low resistance so that it is only necessary to have a low pressure set up in the active portion of the coil to force a very large current through the coil and the short circuited commutator bars. The heating effect of this current is sufficient to burn out the coil.

Cutting Out Damaged Armature Coils.—To cut out a damaged coil from an armature, first, disconnect the coil from the commutator, and after cutting off the leads, insulate the exposed parts with tape. Then connect the commutator bars (which were connected with the leads) with a wire of the same size as the wire winding.

To remove the coil entirely, cut the band wire or remove the wedges, and lift up a sufficient number of leads and coils to permit of the removal of the damaged coil.

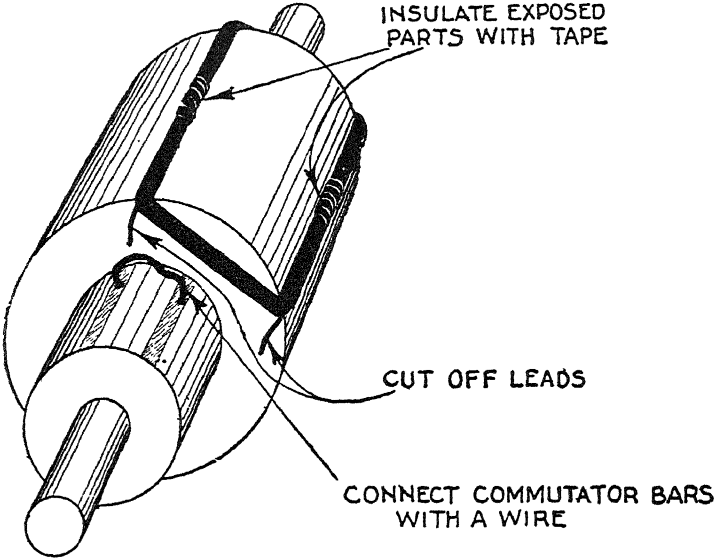


FIG. 894.—Method of cutting out damaged armature coil.

Grounds in Armatures.—These faults occur when the armature coils become connected to the frame or core of the armature. When this grounding is confined to a single coil, it is not in itself liable to do damage. A simple method of locating a grounded coil is illustrated in fig. 895.

Ques. **What is the advantage of this test?**

Ans. The damaged coil can be located without unsoldering the coils from the commutator, which is sometimes a difficult operation without proper tools; further, the fault can frequently be repaired without disconnecting any of the wires if its exact position be determined.

Magneto Test for Grounded Armatures.—A magneto test

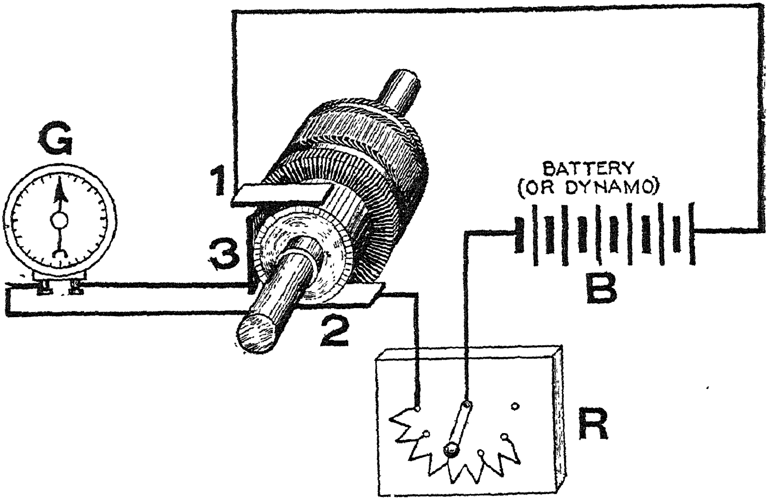


Fig. 895.—Method of locating grounded armature coil. B, is a battery or dynamo circuit giving a current of a few amperes through the armature by its own brushes (1 and 2). At G, is placed a roughly made galvanometer, to carry some 25 amperes or so, one terminal being in connection with the shaft of the armature, and the other attached to a movable brush 3. Since the function of the particular galvanometer is simply to show a deflection when a current is passing, and to mark zero when there is none, a coil of thick wire with a pocket compass in the center will do all that is required, but care must be taken to remove it sufficiently far away from the disturbing effects of the armature magnetism. The manner of testing is as follows: Assume a steady current to be flowing from battery B, through the armature; touch the commutator with brush 3, and a current will flow through G. Slowly rotate the armature or the brush 3, until the galvanometer G, shows no deflection. The coil in contact with 3, will be found to be *grounded*. A hand regulator or rheostat R, may be inserted in series with the battery or dynamo circuit to regulate the strength of the current passing.

for grounded armatures is not to be recommended, as armatures often possess sufficient static capacity to cause a magneto to ring even though there be no leak. This is due to the alternating current given by the magneto for when the circuit has capacity it acts as a condenser and at each revolution of the armature of the magneto a rush of current goes out and returns, charging the surfaces of the conductor alternately in opposite directions, and ringing the bell during the process.

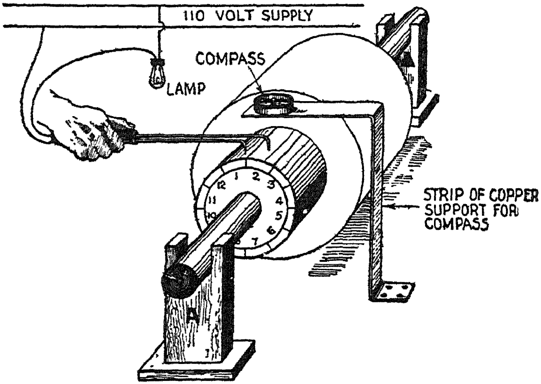
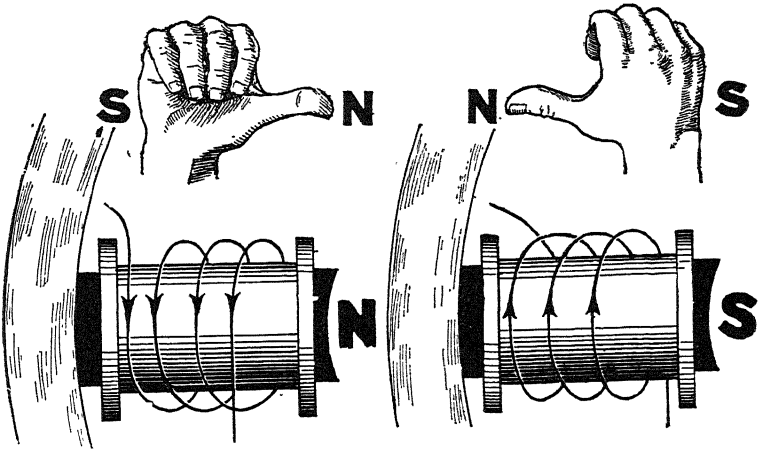


Fig. 896.—Locating reversed coil by use of compass. The armature rests in a support A, that permits of rotating the armature as the test progresses. A strip of copper is bent over the armature, as indicated, and a compass placed upon it. Current from an incandescent lamp test circuit is then applied to adjacent commutator bars that are connected to the coils that lie in the slot that is immediately under the compass. Assume that the compass needle is deflected to the right on touching bars 1 and 2, and bars 2 and 3, there being two coils per slot. Rotate the armature until the next slot comes under the compass and touch the test points to bars 3 and 4, and then to bars 4 and 5, and so on all round the commutator. The compass deflections obtained should be always in the same direction. Any pair of adjacent bars touched by the test points causing a reversed deflection, includes a coil, the leads of which have been brought down to the commutator in reversed order. In order to test the effectiveness of the method, it is necessary to only apply the test points to adjacent commutator bars in reversed order and observe that the compass deflection is thereby reversed.

Breaks in Armature Circuit.—A partial or complete break in the armature circuit is always accompanied by heavy sparking at the commutator, but not, as a rule, by an excessive heating of the armature or slipping of the belt, and this enables the fault to be distinguished from a short circuit. The faulty part can always be readily located by the "flat" which it produces upon the surface of the commutator. The armature circuit being open at the faulty part, heavy sparking results at every half revolution as the brushes pass over it, and as a consequence the corresponding segments become "pitted" or "flattened" with respect to the others; they may easily be discovered on examination.



FIGS. 897 and 898.—Polarity of field coils. ***Whatever be the number of poles, adjacent poles must always be of different polarity.*** A fault in this respect affects the working of the machine, thus the greater the number of wrongly connected poles and the less will be the inductive effect. The results of wrongly connected poles are: 1, too low armature voltage; 2, heavy sparking; 3, internal currents in the armature winding, resulting in heating. ***Hand rule for polarity:*** If the coil be grasped in the right hand, so that the fingers point in the direction in which the current is flowing in the wires, the thumb extended will point in the direction of the north pole.

Breaks in the armature circuit may occur in either the commutator or in the coils of the armature. To ascertain whether it be in the latter, carefully examine the winding of the faulty coil.

The defect may be sought for more particularly at the commutator end of the armature, as breaks in the wire are most frequent where the

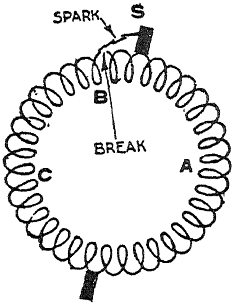
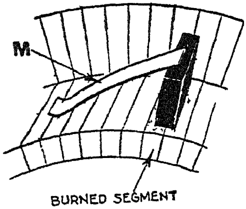


FIG. 899.—Effect of break in armature wire. If the armature wire be perfect, that is, without a break, the current passing in through the upper brush will divide into two equal parts, and one half will flow through the one side and the other half through the other side of the winding; these halves will meet at the lower brush. If there be a break as indicated at B, then the only path by which the current can reach the lower brush is through side A. If the current flowing through the armature have a sufficiently high voltage, it will be able to jump over the break at B, as indicated and thus establish a path through the C side of the wire.



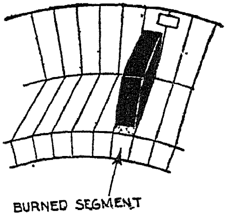


FIG. 900.—Test for break in armature wire. A strip of metal M, is placed against the brush or holder with the end bearing uponthe face of the commutator. If the strip M, be bent so that it can be made to bear upon the commutator some distance ahead of the brush, the machine will generate as long as the strip is in position. By running the armature for a few minutes with the strip in place, the segments connected with the defective wire will be burned and then upon stopping the machine, the broken wire can be located.

FIG. 901.—Repair for broken armature wire. *Bridge the break* by making a connection between the burned segment and the one back of it. This connection can be made by soldering a strip of brass to the two shanks, as shown.

connections are made with the commutator segments. If no break be discovered, try passing a heavy current through the faulty coil by means of the brushes.

If a partial break exist with sufficient contact to pass a current, the coil will be heated at that point and may be discovered by running the fingers over the coil.

When located, the fault may be repaired by rewinding the coil, or carefully cleaning the broken ends and jointing.

The fault may also be temporarily repaired by soldering the adjacent commutator segments together without disconnecting the coil.

TEST QUESTIONS

1. *How are many of the faults which occur in armatures avoided?*
2. *What are the chief faults to which armatures are subjected?*
3. *What indicates a short circuit in individual coils?*
4. *How is a faulty coil located?*
5. *What indicates a short circuit between adjacent coils?*
6. *What kind of armatures are susceptible to this fault?*
7. *What may be said with regard to short circuits between an inductor and core of armature?*
8. *What causes short circuits between sections through binding wires?*
9. *What is the remedy for a partial short circuit in armatures?*
10. *Why do armature coils sometimes burn?*

11. *How are damaged armature coils cut out?*
12. *What causes grounds in armatures?*
13. *What is the magneto test for grounded armatures?*
14. *What is the indication of a partial or complete break in armature circuits?*

CHAPTER 30

Care of the Commutator and Brushes

Conditions for Best Operation.—For satisfactory operation, the brushes and commutator must be kept in good condition. To this end the main thing to be guarded against is the production of sparks at the brushes. If care be taken in the first instance to adjust the brushes to their setting marks, and to regulate their pressure upon the commutator, and afterwards to attend to the lead as the load varies, so that little or no sparking occurs, and also to keep the brushes and commutator free from dirt, grit, excessive oil, etc., the surface of the commutator will assume a dark burnished appearance and wear will practically cease. Under these circumstances the commutator will run cool, and will give very little trouble.

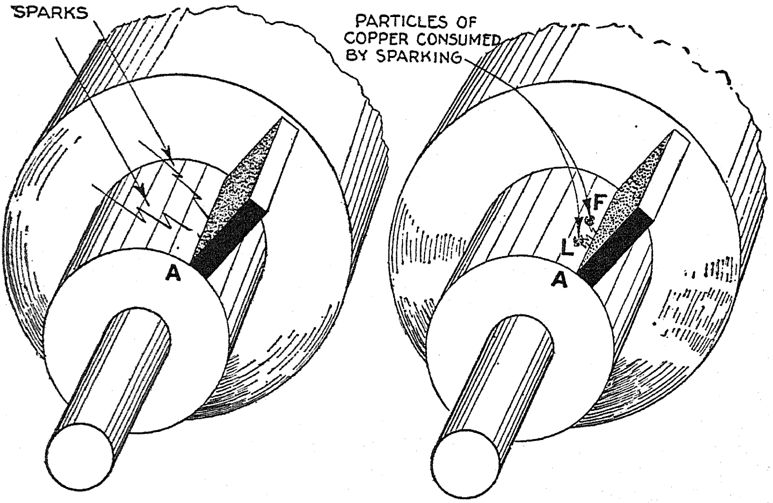
In order to maintain these conditions it will only be necessary to see that the brushes are kept in proper condition and fed forward to their setting marks, as they wear away, and that the commutator is occasionally polished.

If the pressure of the brushes upon the commutator be too great, or their adjustment faulty, or the commutator be allowed to get into a dirty condition, sparking will result, and, if not at once attended to and remedied, the brushes will quickly wear away, and the surface of the commutator will be destroyed.

As this action takes place, in the earlier stages, the surface of the commutator will become roughened or scored, resulting in jumping of the brushes, and increased sparking; in the later stages, the commutator will become untrue and worn into ruts, moreover, owing to the violent sparking which takes place through this circumstance, the machine will quickly be rendered useless.

Ques. How is the commutator easily tested as to the condition of its surface?

Ans. It is readily tested by resting the back of the finger nail upon it while in motion; the nail being very sensitive to any irregularities, indicates at once any defect.



Figs. 902 and 903.—Damage to commutator segments due to sparking. *Each spark burns out a particle of copper from the surface of the commutator*. For instance, fig. 902 shows two sparks as segment A, passes from under the brush, with resulting burns L and F, as shown in fig. 903.

Ques. What causes grooves or ridges to be cut in the commutator?

Ans. They result from using brushes with hard burnt ends which are not pliable; also by too great a pressure of the brush upon the commutator surface.

Sparking at the brushes is expensive and detrimental, chiefly because it results in burning the brushes and also the commutator, necessitating their frequent renewal. Every spark consumes a particle of copper, torn from the commutator or brush. The longer the sparking continues, the greater the evil becomes, and the remedy must be applied without delay.

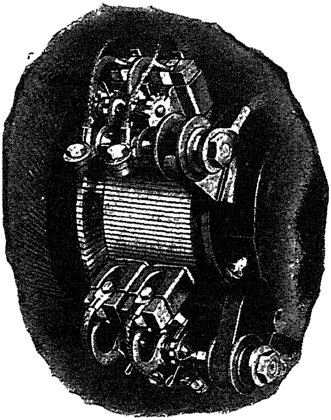


FIG. 904.—Bissell brush gear. The brushes are held in the brush holders radially and work equally well with armature running in either direction. Brushes can be renewed and adjustment made while machine is in operation.

Ques. What attention should be given to the brushes?

Ans. At certain intervals, according to the care taken to reduce sparking and the length of time the machine runs, the brushes will fray out or wear unevenly, and will therefore need trimming. They should then be removed from the brush holders and their contact ends or faces examined. If not truly square, they should be filed or clipped with a pair of shears, the course of treatment differing with the type of brush.

If the machine be fitted with metal strip brushes, frayed ends should be clipped square with a pair of shears, the ends thoroughly cleaned from any dirt or carbonized oil, and replaced in their holders. Gauze and wire brushes require a little more attention.

When their position on the commutator has been well adjusted and looked after, so that little or no sparking has taken place, it is generally only necessary to wipe them, clean the brushes and clip off the fringed edges and corners with the shears, or a pair of strong scissors.

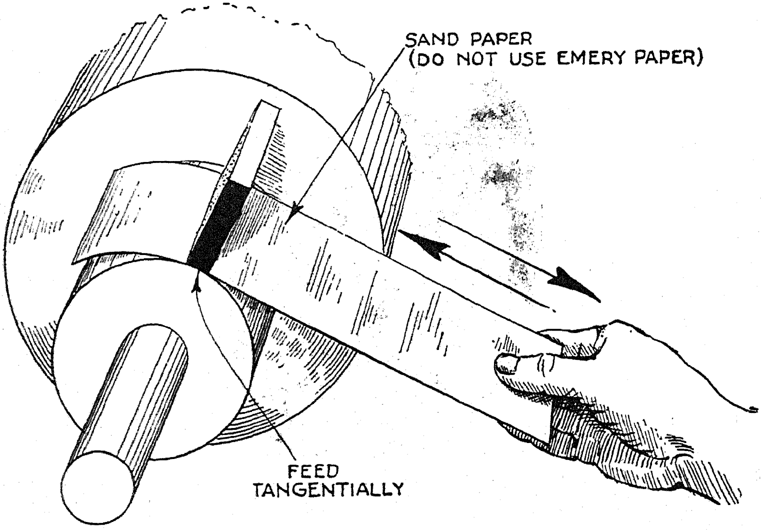


FIG. 905.—Method of truing commutator with a strip of fine sand paper. Do not use emery paper.

If, however, the machine has been sparking, the faces will be worn or burnt away, and probably fused. If such be the case, they will need to be put in the filing clamp, and filed true.

A convenient method of trimming carbon brushes, or of bedding a complete new set of metal brushes, is to bind a piece of sand paper, face outward, around the commutator after the current has been shut off, and then mount the carbon or metal brushes in the holders, adjusting the tension of the springs so that the brushes bear with a moderately strong pressure upon the sand paper. Then let the machine run slowly until the ends of the brushes are ground to the proper form.

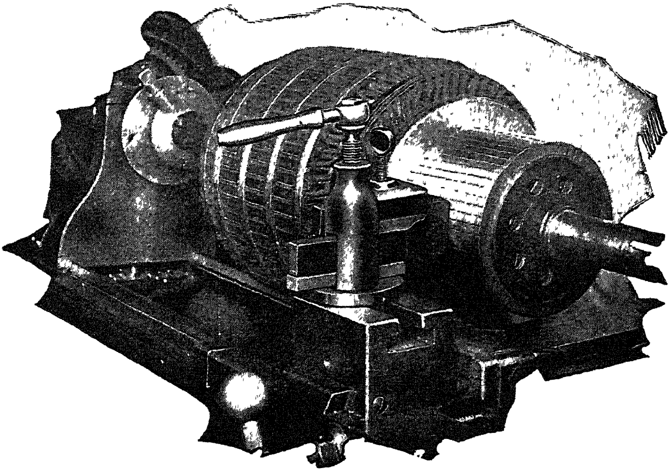


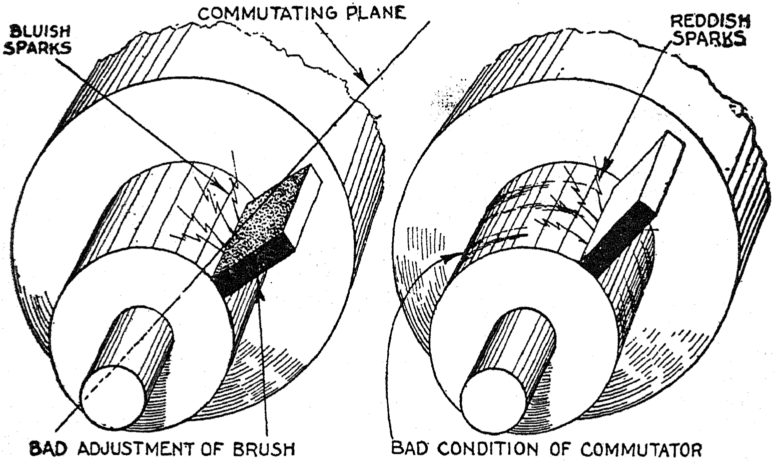
FIG. 906.—Lathe application of Cass commutator smoothing stone. Where it is necessary to remove an armature from a motor for purposes other than truing the commutator a very convenient method is to mount the Cass smoothing stone in a box tool holder made to fit the tool post of a lathe, as shown.

Filing Clamp.—As usually made, it consists of two pieces of metal, both shaped at one end to the correct angle, to which the brushes must be filed. One of the pieces of metal (the back part) has a groove sufficiently large to accommodate the brush, which is clamped in position by the other piece of metal and a pinching screw.

If the clamp be not supplied with the machine a convenient substitute can be made out of two pieces of wood about the same width as the brush. One end of each piece is sawn to the correct angle, and the brush placed between the two.

In filing, the brush is fixed in the clamp, with the toe or tip projecting slightly over the edge of the clamp, and the latter being fixed in a vise, the brush is filed by single strokes of a smooth file made outwards, the file being raised from contact with the brush when making the back stroke.

Sparking.—In all well designed machines *there are certain positions upon the commutator for the brushes at which there will be* ***no sparking*** so long as the commutator is kept clean and in good condition. In other dynamos, badly designed or constructed, sparking occurs at all positions, no matter where the brushes are placed, and in such dynamos it is therefore impossible to prevent this no matter how well they are adjusted.



FIGS. 907 and 908.—Two kinds of sparks due to bad adjustment of brushes and bad condition of commutator.

Ques. What two kinds of sparking may be generally distinguished?

Ans. One kind of sparking is that due to bad adjustment of the brushes, and a second kind, that due to bad condition of the commutator.

Sparks due to bad adjustment of the brushes are generally of a bluish color, small when near the neutral plane, and increasing in violence and brilliancy as the brushes recede from the correct positions upon the commutator.

When sparks are produced by dirty or neglected state of the commutator, they are distinguished by a reddish color and a spluttering or hissing. When due to this last mentioned cause, it is impossible to suppress the sparking until the commutator and brushes have been cleaned. In the former case, the sparks will disappear as soon as the brushes have been rotated into the neutral points.

Another class of sparks appear when there is some more or less developed fault, such as a short circuit, or break in the armature or commutator. These are similar in character to those produced by bad adjustment of the brushes, but are distinguished from the latter by their not decreasing in violence when the brushes are rotated toward the neutral plane.

Having distinguished the classes of sparks which appear at the commutator of a dynamo, it remains to enumerate the causes which produce them. These are:

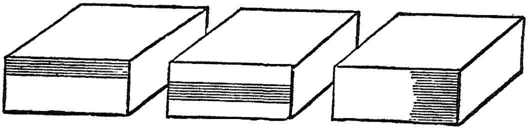
1. Bad adjustment of brushes;
2. Bad condition of brushes;
3. Bad condition of commutator;
4. Overload of dynamo;
5. Loose connections, terminals, etc.;
6. Breaks in armature circuit;
7. Short circuits in armature circuit;
8. Short circuits or breaks in field magnet circuit.

Bad Adjustment of Brushes.—When sparking is produced by bad adjustment of the brushes, it may be detected by rotating or shifting the rocker, by the indication that the sparking will vary with each movement.

To obtain good adjustment of the brushes, it will be necessary to rock them gently backward and forward, until a position is found at which the sparking disappears.

Ques. If, in rocking the brushes, a position cannot be found at which the sparking disappears, what is the probable cause of the trouble?

Ans. The brushes may not be set with the proper pitch, that is, they may not be separated at a correct distance, or the neutral plane may not be situated in the true theoretical position upon the commutator through some defect in the winding, etc.



FIGS. 909 to 911.—Brushes making bad contact. A brush making a bad contact, as only at the shaded portion of figs. 909 and 910, will not allow the short circuited coil enough time to reverse, causing sparking and heating. The latter will also result from bad contact on account of the surface being too small for the current to be carried off. This form of bad contact is worse than that shown in fig. 911, where the area of contact surface only is lessened. If the brushes do not make good contact, they should be ground down.

In this last named case, the brushes may be strictly adjusted to their theoretically correct positions before starting the machine; then, when the machine is started and the load put on, violent sparking occurs, which cannot be suppressed by shifting the rocker.

If, however, one set of brushes only be observed, it will generally be found that, at a certain position, the sparking at the set of brushes under observation ceases or is greatly reduced, while sparking still occurs at the other set. When this position is found, the rocker should be fixed by the clamping screw, and the brushes of the other set at which sparking is still occurring adjusted by drawing them back or pushing them forward in their holders until a position is found at which the sparking ceases.

Correct position of the brushes and the suppression of sparking is a matter of importance, and any time spent in carefully adjusting the brushes will be amply repaid by the decreased attention and wear of the brushes and commutator.

Bad Condition of Brushes.—If the contact faces of the brushes be fused or covered with carbonized oil, dirt, etc., *there will be bad contact which is accompanied by heating and sparking.* Simple examination will generally reveal whether this be the case. The remedy is to remove the brushes, one at a time if the machine be running, clean, file if necessary, trim, and readjust.

If the brushes be exceedingly dirty, or saturated with oil, it will be necessary to clean them with turpentine, benzoline, or soda solution, before replacing.

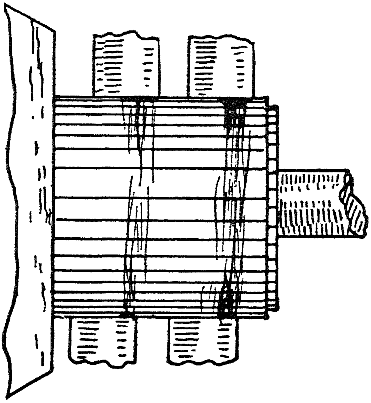


FIG. 912.—Rough and grooved commutator due to improper brush adjustment and failure to keep brushes in proper condition.

Bad Condition of Commutator.—If the surface of the commutator be rough, worn into grooves, or eccentric, or if there be one or more segments loose or set irregularly, *the brushes will be thrown into vibration, and sparking will result.*

A simple examination of the commutator will readily detect these defects. A rough and uneven commutator is due to bad adjustment of brushes, bad construction of commutator, and to neglect generally.

If allowed to continue, it results in heavy sparking at the brushes, and the eventful destruction of the commutator. The fault may be remedied by filing or re-turning the commutator.

Ques. How is an untrue commutator detected?

Ans. An untrue commutator is indicated when the machine is slowed down, by a visible eccentricity, or by holding the hand, or a stick, in the case of a high tension machine, against the surface while revolving, when any irregularity or eccentricity will be apparent by the vibration or movement of the stick.

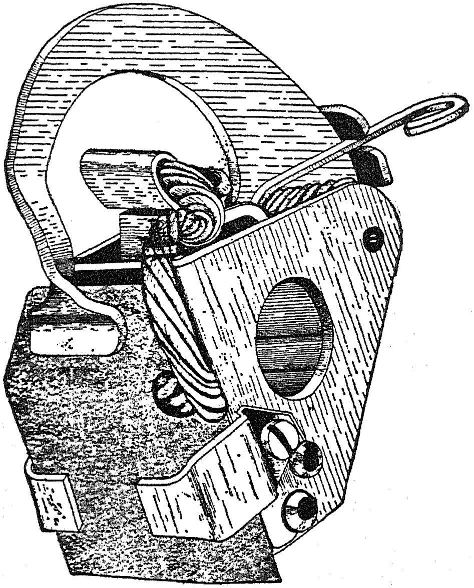


FIG. 913.—Crocker-Wheeler reaction type brush holder with brush.

The only remedy for an untrue commutator is to re-turn it in the lathe.

Ques. What should be done in case of high segments?

Ans. They should be gently tapped down with a mallet, and if possible the clamping cones at the commutator end should be tightened.

If it be impossible to hammer the segments down, they should be filed down to the same diameter as the rest of the commutator, or the commutator re-turned. For low segments, the only remedy is to pull out the segments, or turn commutator down to their level.

Ques. Explain the term "flats on the commutator."

Ans. This is the name given to a peculiar fault which develops on one or more segments of the commutator.

It is not confined to dynamos of bad design or construction, but frequently appears on those of the highest class, and may be recognized as a "pitting" or "flattening" of one or more segments.

Ques. What is the effect of flats on the commutator?

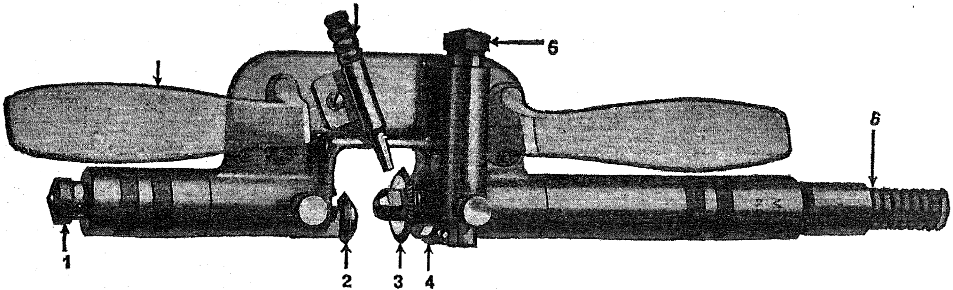
Ans. Sparking at the brushes.

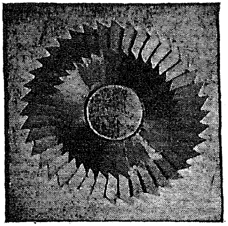
Ques. What are the causes which produce flats?

Ans. Periodical jumping of the brushes due to a bad state of the commutator, bad joint in the driving belt, a flaw, or a difference in the composition of the metal of the particular bar upon which it appears. Frequently flats may be traced to a more or less developed fault, such as a break, either partial or complete, in the armature coil.

The break may occur either in the coil itself, or at the point where its ends make connection with the lug of the commutator, or at the point where the lug is soldered to the segment.

Ques. What should be done in case of flats?





FIGS. 914 and 915.—Imperial undercutter, showing view of V-shaped milling cutter. 1, micrometer screw to adjust V-shaped slot guide; 2, V-shaped roller guide to ride in an adjacent slot to guide the cutter; 3, V-shaped milling cutter which cuts a V-shaped slot. Slotting saws for U-shaped slots may be used if preferred; 4, depth gauge to regulate depth of slot; 5, micrometer screw to adjust depth gauge; 6, flexible shaft operated by ¼ *h.p.*, 1,750 *r.p.m.* motor.

Ans.—The brushes should be examined to see if any periodical vibration take place. If such be the case, the cause should be removed, the flat carefully filed or turned out, and the brushes readjusted.

If it be due to a difference in the composition of the metal of which the segment is made, the flat will exist as long as the particular segment is in use, and will need periodic attention.

With hard drawn copper or phosphor bronze segments, this fault is rarely due to this last mentioned cause. It is more frequently due to bad soldering, of the conductors to the lugs, or of the lugs to the segments. In all cases of flats on the commutator, if the disconnection in the armature circuit be not complete, and cannot be readily located, the effect of re-soldering or sweating the ends of the coils into the lugs should be tried. Flats may also frequently be cured by drilling and tapping a small hole in the junction between the lug and the segment, and inserting a small screw, or bit of screwed copper or brass wire, afterwards filing down level with the surface of the commutator.

Segments Loose or Knocked In.—When the segments are loose, it is an indication that the clamping ring or cone has worked loose. This should therefore be tightened up, and the commutator re-turned if necessary.

Ques. How should low commutator segments be treated?

Ans. The commutator surface may be turned down to the level of the low segment, or the latter may be pulled out again to its former level, this latter being the preferable method, if it can possibly be effected.

Ques. How is a commutator segment pulled out to its correct position?

Ans. A hand vise is firmly clamped to the lug, or a loop of copper wire is passed round the conductor where it joins the commutator.

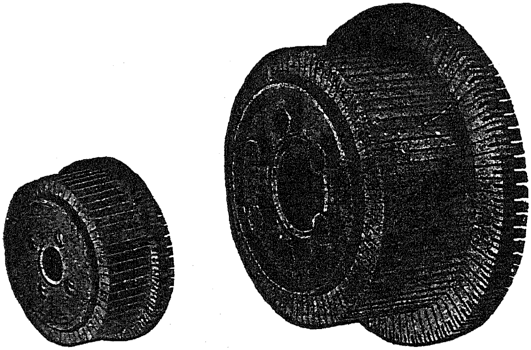
A bar of iron, to act as a lever, is supported on a fulcrum over the commutator, and one end of the bar is passed through the loop or vise. Pressure is applied to the other end which will generally bring the segment up to its proper position.

NOTE.—***Adjustment of brushes and brush rigging.*** To obtain proper brush spacing set up the studs with brush holders in place, and wrap the commutator with a long strip of paper covering its whole circumference. Mark the lapping point of this paper. Remove the paper. Spread it out on a flat surface and divide the space between the marked "lapping points" into as many equal divisions as there are main poles on the dynamo. Replace the paper around the commutator and adjust the brush studs until the toes of the brushes of the different studs just touch these marks. Bolt the brush holders, being careful not to change the position of the studs. Mount the brush holders on the studs. Instructions are usually attached on tag to brush rigging. Parallelism of the studs and commutator segments should be checked if these become warped, sprung or swollen. All brush holders should be at the same distance from the commutator, not over ⅛ in. at the inboard and outboard ends, and the toes of all brushes on one stud should line with the edge of one segment. If a stud be out of line in either of these directions, file the insulating collars to correct it.

Care of Commutators.—The surface of a commutator should always be kept free of carbon and copper dust. A commutator can be best cleaned by rubbing a kerosene soaked flannel cloth over its surface.

Never apply kerosene or any other combustible while machine is running, as sparking at the brushes will ignite it.

Avoid using so called commutator compounds, as they will ruin a commutator in a very short period.



Figs. 916 and 917.—Bissell commutators. The segments are of hard drawn copper and are insulated from each other and from the shell by mica.

From time to time the commutator should be wiped with a piece of canvas lubricated slightly with a small quantity of vaseline or sperm oil.

If these be not obtainable a good grade of light lubricating oil can be substituted, but lubricants should be used sparingly and the commutator should never be left in a greasy condition.

Cotton waste should never be used.

How to Re-turn a Commutator.—In re-turning the commutator, the armature should first be carefully taken out of the armature chamber, avoiding knocks or blows of any kind. The whole of the winding should then be wrapped in calico or

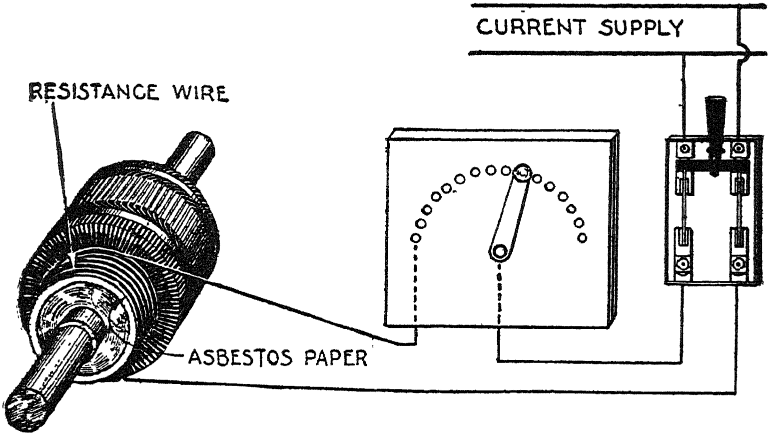
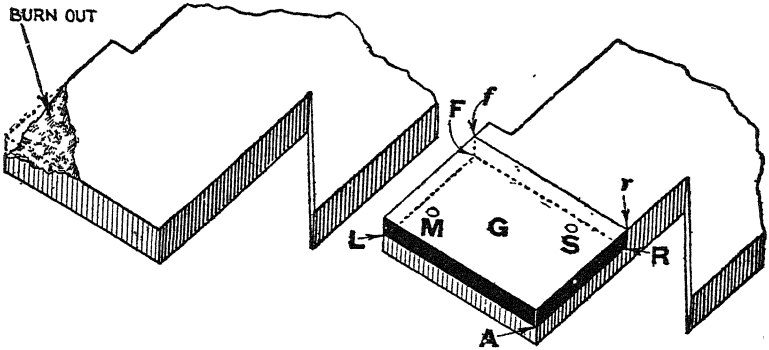


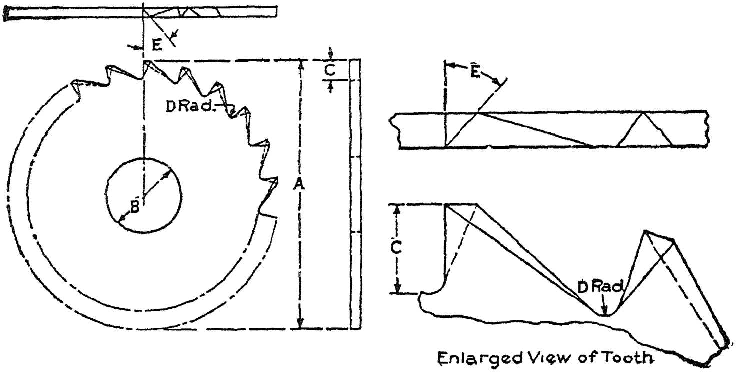
FIG. 918.—Method of baking commutator. Cover commutator with a layer of asbestos paper and wrap around this resistance wire as shown. Connect to main with a rheostat and switch. The heat can be regulated to the desired temperature by means of the rheostat. The size and length of the resistance wire will depend upon the size of the commutator and supply voltage.



FIGS. 919 and 920.—Method of repairing burn out in commutator bar. Fig. 919 shows burn out and fig. 920 repair. File down the bar to the surfaces LARF and fFRr. Carefully fit a copper strip to fill the space removed from bar and sweat the strip to the bar. To prevent possibility of the strip flying out in case the commutator overheat and melt the solder, reinforce the joint with one or more rivets, as at M and S. The cut for a patch of this kind can be quickly made if a milling machine or shaper be handy, otherwise a good sharp file will serve the purpose.

canvas before the armature is put into the lathe, to prevent any particles of metal becoming attached to the surface of the armature at the time the commutator is being turned. The armature should on no account be rolled upon the floor, or subjected to blows or knocks while being put into the lathe.

In re-turning the commutator, a sharp pointed tool should be used with a very fine feed. A broad nosed tool should not be used, as it is liable to burr over the segments.



FIGS. 921 to 925.—Saw for commutator grooving machine. The teeth should be re-sharpened with angles approximately as shown above.

After turning, the commutator should be lightly filed with a dead smooth file, and finally polished with coarse and fine sandpaper. After the commutator has been turned and polished, the insulation between the segments should be lightly scraped with the tang of a small file to remove any particles of metal or burrs which might short circuit the commutator.

The points where the armature wires are soldered to the lugs should also be carefully cleaned with a brush, and should then receive a coat or two of shellac varnish.

While the commutator is being turned, care should be taken that the setting marks for the adjustment of the brushes are not turned out if these be present. The same care should be used in putting the armature back into the armature chamber as was used in taking it out, otherwise the insulation may be damaged.

Brushes.—The ends of all brushes should be fitted to the commutator so that they make good contact over their entire

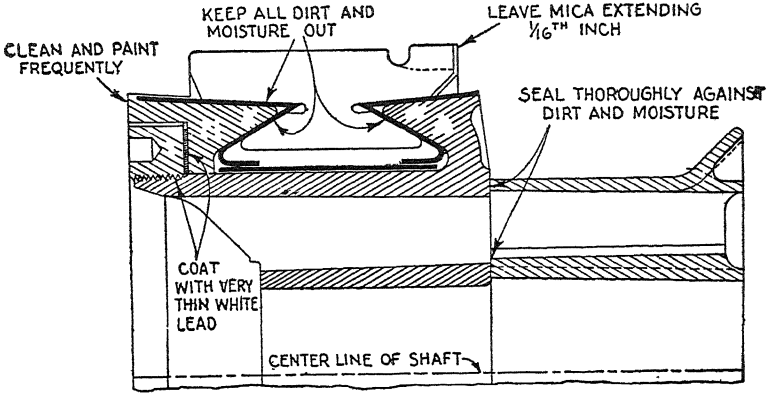


FIG. 926.—Sectional view of railway motor commutator to indicate precautions to be taken for satisfactory operation.

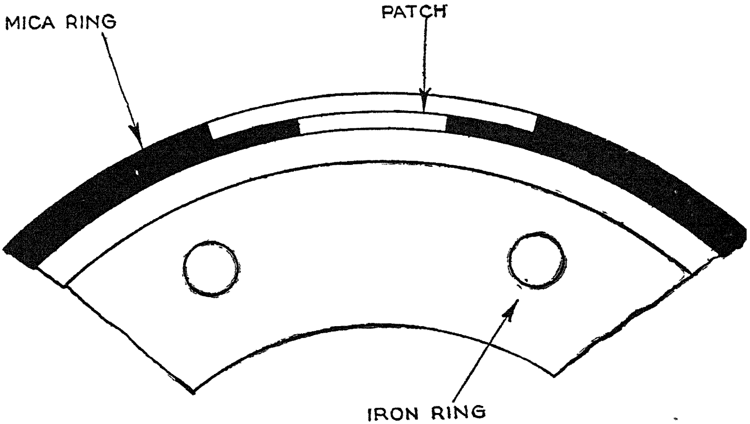


FIG. 927.—Method of patching commutator mica and ring. Sometimes the mica ring on the rear end is punctured. In that event a number of bars in the neighborhood of the ground will have to be taken out. The burned mica should be cut out and a patch put on. When the trouble occurs on the front end of the commutator, remove the ring and cut out the bad mica. The patch can be made as here shown. This new mica must be a trifle thicker than the original mica removed, for it will squeeze together somewhat when the ring is drawn up tight and the commutator heated. After the repair, test the commutator for grounds.

bearing face. This can be most easily accomplished after the brush holders have been adjusted and the brushes inserted. Lift a set of brushes sufficiently to permit a sheet of sandpaper to be inserted.

Lubrication.—The bearings of all machines which are in constant use should be flushed out with kerosene, and fresh oil replaced, monthly.

Never use any oil that has been used in bearings before as it contains fine particles of metal which will cause undue wear on the shaft and bearings.

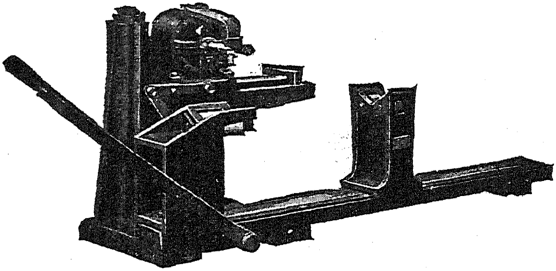


FIG. 928.—General Electric commutator grooving machine; stationary model. ***In construction,*** the rotating saw is mounted on the end of the motor shaft which is extended and supported by an offset bearing, which readily permits the grooving of commutators having ears. Owing to the small size of the motors used with these machines, no starting resistance is necessary.

The bearings should and must be kept free and clean from grit, all foreign substances should be removed.

If the machine be new, the oil should be drained out after the first week's run and replaced with fresh, clean oil.

The oil rings should be carefully watched to see that they revolve freely and carry sufficient oil to the shaft.

Ques. Should the commutator be run without any lubricant?

Ans. In most cases it will be found that a little lubricant is needed in order to prevent the brushes cutting the commutator; this is especially the case when hard strip brushes are used.

The quantity of oil applied should be very small; a few drops smeared upon a piece of clean rag, and applied to the commutator while running, being quite sufficient.

Ques. What kind of oil should be used on the commutator?

Ans. Mineral oil, such as vaseline, or any other hydrocarbon.

FIG. 929.—Commutator hand scraper. This tool is for removing mica fins which are left in the slot by the grooving saw. A triangular curved file is sometimes used for removing the copper projections, but the removal of a very thin portion of the commutator surface by turning in a lathe, using a special high speed steel tool (trade name No. 3 Stellite) is recommended. The remaining copper burr left on the trailing edge of each commutator bar can be removed by the hand scraper above illustrated. A final polishing with sandpaper will make a smooth surface which is necessary for good commutation and long life of brush.

Animal or vegetable oils should be avoided, as they have a tendency to carbonize, and thus cause short circuiting of the commutator, with attendant sparking.

Short Circuits in Commutator.—These are of frequent occurrence, and result in heating the armature and sparking at the brushes. They are caused either by metallic dust or particles lodging in the insulation between the segments, or by the deterioration of the commutator insulation.

To remedy, the insulation between the segments should be carefully examined, and any metallic dust, filings, or burrs cleaned or scraped out. When the commutator is insulated with asbestos or pasteboard (as is often the case in dynamos of European make), short circuits very frequently occur through the insulation absorbing moisture or oil, which is subsequently carbonized by the sparking at the brushes.

In faults of this description the only remedy is to expel all moisture from the commutator insulation by means of heat, and scrape out all metallic dust which may be embedded in the surface of the insulation. If this do not effect a cure, it will be necessary to dig out the insulation, as far as possible, with a sharp tool, and drive in new insulation.

Oil should not be used on commutators insulated with these materials, but only asbestos dust or French chalk.

Burnt Mica.—Trouble is sometimes experienced from the burning out of mica insulation between segments.

This is most commonly caused by allowing the mica to become oil soaked or by the bars loosening and thus allowing foreign conducting material to work its way in between them. It is rarely, if ever, definitely traced to excessive voltage between bars. When this burning does occur it may be effectively stopped by scraping out the burned mica and filling the space with a solution of sodium silicate (water glass), or other suitable insulating cement.

The commutator assembly bolts should be frequently tested, if found to be loose, they should be tightened. In tightening up commutator bolts, do not tighten one bolt as far as it will go, but tighten all bolts evenly so that the tension of end plate will be uniform all around.

NOTE.—*So urgent* was the need of positive and dependable insulation that more than twenty-five years ago many scientists were busily engaged in experimentation with various materials, searching untiringly for the substance, or combination of substances, that would incorporate the qualities recognized as so essential. Progress was slow and disappointments many, but in time certain of these pioneers demonstrated that they were on the right track, and were rewarded by eventual success.

NOTE.—*Pure mica* had been found admirably suited in nearly all respects for insulating service. It is tough and flexible. It can endure high temperatures. It is chemically stable. Its dielectric strength is high and it resists higher puncture voltage than any of the other known insulating materials.

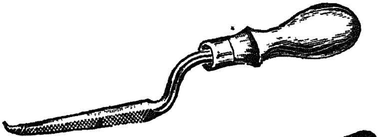
NOTE.—*Mica,* which has become so important in industry because of its excellent insulating capacity occurs abundantly throughout the world in numerous forms and varying degrees of purity. There are "muscovite" or white mica; "phlogopite" or amber mica; "blotite" or black mica; "paragonite" or sodium mica; "lepidolite" or lithium mica; "lepidomelane" or iron mica; "roscoelite" or vanadium mica; and other varieties, but the muscovite of India and phlogopite of Canada excel all others in their purity and uniform quality. These two varieties of mica take front rank over all others because of their purity and uniform physical properties. Impurities in mica occur in the form of very thin films of other substances adhering to the layers of mica. This film is so thin that to the naked eye it looks much as if the layer of mica had been rubbed with a soft lead pencil, but it would be sufficient to conduct electric current and thereby destroy the effectiveness of such a piece of mica for insulating purposes.

Ques. What is the object of undercutting mica?

Ans. The object of undercutting the mica of commutators is to remove the mica between the copper segments so that the segments will wear evenly.

The removal of all the mica between the segments is imperative. Mica is built up of flakes of thin layers, and if the thinnest fin or section is left along the side of the slot, the brushes will be raised off the commutator, causing poor commutation, distinguishable by spitting and burning, exactly as though there were no undercutting at all.

Tools for Undercutting Mica.—Many tools are now on the market, some hand operated and some motor driven, by means of which commutators can be undercut in a workmanlike manner and at reasonable cost. Electrical manufacturers and large shops often have efficient tools for this purpose, designed and built in their own shops. An effective hand tool is the slotting file, illustrated in fig. 929-1. This type of tool cuts a V-shaped



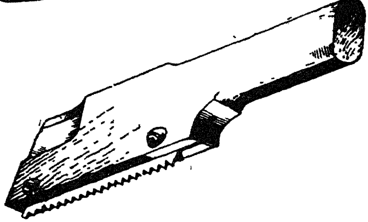


Fig. 929-1.—Showing slotting file for undercutting mica on commutator.

Fig. 929-2.—Showing method of mounting hacksaw blade in holder for undercutting of commutator mica.

slot and can be obtained with either a 40° or 60° angle between the cutting edges. It is an excellent tool for undercutting commutators of moderate size as well as for beveling the edges of square bottom or U-shaped slots.

A piece of hacksaw blade, mounted in a suitable holder, is often used for undercutting where the amount of work to be done does not justify the purchase of special equipment. Such a tool is satisfactory providing a sharp blade which cuts the

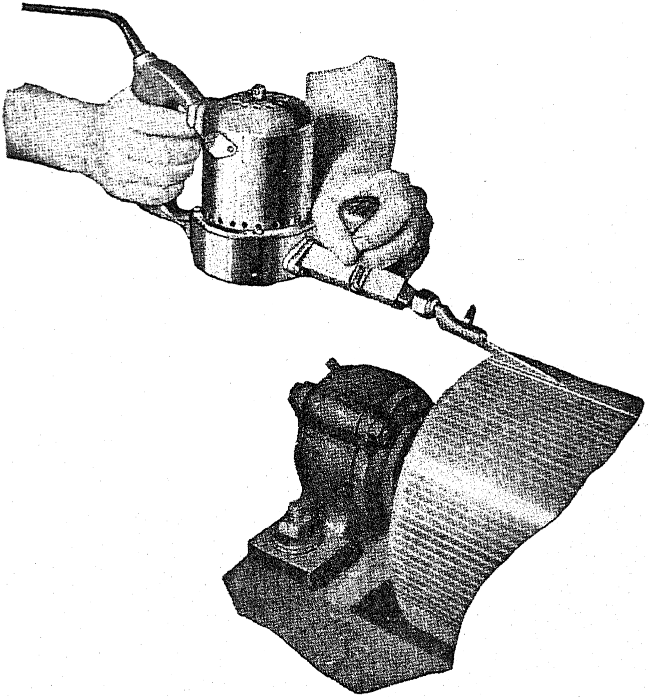


Fig. 929-3.—The reciprocating type undercutter shown requires little clearance between brush arms and cuts close to the commutator risers. As a general rule, the best results will be obtained by supporting most of the weight in the hands so that the file touches the commutator lightly and the motor operates at nearly full speed.

mica freely is always used. If the blade is allowed to become dull it tends to drag the mica from the slot and may be open to the same objection as the hook-shaped scraper previously mentioned.

A motor driven undercutter of the reciprocating type is shown in fig. 929-3. This type tool is easy to guide, cuts rapidly, and permits cutting clear up to the commutator risers. It is suitable for use on commutators of almost any size and has the advantage of requiring little clearance between the brush arms. The cutting blade is a V-shaped file.

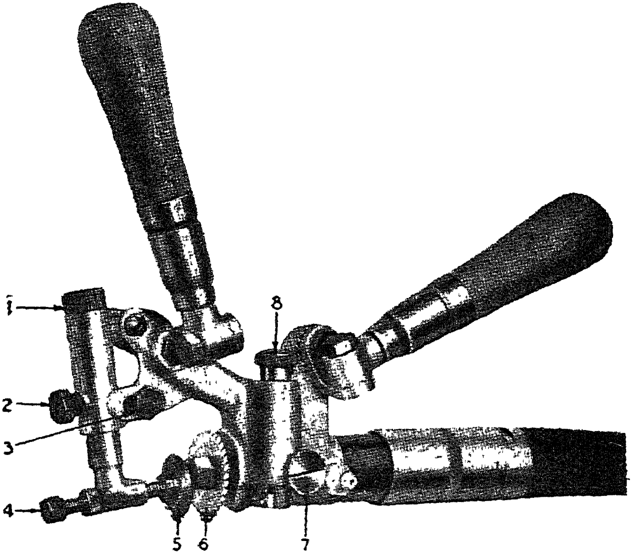
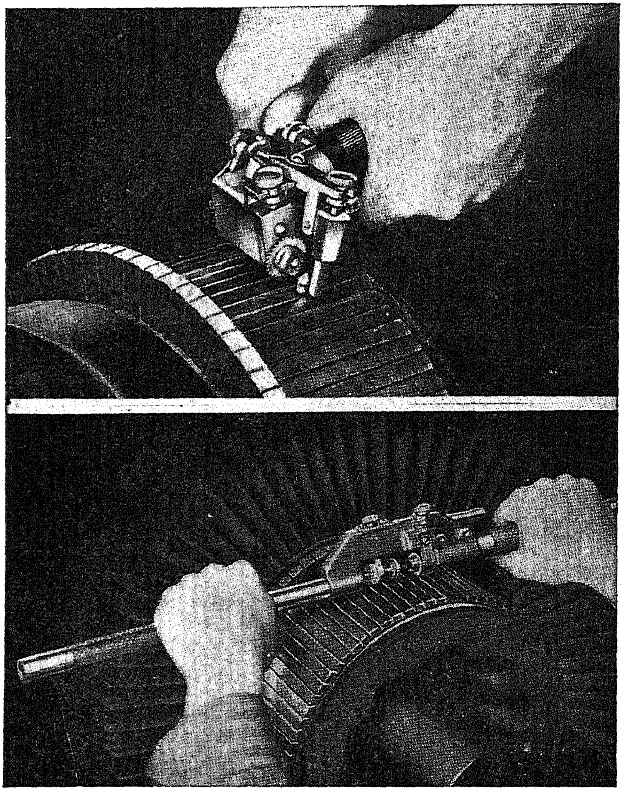


Fig. 929-4.—Typical rotary mica undercutter. Rotary type mica undercutters are generally preferred for their speed and the quality of work performed.

When a large amount of undercutting is to be done, the motor driven, rotary type cutter undoubtedly has preference because of its speed and the quality of work performed. There are many types of machines of this general class on the market. Some are designed for mounting on a lathe or other machine tool. Others are complete shop units, capable of holding an armature on centers, or other type of support, while the commutator is being undercut.



Figs. 929-5 and 929-6.—Showing undercutting of commutator mica with rotary type tools.

Still others are portable, designed for use without removing the armature from its bearings, although some types require the removal of one or more brush arms. In some types the small driving motor is an integral part of the unit, while in other types, the motor is connected to the saw or cutter through the medium of a flexible shaft.

Each type of undercutting tool has certain advantageous features. The type shown in fig. 929-4 illustrates several features that are desirable in undercutting equipment. Adjustable handles can be adapted to the convenience of the operator. Either a V-shaped or a U-shaped cutter (6) can be used. The slot guide wheel (5) has three adjustments, one for vertical position (1, 2), one for commutator curvature (3) and one for bar width (4). A depth gauge (7, 8) maintains uniform depth of slot. A similar machine, with the axis of the flexible shaft at right angles to the cutter axis, is adapted to use where there is limited clearance between brush arms. Standard cutters are available from .015 in. to .045 in. in thickness.

Before beginning the work of undercutting, the commutator surface should be turned, ground or stoned, as its previous condition may dictate. All grooves, ridges, eccentricity, flat spots, and other surface faults should be eliminated and except for final polish, a true cylindrical surface established. *No lubricant of any kind should be used in undercutting and lubricant should not be applied to a commutator that has been undercut.* The presence of oil or grease may result in an accumulation of carbon or copper dust in the slots, causing short circuits and damage to the armature coils.

For a similar reason, artificially lubricated brushes from which any oil or wax may be driven in the course of operation should not be used on a slotted commutator. Where oil may creep in from the bearings or where the machine operates in a moist, oily or dirty location, it is often advantageous, after slotting, to coat the slots with a good air-drying, insulating varnish. After this is thoroughly dry, it should be removed from the outer surface of the commutator with sandpaper or a commutator stone.

Form of Slots.—The question of preferable slot form has led to a great deal of discussion. The square bottom or U-shaped slot, fig. 929-7, has the advantage, when the work is carefully done, of being effective until the commutator has worn down the full depth of the undercut. Since non-abrasive brushes are now used on most undercut commutators, the need for frequent re-slotting is avoided. However, accumulated dust is not thrown out from the U-shaped slot by the action of centrifugal force as readily as it is from the V-shaped slot. It is best not to cut U-shaped slots deeper than 1/32 inch, or at most 3/64 inch for mica of average thickness.

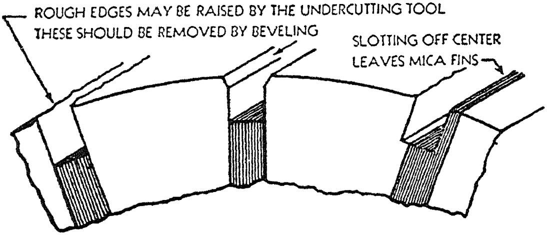


FIG. 929-7.—Showing U-shaped commutator slots. The depth of U-shaped slots should not appreciably exceed the thickness of the mica. Bar edges should be beveled and all mica fins removed. This beveling accomplishes two things; it removes the burrs caused by the stone dragging copper over the slots, and eliminates the sharp edge at the entering side of the bar under a brush. The bevel on the bars is done with a special beveling tool and should be about 1/32 chamfer at 45 degrees, for medium thickness of bars. For thinner or wider bars, the beveling can be changed accordingly.

When cutting U-shaped slots with a rotary cutter it is impossible to prevent the cutter from coming in contact with the sides of the bars, and wherever this occurs, some of the copper is cut or dragged off. Sometimes the dragging or tearing action is pronounced. This leaves jagged edges on the commutator segments and also has the effect of cold-drawing on the side of the bar, which causes a hardening of the copper at that point.

No matter how carefully the surface of the commutator may be smoothed or polished after slotting, there is a knife edge of hardened copper at the edges of each bar. This hardened edge will not wear down uniformly with the softer center of the bar and after a time will have a tendency to cause the bar edges to act as scrapers against the brush face. It is, therefore, advisable always to bevel the edge of the commutator bars as indicated in fig. 929-7. A beveled face of about 1/64 inch is usually sufficient to remove any roughness or edge hardening that might be disturbing to the brush faces. A slotting file, like that shown in fig. 929-1 or a suitable shaped scraper is an effective tool for this purpose.

It is also highly important to see that no fins of mica are left along the sides of the slots. Often the undercutting tool does not follow the line of the mica perfectly, leaving thin edges of uncut mica in the slots. This faulty condition is sometimes described as *feather-edge mica.* These mica fins may prove almost as troublesome as an unslotted commutator. After undercutting, every slot should be closely inspected and all mica fins removed with a knife blade or other suitable tool.

V-shaped slots are usually cut either with a slotting file or with a V-tooth rotary cutter. The latter are available with a 40°, 50° or 60° angle between the cutting edges; 40° cutters are generally preferred for thin mica; 50° for medium mica and 60° for thick mica. A cut 1/16 inch deep and accurately centered on the mica will leave 1/32 inch free copper above the mica if a 40° cutter is used on .023 inch mica; a 50° cutter on .029 inch mica or a 60° cutter on .036 inch mica.

It is very important when cutting V-shaped slots to keep the cutter accurately centered on the mica. In the typical example illustrated in fig. 929-8 a departure of less than $\frac{1}{64}$ inch from the center line of the mica would allow a mica fin to reach the commutator surface. Mica fins in V slots, being wedge shaped, are more difficult to remove than the fins of uniform thickness left at the sides of U-shaped slots by inaccurate centering of the cutter. However, the fact that V-shaped slots keep free from deposit at very low speed and do not require a separate operation for beveling of the bar edges, causes this form of slot to be preferred by many operators.

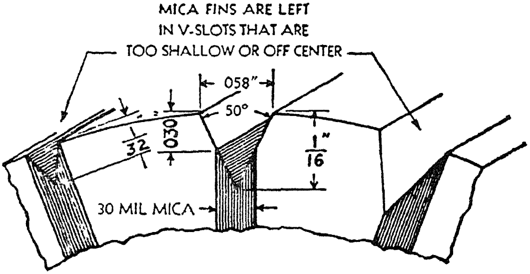
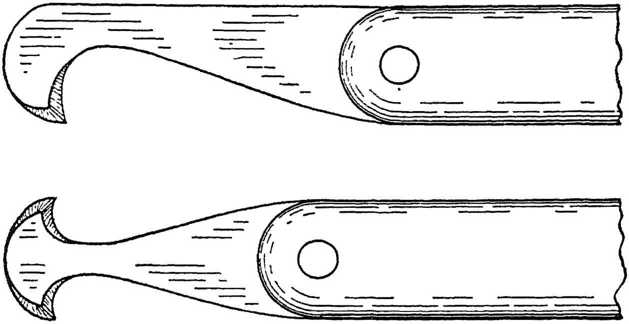


FIG. 929-8.—Showing V-shaped commutator slots. This type of commutator slot has the advantage over the U-shaped slot in that it keeps free of deposits at low commutator surface speeds. It also obviates the necessity for beveling; it requires, however, very accurate centering and workmanship.

Mica Fins.—A frequent source of trouble on undercut commutators is variously described as *feather-edge mica*, *side mica* or *mica fins*. These terms refer to the thin edges of mica often left along the sides of the slots through failure to center the cutter accurately on the mica, deviation from a straight line parallel to the commutator segments, or insufficient depth of V-shaped slots. Commutator wear may also reach mica fins not in evidence immediately after undercutting.

Troubles traceable to feather-edge mica are encountered with such frequency on commutating equipment, and the cause is so often overlooked in the search for less tangible faults, that the avoidance of this condition justifies special care. It results in difficulties of the same type as those encountered on non-undercut commutators when the mica becomes "high". In fact, it may be even more troublesome than ordinary high mica due to the tendency for small particles of mica to break loose and become embedded in the brush faces. Sparking, bar burning, picking up of copper by the brush faces and noisy operation are among the operating difficulties often traced to this fault.



Figs. 929-9 and 929-10.—Typical hand tools for removal of mica fins.

After undercutting the commutator, or whenever faulty operation indicates the possible presence of feather-edge mica, every slot on the commutator should be inspected carefully. If mica fins are detected, they should be removed with a knife blade or other suitable tool.

An effective tool for this purpose can be made by grinding a hook-shaped cutting edge at the end of a hacksaw blade and attaching a suitable handle. This type of tool can be drawn through the slot, as illustrated in fig. 929-11, cutting at the root of the side mica on one side and slightly chamfering the opposite edge of the slot at the same time. Of course frequent resharpening will be necessary to insure complete removal of the mica. After completing this operation the slots and armature windings should be blown out thoroughly to remove all loose particles of mica and copper.

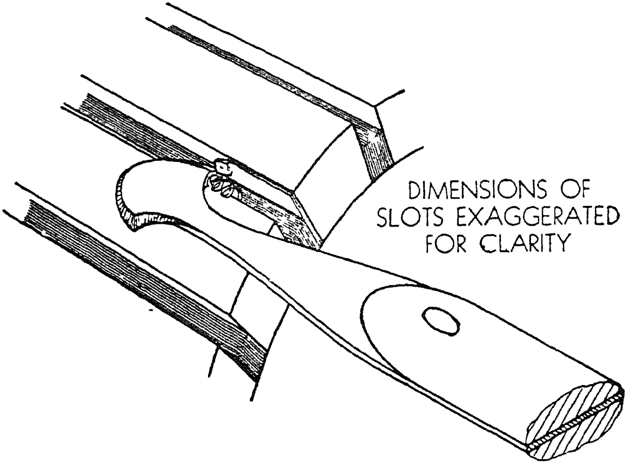


Fig. 929-11.—Illustrating removal of mica fins and chamfering edge of commutator bar with home made tool.

Canvas Wiper.—Another home made device which has proved effective in maintaining good brush performance, is the canvas wiper, fig. 929-12. Several layers of six- or eight-ounce hard-woven canvas or duck are folded over the end of a strip of strong pliable wood of suitable dimensions and secured by rivets. Counter-sinking the strip at the points where the rivets are inserted reduces the danger of the rivet heads making contact with the commutator.

The canvas is held against the commutator under heavy pressure and rubbed slowly back and forth. This removes oil, grease and smudge from the commutator surface without hazard of the hand coming in contact with live parts of the machine.

Applied with sufficient frequency, it removes the oxidation at bar edges caused by sparking and may forestall the development of serious bar burning. However, it does not destroy the desirable oxide or electrographitic surface film on which good brush performance is largely dependent. Maintenance departments which have adopted the use of the canvas wiper as regular practice have found commutator maintenance greatly reduced.

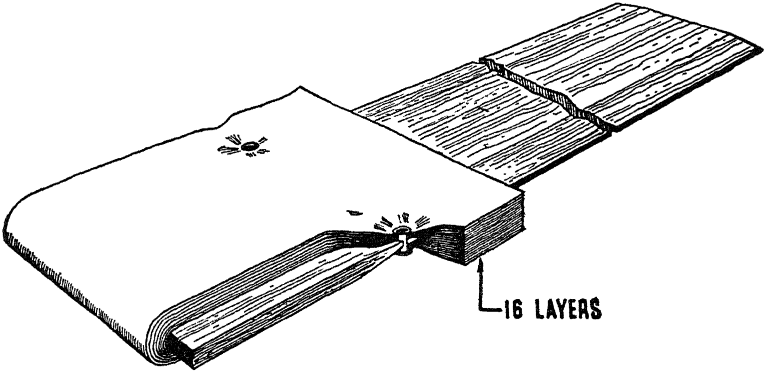


FIG. 929-12.—Illustrating construction method of simple but effective canvas wiper.

Frequency of application depends on the tendency for surface deposit to accumulate. With moderate accumulation, daily application is recommended while more severe conditions may require application at shorter intervals.

This has proved a very effective method of establishing and maintaining a good commutator surface with a minimum of major resurfacing operations.

Appearance of Good Commutator.—A commutator in good condition should be clean, true and smooth and have a medium polish.

The surface should have a stable, copper-oxide-carbon color film (not a bright copper surface) and the mica should be undercut.

The commutator should be kept clean and well polished. If necessary the commutator should be cleaned occasionally with a pad of canvas or other similar hard-woven non-linting material.

FIG. 929-13.—Method of application of canvas wiper to commutator. Holding the strip at right angles to the machine shaft is usually the most convenient method of application on small machines. *(Courtesy National Carbon Company, Inc.)*

TEST QUESTIONS

1. *What are the conditions for best operation of the brushes and commutator?*
2. *How is the commutator easily tested as to the condition of its surface?*
3. *What causes grooves or ridges to be cut in the commutator?*
4. *In the operation of the brushes what should be guarded against?*
5. *How is sparking at the brushes prevented?*
6. *What kind of oil should be used on the commutator?*
7. *When the position of the commutator has been well adjusted what should be looked after?*
8. *What is the ordinary method of truing a commutator?*
9. *Describe two kinds of sparking, and their remedy.*
10. *Name eight causes which produce sparking.*
11. *How is sparking protected when caused by bad adjustment of brushes?*
12. *If, in rocking the brushes, a position cannot be found at which the sparking disappears, what is the probable cause of the trouble?*
13. *Describe three kinds of poor brush contact?*
14. *What happens when the contact faces of the brushes be fused or covered with carbonized oil, dirt, etc.?*
15. *What is the effect on the brushes if the surface of the commutator be rough, worn in the grooves, or eccentric?*
16. *How is an untrue commutator detected?*
17. *What should be done in case of high segments?*

18. *What are "flats on the commutator" and the effect of the same?*
19. *What causes flats?*
20. *How should low commutator segments be treated?*
21. *How is a commutator segment pulled out to its correct position?*
22. *Give some points relating to the care of commutators.*
23. *Describe the method of returning a commutator.*
24. *Why should sand paper be used instead of emery paper in truing a commutator?*

CHAPTER 31

Heating

The excessive heating of the parts of dynamos and motors is probably the most frequent and annoying fault which arises in operation.

When the machine heats, *it is a* ***common mistake*** *to suppose that any part found to be hot is the seat of the trouble.*

Hot bearings may cause the armature or commutator to heat, or vice versa.

All parts of the machine should be tested to ascertain which is the hottest, since heat generated in one part is rapidly diffused. This is best done by starting with the machine cold; any serious trouble from heating is usually perceptible after a run of a few minutes at full speed with the field magnets excited.

Heating may be due to various electrical or mechanical causes, and it may occur in the different parts of the machine, as in:

1. The connections;
2. The brushes and commutator;
3. The armature;
4. The field magnet;
5. The bearings.

Ques. How is heating detected?

Ans. By applying the hand to the different parts of the machine if low tension, or a thermometer if high tension, and also by a smell of overheated insulation, paint, or varnish.

Ques. What should be done if the odor of overheated insulation, paint or varnish be noticeable?

Ans. It is advisable to stop the machine at once, otherwise the insulation is liable to be destroyed.

Ques. What is the allowable rise of temperature in a well designed machine?

Ans. It should not exceed 80° Fahr., above the surrounding air, and in the case of the bearings, this temperature ought not to be reached under normal conditions of working.

If this limit be exceeded after a run of six hours or less, it indicates a machine either badly designed and probably with the material cut down to the lowest possible limit with a view to cheapness, or some fault or other which should be searched for and remedied as early as possible, otherwise the machine will probably be destroyed.

Ques. How should the rise of temperature be measured?

Ans. It is not sufficient to feel the machine with the hand, but special thermometers must be placed on the armature winding, immediately on stopping the machine, covering them with cotton or wool to prevent cooling.

Readings must be taken at short intervals, and continued till no further rise of temperature is indicated.

Heating of Connections.—A rise of temperature of the connections may be due to either excessive current, or bad contacts, or both. The terminals and connections will be excessively heated if a larger current pass through them than they are designed to carry. This nearly always results from an overload of the dynamo, and if this be rectified, the heating will disappear.

If the contacts of the different connections of the dynamo be not kept thoroughly clean and free from all grit, oil, etc., and the connections themselves be not tightly screwed up, heating will result, and the connections may even become unsoldered.

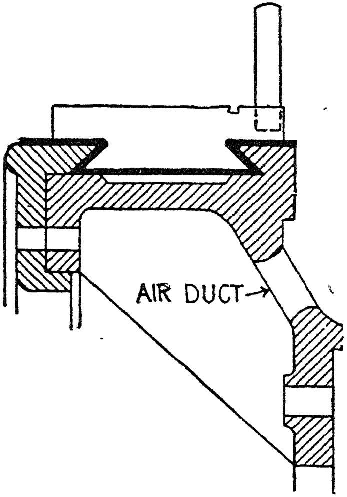


Fig. 930.—Ventilated commutator; sectional view showing air ducts. *Air* is frequently circulated through a commutator in order to maintain it at a sufficiently low temperature, suitable openings being provided for this purpose as shown.

Heating of Brushes, Commutator and Armature.—When heating occurs in these parts, it may be due to any of the following causes:

1. Excessive current;
2. Hot bearings;
3. Short circuits in armature or commutator;

4. Moisture in armature coils;
5. Breaks in armature coils;
6. Eddy currents in armature core or conductor.

Ques. What may be said with respect to excessive current?

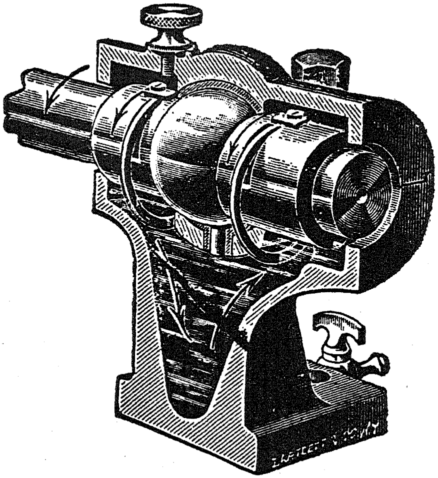


FIG. 931.—Self-oiling and self-aligning bearing. The self-oiling feature consists of rings which revolve with the shaft, and feed the latter with oil continually, which they bring up from the reservoir below. The dirt settles to the bottom, and the upper portion of the oil remains sufficiently clean for a long time, after which it is drawn off, and a fresh supply poured in through holes provided in the top. These latter are often located directly over the slots in which the rings are placed, so that the bearings can be lubricated immediately by means of an oil cup if the rings fail to act or the reservoir become exhausted. The bearing is made self-aligning by providing the bearing proper with an enlarged central portion of spherical shape, held in a spherical seat formed in the pedestal by turning, milling, or by casting Babbitt or other fusible metal around it, thus allowing the bearing to adjust itself to the exact direction of the shaft. The upper half of the box can be taken off to facilitate renewal, etc., and to permit the armature to be removed.

Ans. When a dynamo is overloaded, the temperature of the armature will rise to a dangerous extent, depending upon the degree to which the safe capacity of the machine is exceeded, and heavy sparking of the brushes will also result.

If the overload be not removed, the insulation of the armature may be destroyed.

Ques. State some causes of hot bearings.

Ans. Lack of oil; presence of grit or other foreign matter in the bearings; belt too tight; armature not centered with respect to pole pieces; bearings too tight; bearings not in line; shaft rough or cut.

Ques. What is the effect of hot bearings?

Ans. Besides giving trouble themselves, the heat may be conducted along the armature shaft and core, thus giving rise to excessive heating of the armature.

Points Relating to Hot Bearings

1. Use good oil;
2. See that oil cups or reservoirs are full and all oil passages clear;
3. In self-oiling and splash systems where the oil is used over again, it should be kept in clean condition by frequent straining;
4. Keep bearings clean and properly adjusted;
5. Maintain bearings in good alignment;
6. Avoid tight belts;
7. Examine the air gap or clearance between armature and pole faces and see that they are uniform.

Ques. What troubles are encountered with short circuits in the armature or commutator?

Ans. This results in sparking at the brushes, and in the heating of one or more of the armature coils, and even in the burning up of the latter if a bad case.

When the armature is overheated, and the defect does not proceed from an overload or the causes mentioned below, the dynamo should be immediately stopped and tested for this fault.

Ques. What will happen with an overheated commutator?

Ans. It will decompose carbon brushes and cover the commutator with a black film, which offers resistance and increases the heat.

Ques. What should be done if carbon brushes become hotter than the other parts?

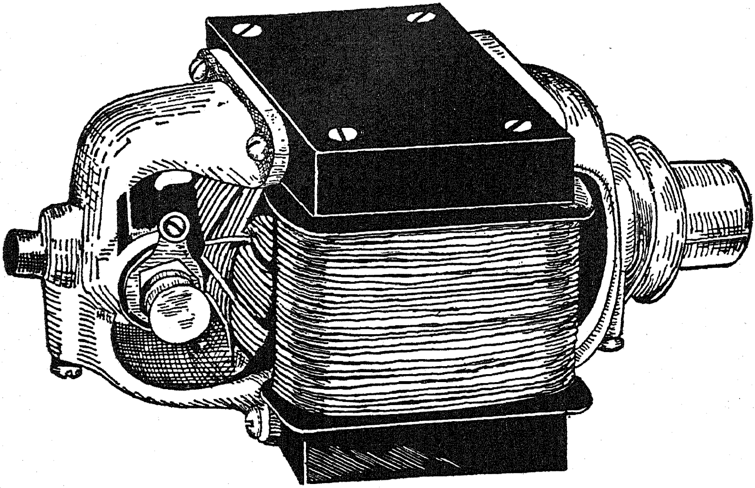


Fig. 932.—Eck-Manchester type motor. It is a very small size unit and is designed for special purposes where very little room is available. The motor occupies a space of 2½″ × 4⅜″ between bearings and develops 1⁄16 horse power at 2,000 *r.p.m.* The frame of this motor is made of high permeability steel so as to reduce the weight to a minimum. The armature is of the hand wound bipolar type built up of thin punchings. The armature, after being wound, is baked at high temperature for a prolonged period and then dipped while hot in insulating varnish. Pulley is one inch in diameter and takes a ¼ inch round belt. Weight of motor 5½ pounds.

Ans. Use higher conductivity carbon.

Reduce length of brush by adjusting holder to grip brush nearer the commutator. Reinforce brushes with copper gauze, sheet copper or wires, or use some form of combined metal and carbon brush. Increase size or number of brush if necessary, so the current does not exceed 30 amperes per sq. in. of contact.

Brushes heat sometimes due to too much friction. They should not press against the commutator more than is necessary for good contact.

Ques. Give some causes for heating of armature.

Ans. Eddy currents; moisture; short circuits; unequal strength of magnetic poles; operation above rated voltage, and below normal speed.

Ques. What trouble is encountered with eddy currents?

Ans. Considerable heating of the whole of the armature results, which may even extend to the bearings.

Ques. How can this be overcome?

Ans. There is no remedy for eddy currents other than the purchase of a new armature, or reconstruction.

The fault may be detected by exciting the field magnets and running the machine on open circuit, with the brushes raised off the commutator for some time, when the armature will be found to be excessively heated.

Ques. How does moisture in the armature coils affect the armature?

Ans. The effect of this fault being to practically short circuit the armature, a heating of the latter results. In bad cases, steam or vapor is given off.

Ques. What is the effect of short circuits in the armature?

Ans. It produces overheating.

Ques. What trouble is likely to occur when the armature is not centered in the armature chamber?

Ans. A heating of the bearings is liable to be occasioned through the attractive forces developed by the center of the armature core not being parallel with the center of the armature chamber or bore, or through the core being nearer one pole piece than the other.

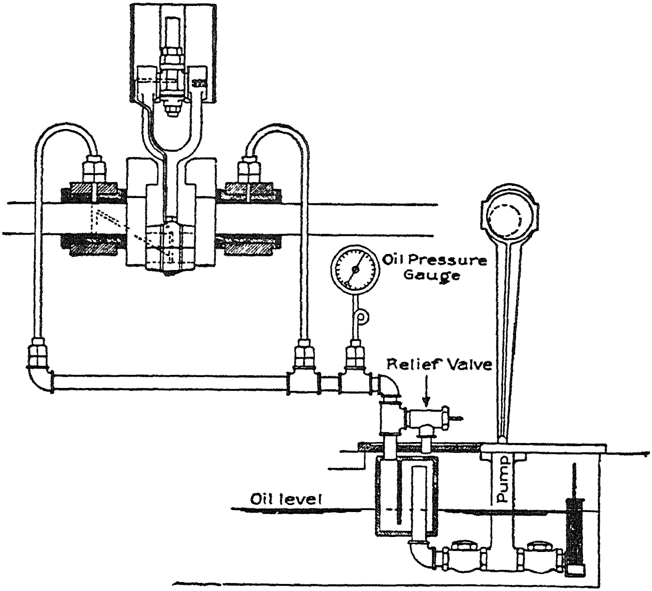


FIG. 933.—Forced system of lubrication as applied to engine of General Electric generating set. In engines employing the forced system of lubrication the crank pit, which is formed by the columns, is accessible through doors in the front and back of the engine. The base of the engine forms an oil tank to which is attached a small plunger pump driven by an eccentric on the shaft. The lubricant is carried under pressure to the various parts of the engine by the mechanism shown in the accompanying diagram. The oil is forced by a pump to a groove in the main bearing; and a drilled hole in the shaft connects this groove with the crank pin. From the crank pin box the oil is further forced to the wrist pin through the pipe running along the side of the connecting rod. The passage in the cross head allows the oil to be forced from the wrist pin to the guides. As the oil is forced from one bearing to another, it is quite important that the bearing caps be set tight, otherwise the oil will escape before reaching the last bearing. After passing through the bearings, the oil is collected in the base, strained and used again. The oil should be free from foreign substances, and to guard against the introduction of any foreign matter, a strainer, which may be taken out for examination or cleaning, is attached to the suction valve of the pump. An oil pressure of from 10 to 20 lbs. should be maintained, and may be regulated by adjusting the set screw on the relief valve of the oiling system.

This may result from unequal wearing of the bearings, and therefore the bearings should either be relined or the bolt holes of the bearings readjusted, or the bearings packed up until the armature is correctly centered.

Ques. What happens in case of breaks in the armature coils?

Ans. This fault results in local heating of the armature.

It is because resistance is interposed in the path of the current at the fracture. It always results in sparking at the brushes, and the heating being confined to the neighborhood of the break.

Ques. What are the effects of operation above the rated voltage and below normal speed?

Ans. Voltage above normal is a possible cause of heating, and operation below normal speed calls for an increase of field strength and reduces the effective ventilation, thus tending to cause heating.

Ques. How may the field magnets become heated?

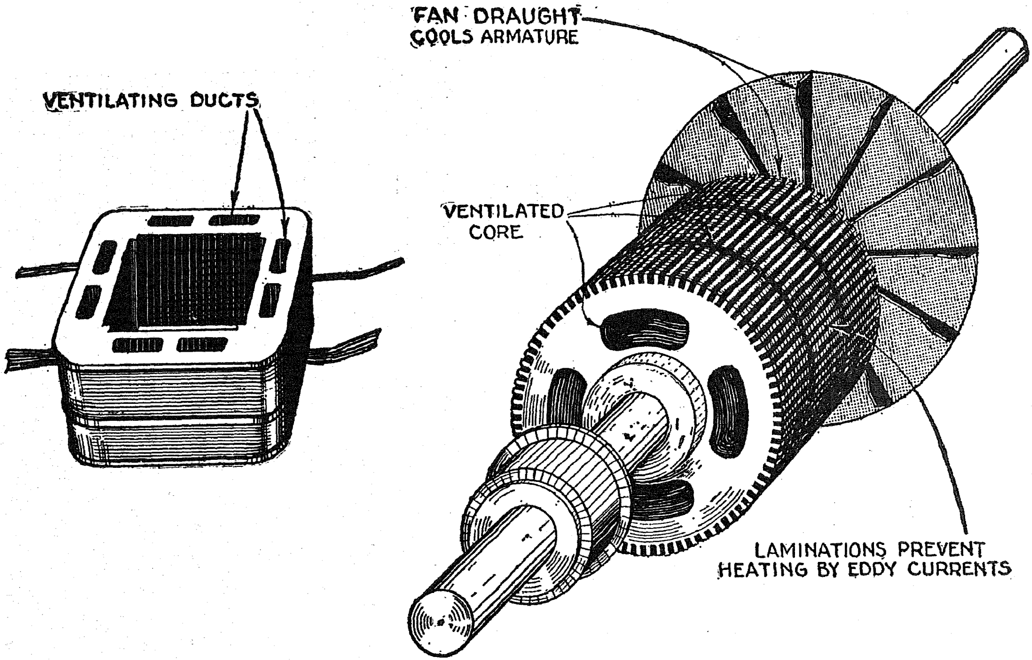
Ans. By excessive field current; eddy current in pole pieces; moisture; short circuits.

Ques. What may be said with respect to excessive field current?

Ans. When heating results from this cause, all the exciting coils will be heated equally.

It may be due to excessive voltage, in the case of shunt dynamos; or to an overload in the case of compound and series dynamos. In either case it may be remedied by reducing the voltage or overload.

If due to the coils being incorrectly coupled up, that is, coupled up in parallel instead of in series, it will be necessary to rectify the connections or insert a resistance in series.



FIGS. 934 and 935.—Methods of preventing dynamos overheating. Fig. 934, ventilated field coil; fig. 935, ventilated core and fan forced draught, also insulation against eddy currents by laminated core.

Ques. State the causes of eddy currents in the pole pieces.

Ans. This fault may be due to defective design or construction of the armature. Slotted armatures are particularly liable to cause this fault, if the teeth and air gap be not properly proportioned. The defect may also be occasioned by variation in the strength of the exciting current.

If due to this latter cause, it will be accompanied by sparking at the brushes. If a shunt dynamo, insert an ammeter into the shunt circuit, and note if the deflection be steady. If this be not the case, the variation in the current most probably results from imperfect contacts thrown into vibration.

Ques. How is the insulation affected by moisture?

Ans. Moisture tends to decrease the insulation resistance, thus in effect producing a short circuit with its attendant heating.

Ques. How is moisture in the field coils detected?

Ans. It is easily detected by applying the hand to the coils, when they will be found to be damp, and in addition steam or vapor will be given off where the machine is working.

The fault may be remedied by drying and varnishing the coils.

Ques. What is the indication of short circuits in the field coils?

Ans. Unequal heating of the field coils.

If the coils be connected in series, the faulty coil will be heated to a less extent than the perfect coils; if connected in parallel, the faulty coil will be heated to a greater extent than the perfect coils. The former can thus be easily located.

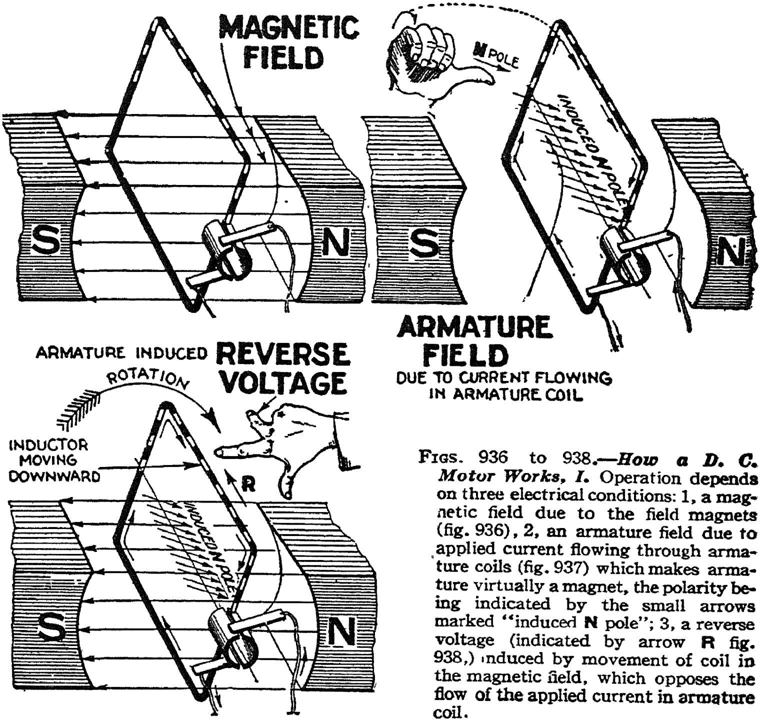
TEST QUESTIONS

1. *What common mistake is made in regard to heating?*
2. *How is heating detected?*
3. *What is the allowable rise of temperature, and how measured?*
4. *What causes heating of the brushes; of the bearings?*
5. *What causes the armature to heat?*
6. *What is the effect of eddy currents?*

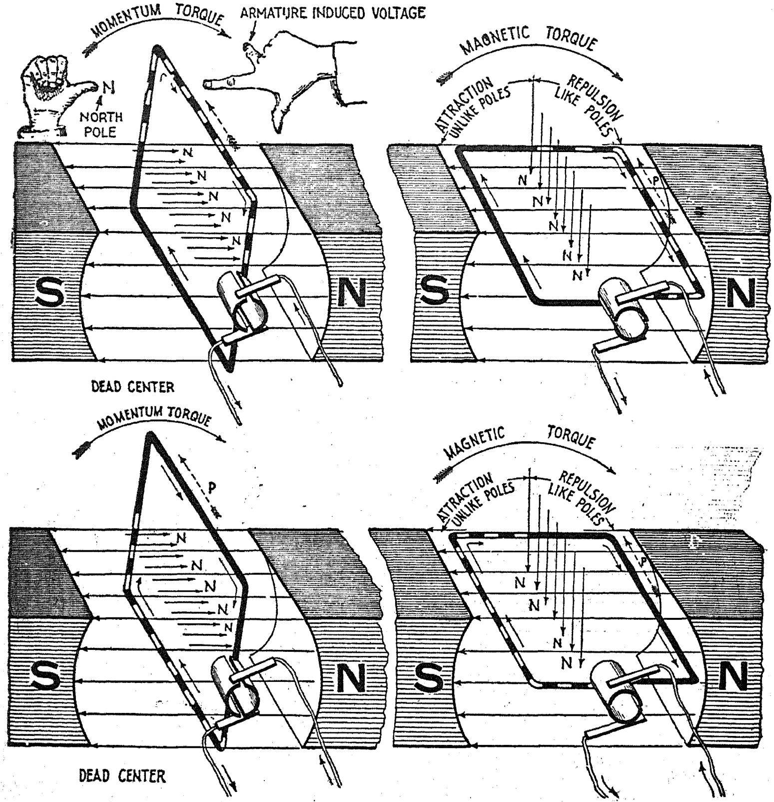
CHAPTER 32

D. C. Motors

An electric motor is just the reverse of a dynamo; it is *a nachine for converting electrical energy into mechanical energy.*



Figs. 936 to 938.—***How a D. C. Motor Works, I.*** Operation depends on three electrical conditions: 1, a magnetic field due to the field magnets (fig. 936), 2, an armature field due to applied current flowing through armature coils (fig. 937) which makes armature virtually a magnet, the polarity being indicated by the small arrows marked "induced **N** pole"; 3, a reverse voltage (indicated by arrow **R** fig. 938,) induced by movement of coil in the magnetic field, which opposes the flow of the applied current in armature coil.



FIGS. 939 to 942.—*How a D. C. Motor Works, II:* Cycle of operation: Fig. 939, beginning of revolution, armature and magnet poles in opposite directions and hence *they* ("like" poles) *oppose each other*. This is the dead center position as there is no magnetic tendency to rotate armature, since magnetic lines of magnets and armature are parallel, but *momentum* of the armature (assumed to be rotating) carries it past this dead center (just as a steam engine passes its dead center), then a clockwise torque is produced by the opposition of like poles. Fig. 940, ¼ revolution position; armature poles at right angles or midway between magnet poles; here the torque is due to ***the equal turning forces of repulsion of like poles and attraction of unlike poles***. Fig. 941, ½ revolution position; at this instant ***the armature polarity is reversed*** by the reversal of current flowing in the armature coil due to brushes passing to opposite segment of commutator, the magnetic lines being parallel, give a second dead center ***with like poles repelling each other*** in a similar manner as in fig. 939, ***momentum carrying the armature past the dead center***. Fig. 942, ¾ revolution position, armature poles *again* at right

The electrical energy delivered by the dynamo must be obtained from a steam engine, gas engine, or other power; the mechanical energy obtained from the motor comes from the energy of the current flowing through its armature and field.

Ques. What is the construction of a motor?

Ans. It is constructed in the same manner as a dynamo.

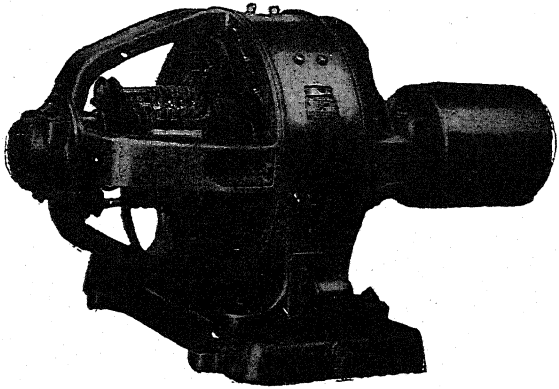


FIG. 943.—General Electric *d.c.* Motor (3 to 200 *h.p.*) Six external leads are brought out on both shunt and compound motors.

Any machine that can be used as a dynamo will, when supplied with electrical power, run as a motor, and conversely, a motor when driven by mechanical power, will supply electrical energy to the circuit connected to it. Dynamos and motors, therefore, are convertible machines, and the differences that are found in practice are largely mechanical; they arise chiefly from the conditions under which the motor must work. Hence, the study of the motor begins with a knowledge of the dynamo, and

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FIGS. 939 to 942.—*Text continued.*
angles or midway between magnet poles; here (as in fig. 940) the torque is due to the equal *turning forces of repulsion of like poles* and *attraction of unlike poles*. Now, at all times the rotation of the armature induces an electric pressure in the coil in a direction opposite to the current applied to the armature as indicated by the dotted arrow, called the ***reverse voltage;*** which tends to reduce the current applied to armature.

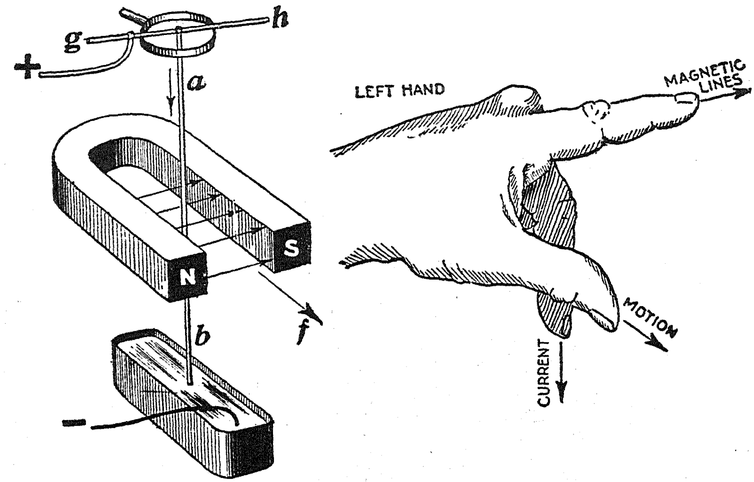


FIG. 944.—Principle of the electric motor as illustrated by experiment showing effect of magnetic field on a wire carrying an electric current. Let a vertical wire *ab* be rigidly attached to a horizontal wire *gh*, and let the latter be supported by a ring or other metallic support as shown, so that *ab* is free to oscillate about *gh* as an axis. Let the lower end of *ab* dip into a trough of mercury. When a magnet is held in the position shown and a current from a cell is sent through the wire as indicated, the wire will move in the direction shown by the arrow *f*, that is, at right angles to the direction of the lines of magnetic force Let the direction of the current in the wire be reversed, then the direction of the force acting on the wire will be found to be reversed also. The conclusion is that *a wire carrying a current in a magnetic field tends to move in a direction at right angles both to the direction of the field and to the direction of the current.* The relation between the direction of the magnetic lines, the direction of the current, and the direction of the force, is often remembered by means of the following rule, known as the *motor rule,* and which differs from the dynamo rule only in that it is applied to the fingers of the *left hand* instead of to those of the right. *Let the forefinger of the left hand point in the direction of the magnetic lines of force and the middle finger in the direction of the current sent through the wire, then will the thumb, at right angles to the other two fingers, point in the direction in which the wire is urged.*

NOTE.—***One difference*** between a dynamo and a motor is, that whereas the brushes are advanced in the direction of rotation in a dynamo, to keep them ahead of the neutral line under load, in a motor they are moved the other way because armature reaction is different in a motor than in a dynamo.

NOTE.—In the dynamos and motor ratings of machines by manufacturers the *r.p.m.* rating when run as a dynamo is a little higher than when run as a motor. Thus one manufacturer rates a certain machine at 1,175 *r.p.m.* as a dynamo, and at 1,000 *r.p.m.* as a motor. The lower speed as a motor is partly due to the fact that the dynamo operates with a rheostat in series in the field and so with weaker field.

accordingly the student should understand thoroughly all the fundamental principles of the dynamo, as already given, before proceeding further with the study of the motor.

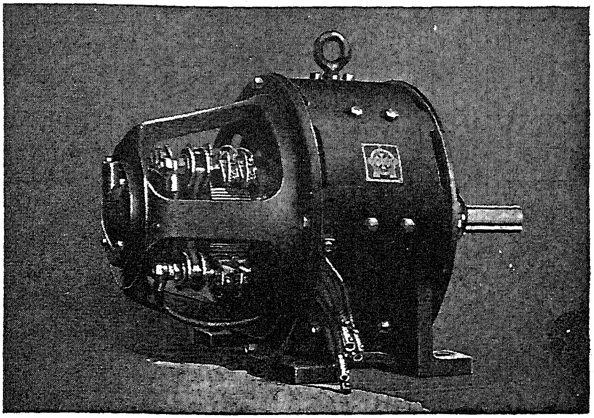


FIG. 945.—Reliance type T, motor with ball bearings.

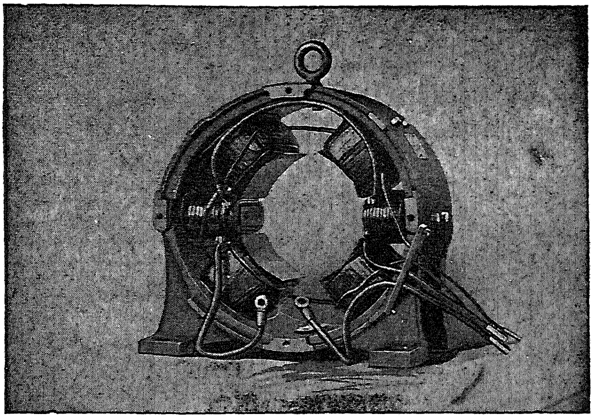
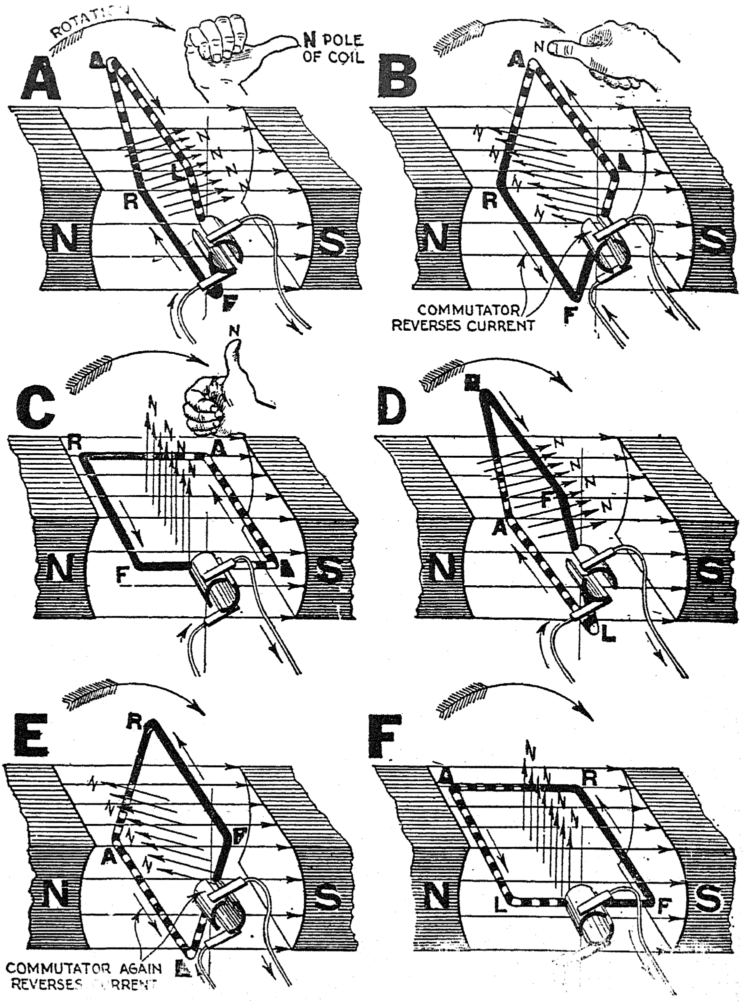


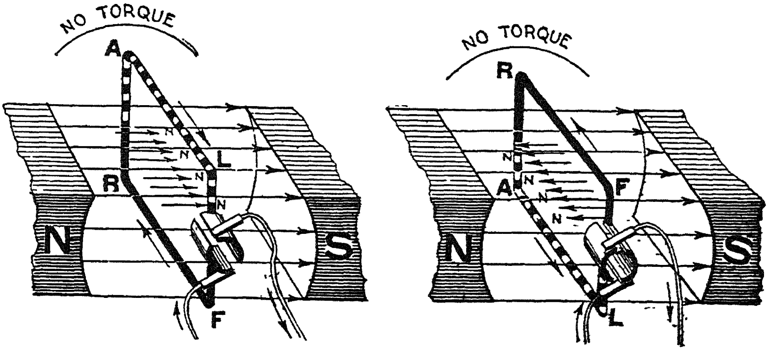
FIG. 946.—*Reliance motor construction 1.* Field frame with main poles and coils, also commutating poles and coils.



FIGS. 947 to 952.—*How a D. C. motor works. III.* Fig. **A**, current flowing through the coil, LARF, induces a N, pole on the side next to the S, pole of the field magnet and a S, pole on the side next to the N, pole of the field magnet; the attraction of unlike poles causes the coil

Principles of the Motor.—All the early attempts to introduce motors failed, chiefly because the law of the conservation of energy was not fully recognized. This law states that *energy can neither be created nor destroyed.*

Early experimenters discovered, by placing a galvanometer in a circuit with a motor and battery, that, *when the motor was running, the battery was unable to force through the wires so strong a current as that which flowed when the motor was standing still.* Moreover, the faster the motor ran, the weaker did the current become.



FIGS. 953 and 954.—*D.C. Motor principles, 1. A single coil motor has "dead centers,"* the same as a one cylinder steam engine. Fig. 953, coil in vertical position; fig. 954, coil in second vertical position (180° from position fig. 953). When the plane of the coil is perpendicular to the field, the poles induced in the armature are parallel to field for either vertical position of the coil, that is, the induced lines of force and field lines of force are parallel and in the same planes, hence no turning effect is produced. Of course, in practice, where there is a multiplicity of coil, there can be no "dead centers." An undistorted field is here assumed.

FIGS. 947 to 952.—*Text continued.*

to turn in the direction indicated by the arrow. Fig. **B**, As the coil passes its vertical position, the commutator reverses the current, which reverses the induced pole as shown; the repulsion of like poles rotates the coil as indicated by the arrow. Fig. **C**, shows coil in a horizontal position; in this position both *attraction* and *repulsion* of *unlike* and *like* poles respectively act equally to rotate the coil. Fig. **D**, shows coil just before reaching its vertical position; here the coil is rotated principally by the attraction of *unlike* poles Fig. **E**, shows coils just after passing vertical position with reversal of current which maintains the proper relation of induced and field poles to continue the rotation in the same direction. Fig. **F**, coils again in horizontal position showing equal attraction and repulsion of poles.

Ques. Why does less current flow when the motor is running than when standing still?

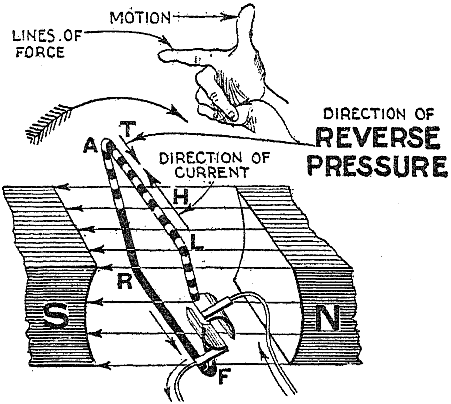
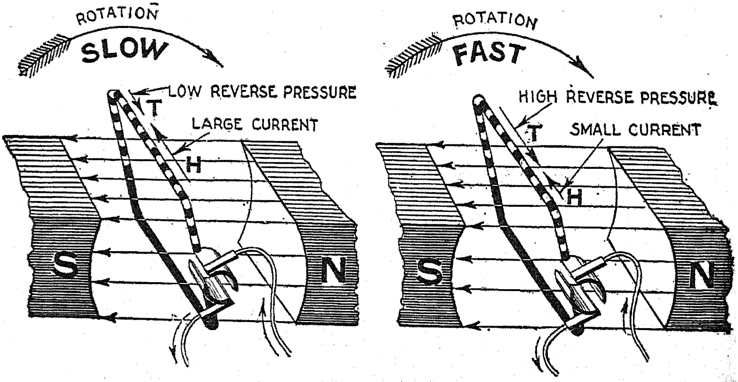


FIG. 955.—*D.C. Motor principles, 2. The rotation of the coil in the magnetic field induces a reverse pressure which opposes the flow of current in the coil.* Applying Fleming's rule to inductor LA, which is moving upward, it is seen that the induced pressure T, is in a direction directly opposite to that of the current H, and so opposes its flow; it is accordingly called the *reverse pressure.*



FIGS. 956 and 957.—*D.C. Motor principles, 3. The amount of current flowing through the coil decreases as the speed increases.* As the speed of rotation increases the reverse pressure increases, thus presenting more and more opposition to the current in the coil which reduces the amount of flow.

Ans. Because the motor, on account of its rotation acts as a dynamo and thus tends to set up in the circuit a *reverse pressure.*

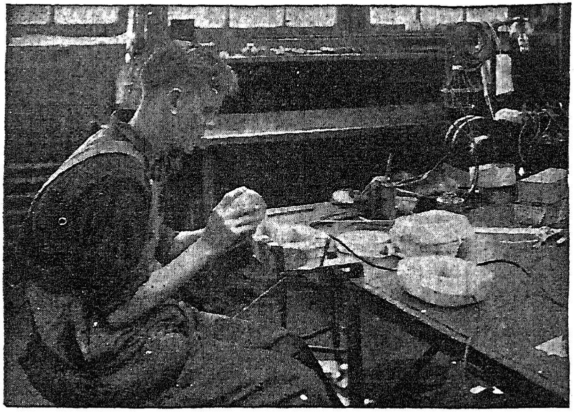
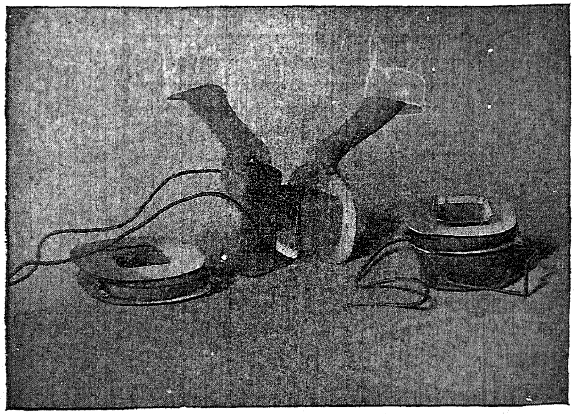


FIG. 958.—***Reliance motor construction 2.*** Field coil being taped with linen tape, half lapped. Note re-enforcements at corners and lead protection. Coil in foreground is ready for dipping and baking.



FIGS. 959 to 961.—***Reliance motor construction 3.*** A compound field coil being assembled on press board and fibre spool.

Ques. What is the real driving force which causes the armature of a motor to rotate?

Ans. *The propelling drag,* that is, the drag which the magnetic field exerts upon the armature wires through which the current is flowing, or in the case of deeply toothed cores, upon the protruding teeth.

The Propelling Drag.—In fig. 962, is shown the condition which prevails when a conductor carrying no current is placed in a uniform magnetic field. The magnetic lines pass straight from one pole to the other. The field is not distorted whether the conductor be at rest or in motion, so long as there is no flow of current. This represents the condition in the air gap of a motor or dynamo, when no current is flowing in the armature.

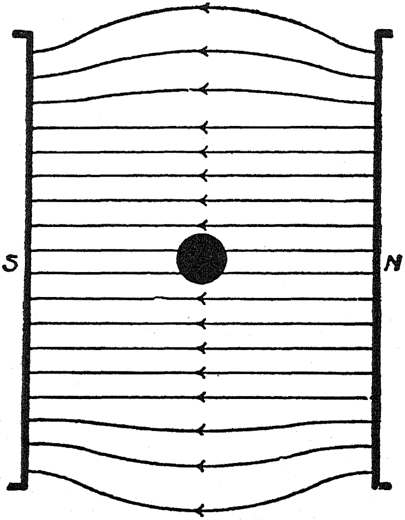
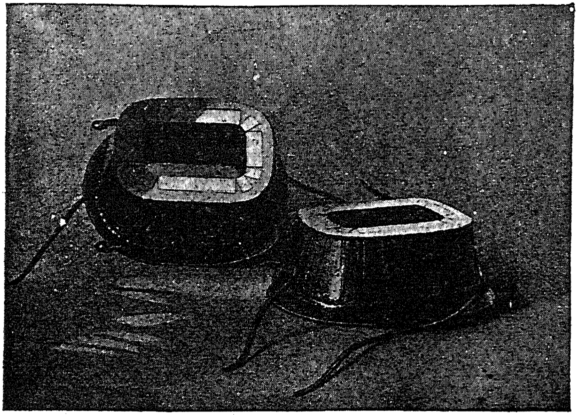


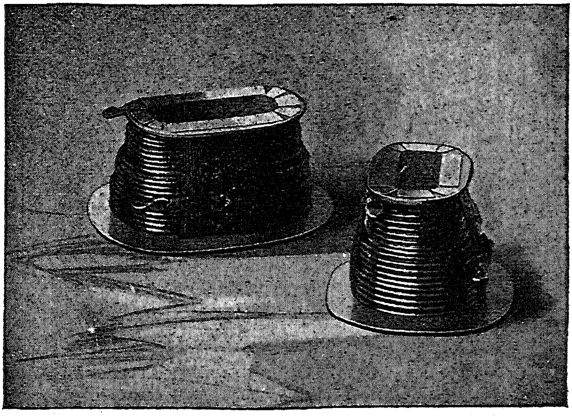
FIG. 962.—Conductor, lying in a magnetic field and carrying no current; the field is not distorted whether the conductor be at rest or in motion.

Ques. What happens when a current flows in the conductor of fig. 962?

Ans. It sets up a magnetic field of its own as in fig. 968.



Figs. 963 and 964.—*Reliance motor construction 4.* Completed shunt field coil with stabilizing winding.



Figs. 965 and 966.—*Reliance motor construction 5.* Commutating coils.

Ques. What is the effect of this magnetic field?

Ans. It distorts the original field (fig. 962) in which the

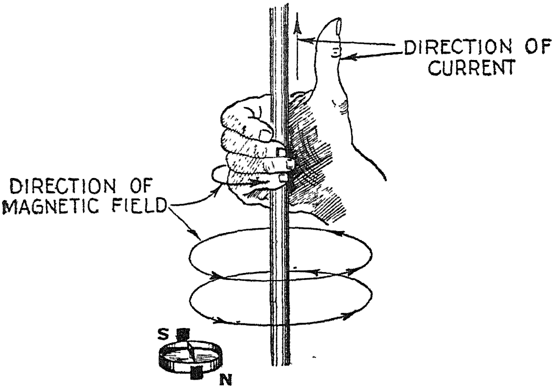


FIG. 967.—Magnetic field in a plane at right angles to a wire carrying an electric current

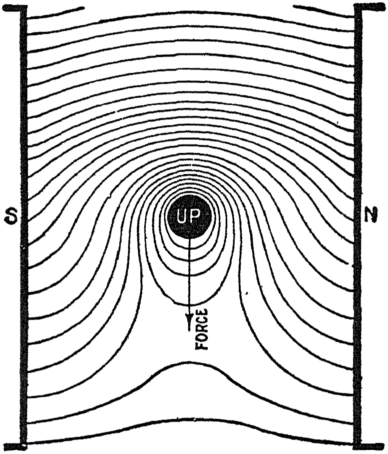


FIG. 968.—Conductor carrying a current in a magnetic field. The current flowing in the conductor sets up a magnetic field which distorts the original field as shown, making the magnetic lines denser on one side and less dense on the other. This results in a force upon the wire, which, in the case of a dynamo (fig. 975) opposes its movement, and which forms the *propelling drag* in the case of a motor (fig. 976.)

conductor lies, making the magnetic lines denser on one side and less dense on the other as in fig. 968.

Ques. What is the nature of these distorted magnetic lines?

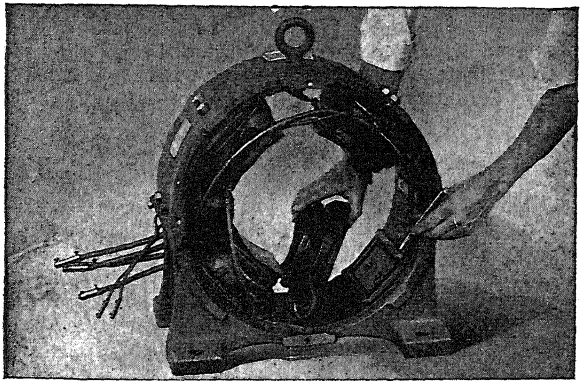


FIG. 969.—*Reliance motor construction 6.* Support which keeps coil securely in place.

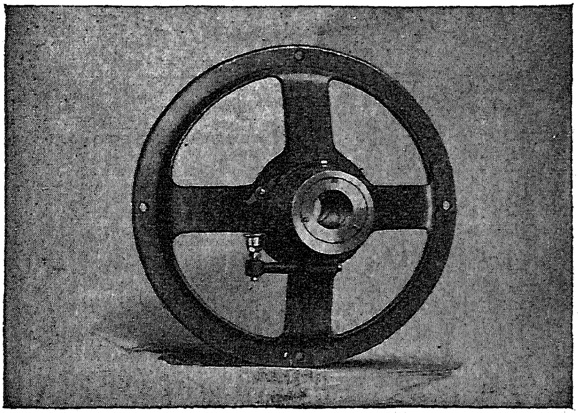


FIG. 970.—*Reliance motor construction 7.* Back bearing bracket containing self-closing oil hole cover, large oil overflow cup, and pocket under the oil well for sediment.

Ans. They tend to shorten themselves to their original form of straight lines.

Ques. What effect has this on the conductor?

Ans. It produces a force on the conductor tending to push it in the direction indicated by the large vertical arrows, fig. 971.

The distorted magnetic lines may be regarded as so many rubber bands tending to straighten themselves; the result then is clearly to force the conductor in the direction indicated.

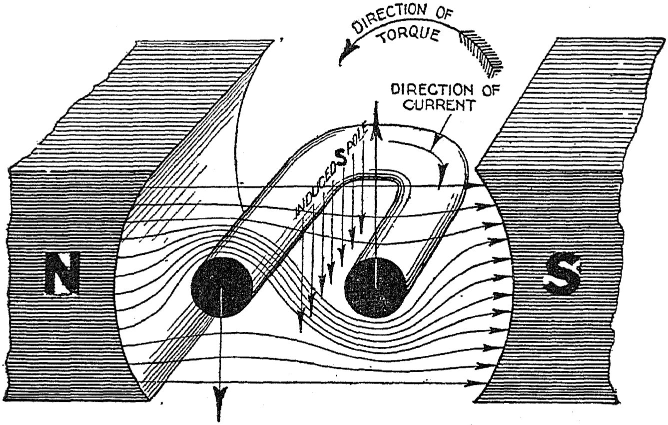


FIG. 971.—*D.C. Motor principles 4.* Force of a magnetic field on a coil carrying a current due to the distortion of the field.

According to Lenz' law, the direction of the current in the armature of a dynamo is such as to oppose the motion producing it. When the armature of a dynamo is rotated, the bending of the lines of force of the main magnetic field due to armature reaction acts as a drag against the motion of the armature. Armature reaction increases with the increase of the armature current. Therefore, the effect of the drag increases with the increase of load and requires an additional expenditure of power to drive the armature.

In a motor, the direction of the actuating current is the reverse of that of the armature current of a dynamo, consequently, the armature reaction which constitutes a drag, acting against rotation of the armature of a dynamo, becomes a pull in the direction of rotation of the armature of a

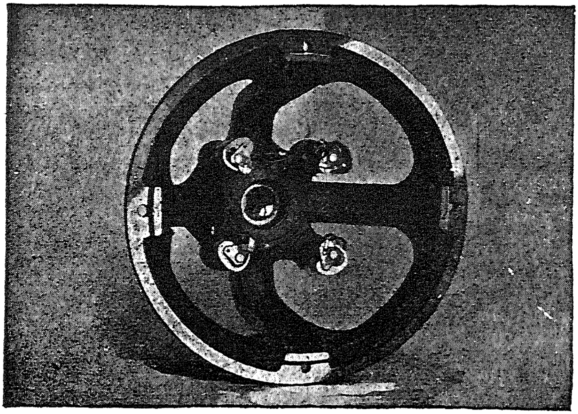
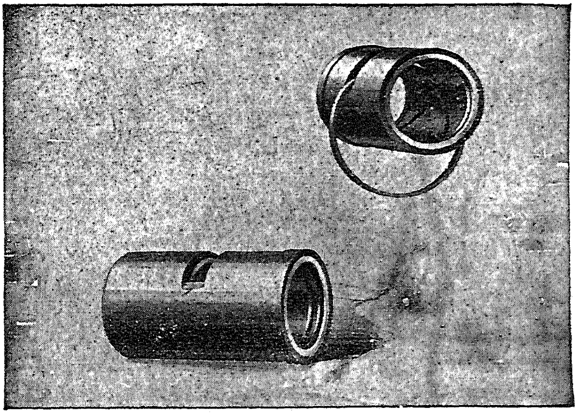


Fig. 972.—***Reliance motor construction 8.*** Front bearing bracket showing a channel shaped section in the arms, and deep outside ring.

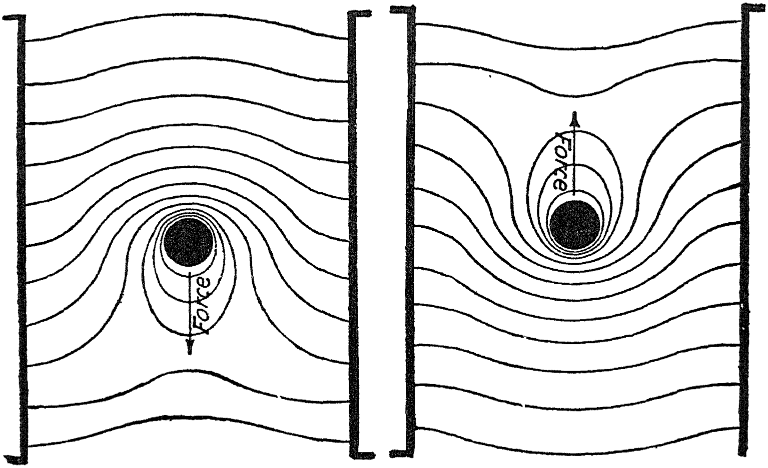


Figs. 973 and 974.—***Reliance motor construction 9.*** Bearings. Grooves for distribution of oil are shown in bearing at the right. At the end of the other bearing are shown the pressure relief grooves. These are drained by a large hole at the bottom.

motor and constitutes its real turning effect or *torque* which is used at the pulley to do mechanical work. The greater the load applied to the motor, the greater will be the amount of current taken from the supply mains, and consequently, the greater the *torque*.

Ques. What are the essential requirements of construction in a motor?

Ans. They are: 1, a magnetic field, 2, conductors placed perpendicular to the field, 3, provision for motion of the conductors across the field in a direction perpendicular to both themselves and the field, and 4, provision for current reversal.



Figs. 975 and 976.—Action of the magnetic force in a dynamo and motor. In the first instance according to Lenz' law, the direction of the current induced in the wire is such as to oppose the motion producing it. In the operation of a motor, the current supplied in flowing through the armature winding distorts the field and thus produces rotation. In the figures, the direction of the force is clearly indicated, remembering that the distorted lines of force act like rubber bands tending to straighten and shorten themselves.

The Reverse Pressure.—When an electric current flows through some portion of a circuit in which there is an electric pressure, the current will there either receive or give up energy.

according to whether the pressure acts *with* or *against* the current.

This is illustrated in fig. 979 which represents a circuit in which there

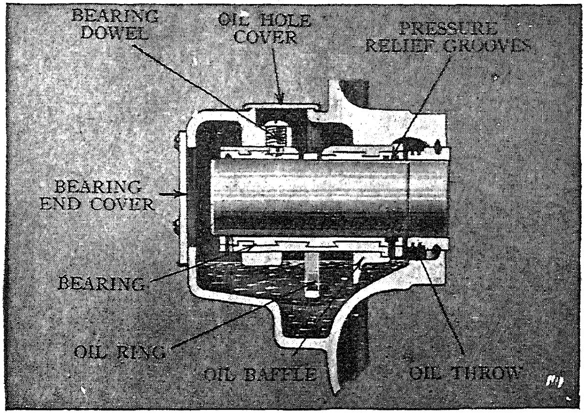


Fig. 977.—***Reliance motor construction 10.*** Cross sectional view showing bearing construction and precautions taken to keep oil from inside of motor.

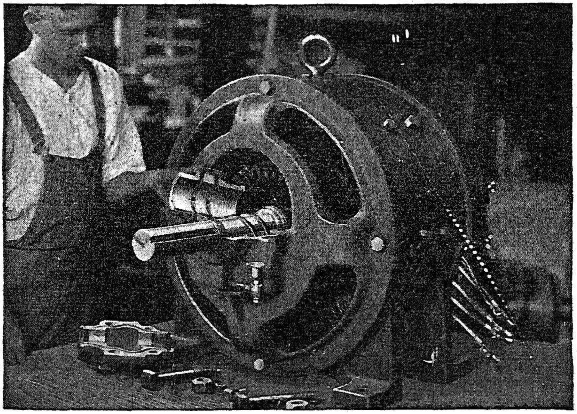


Fig. 978.—***Reliance motor construction 11.*** Split bearing with upper section removed.

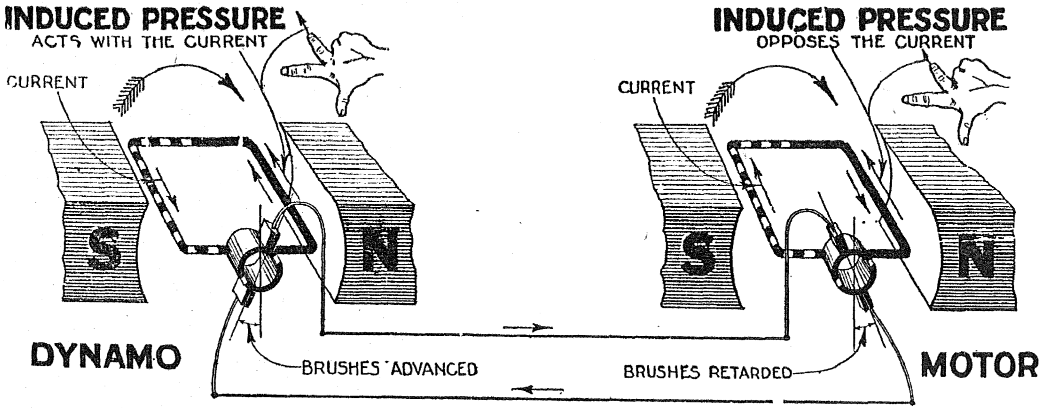


FIG. 979.—Circuit with dynamo and motor. Whenever current flows through some portion of a circuit in which there is an electric pressure, the current will there either receive or give up energy according to whether the electric pressure acts *with* the current or *against* it. In the figure, the dynamo and motor are rotating clockwise, and hence each generates an electric pressure tending upwards from the lower brush to the higher. In the dynamo, where energy is being supplied to the circuit, the induced electric pressure is in the same direction as the current, while in the motor where work is being done and energy is leaving the circuit, the induced electric pressure is in a direction which opposes the current.

is a dynamo and a motor. Each is rotating clockwise and accordingly each generates a pressure tending upward from the lower to the upper brush. In both cases the upper brush is positive. In the dynamo, however, where energy is being supplied to the circuit, the pressure is in the same direction as the current, and in the motor, where work is being done, the pressure is in the reverse direction to that of the dynamo.

Ques. Describe similar conditions which prevail in the operation of a dynamo.

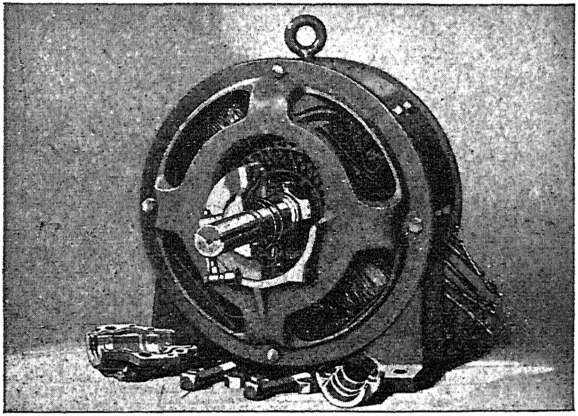


Fig. 980.—***Reliance motor construction 12.*** Lower section of split bearing housing partially rotated.

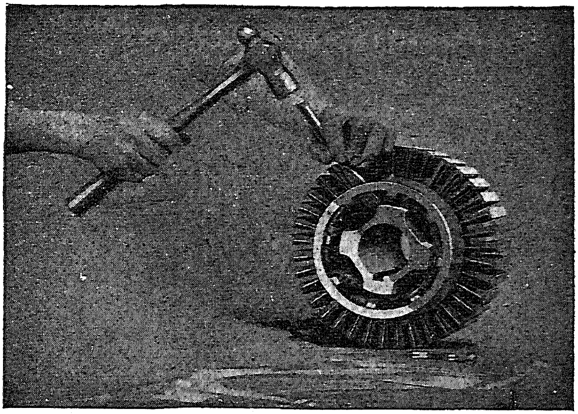


Fig. 981.—***Reliance motor construction 13.*** Armature core showing cast iron spider on which laminations are mounted and method of keying end flange in place. The keys are split at the ends and spread with a chisel, as shown. This construction prevents the keys coming out circumferentially. Any danger of their breaking out is eliminated by ¾ in. section of metal beyond the ker

Ans. When no current is being generated by the dynamo, little power is required to drive it, but when the external circuit is closed and current is forced through it against more or less resistance, work is being done, hence more power is required.

In other words, there is an opposition to the mechanical force applied at the pulley which is proportional to the electric power delivered by the dynamo. An opposing reaction or *reverse pressure* then is set up in a dynamo when it does work.

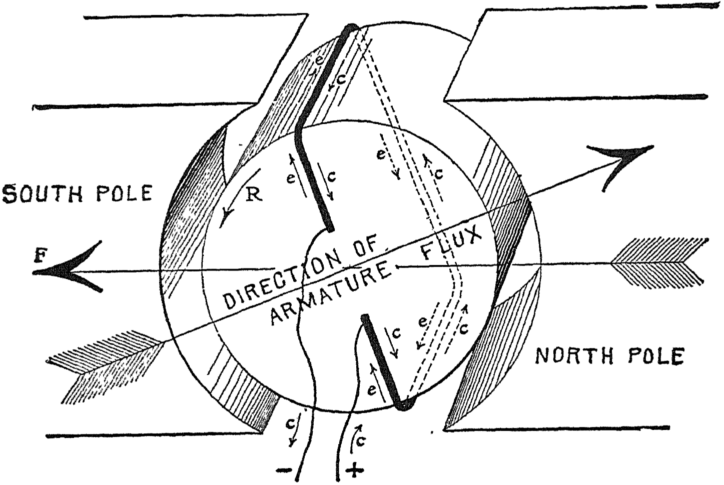
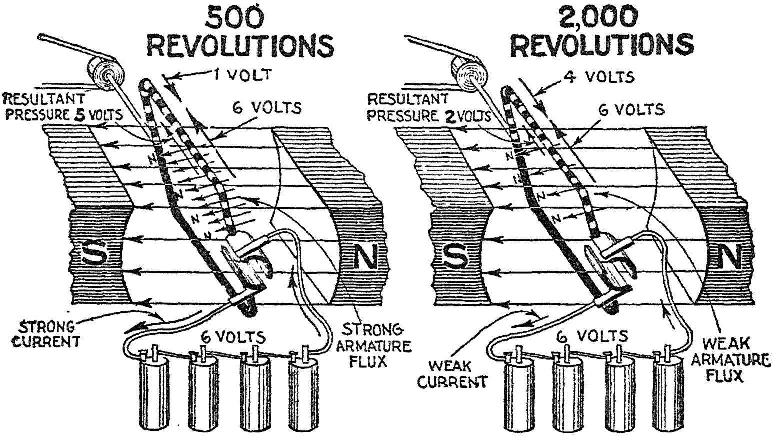


FIG. 982.—Showing relative directions of armature current and reverse electric pressure of a motor. When a motor is in operation, the wires around the periphery of its armature "cut" the magnetic lines of force produced by the field magnet exactly as in the case of the dynamo. Consequently, an electric pressure is induced in each wire, as in the dynamo armature. This induced electric pressure is in opposition to the flow of current due to the electric pressure of the supply circuit, and tends, therefore, to keep down the flow of current. The figure shows a single loop of wire, on the armature core connected directly to the source of electricity. With current flowing in the loop in the direction indicated by the arrows marked *c*, a magnetic field is set up in the direction indicated by the large arrow marked "direction of armature flux." With the field magnet energized so as to produce a field in the direction indicated by the large arrow F, the reaction between the two fields will turn the armature core in the direction indicated by the other arrow. As the core turns, the upper wire of the loop will cut the flux under the south pole of the field magnet, and the other side of the loop will cut the flux under the north pole. The result will be the induction of a reverse electric pressure in the loop, the direction being indicated by the small arrows marked *e*. The actual flow of current in the armature is that due to the difference between the impressed and reverse voltage; the latter is proportional to the speed of the armature, the



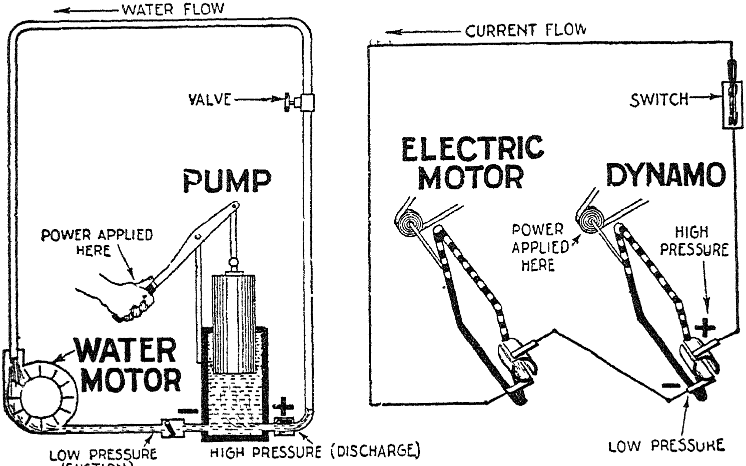
FIGS. 983 and 984.—Diagrams illustrating *reverse pressure*. Fig. 983 motor at slow speed; fig. 984 motor at high speed. *In the operation* of a motor, the conductors revolving in a magnetic field have induced in them a voltage which opposes the applied voltage; this is called the *reverse pressure* and it is proportional to the speed. Now assume that the applied voltage or *forward pressure* is 6 volts and with a speed of 500 *r.p.m.* as in fig. 983 the induced reverse pressure is 1 volt, this gives a resultant pressure of 6−1 =5 volts to produce a flow of current in the winding. Now if the speed be increased to 2,000 as in fig. 984 the reverse pressure will increase to 4 volts, giving a resultant pressure of 6−4 =2 volts available for current flow.

FIG. 982.—*Text continued.*

number of armature wires and the strength of the magnetic field in the air gaps between the armature and the pole faces. The speed of a motor supplied with current at constant voltage varies directly with the reverse electric pressure also with other conditions fixed, the stronger the field, the slower the speed. Weakening the field will increase the speed up to the point where the increase in reverse electric pressure due to the increased speed cuts down the armature current below the value necessary to give the requisite pull at the armature periphery. When this point is reached, any weakening of the field will reduce the speed of the armature. The pull or *torque* of a motor armature is directly proportional to the strength of the magnetic field, and to the strength of the armature current, the number of armature inductors being fixed. In a field of constant strength, therefore, the pull of the armature depends on the amount of current passing through the winding. The torque must be just sufficient to overcome the load; if in excess, the speed will increase until the increase of the reverse electric pressure reduces the current and the increase of speed increases the load to the point of equilibrium between load and torque. If the torque be insufficient for the load, the speed will diminish until equilibrium is established, assuming the motor to be running on constant voltage circuit.

Ques. In the operation of a motor what is the nature of the reverse pressure?

Ans. It is proportional to the velocity of rotation, the strength of the magnets, and to the number and arrangement of the wires on the armature, that is, the reverse voltage depends on the *rate* at which the lines of force are cut.



Figs. 985 and 986.—Water and electric circuits; hydraulic analogy between pump-water motor and dynamo-electric motor installations. In the diagrams

The pump	corresponds to	the dynamo
The discharge pipe	" "	the + wire
The suction pipe	" "	the − wire
The valve	" "	the switch
The water motor	" "	electric motor
The water pressure (called head)	" "	electric pressure (called voltage)
The flow in galls. per minute	" "	amperes
The size of pipe	" "	size of conductor
The foot pounds	" "	watts

The points of highest pressure are at the discharge valve and positive brush; the points of lowest pressure at the suction valve and negative brush. The larger the diameter of the pipes the less resistance is offered to the flow of water, and the larger the diameter of the conductors, the less resistance is offered to the flow of electricity. The more water required by the water wheel, the more power is required to drive the pump. The more electricity required by the motor, the more power is required to drive the dynamo.

Ques. Describe an experiment which shows the existence of a reverse pressure in a motor.

Ans. The apparatus required consists of a small motor,

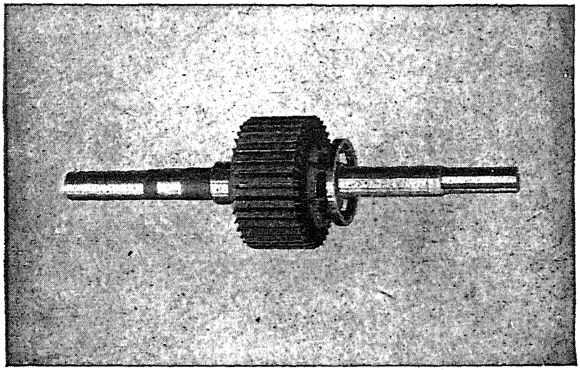
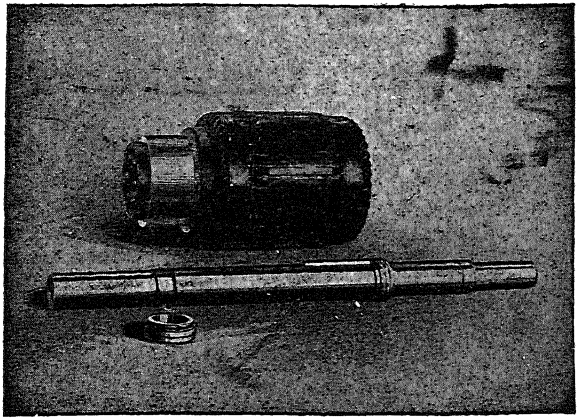


FIG. 987.—*Reliance motor construction 14.* Armature core with shaft. The flange acts as a support for the armature coils and the pressed steel fingers provide an end support for the laminations extending to the edge of the teeth.



FIGS. 988 to 990.—*Reliance motor construction 15.* Armature with shaft removed.

battery, and ammeter. They should be connected in one circuit and the deflection of the ammeter observed when the armature is held stationary, and when it rotates with various loads.

In an experiment of this kind made on a motor with separately excited magnets, the following figures were obtained:

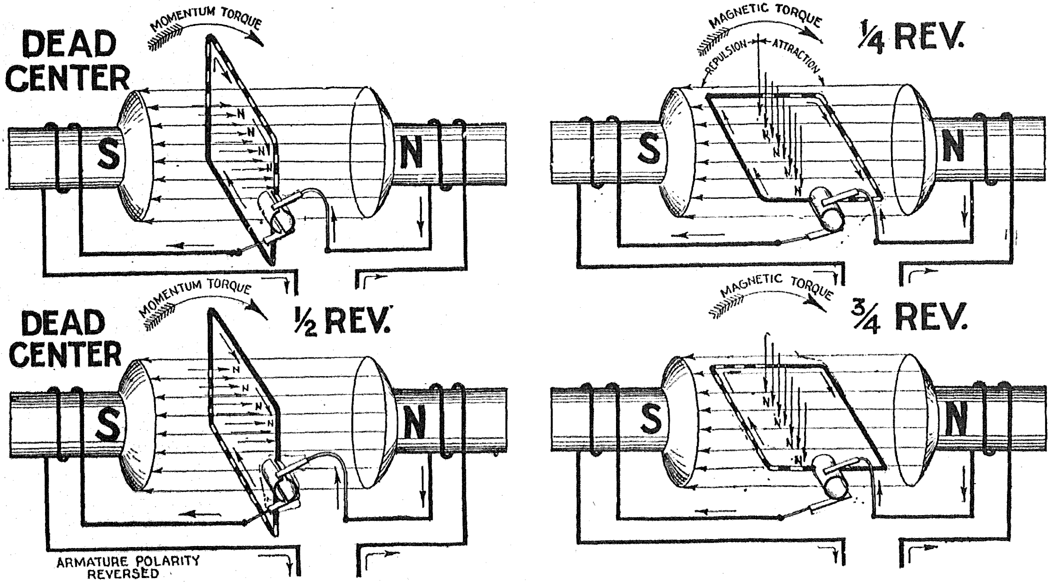
Revolutions per minute	0	50	100	160	180	195
Amperes	20	16.2	12.2	7 8	6 1	5.1

Apparently, if the motor had been helped on to run at 261½ revolutions per minute, the current would have been reduced to zero. In the last result obtained, the current of 5.1 amperes was absorbed in driving the armature against its own friction at the speed of 195 revolutions per minute.

Ques. Explain the action of the current supplied to a motor for its operation.

Ans. The motor current passing through the field magnets polarizes them and establishes a magnetic field, and entering the armature, polarizes its core in such a way that the positive pole of the core is away from the negative pole of the magnetic field, and the negative pole is away from the positive pole of the magnetic field. The magnetic repulsions and attractions thus created cause the armature to rotate in a position of magnetic equilibrium or so as to bring its positive and negative poles opposite the negative and positive poles respectively of the magnetic field. It is evident that unless suitable means were provided to reverse the polarity of the armature core at the instant it reached the position of the magnetic equilibrium, the armature would not rotate any further. The construction is such that the polarity of the armature core, or the direction of the current in the armature coils is reversed at the proper instant automatically by the commutator, thus giving continuous rotation.

The operation of a series motor is shown in figs. 991 to 994.



FIGS. 991 to 994.—***How a series motor works.*** *Cycle of operation.* Fig. 991 beginning of revolution, armature and magnet poles in opposite directions and hence they ("like" poles) oppose each other; "dead center" position, no tendency to rotate except that due to momentum if armature be in motion; fig. 992 ¼ revolution postion; armature poles at right angles or midway between magnet poles; here the torque is due to the equal turning forces of repulsion of like poles and attraction of unlike poles; fig. 993 ½ revolution position; at this instant the armature polarity is reversed by the reversal of current flowing in the armature coil due to brushes passing to opposite segment of commutator; the magnetic lines being parallel, give a second dead center with like poles, repelling each other similar as in fig. 991 momentum carrying the armature past the dead center; fig. 994 ¾ revolution position, armature poles again at right angles or midway between magnet poles; here (as in fig. 992) the torque is due to the equal turning forces of repulsion of like poles and attraction of unlike poles. Now at all times the rotation of the armature induces an electric pressure in the coil in a direction opposite to the current applied to the armature.

Direction of Rotation of Motors.—In the case of either a motor, or a dynamo used as a motor, the direction in which the armature will rotate is easily found by the left hand rule, as illustrated in fig. 1,010, when the polarity of the field magnets and the direction of currents through the armature are known.

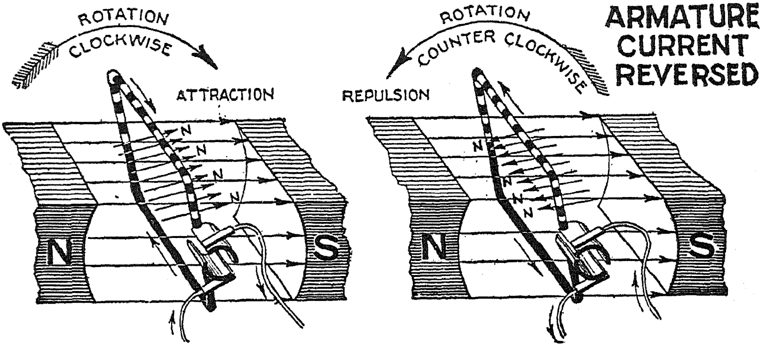


Fig. 995 and 996.—*D.C. Motor principles, 5. If the current through the coil be reversed (by reversing in external circuit) the direction of rotation is reversed.* In fig. 995 coil turns clockwise due to attraction of unlike poles; in fig. 996 coil turns counter-clockwise due to repulsion of like poles.

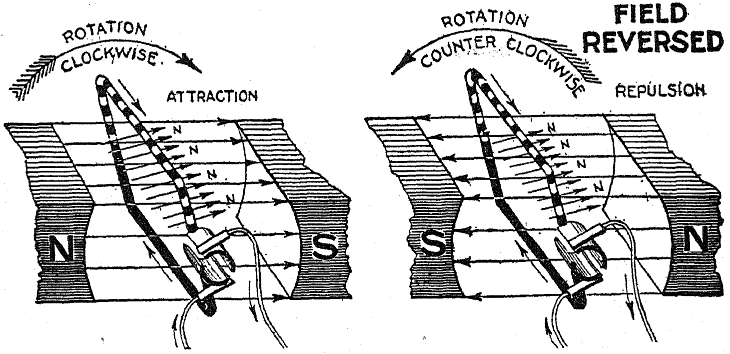


Fig. 997 and 998.—*D.C. Motor principles, 6. If the polarity of the field be reversed* (in practice by reversing the field current through the electro-magnet) *the direction of rotation is reversed.* In fig. 997, coil turns clockwise due to attraction of unlike poles; in fig. 998, coil turns counter-clockwise due to repulsion of like poles.

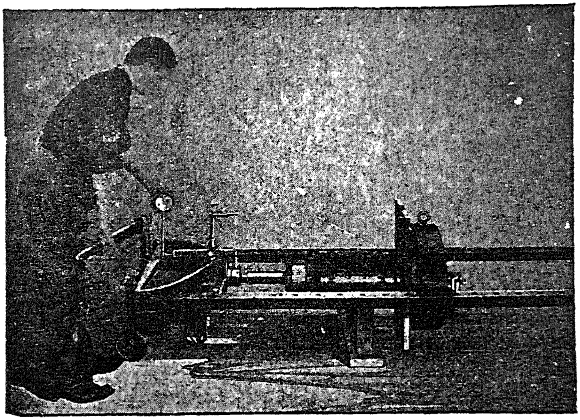
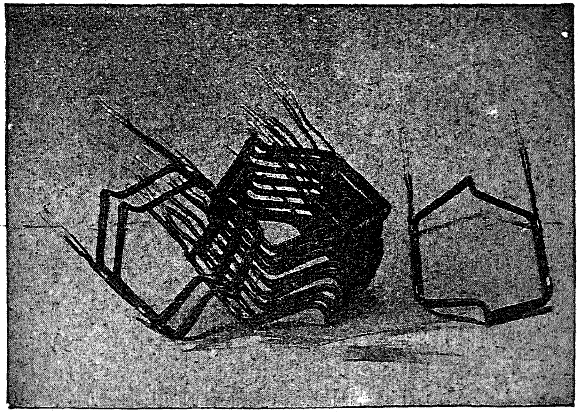


Fig. 999.—*Reliance motor construction 16.* Forcing out armature shaft.



Figs. 1,000 and 1001.—*Reliance motor construction 17.* Armature coils after first baking and ready for taping.

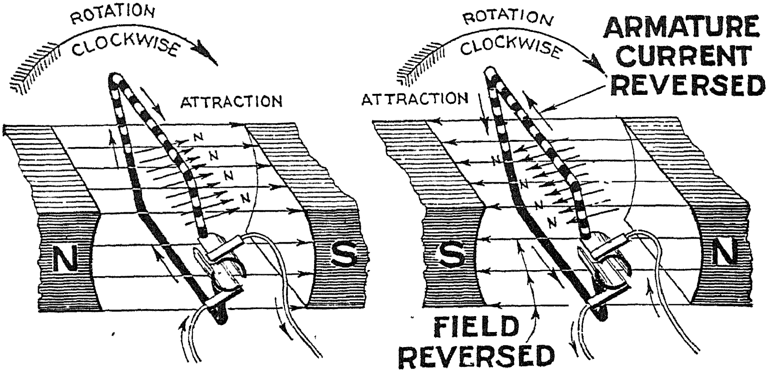
Ques. How may the rotation of a motor be reversed?

Ans. By reversing either the current through the fields, or the current through the armature.

The effect of this is shown in figs. 995 to 998.

Ques. What will happen if both currents be reversed?

Ans. The motor will run in the same direction as before.



Figs. 1,002 and 1,003.—***D.C. Motor principles, 7.*** *If the polarity of both the field and coil be reversed, the direction of rotation remains the same.* Before and after reversal (figs. 1,002 and 1,003) the attraction of unlike poles rotates the coil in the same direction.

Ques. What is the effect of supplying current to a series dynamo?

Ans. It depends on the method of connection as shown in figs. 1,006 and 1,007.

Ques. What is the result of reversing the direction of current at the terminals of a series motor?

Ans. It will not change its direction of rotation, since the current still flows through the armature in the same direction as through the field.

Ques. What is the behavior of a shunt dynamo when used as a motor?

Ans. Its direction of rotation remains unchanged.

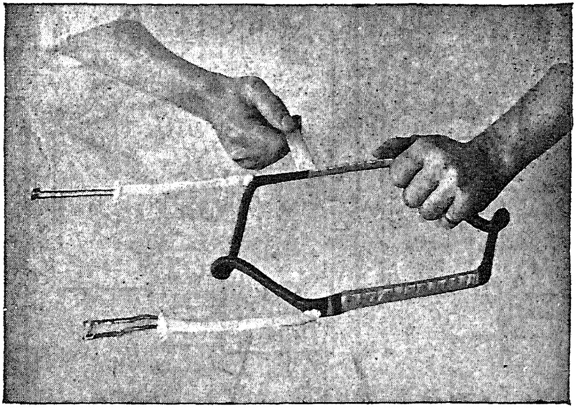


FIG. 1,004.—*Reliance motor construction 18.* Taping armature coils with oiled muslin.

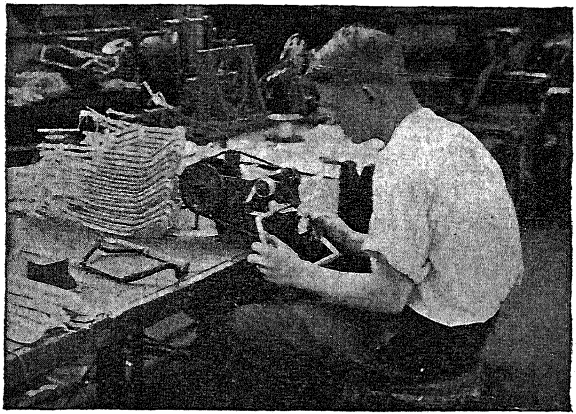
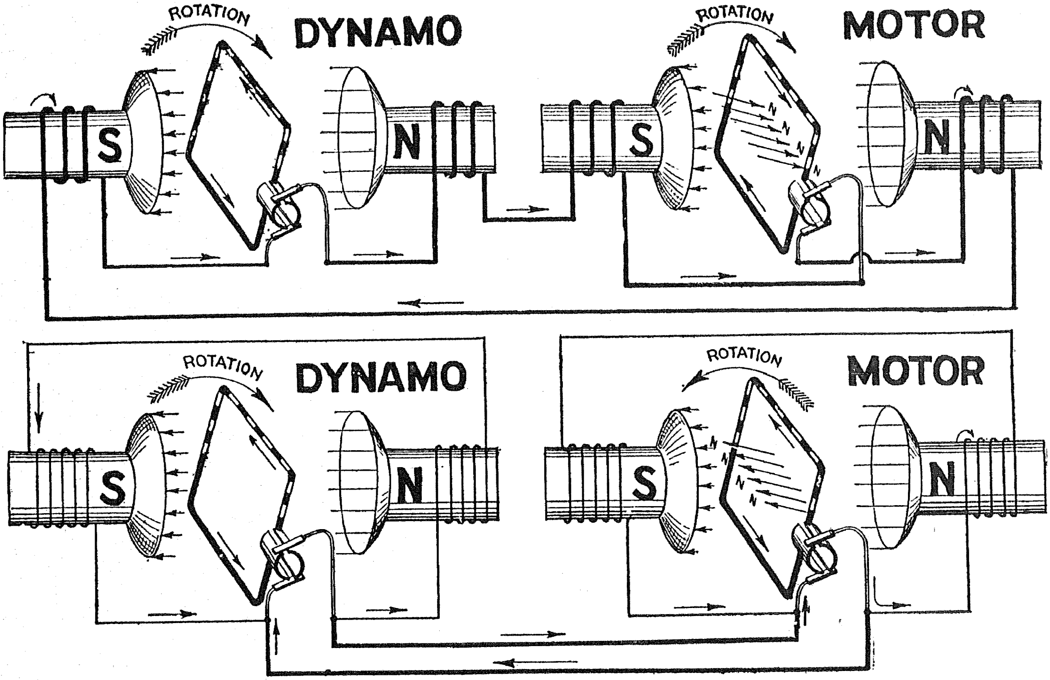


FIG. 1,005.—*Reliance motor construction 19.* Taping armature coils with cotton tape.



Figs. 1,006 to 1,009.—Relative rotation of dynamos and motors. Figs. 1,006 and 1,007 series machines; figs. 1,008 and 1,009, shunt machines. An inspection of the diagrams will show that they rotate in the same direction when so connected that the current in the armatures flow in opposite directions, and rotate in opposite directions when the current flows in the same direction.

Ques. Why is this?

Ans. Because if the connections be such that the current supplied will flow through the armature in the same direction as when the machine is used as a dynamo, the current through the field will be reversed, since the field windings are in parallel with the brushes.

Armature Reaction in Motors.—In the operation of a motor the reaction between the armature and field magnets distorts the field in a similar manner as in the operation of a dynamo.

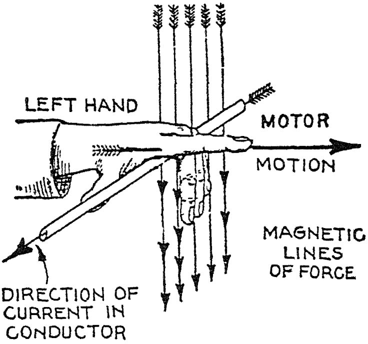


Fig. 1,010.—The "left hand rule" for direction of motion in motors. *Place the left hand,* as shown, *so that the thumb points in the direction of the current, the 3rd, 4th and 5th fingers in the direction of the lines of force, then will the 2nd or forefinger, at right angles to the others, point in the direction in which the conductor is urged.*

A current supplied from an outside source magnetizes the armature of a motor and transforms it into an electro-magnet, whose poles would lie nearly at right angles to the line joining the pole pieces, were it not for the fact that *negative* lead must be given to the brushes.

Negative lead is the amount of backward advance of the brushes against the direction of the rotation of the armature, measured in degrees from the neutral plane.

If the brushes be given positive lead, that is, placed in advance of the neutral plane *in the direction of rotation*, the cross magnetizing force is converted into one that tends to increase that of the field magnets, while if they be given negative lead, it tends to demagnetize the field magnet.

Since with positive lead the armature polarity strengthens that of the field magnet, it is possible, disregarding sparking, to operate a motor without any other means being taken to magnetize the field magnets, because the armature will induce a pole in the field magnet and then attract itself toward this induced pole.

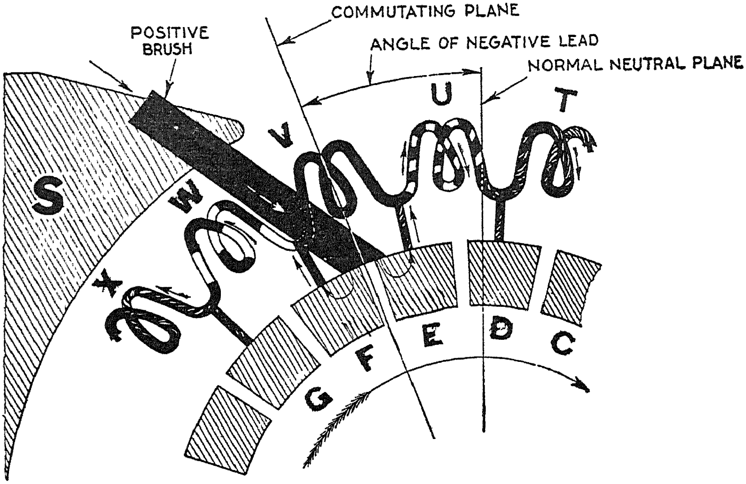


FIG. 1,011.—Current commutation in a motor. Considering the coil W, which is ascending, current is flowing through it from the top brush, while it is itself the seat of an electromotive force that tends to stop or reverse its current. The condition for sparkless commutation requires that during the interval the coil is short circuited by the brush, the coil should be passing through a field that is not only sufficiently strong but one that tends to reverse the direction of its current. The coil is already in such a field, hence, commutation must take place *before* it passes out of this field. To accomplish this the brushes must be shifted backward, that is, given *negative lead,* to overcome sparking. In other words, the *commutating plane* must be shifted *back* of the neutral plane in a motor instead of being placed *in advance* as in a dynamo.

Ques. What effect has the cross magnetizing force on the field?

Ans. It tends to shift the field around in a direction opposite to that of the rotation.

Ques. What are the conditions of minimum sparking?

Ans. The same conditions must obtain as in a dynamo,

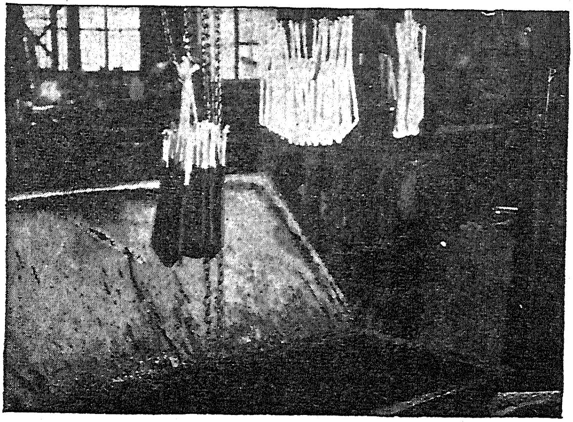


Fig. 1,012.—***Reliance motor construction 20.*** Second dipping of armature coils followed by baking.

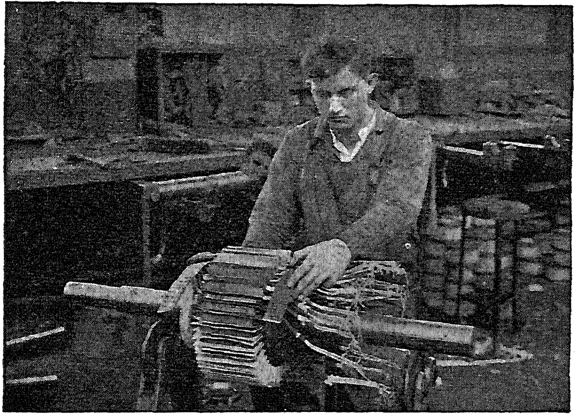


Fig. 1,013.—***Reliance motor construction 21.*** Slot cell insulation which extends ½ in. beyond the core. Note strips of press board taped into continuous rings which insulate top and bottom layers of armature coils at the head.

that is, the current in the coil undergoing commutation must be brought to rest and started again in the opposite direction. This involves that while the coil is short circuited by the brush, it should be passing through a field that tends to reverse the direction of the current. Since the coil is already in such a field, the act of commutation must take place before it passes out of this field. Accordingly, a negative lead must be given the brushes.

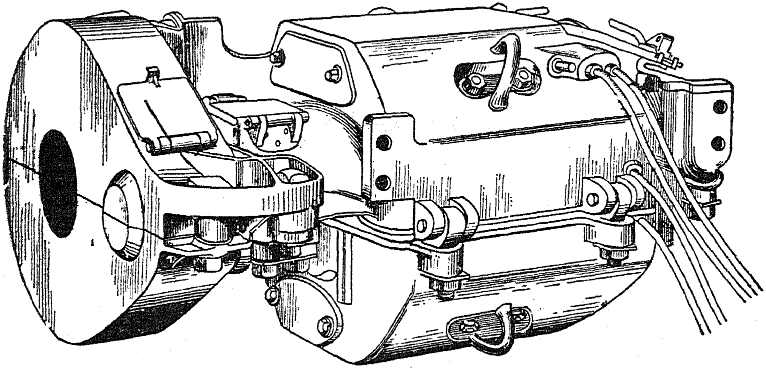


FIG. 1,014.—Railway motor. This type of motor, since it must operate under cars, has taken on the peculiar form under which it is most familiar. As illustrated, the case is of such shape that compactness and water proofing are secured, and the means of attachment to the car axle and support from the axle and truck frame are provided.

Method of Starting a Motor.—Although motors and dynamos are practically similar in general construction and either one of them will act as the other when suitably traversed by an electric current, there are certain differences between the connections and accessories of a machine operated as dynamo and one employed as a motor.

For instance, when a machine is operated as a dynamo, it is first driven up to a speed until it has excited itself to the right pressure, and then it is connected to the circuit; but when a machine is used as a motor it will not start until it has been connected to the circuit, and this must not be done until the proper precautions have been taken to ensure

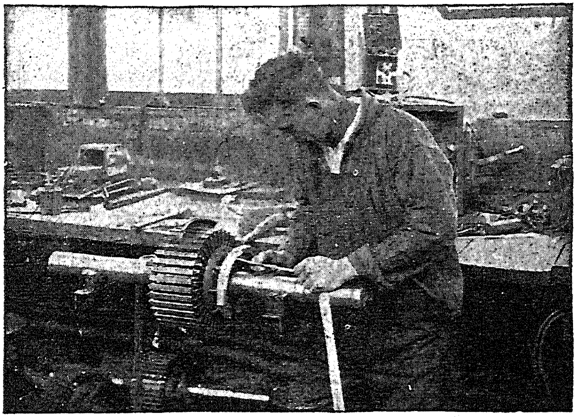


FIG. 1,015.—*Reliance motor construction 22.* Strips of hard fibre are taped to the coil supporting ring. One layer of oiled muslin tape is followed by one of cotton tape.

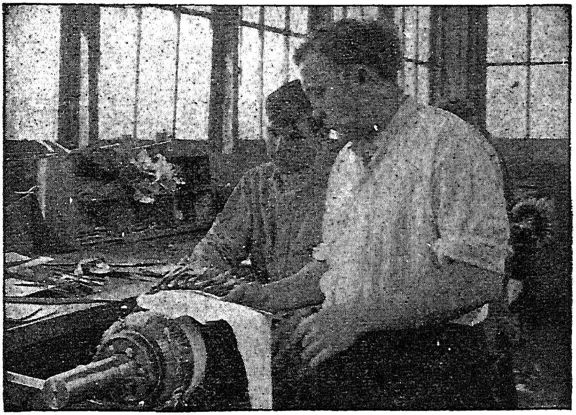
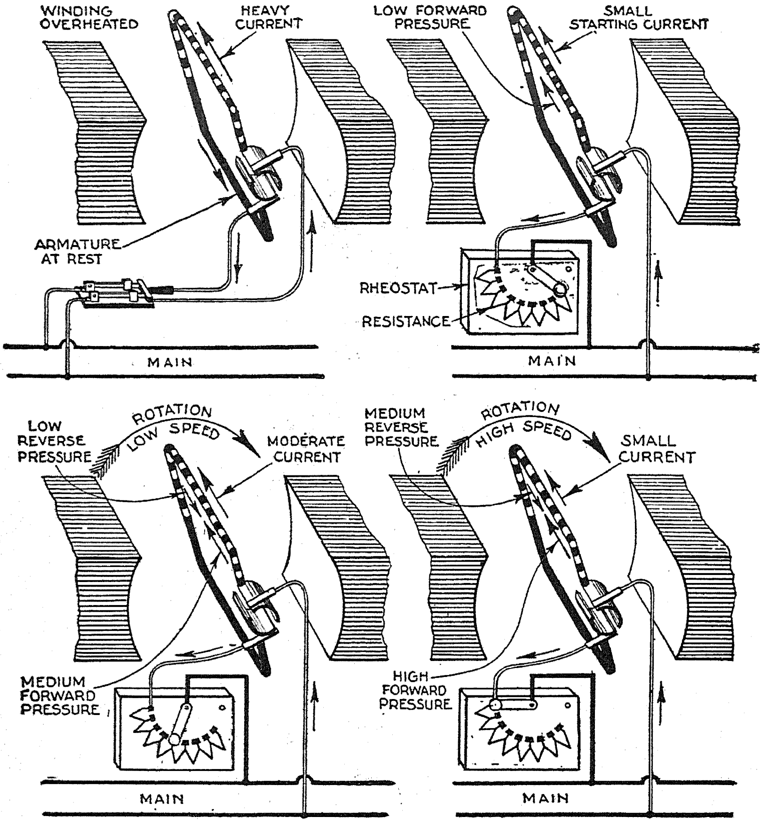


FIG. 1,016.—*Reliance motor construction 23.* Inserting canvas insulation at front head of armature between the coils and leads.



FIGS. 1,017 to 1,020.—Diagrams illustrating necessity for using a rheostat in starting a motor. If, when the motor is at rest, the entire pressure be applied to the armature by closing a switch as in fig. 1,017 the initial rush of current through the armature would be so great that there would be danger of burning out the coils before the armature reached a speed such as would give a reverse voltage high enough to cut down the current to a safe value. Figs. 1,018 to 1,020, show how the current is kept within safe limit in starting by the use of a rheostat.

NOTE.—***Starting without using rheostat*** would cause very serious mechanical shock to the motor and all its parts; an abnormal current would blow fuses and make trouble at other parts of the distribution system; the enormous pull would throw off the belt or produce a rapid increase in speed of the driven machinery which is utterly impractical for it to sustain.

that the current, which will pass through it when so connected, will not be excessive and thereby result in serious injury to the motor. For this reason a rheostat or variable resistance, commonly called a starting box is usually inserted in the armature circuit of a motor to prevent an undue rush of current before the motor attains its speed, and subsequently the speed is regulated by the cutting in or out of the circuit of certain extra resistances which constitute the controller used on a series motor requiring variable torque at variable speed, as in the case of elevator or electric traction service.

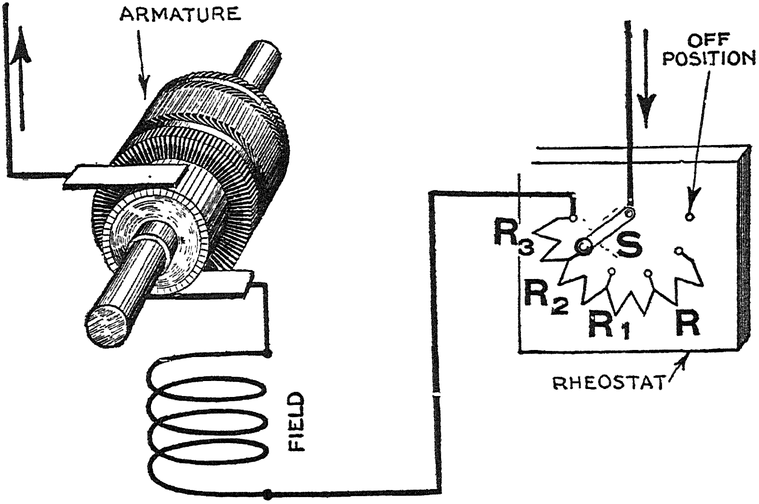


FIG. 1,021.—Series motor connections. ***A series motor*** on a constant voltage circuit does not have a constant field strength, and does not run at uniform speed. If the load be taken off it will run at excessive speed. To start the motor, the circuit is completed through a variable resistance or rheostat by moving the switch S, so that the resistances R, R_1, R_2, R_3, are gradually cut out of the circuit. To stop, the switch S is moved back to its "off" position.

Classes of Motor.—Motors are classified in the same manner as dynamos. The fields may be either bipolar or multi-polar, and with respect to the type of armature winding employed, motors are classed as:

1. Series wound:

2. Shunt wound;
3. Compound wound.

Series Motors.—A series motor is one in which the field magnet coils, consisting of a few turns of thick wire, are connected in series with the armature so that the whole current supplied to the motor passes through the field coils as well as the armature. Fig. 1,021 is a diagram of a series motor showing the connections and rheostat.

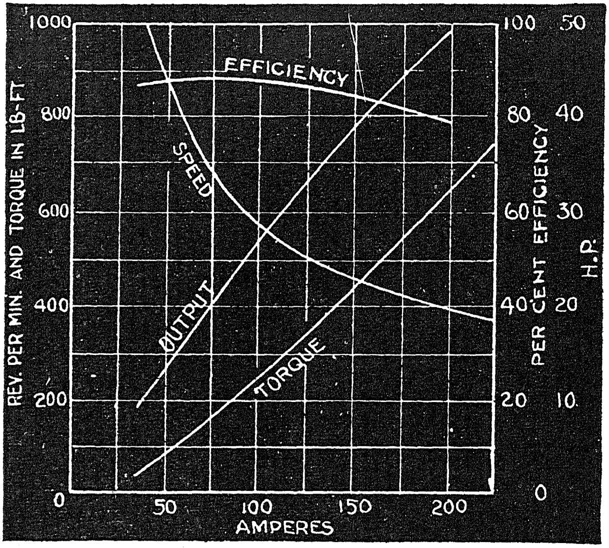


FIG. 1,022.—Characteristic curves for a Westinghouse type MC-50 230 volt series wound enclosed motor for a steel mill crane and hoist service.

Ques. What are the characteristics of a series motor?

Ans. The field strength increases with the current, since the latter flows through the magnet coils. If the motor be run on a

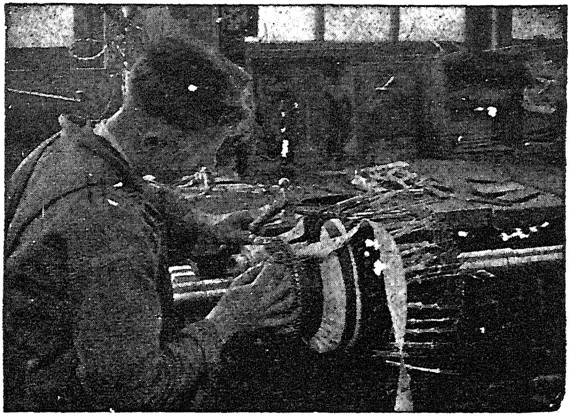


FIG. 1,023.—*Reliance motor construction 24.* A strip of canvas is woven between the top leads as they are connected to commutator.

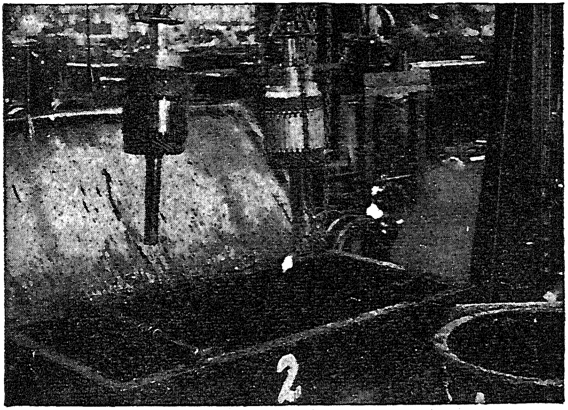


FIG. 1,024.—*Reliance motor construction 25.* Complete armature is immersed in oil proof and water proof insulating varnish. This is followed by a final baking.

NOTE.—***Effect of increase of load on series motor:*** It slows down due to the fact that it has not enough current flowing through it to furnish the required pull, but as it slows down and current begins to rise, the field is getting stronger, which helps out on the pulling effect but acts against the decrease of reverse pressure. Hence a much greater change in speed occurs for a given change in current than would be found for the same machine wound as a shunt motor.

constant voltage circuit, with light load, it will run at a very high speed; again, if the motor be loaded heavily, the speed will be much less than before.

Ques. For what kinds of service are series motors not suited?

Ans. Series motors should not be employed where the load may be entirely removed because they would attain a dangerous speed. They should not be used for driving by means of belts, because a sudden release of the load due to a mishap to the belt would cause the motor to "run away."

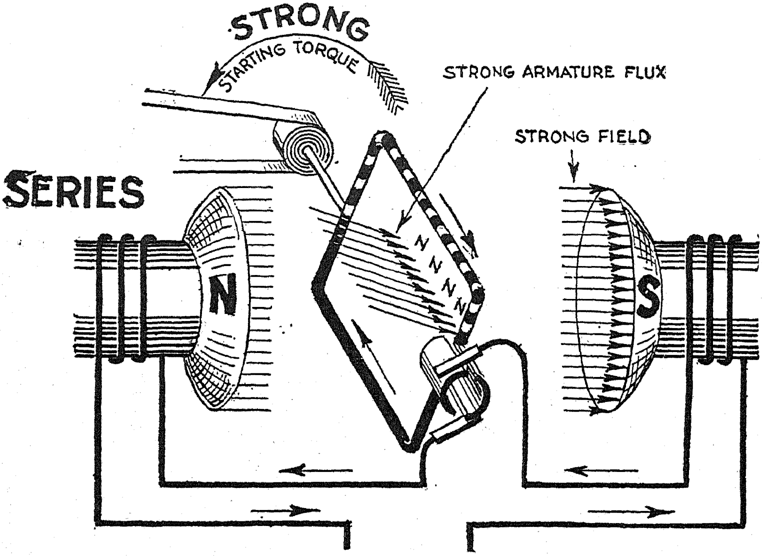


FIG. 1,025.—*D.C. Motor principles, 8. A series motor has a strong starting torque.* Since all the current flows through the magnets as well as through the armature coil, and since very little reverse pressure is developed at starting the turning force is considerable.

Very small series motors may be used with belts since their comparatively large frictional resistance represents an appreciable load, restraining the motor from reaching a dangerous speed.

Ques. For what service are series motors adapted?

Ans. For gear drive.

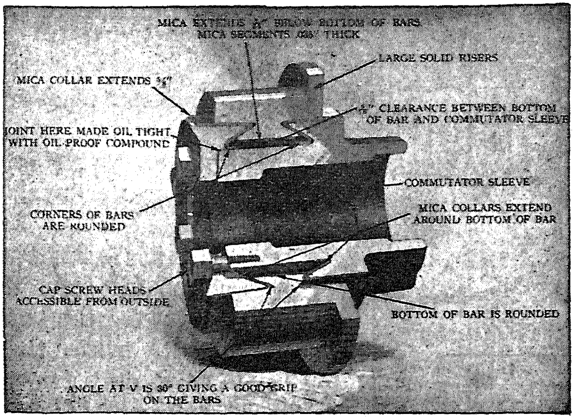


FIG. 1,026.—***Reliance motor construction 26.*** Sectional view of commutator.

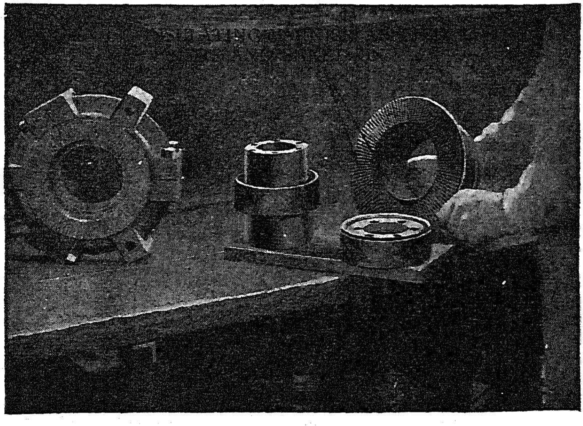
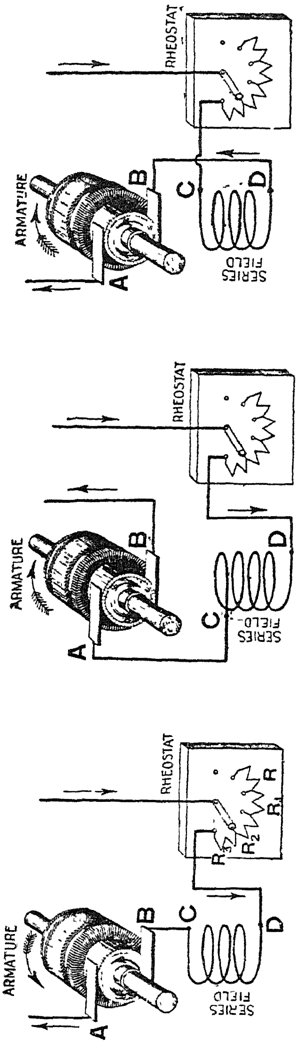


FIG. 1,027.—***Reliance motor construction 27.*** Commutator ready for assembly on sleeve with metal V ring and mica collars. After assembling a special varnish treatment is applied to both the front and rear of the commutator.



FIGS. 1,028 to 1,030.—Reversing the direction of rotation of a series motor. Fig. 1,028 shows the connections for counter clockwise rotation. The motor may be reversed. 1, by allowing the current to flow in its original direction (from D to C) in the field magnet coils, and altering the direction of the armature current by changing the two connections on the brushes A and B, thus connecting C to A and B to the return wire as in fig. 1,029, or 2, by leaving the direction of the current in the armature in its original direction, and reversing that of the field current, as in fig. 1,030. If the wires leading to the rheostat and motor directly, were reversed there would be no reversal of the motor, because by so doing, both the armature and field magnet currents would be reversed.

In the case of a sudden release of the load, the gears provide some load on account of the frictional resistance of the gear teeth.

Ques. What advantage is obtained with series motors with respect to the connections?

Ans. A single wire only proceeds from the rheostat to the motor, so that, with the return wire, only two wires are required.

Ques. For what service are series motors especially adapted?

Ans. Series motors are used principally for electric railways, trolleys, and electric vehicles, and similar purposes, where an attendant is always at hand to regulate or control the speed. They are also used on series arc light circuits in which the current is of constant strength.

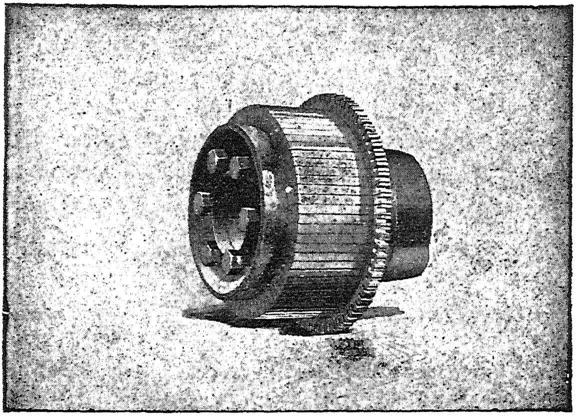


FIG. 1,031.—***Reliance motor construction 28.*** Completed commutator.

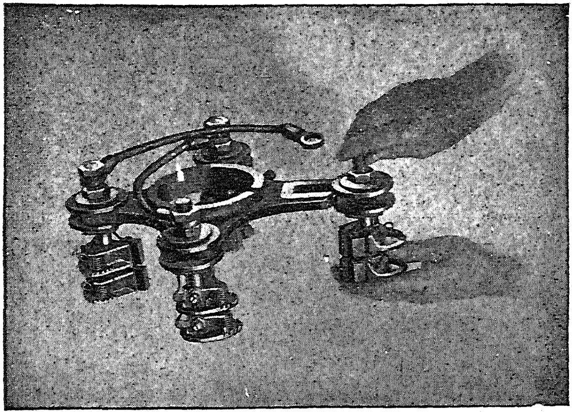
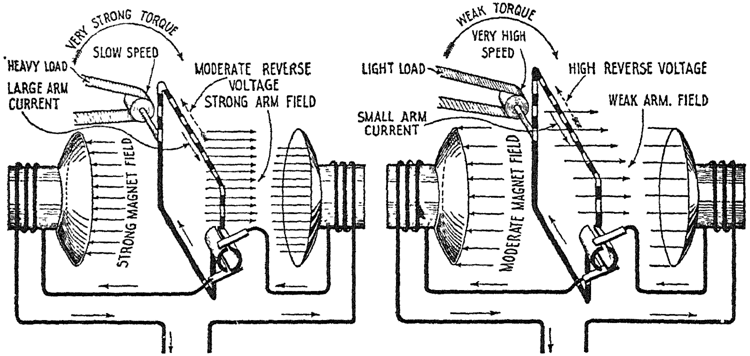


FIG. 1,032.—***Reliance motor construction 29.*** Brush yoke with brush studs, insulation and brush holders.

NOTE.—***A series motor*** running without load may speed up to the point where it wrecks itself. It is necessary on this account to be always attended by someone whose duty it is to regulate the speed.

Very small motors are generally provided with series windings.

Shunt Motors.—A shunt motor may be defined as one in which the field coils are wound with many turns of comparatively fine wire, connected in parallel with the brushes. The current then is offered two paths: one through the armature, and one through the field coils.



Figs. 1,033 and 1,034.—***D. C. Motor Principles 9.***—*Series motor with variable load.* Since the same current passes through both the armature and field coils *the strength of the magnet field varies with that of the armature field.* Now if a heavy load cause the motor to slow down as in fig. 1,033, the reverse voltage will be reduced and a large current will flow through both armature and magnets producing a very strong torque to carry the load. Again, if the load be reduced, as in fig. 1,034, the motor will speed up and increase the reverse voltage which by cutting down the current will weaken both the armature and magnet fields until equilibrium with the load is established.

NOTE.—***A shunt motor*** is commonly though *erroneously* called a *constant speed motor.* In small shunt motors the change in speed from no load to full load is about 6 per cent, while in large ones it is less.

NOTE.—***Weakening the field*** of a shunt motor as by putting resistance in series with the magnet winding and decreasing current through it, will cause it to increase its speed. Weakening the field reduces the reverse pressure. This causes an increase in current through the armature and a pulling effort is produced more than that which is required for the load. The motor accelerates until the reverse pressure is increased to cut down the current again to that required to propel the load.

Ques. What may be said with respect to the speed of a shunt motor?

Ans. It is practically constant with varying loads.

The variation of speed ranges from $\frac{1}{10}$ to 5 per cent., except in the case of small motors, in which the variation may be much greater.

Ques. How should a shunt motor be started?

Ans. To properly start the machine, the field coils must be fully excited.

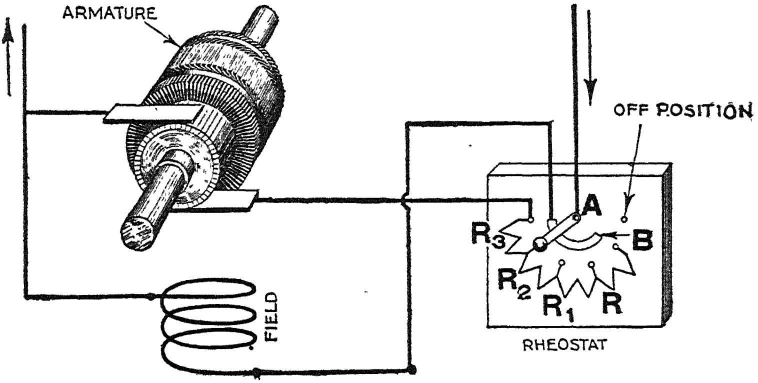


FIG. 1,035.—Shunt motor connections. *A shunt motor* runs at constant speed on a constant voltage circuit. In connecting the motor in circuit, the field coils must be placed in circuit first, so that there is a certain amount of field strength to produce rotation of the armature and thus prevent excessive current through the armature. If the field magnets were not put in the circuit first, the armature, at rest on receiving current, would probably burn out, because it is of low resistance, and would take practically all the current supplied, especially since no reverse voltage is generated in the armature at rest. The method of starting is shown in the illustration. To start, the switch is closed, and the rheostat lever pushed over so as to make contact with A and B, thus *first* exciting the magnets. On further movement of the lever, the rheostat resistances R, R_1, R_2, R_3, etc., are gradually cut out as the speed increases, until finally all the resistance coils are cut out. To stop, the lever is brought back to its off position.

It is, therefore, necessary to switch the magnet coils immediately on to the voltage of supply, while a variable resistance must be provided for the armature circuit. To get both connections at the same time, rheostats for shunt motors are arranged as shown in fig. 1,035.

Influence of Brush Position on Speed.—In the case of a shunt motor supplied with current at constant pressure, the speed is a minimum when the brushes are in the neutral plane, and the effect of giving the brushes either positive or negative lead is to increase the speed, especially with little or no load.

Ques. Why does the speed increase?

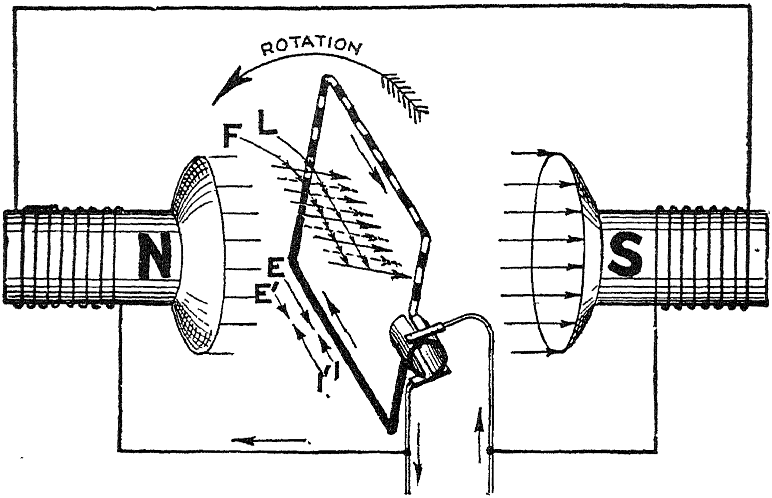
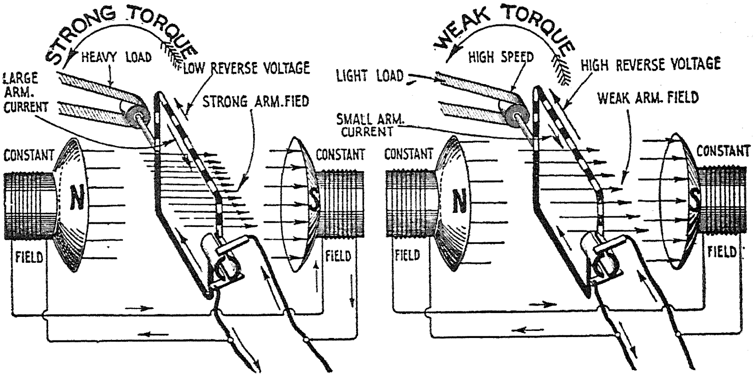


Fig. 1,036.—*Motor Principles, 10. A shunt motor* (sometimes erroneously called "constant speed motor"), *varies its speed when the load changes.* With no external load the motor will run at maximum speed, inducing a high reverse voltage E, this will permit only a small armature current I, giving light armature flux L, sufficient to balance the load. *Now,* if a load be thrown on, it will reduce the speed. This in turn causes the reverse voltage to decrease as from E, to E', thus increasing the current through the armature, say from I to I'; this causes the flux to increase from L, to F, to balance the load. In practice the variation of speed is so *small* that the term "constant speed" is usually applied, though wrong.

Ans. When the brushes are shifted from the neutral plane, the reverse voltage between the brushes is decreased, speed remaining unchanged. Accordingly, the pressure in the supply mains forces an increased current through the armature thus producing an increased armature pull which causes the speed



Figs. 1,037 and 1,038.—*D. C. Motor Principles 11.—Shunt motor with variable load. The strength of the magnet field remains constant while that of the armature field varies.* Now if a heavy load cause the motor to slow down as in fig. 1,037, the reverse voltage will be reduced allowing more current to flow through the armature which increases the torque till equilibrium is established between torque and load. Again, if the load be reduced, the motor will speed up, and since the field strength remains constant (instead of being reduced as in the series motor) this acceleration is quickly checked by the rapid rise of reverse voltage, there being very little difference in speed for either heavy or light load.

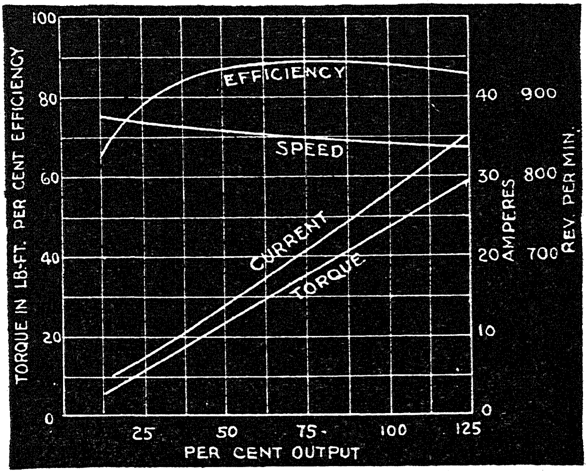


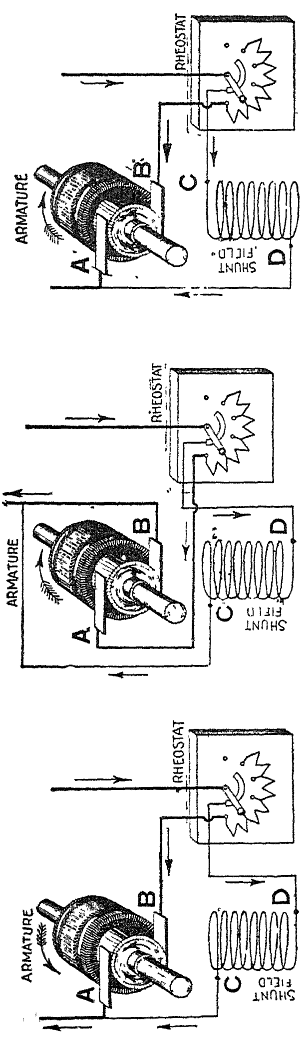
Fig. 1,039.—Characteristic curves for a General Electric type RC, 7½ horse power 230 volt commutating pole shunt wound motor of open construction.

to increase until the reverse voltage reaches a value sufficiently large to reduce the current to the value required to supply the necessary driving torque.

Compound Motors.—This type of motor has to a certain extent, the merits of the series motor without its disadvantages, and is adapted to a variety of service. If the current flow in the same direction through both of the field windings, then the effect of the series coil strengthens that of the shunt coil; this strengthening is greater, the larger the armature current.

Ques. Mention some characteristics of the compound motor.

Ans. Since it is a combination of the shunt and series types, it partakes of the properties of both. The series winding gives it strong



FIGS. 1,040 to 1,042.—Reversing the direction of rotation of a shunt motor. FIG. 1,040 shows the connections for counter clockwise rotation. The motor may be reversed: 1, by allowing the current to flow in its original direction through the field magnet coils (from D to C), and reversing its direction through the armature (from A to B) as in fig. 1,041, or 2, by allowing the armature current to flow in its original direction (from B to A) and reversing the current through the field coils (from C to D) as in fig. 1,042.

torque at starting (though not as strong as in the series motor), while the presence of the shunt winding prevents excessive speed. The speed is practically constant under all loads within the capacity of the machine.

Compound motors are used where there is a heavy load to be started as with the series motor and where at the same time the speed limiting characteristics of the shunt wound motor is desired. A compound wound motor should be used in preference to shunt wound motor where either the motor or the machine is to be started or reversed at frequent intervals, also where the load fluctuates and a fly wheel may be used to advantage. In the latter case, the motor speed drops off as the load comes on, allowing the fly wheel to give up some of its stored energy. For severe mill service such as binding rolls the motors are heavily compounded, having only enough shunt winding to limit the light load operating speed. At heavier loads these motors have all the operating features of series motors.

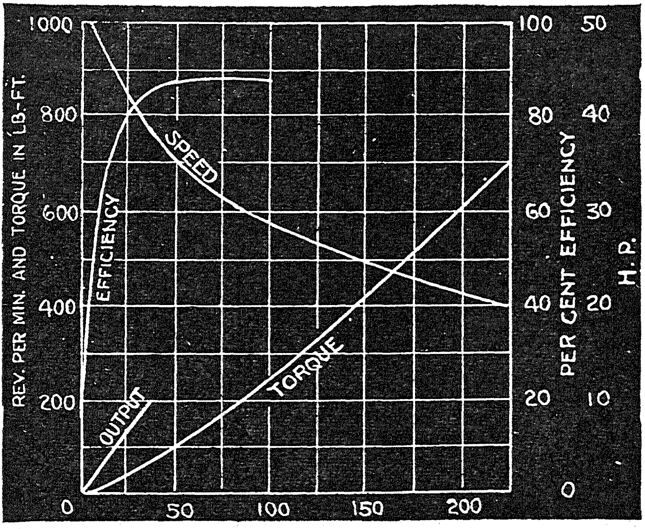


FIG. 1,043.—Characteristic curves for a Westinghouse type MC-50, 230 volt compound wound enclosed motor for a steel mill crane and hoist service.

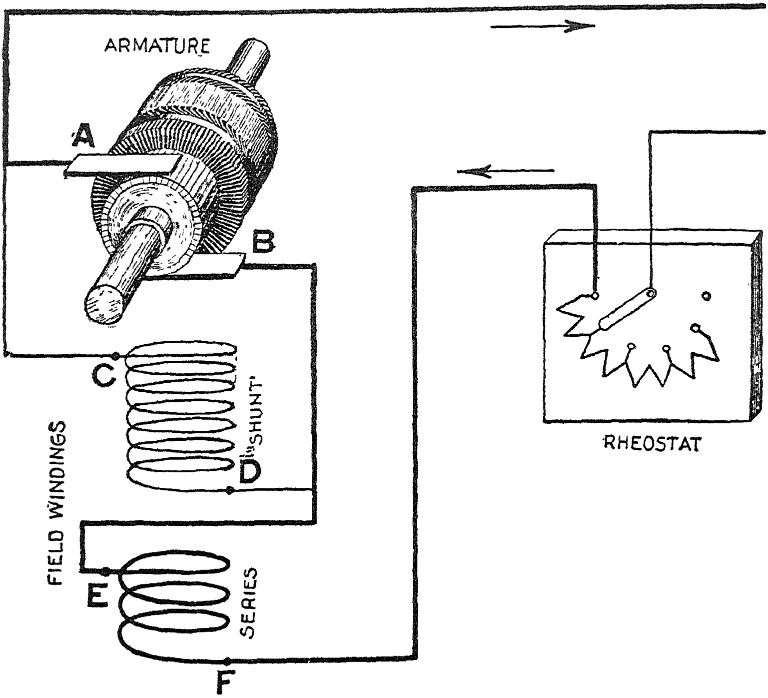


FIG. 1,044.—Compound motor connections for starting from a distant point. ***A compound winding*** may be used on motors for many different purposes. If the current flow in the same direction through both windings, then the effect of the series coil strengthens that of the shunt coil. This strengthening increases with the load. Thus the motor gets, at increasing load, a stronger magnetic field, and will therefore, if the voltage remain constant, run slower than before. Accordingly, for a given current, the starting power will be greater than that of a shunt motor. With a decreasing load the motor will run faster. The compound motor has, to a certain extent, the merits of the series motor without its disadvantages. In the case of compound motors the starting at a distance with only two mains may be effected, just as in the case of the series motor. The connections are shown in the diagram. If the motor be regarded as being without the shunt coil, then it is connected up exactly as the series motor in fig. 1,021. The current coming from the starter enters the series coil at F, flows through the series coil and leaves it at E, flowing from there to the armature brush B, through the armature to brush A, and from there through the second main back to the dynamo. The shunt winding is connected directly with the armature brushes A and B, and gets at starting, therefore, only a very small voltage, hence its field is nearly ineffective. But on account of the series winding, the motor starts as a series

Ques. Describe the connections for starting a compound motor at a distance.

Ans. Control at a distance can be effected with only two wires, just as in the case of a series motor. In the diagram fig. 1,044, the current coming from the rheostat enters the series coil at F, and leaves it at E, thence it flows to the armature brush B, through armature to brush A, and from here back to the dynamo. The shunt winding, which is connected across the brushes, gets a very small voltage at starting and is accordingly very ineffective. The motor then starts as a series motor. The starting effect is smaller than in a series motor because of the fewer turns in the series winding, most of the available space being occupied by the shunt coils.

Power of a Motor.—The word "power" is defined as *the rate at which work is done*, and is expressed as the quotient of the work divided by the time in which it is done, thus:

$$\text{power} = \frac{\text{work}}{\text{time}}$$

The difference between power and work should be clearly understood.

FIG. 1,044.—*Text continued.*

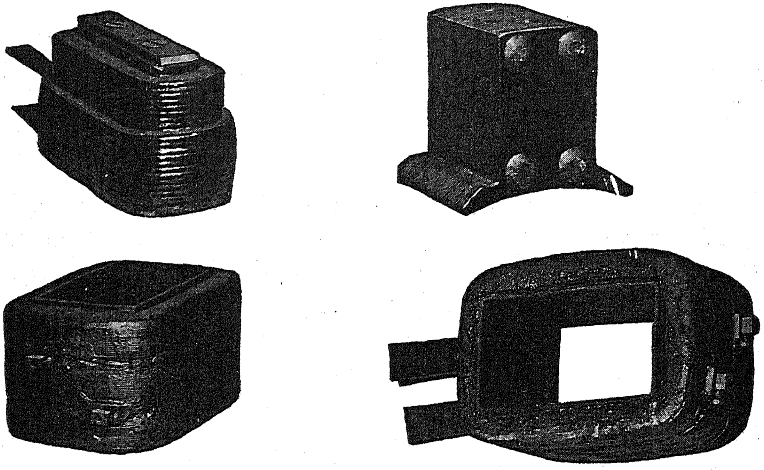
motor. Obviously such a motor will not develop a very large starting power like a real series motor, for, on account of the large space occupied by the shunt coils, there is less space available for the series coils than with a series motor. A compound motor may, however, even with this arrangement, be easily started, provided the load on starting be not too heavy. When once running the armature will produce a reverse voltage and the shunt coil will be supplied with nearly the full terminal voltage.

NOTE.—***Compound motor connections test.*** To ascertain that the series and shunt windings are connected *accumulatively* the following test may be made: Close the main line switch *momentarily*, with machine connected as a series motor (that is, with the shunt circuit open); if the direction of rotation when running thus is the same as when running as a compound motor, it is connected accumulatively. If not, it is connected differentially and in this case it will be necessary to reverse either the series or the shunt connections at the controller.

Work is the overcoming of resistance through a certain distance. It is measured by the product of the resistance by the space through which it is overcome, thus:

$$\text{work} = \text{distance} \times \text{space}$$

For instance, in lifting a body from the earth against the attraction of gravity, the resistance is the weight of the body, and the space, the height to which the body is raised, the product of the two being the work done.



Figs. 1,045 to 1,048.—Westinghouse field construction for small motors. Fig. 1,045, commutating pole and coil; fig. 1,046, laminated pole piece; fig. 1,047, shunt field coil; fig. 1,048, compound field coil. In fig. 1,045 the coil is wound with heavy copper wire or strip, treated to resist oil and moisture. In fig. 1,046, the pole piece is proportioned to give graduated air gap, reducing distortion of flux in air gap, and insuring quiet operation. The pole is fastened to yoke by two bolts. In fig. 1,047 the shunt field coil is wound on metal spools which prevent any movement of the coils; they are carefully insulated and treated to resist oil and moisture, also protected by outside layer of cord.

The unit of work is the *foot pound*, which is *the amount of work done in overcoming a pressure or weight equal to one pound through one foot of space.*

The unit of power is the *horse power* which is equal to 33,000 *foot pounds of work per minute, that is:*

$$\text{horse power} = \frac{\text{foot pounds per minute}}{33{,}000}$$

The unit of power was established by James Watt as the power of a strong London draught horse to do work during a short interval, and used by him to measure the power of his steam engines.

In order to measure the mechanical power of a motor, it is necessary to first determine the following three factors upon which the power developed depends:

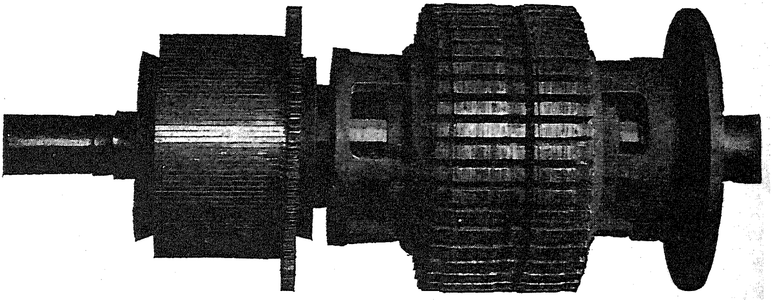


FIG. 1,049.—Westinghouse armature core and commutator assembled on sleeve in large machines.

1. Pull of the armature, in pounds;
2. Distance in feet at which the pull acts from the center of the shaft;
3. Revolutions per minute.

Example.—If the armature pull of a motor having a two foot pulley be such that a weight of 500 lbs. attached to the rim, is just balanced, and the speed be 1,000 revolutions per minute, what is the horse power?

Here, the distance that the pull acts from the center of the shaft is one foot, hence for each revolution the resistance of 500 pounds is overcome through a distance equal to the circumference of the pulley or

$$\pi \times \text{diameter} = 3.1416 \times 2 = 6.2832 \text{ feet.}$$

The *work done* in one minute is expressed by the following equation:

$$\left\{\begin{matrix}\text{work}\\ \text{per}\\ \text{minute}\end{matrix}\right\} = \left\{\begin{matrix}\text{weight}\\ \text{in lbs.}\end{matrix}\right\} \times \left\{\begin{matrix}\text{circumference}\\ \text{of pulley}\\ \text{in feet}\end{matrix}\right\} \times \left\{\begin{matrix}\text{revolutions}\\ \text{per minute}\end{matrix}\right\} = \text{foot pounds}$$

$$= \quad 500 \quad \times \quad 6.2832 \quad \times \quad 1{,}000 \quad = 3{,}141{,}600$$

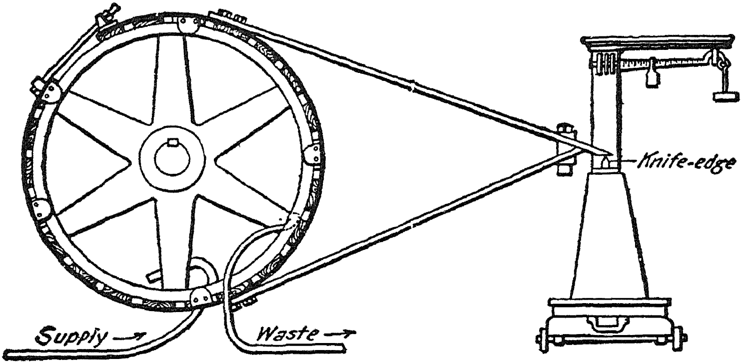


FIG. 1,050.—Prony brake for determining brake horse power. ***It consists of*** a friction band ring which may be placed around a pulley or fly wheel. and attached to a lever bearing upon the platform of a weighing scale in such a manner that the friction between the surfaces in contact will tend to rotate the arm in the direction in which the shaft revolves. This thrust is resisted and measured *in pounds* by the scale. In setting up the brake the distance between the center of the shaft and point of contact (knife edge) with the scales must be accurately measured, *the knife edge being placed at the same elevation as the center of the shaft.* An internal channel permits the circulation of water around the interior of the rim as shown, to prevent overheating.

Hence, the power developed is

$$3{,}141{,}600 \div 33{,}000 = 95.2 \text{ horse power.}$$

Ques. What is "brake" horse power?

Ans. The net horse power developed by a machine at its shaft or pulley; so called because a form of brake is applied to the pulley to determine the power.

Ques. Describe the apparatus used in making a brake test.

Ans. Tests of this kind are usually made with a Prony brake as shown in fig. 1,050. It consists of a band of rope, or strip iron as shown, to which are fastened a number of wooden blocks, several carrying shoulders to prevent the contrivance slipping off the wheel rim. The brake band is drawn tight, as shown, so that the blocks press against the surface all around. The brake thus formed is restrained from revolving with the pulley by two arms attached near the top and bottom centers of the wheels, and joined at the opposite ends to form a lever which bears upon an ordinary platform scale, a suitable leg or block being arranged to keep its end level with the center of the shaft.

By this arrangement the amount of friction between the brake band and the revolving wheel is weighed upon the scales. Since the brake fits tightly enough to be carried around by the wheel, but for the arms bearing upon the scale, the amount of frictional power exerted by the wheel in turning free within the blocks may be transmitted and measured, just as would be the case were a machinery load attached, instead of a friction brake.

Ques. Why must the point of contact of the brake with the scales be level with the center of the shaft?

Ans. In order to determine the force acting at right angles to the line joining the point of contact and center of the shaft.

Ques. What is the distance between the center of the shaft and point of contact with the scales called?

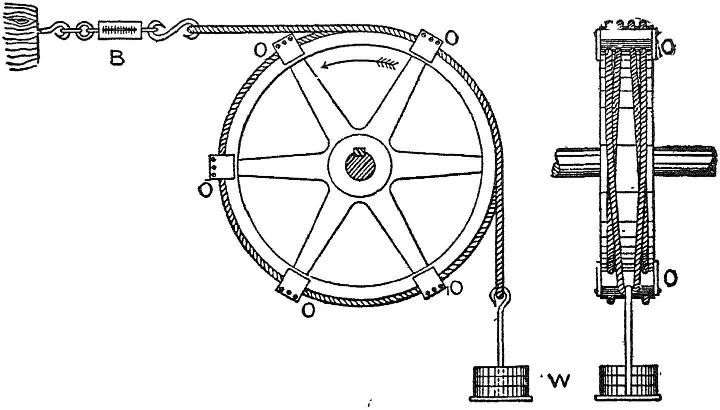
Ans. The lever arm.

Ques. What three quantities must be determined in a test in order to calculate the brake horse power?

Ans. The lever arm, the force exerted on the scales, and the revolutions per minute.

Ques. How is brake horse power calculated?

Ans. From the following formula:



Figs. 1,051 and 1,052.—Side and end view of rope brake. This type of brake is easily constructed of material at hand and being self-adjusting needs no accurate fitting. For large powers the number of ropes may be increased. It is considered a most convenient and reliable brake. In the figure the spring balance, B, is shown in a horizontal position. This is not necessary; if convenient the vertical position may be used. The ropes are held to the pulley or fly wheel face by blocks of wood, O. The weight at W, may be replaced by a spring balance if desirable. To calculate the brake horse power, subtract the pull registered by the spring balance, B, from the weight W. The lever arm is the radius of the pulley plus one-half the diameter of the rope. The formula is,

$$^{*}\text{B. H. P.} = \frac{2\pi \text{ R N (W} - \text{B)}}{33{,}000}$$

$$= .0001904 \text{ R N (W} - \text{B)}$$

In the formula R = radius from center of shaft to center of rope; N = *revolutions* per minute; W = weight; B = pull on spring balance.

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*NOTE.—If B be greater than W, the engine is running in the opposite direction; in this case use the formula B. H. P. = .0001904 R N (B − W).

$$\text{B.H.P.} = \frac{2\pi L N W}{33{,}000}$$

in which

B. H. P. = brake horse power;
L = lever arm, *in feet;*
N = number of revolutions per minute;
W = force *in pounds* at end of lever arm as measured by scales.

Example.—In making a brake test on a motor, the lever arm of the brake is 3 ft., and the reading of the scales is 30 lbs. When the motor is running 1,000 revolutions per minute, what is the brake horse power?

Substituting the given values in the formula,

$$\text{B. H. P.} = \frac{2\pi \times 3 \times 1{,}000 \times 30}{33{,}000} = 17.1$$

Now, if the voltmeter and ammeter readings be 220 and 65 respectively, what is the efficiency of the motor at this load?

The amount of power absorbed by the motor, or in other words, the *input* is

$$\text{E. H. P.} = \frac{220 \times 65}{746} = 19.16$$

and since the output is 17.1 horse power,

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{brake horse power}}{\text{electrical horse power}} = \frac{17.1}{19.16} = 89\%.$$

Speed of a Motor.—The normal speed at which any motor will run is such that the sum of the reverse pressure and the drop in the armature will be exactly equal to the voltage applied at the brushes. The drop in the armature is the difference between the applied voltage and the reverse voltage.

Mutual Relations of Motor Torque and Speed.—The character of the work to be done not only determines the condition of the motor torque and speed required, but also the suitability of a particular type of motor for a given service. There are three general classes of work performed by motors, and these require the following conditions of torque and speed:

1. Constant torque at variable speed;

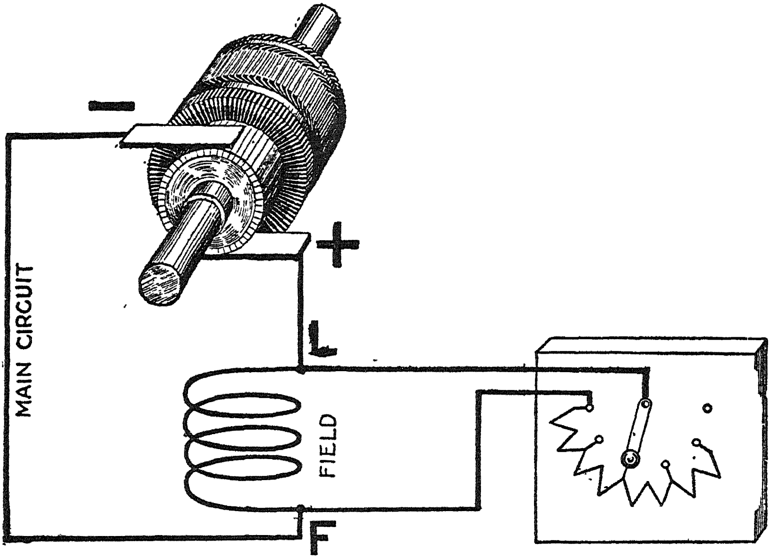


FIG. 1,053.—Two path LF method of speed regulation of series motor. *A rheostat* is connected in shunt to the field coils as shown. The current from + brush divides at L between the magnet coils and the rheostat coils; the higher the resistance of the rheostat the less current passes through it, and the more through the magnet coils, hence the stronger the field magnet.

Suitable for driving cranes, hoists, and elevators, etc., where the load is constant and has to be moved at varying rates of speed.

2. Variable torque at constant speed;

Suitable for driving line shafting in machine shops, which must run at constant speed regardless of variations of torque due to variations in the number of machines in operation at a time, or the character of work being performed.

3. Variable torque at variable speed.

Suitable for electric railway work. For example: when a car is started, the torque is at its maximum value and the speed zero, but as the car gains headway, the torque decreases and the speed increases.

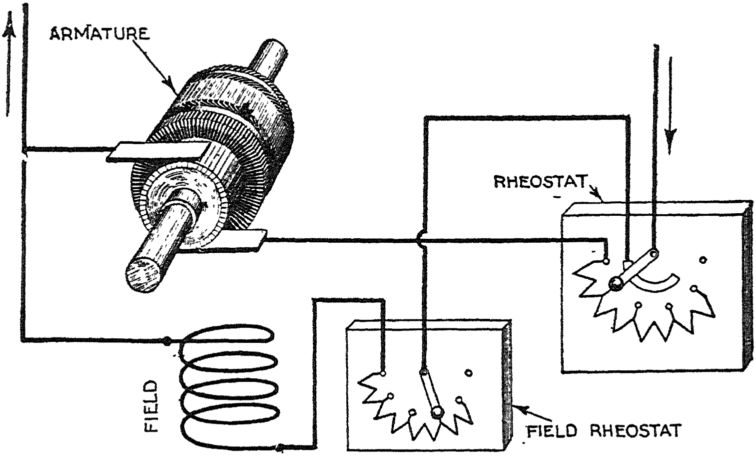


FIG. 1,054.—Speed regulation of a shunt motor. ***The speed of a motor*** depends on the voltage of the current supplied and the field strength. The motor tends to rotate so fast as to produce a *reverse voltage* nearly equal to that supplied to the brushes; hence, the speed varies with the voltage supplied. By decreasing this voltage then, the speed is decreased. Accordingly, the speed may be reduced by inserting, by means of a rheostat, a resistance in series with the motor. By inserting this resistance in the field circuit, the voltage at the terminals of the motor is lowered, thus giving the condition necessary to reduce the speed. The arrangement for speed regulation shown in the figure includes a starting regulator and a shunt regulator.

Speed Regulation of Motors.—The speed of motors connected to constant voltage circuits is usually regulated by the two following methods:

1. By inserting resistances in the armature circuit of a shunt motor;

2. By varying the strength of the field of a series motor.

The first method is sufficiently explained under fig. 1,054 and the second method is illustrated in fig. 1,055. The controller switch S is so arranged that a greater or lesser number of field coils can be inserted in the field circuit. When the switch arm is on point 1, the motor current will flow through all the field windings, and the strength of the field will be at its maximum.

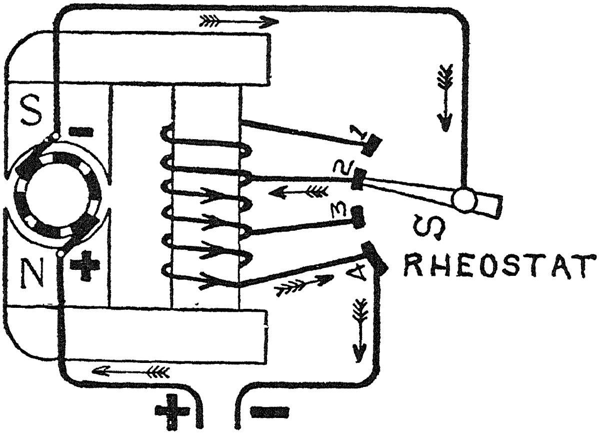


FIG. 1,055.—Variable field method of speed regulation of series motor. ***The field winding*** is divided into a number of sections with leads connecting with switch contact points as illustrated. The speed then is regulated by cutting in or out of the circuit sections of the field winding thus varying the strength of the field.

When the switch arm is moved so as to successively occupy positions 2, 3, and 4, thus cutting out of circuit a greater and greater number of field coils the strength of the field will be gradually decreased until practically all of the motor current is led or wired through the armature. Under these conditions, when the field of a motor is at its maximum strength, the motor torque will be at a maximum for any given strength of current, and the reverse electromotive force will also be at a maximum for any given speed, therefore, when the field strength is increased the speed will decrease and *vice versa*.

Ques. What results are obtained by this method of regulation?

Ans. The speed of a series motor may be nearly doubled, that is, if the lowest permissible speed of the motor be 250 revolutions per minute it can be increased to nearly 500 revolutions per minute by changing the field coil connections from series to parallel.

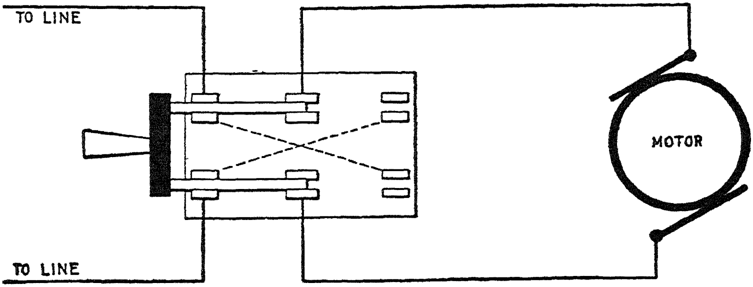


FIG. 1,056.—Double throw, double pole switch for reversing direction of rotation of a motor. The direction of rotation can be reversed by changing the direction of current in either the armature or the field coils. It is preferable, however, to reverse the direction of rotation by changing the direction of current through the armature. The switch is wired as shown, means of reversal being provided by running the wires as indicated by the dotted lines.

It is on this account, as much as on their powerful starting torque, that series motors have been until recently almost exclusively employed for electric traction purposes.

Series Parallel Controller.—When two motors are used in electric railway work, their armatures are connected in series with each other and an extra resistance which prevents the passage of an excessive current through the armature before the motor starts.

As the speed of the car increases, the extra resistance is gradually cut out of circuit and the field winding connections changed from series to parallel by means of a series parallel controller, which finally connects each motor directly across the supply mains, or between the trolley line and the track or ground return.

Efficiency of a Motor.—The commercial efficiency of a motor is *the ratio of the output to the input.*

As a rule, the power developed by a motor increases as the reverse voltage generated by it decreases, until this voltage equals one half of the voltage applied at the brushes. After this point is reached, the power developed by the motor decreases with the decrease of the reverse voltage. Therefore, a motor performs the largest amount of work when its reverse voltage is equal to one half the impressed voltage.

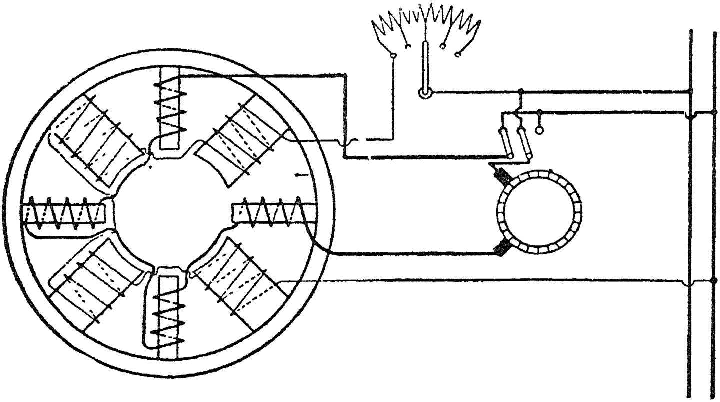


FIG. 1,057.—Wiring diagram, showing electrical connections between the armature, field, and interpoles of an interpole motor. As the name implies, an interpole motor has in addition to the main poles, a series of interpoles which are placed between the main poles, and whose function is to assist in the reversal of the current under the brushes. They provide a separate commutating field of a correct value at all loads and speeds, and their windings are for this purpose connected in series with the armature. The proper functioning of the interpoles is independent of the direction of rotation of the armature, also of the load carried over the whole speed range. In an ordinary motor without interpoles, commutation is assisted by a magnetic fringe emanating from the main poles, but as the value of this fringe is altered by the load of the motor and by rheostatic field weakening, if higher speeds be desired from such a machine, commutation becomes imperfect and sparking results, making a readjustment of the brushes necessary.

The efficiency of a motor as just stated is *the ratio of the output to the input*; this is equivalent to saying that the efficiency of a motor is equal to *the brake horse power divided by the electrical horse power.*

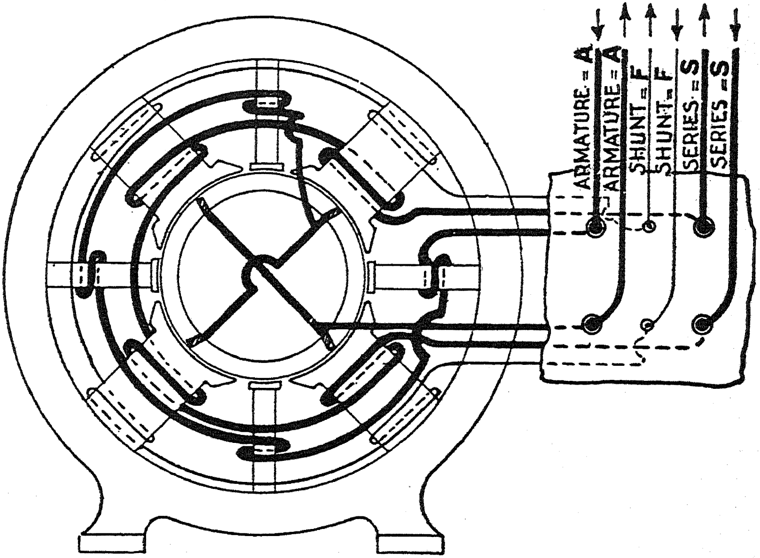


FIG. 1,058.—Connection diagram for compound inter-pole motor; variable speed. Arrows indicate direction of current for accumulative compound right hand rotation. ***In case*** the direction of rotation is to be changed, reverse the armature connections at controller. In order to be sure that series and shunt windings are connected accumulatively, the following test may be made. Close the main line switch, *momentarily*, with machine connected as a series motor (that is, with the shunt circuit open). If the direction of rotation when running thus be the same as when running as a compound motor, it is connected accumulatively, if not, it is connected differentially, and in that case it will be necessary to reverse either the series or the shunt connections at the controller.

The electrical horse power is easily obtained by multiplying the readings taken from volt meter and ammeter, which gives the watts, and dividing the product by 746, the number of watts per horse power. That is:

$$\text{Electrical horse power} = \frac{\text{volts} \times \text{amperes}}{746} = \frac{\text{watts}}{746}$$

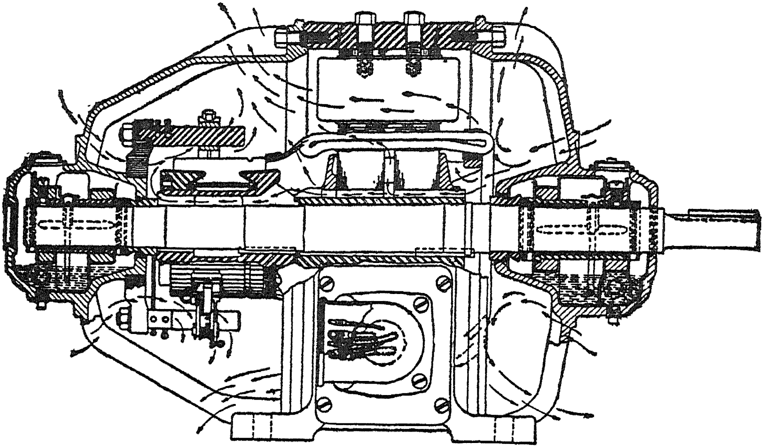


FIG. 1,059.—Sectional view of General Electric type C.D. commutating pole motor showing construction and ventilation.

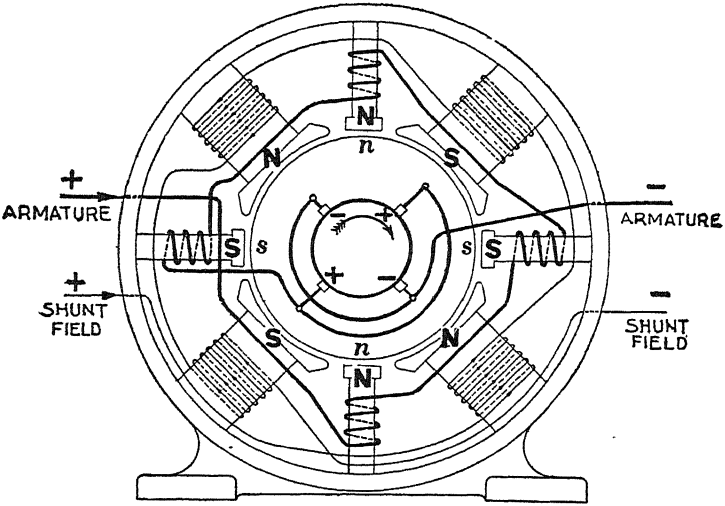


FIG. 1,060.—Connection diagram for four pole shunt wound inter-pole motor. For counter clock-wise rotation reverse direction of field current, but do not change the internal connections.

Interpole Motors.—An interpole motor has in addition to the main poles, a series of interpoles, placed between the main poles. The object of these poles is to provide an auxiliary flux or "commutating" field at the point where the armature coils are short circuited by the brush.

Ques. What is the object of the commutating field produced by the interpoles?

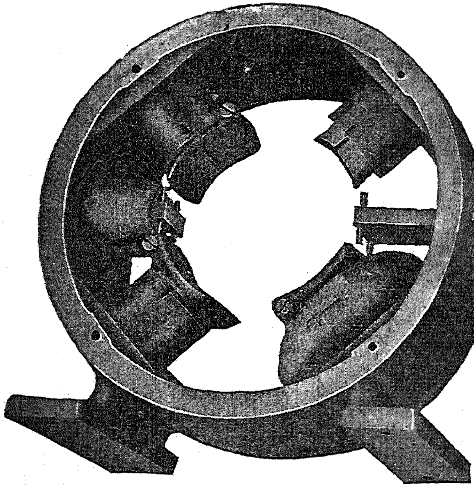


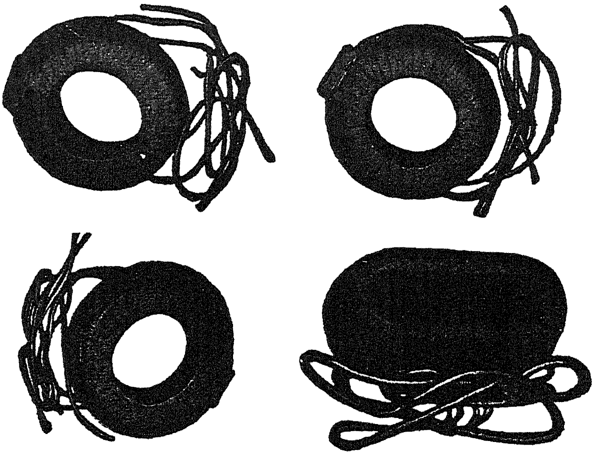
FIG. 1,061.—Diehl *d.c.* motor frame or yoke showing field and interpole coils. The frame is of gray cast iron and the magnet poles pieces of soft ingot iron capped with cast iron shoes. The field coils are held in place by the pole shoes. Holes are drilled on both sides of the yoke to receive the end bonnet fastening screws. These holes are spaced so that the end bonnet is interchangeable. This permits adjustment from floor to ceiling mounting on all sizes and on four-pole motors from floor to side wall mounting by turning the end bonnets without changing the drilling. The end bonnets or covers are cast of gray iron in one piece. The four openings in the end bonnets can be covered by solid cast plates on motors designed for enclosed, watertight or dust proof service. For general protection semi-enclosing wire gauze or wire screen covers may be used.

Ans. Its object is to assist commutation, that is, to help reverse the current in each coil while short circuited by the brush, and thus reduce sparking.

Ques. What is the nature of the commutating field?

Ans. The excitation of the interpoles being produced by series turns, the field will vary with the load, and will, if once adjusted to give good commutation at any one load, keep the same proportion for any other load, provided the iron parts of the circuit be not too highly saturated.

Ques. State briefly how sparking is reduced or prevented by the action of the interpoles.



Figs. 1,062 to 1,065.—Diehl field coils. Figs. 1,062 to 1,064, main pole coils; fig. 1,065, interpole coil. The shunt field coils are of enameled wire, form wound and insulated. They are treated with a finishing coat of insulating varnish which aids materially in resisting the destructive action of oil, moisture and excessive dust or dirt.

Ans. Sparking is due to self-induction in the coil undergoing commutation, which impedes the proper reversal of the current. The action of the interpoles corrects this in that they set up a field in a direction that causes a reversal of the current in the coil while it is short circuited. Thus, the coil at the instant it leaves the brush, is not an idle coil, but has a current flowing in it in the right direction to prevent sparking.

Ques. Mention some of the claims made for interpole motors.

Ans. Constant or adjustable speed, and momentary overloads without sparking; constant brush position; operation at adjustable speeds on standard supply circuits of 110, 220, and 550 volts; constant speed with variable load, reversal without changing the position of the brushes.

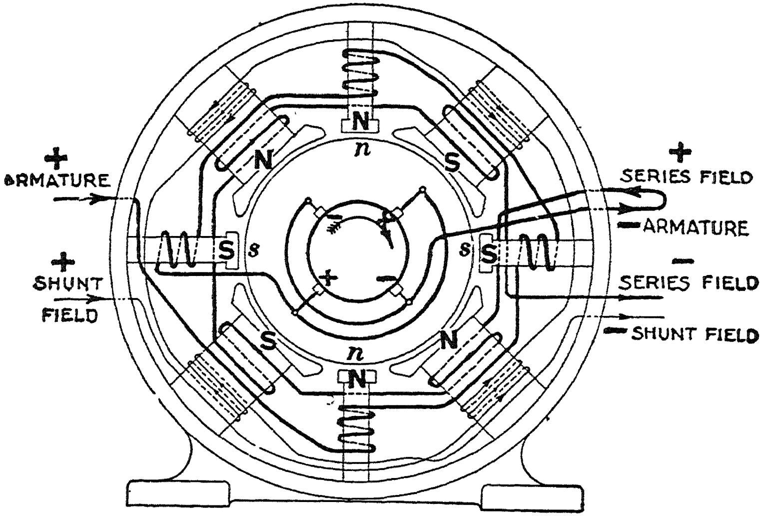


FIG. 1,066.—Connection diagram for four pole compound wound interpole motor. For counter clockwise rotation reverse direction of current in both shunt and series field, but do not change the internal connections.

Adjustable Speed Motors.—There are numerous conditions

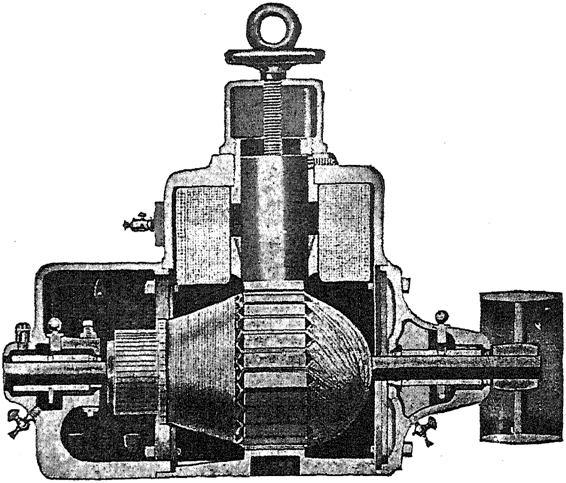


FIG. 1.067—Stow adjustable speed motor; sectional view showing mechanism for adjusting the speed by shifting the pole pieces.

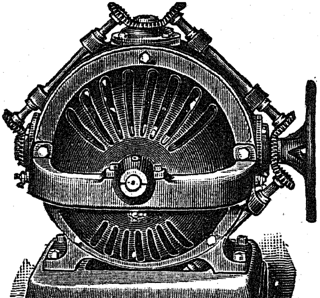


FIG. 1068.—Stow four pole adjustable speed open type motor showing double gear arrangement for shifting the pole pieces.

of service in which it is desired to vary the speed of motors. The speed of a motor may be varied by several methods as by:

1. Shifting the pole pieces;
2. Shifting the armature.

Figs. 1,067 and 1,068 show a typical motor whose speed is adjusted by the first method.

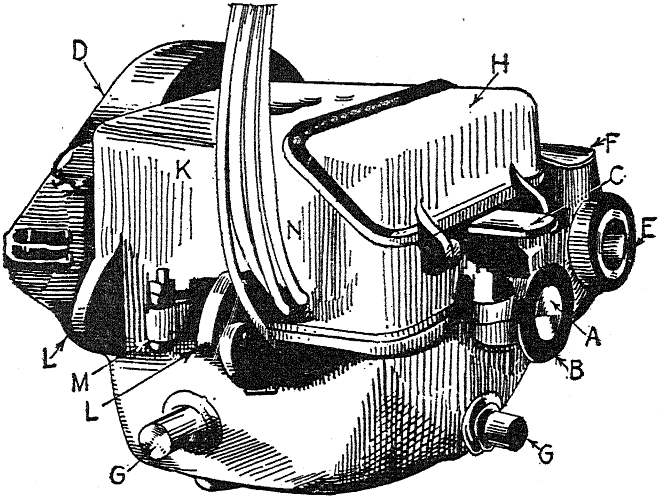


FIG. 1,069.—Direct current railway motor, casing closed. *As shown*, the armature shaft A, projects through its bearing B, lubricated by the grease box C, and is connected with the car axle by gear wheels enclosed in the gear cover D. The gears serve to reduce the speed of the car, and also to increase the effective pull of the motor. The car axle passes through the bearing E, lubricated by the grease box F. The motor is supported on the truck by the lugs G G. The commutator door H gives access to the brushes, while a more complete inspection of the working parts may be obtained by throwing back the upper half of the casing K upon the hinges L,L, after unscrewing two bolts, one of which is shown at M. The insulated cables shown at N, pass through the casing and supply current to the motor.

As shown in the illustration the pole pieces comprise a pole shoe of common form, integrally connected with a cylindrical shell over which the magnetizing coil is wound, and within which is a solid core of high permeability and of a cross section relatively large as compared with the conducting area of the enclosing shell. By means of a hand wheel fig. 1,068 this inner core is adjustable in a direction radial to the center of the armature and is so proportioned that a slight variation in its position within the magnetized shell produces a very considerable difference in the reluctance of the magnetic circuit of which the plunger forms a part.

When the plunger is adjusted so that its inner end comes in contact with the pole shoe, the magnetic circuit is of minimum reluctance and since the strength of the field coil remains constant, the volume of magnetic flux becomes a maximum and the speed minimum or normal, as the plunger is being drawn away from contact with the pole shoe, the air gap is augmented which gradually increases the reluctance of the magnetic circuit as long as the plunger continues to be withdrawn. When the plunger reaches the limit of its outward motion, the reluctance of the magnetic circuit reaches a maximum which causes the speed to reach its highest rate.

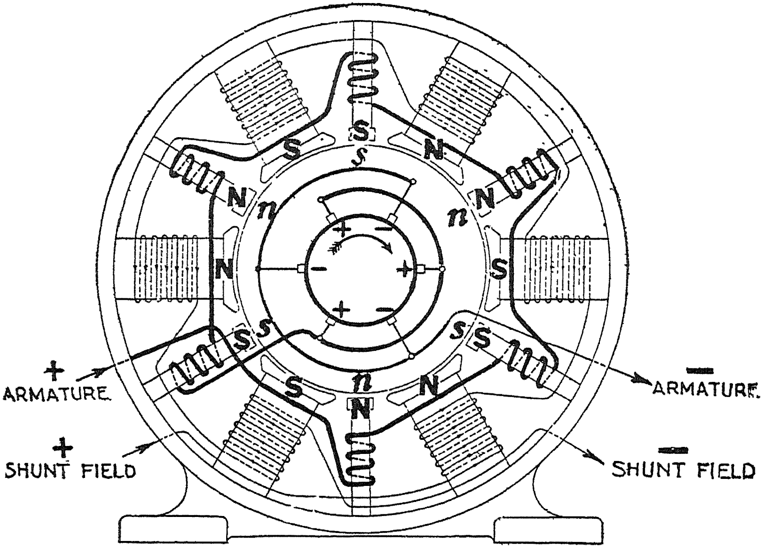


Fig. 1,070.—Connection diagram for six pole shunt wound inter-pole motor. This diagram is to be used when the following formula holds true:

$$\frac{\text{Number of commutator bars} - 1}{\text{Half the number of poles}} = \text{a whole number}$$

If a fractional number be obtained use the diagram fig. 1,071. For counter clockwise rotation reverse direction of current in both shunt and series field but do not change the internal connections.

In the second method of speed adjustment, the armature is gradually shifted along its axle away from its normal position, directly under the main field pole; this results in a gradual change in speed.

With a constant field current the strength of a magnetic field varies inversely as the magnetic reluctance of the magnetic circuit. The lines of magnetism traverse air with great difficulty, and within the range of densities used, iron very easily and steel more readily. In a motor the magnetic circuit or path followed by the lines of magnetism starts in the field pole, crosses the air gap to the armature, traverses the armature to the next

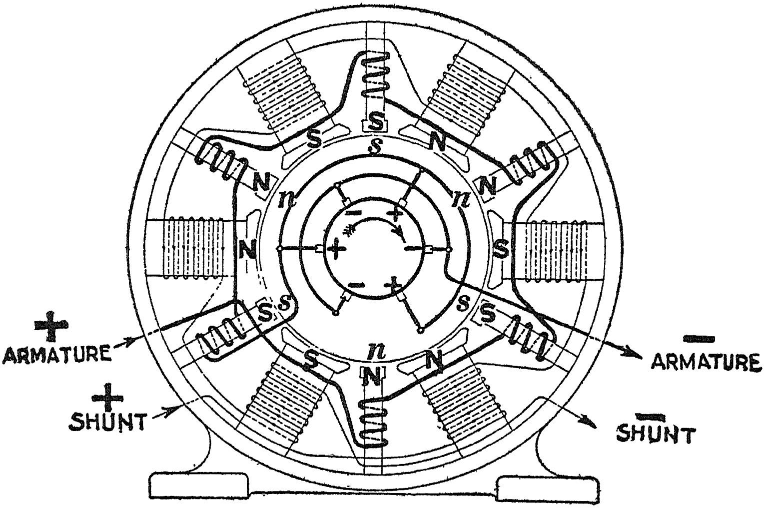


FIG. 1,071.—Connection diagram of six pole shunt wound inter-pole motor. This diagram is to be used when the following formula holds true:

$$\frac{\text{Number of commutator bars}+1}{\text{Half the number of poles}}=\text{A whole number}$$

If a fractional number be obtained, use the diagram fig. 1,070. For counter clockwise rotation reverse direction of field current but do not change the internal connections.

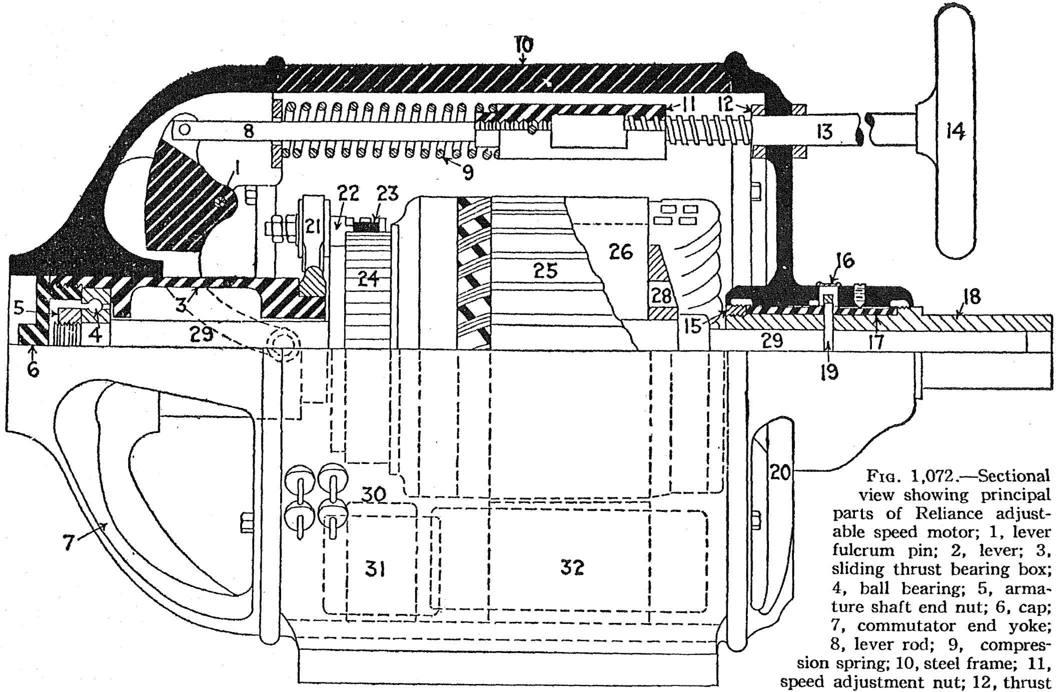


FIG. 1,072.—Sectional view showing principal parts of Reliance adjustable speed motor; 1, lever fulcrum pin; 2, lever; 3, sliding thrust bearing box; 4, ball bearing; 5, armature shaft end nut; 6, cap; 7, commutator end yoke; 8, lever rod; 9, compression spring; 10, steel frame; 11, speed adjustment nut; 12, thrust collars and pins; 13, handwheel rod; 14, hand wheel; 15, sleeve nut; 16, oil well cover; 17, bearing bushing; 18, sleeve; 19, oil ring; 20, pinion end yoke; 21, rocker arm; 22, brush holder stud; 23, brush; 24, commutator; 25, armature; 26, armature laminations; 27, armature coils; 28, armature end plate; 29, armature shaft; 30, leads; 31, axial position of commutating pole; 32, axial position of main field pole.

pole piece, again crosses the air gap and returns by the second pole piece and motor frame to its starting point. By far the greatest part of magnetic reluctance of this entire circuit is at the air gap, and any change in the length or area of the air gap produces almost proportionate changes in the strength of the magnetic field within which the armature rotates and consequently in the speed.

An example of motor employing this principle of speed adjustment is shown in fig. 1,072. In the figure it is seen that the armature shaft 29, at the driving end of the motor slides within a revolving sleeve 18, on which a pulley or pinion may be mounted in the usual manner. A key way is cut in the inner bore of the sleeve and a feather key of liberal proportions firmly embedded in the shaft, slides along this key way and transmits the power from the shaft to the sleeve.

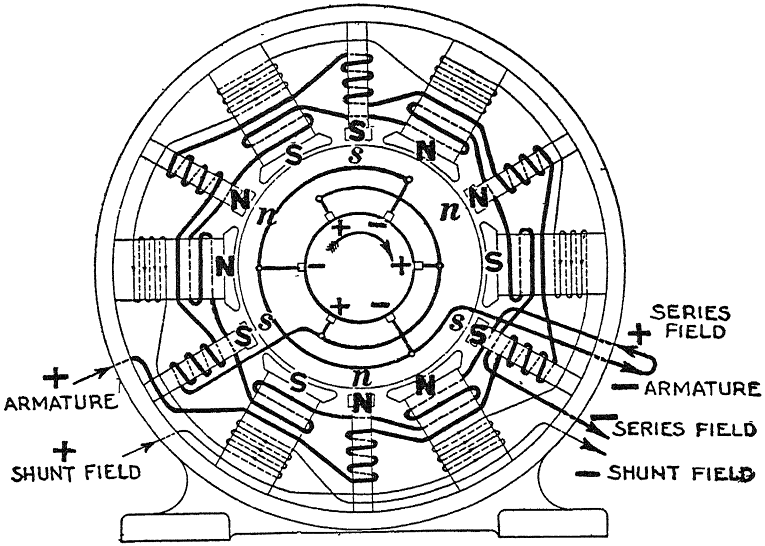


FIG 1,073 —Connection diagram for six pole compound wound inter-pole motor This diagram is to be used when the following formula holds true:

$$\frac{\text{Number of commutator bars} - 1}{\text{Half the number of poles}} = \text{A whole number}$$

If a fractional number be obtained use the diagram fig. 1,074 For counter clockwise rotation reverse direction of current in both shunt and series field but do not change the internal connections.

The sleeve does not move laterally as the armature is shifted for speed adjustment, but is held in position by a shoulder at one end, and a circular nut 15, at the other, bearing against the two end faces of the bronze bearing bushing 17. The shoulders take up any end thrust imparted to the sleeve by the shifting of the armature.

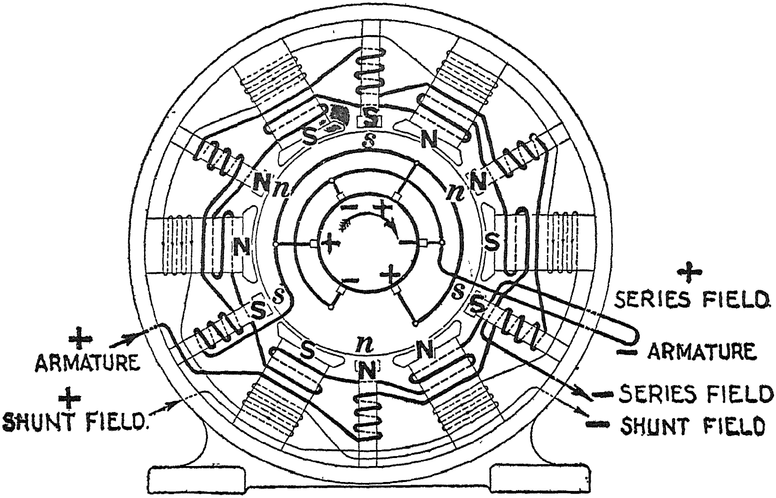


FIG. 1,074.—Connection diagram for six pole compound wound inter-pole motor. This diagram is to be used when the following formula holds true.

$$\frac{\text{Number of commutation bars}+1}{\text{Half the number of poles}}=\text{A whole number}$$

If a fractional number be obtained use the diagram fig. 1,073. For counter clockwise rotation reverse direction of field current but do not change the internal connections.

TEST QUESTIONS

1. *How does a motor differ from a dynamo?*
2. *How does a motor work?*
3. *Why does less current flow when a motor is running than when standing still?*

4. *What is the propelling drag?*
5. *What is the effect of a conductor carrying a current in a magnetic field?*
6. *What are the essential requirements of construction in a motor?*
7. *What causes a reverse pressure in the motor armature winding?*
8. *In the operation of a motor what is the nature of the reverse pressure?*
9. *Describe an experiment which shows the existence of a reverse pressure in a motor.*
10. *Explain the action of the current supplied to a motor for its operation.*
11. *How may the rotation of a motor be reversed?*
12. *What will happen if both armature and field currents be reversed?*
13. *What is the result of reversing the direction of current at the terminals of a series motor, and why?*
14. *What is the behavior of a shunt dynamo when used as a motor?*
15. *Explain armature reaction in motors.*
16. *Give left-hand rule for direction of motion in motors.*
17. *What kind of lead must be given to the brushes?*
18. *How should a motor be started?*
19. *Name three classes of motors.*
20. *What are the characteristics of a series motor?*
21. *For what kind of service are series motors unsuited?*
22. *What kind of series motors may be used with belts?*
23. *For what service are series motors adapted?*
24. *Describe a shunt motor.*

25. *What may be said with respect to the speed of a shunt motor?*
26. *How should a shunt motor be started?*
27. *How does brush position influence the speed of a shunt motor?*
28. *Why does a shunt motor have a weak starting torque?*
29. *What is the behavior of a shunt motor with variable load?*
30. *How is the rotation of a shunt motor reversed?*
31. *Describe the compound motor.*
32. *Mention some characteristics of a compound motor.*
33. *What is the difference between power and work? Define work.*
34. *What is brake horse power?*
35. *Describe the apparatus used in making a brake test.*
36. *What three quantities must be determined in a test in order to calculate the brake horse power?*
37. *How is brake horse power calculated?*
38. *What are the mutual relations between motor torque and speed?*
39. *Mention two methods of regulating the speed of motors.*
40. *What is the efficiency of a motor?*
41. *Sketch field connection diagrams for four and six pole motors of the series, shunt, and compound types, having interpoles.*
42. *What is the object of interpoles.*
43. *What is the nature of the commutating field?*
44. *Mention some of the claims made for interpole motors.*
45. *Explain two methods employed in varying the speed of adjustable speed motors.*

CHAPTER 33

D. C. Motor Control

In operating motors of any considerable size, whether connected to the public supply mains of a central generating station for combined lighting and power service, or to power service mains only, there are certain precautions to be observed in starting, stopping, and regulating the motor, in order that the efficiency of the supply, and indirectly the working of other motors and lamps connected to the mains in the immediate neighborhood, may not be affected by abnormal variations of pressure.

These precautions should be observed also to prevent any danger of the motor itself being subjected to detrimental mechanical shocks and excessive temperatures in the working parts.

Before Starting a Motor.—The general instructions relating to inspection and adjustment, lubrication, etc., which have already been given, should be carefully followed preparatory to starting.

Starting a Motor.—In starting a motor, resistance must be put in series with the armature because, since there is no reverse electromotive force to counteract the applied voltage when the motor is at rest, the switching of the latter direct to the motor would result in an abnormal rush of current. This, in addition to being uneconomical and productive of a drop of voltage in the mains, would injure all except the smallest motors.

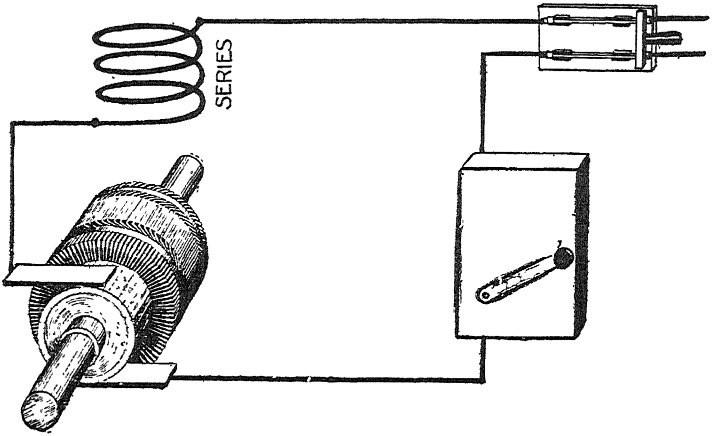


FIG. 1,075.—*Motor control 1.* Plain series motor with starter. The speed varies with the load.

NOTE.—***In starting a motor,*** first see that the bearings contain sufficient oil and that the brushes bear evenly on the commutator. If a circuit breaker be used, close it; then close the main switch. Rotate slowly the handle of the starting rheostat as far as it will go. Care should be taken, in starting the motor, that the handle of the rheostat be not rotated too fast. To stop a motor, open the circuit breaker or switch, which will cut in the resistance of the starting box. Never attempt to stop a motor by forcibly pulling open the starting lever. *Disregard of these instructions may cause burning out of the field coils.*

NOTE.—***A starting rheostat*** consists of a variable resistance, placed in series with the armature, and which may be gradually cut out as the motor speeds up and which can be cut out altogether when the motor has reached nearly normal speed. The total resistance of the starting box must be of such a value that, when it is connected in series with the armature, directly across the motor supply line, the current which flows through the circuit will not be greater than about 150 per cent of the full load current for the motor. The starting box is sometimes designed so that it limits the current to a value not greater than the full load current of the motor.

NOTE.—***Necessity for rheostat.***—The armature of a shunt motor contains .2 ohm resistance. The motor is to run on a 110 volt circuit. Suppose that it be thrown on the circuit suddenly while the armature is standing still, what current will it take? 110 ÷ .2 = 550 amperes—enough current to burn out the winding.

Ques. Describe what occurs in starting a motor.

Ans. When the lever of the starting box is moved to the first contact some of the resistance is cut out of the circuit and current flows through the motor. This produces a torque and starts the armature rotating. The movement of the armature induces a reverse voltage, which, as the speed increases, gradually reduces the applied current. With this reduction of current, the torque is reduced and the speed not accelerated as quickly as at first.

When the applied current has been reduced to a certain value by the increasing reverse voltage, the handle of the starting box is moved to the next contact, and so on till all the resistance in the starting box has been cut out, the motor then attaining its normal speed.

Ques. What is the difference between a starting box and a speed regulator?

Ans. Motor starting rheostats or "starting boxes," are designed to start a motor and bring it gradually from rest to full speed. They are *not* intended to regulate the speed and must not be used for such purpose.

Failure to observe this caution will result in burning out the resistance which, in a motor starter, is sufficient to carry the current for a limited time only, whereas in the case of speed regulators resistance provided is such as will carry the full load current continuously without burning out.

Ques. For what kinds of service are speed regulators used?

Ans. In cases when the speed must be varied, as in traction motors, organ blowers, machine tool drive, etc.

Ques. How long does it take to start a motor?

Ans. Usually from five to ten seconds.

Ques. How is the starting lever operated?

Ans. It is moved progressively from contact to contact pausing long enough on each contact for the motor to accelerate its speed before passing to the next.

Ques. What are the conditions at starting in a series motor?

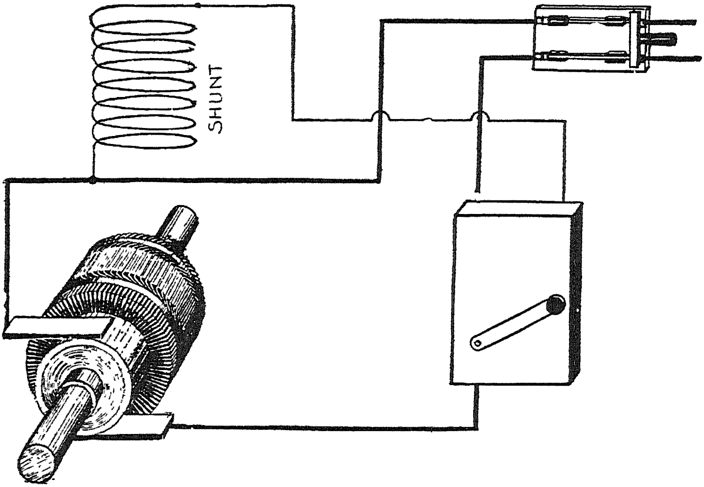


FIG. 1,076.—*Motor control 2.* Plain shunt motor with starter. Speed practically constant, but drops slowly with heavy load.

Ans. There is a rush of current, the magnitude of which depends on the amount of resistance cut out at each movement of the starting lever.

Ques. How are small series motors started on battery circuits?

Ans. By simply closing a switch to complete the circuit, the resistance of the battery being sufficient to prevent a great rush of current while starting.

Ques. How is a shunt motor started?

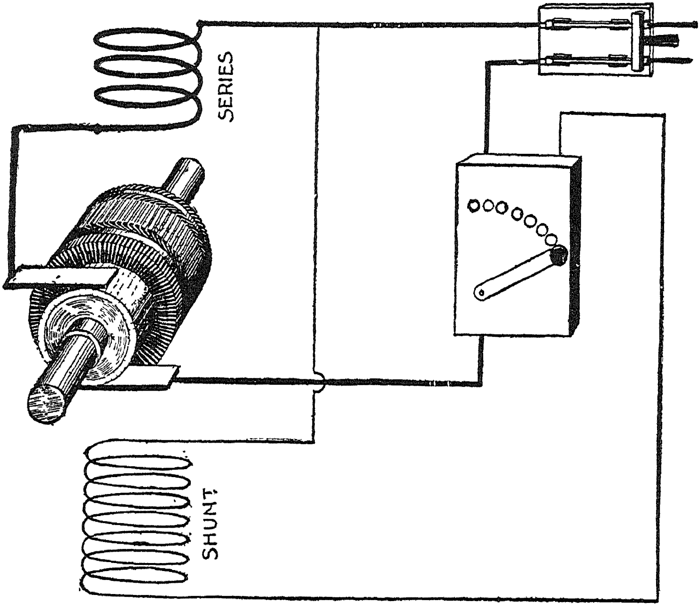
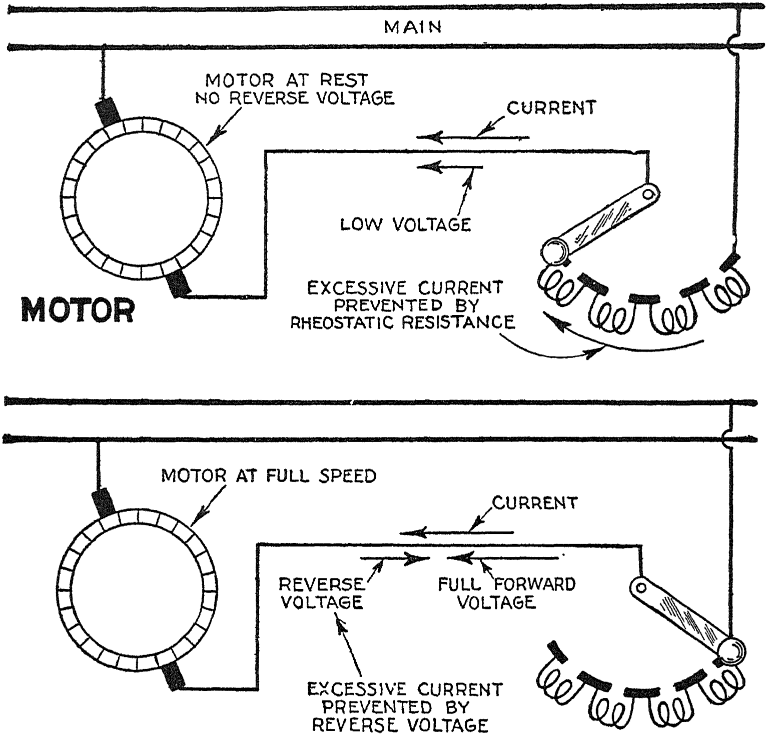


Fig. 1,077.—*Motor control 3.* Plain compound motor. Speed characteristics depend upon design. Series coil tends to decrease speed with load when connected to assist the shunt winding, and when connected in opposition tends to increase the speed with the load. When used to increase the speed it is called a "differential winding."

Ans. In starting a shunt motor, no trouble is likely to occur in connecting the field coils to the circuit. Since the resistance of the armature is very low, it is necessary on constant voltage circuits to use a starting rheostat in series with the armature.

The necessary connections are shown in fig. 1,076. The switch is first closed thus sending current through the field coils, before any passes through the armature. The rheostat lever is then moved to the first contact to allow a moderate amount of current to pass through the armature. The resistance of the rheostat is gradually cut out by further movement of the lever thus bringing the motor up to speed.

Ques. How does the reverse voltage affect the starting of a motor?



Figs. 1,078 and 1,079.—Diagrams illustrating necessity for a rheostat for starting a motor and effect of the reverse voltage

Ans. When a motor is standing still, there is no reverse voltage, and the current taken at first is governed principally by the resistance of the circuit. If the motor be series wound, there is a momentary reverse voltage, due to self-induction while the field is building up. If the motor be shunt wound, self-induction delays the current through the field coils, but that through the armature is not impeded by such cause. When the armature begins to revolve, reverse voltage is developed which increases with the speed. The resistance of the starting box may be gradually cut out as the armature comes to speed. Thus the reverse voltage gradually replaces ohmic drop in limiting the current as the motor comes to speed.

Failure to Start.—This fault, which is liable to occur in a motor of any description, is similar to failure to excite in a dynamo, and is liable to be produced by any of the causes mentioned in connection with the latter fault, excluding insufficient speed, and insufficient residual magnetism.

When a motor fails to start, it should first be ascertained if a supply of electrical energy be available in the mains. This may readily be discovered by means of a voltmeter, or if low tension service, by means of the fingers bridging across the main terminals.

If the supply of energy be present, the contact arm of the starter should be moved into such position that all resistance is inserted into circuit with the motor. This is important, as the motor may start suddenly while trying to ascertain the cause of the stoppage.

Having closed the switch, if the motor fail to start, it will be advisable to remove the load if possible, as the failure may arise from an overload of the machine. This being effected and the motor not starting, the terminals of the latter should be tested by the means already described for voltage. If no voltage be generated, a broken circuit or a defective contact may be looked for in the main fuse, switch, or starting box. The resistance coils of the latter, through the heat developed, frequently break in positions out of sight. If a defective contact of this nature cannot readily be seen, the contact arm should be moved slowly over the contacts, as it is possible the broken coil may be cut out of circuit by this means.

If a difference of pressure exist between the motor terminals, the field magnets will, if shunt or compound wound and in good order, be excited, which may be ascertained by means of a bar of iron. If no magnetism be present, it will of course, indicate a broken or bad connection, either between the terminals of the field coils, or one or more of the coils themselves. If the bar pull strongly, the position of the brushes upon the commutator in regard to the neutral points should be ascertained, and the rocker adjusted, if necessary, to bring them into their correct positions. If this fail to start the motor, the connecting leads from the motor terminals to the brushes and the brushes themselves should be carefully examined for broken or bad connections, and defective contact of the brushes with the commutator. In the latter case, it may arise from a dirty state of the commutator, or from the brushes not being fed properly. If due to these causes, pressing the brushes down upon the commutator with the fingers will probably start the motor. If the failure to start arise

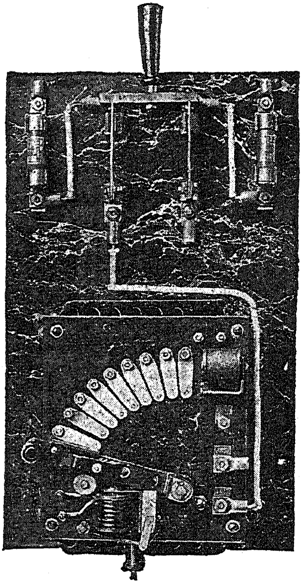


FIG. 1,080.—Starting panel. In installing any kind of motor starting rheostat, it is necessary to provide main line knife switch and fuses in addition to the starting box. The appearance of the installation can be much improved by mounting all of these upon one panel.

from none of these causes, it is probably due to the field coils acting in opposition, or to a short circuited armature. This latter remark applies more especially to motors provided with drum armatures

Precautions with Shunt Motors.--With motors of this type, because of the large amount of self-induction in the shunt windings, it is important to note: 1, that in switching on the field magnet, the current may take an appreciable time to grow to its normal value, and 2, that in switching off, especially with quick break switches, high voltages are induced in the windings, which may break down the insulation.

Ques. What provision is made so that the magnetizing current will have time to reach its normal value?

Ans. The field connections are generally separated from the actual starter, and taken to the main switch, so that wherever the main switch is closed, the current flows through the field coils, before the starting lever is moved.

Ques. How are the connections arranged to avoid excessive voltage in the windings due to self-induction?

Ans. Generally the armature and field magnet circuits are placed in a closed circuit that is never opened.

NOTE.—*Motors* have much the same faults as dynamos, but they make themselves manifest in a different way. An open field circuit will prevent the motor starting, and will cause the melting of fuses or burning out of the armature. A short circuit in the fields, if it cut out only a part of the winding, will cause the motor to run faster and very likely spark badly. If the brushes be not set exactly opposite each other, there will also be bad sparking. If they be not at the neutral point, the motor will spark badly. Brushes should always be set at the point of least sparking. If it become necessary to open the field circuit, it should be done slowly, letting the arc gradually die out. A quick break of a circuit in connection with any dynamo, or motor is not advisable, as it is very likely to break down the insulation of the machine. The ordinary starting box for motors is wound with comparatively fine wire and will get very hot if left in circuit long. The movement of the arm from the first to the last point should not occupy more than thirty seconds and if the armature do not begin to move at the first point, the arm should be thrown back and the trouble located.

In other cases, in order that the rise of voltage may not injure the insulation when the shunt is opened, a special form of main switch is sometimes used which, before breaking from the supply, puts a non-inductive resistance across the shunt of the motor. This is a *flashing resistance.*

Ques. Explain shunt motor control from a distant point.

Ans. The starter and switch are placed at the desired point and the two main wires and the field wires run from that point to the motor.

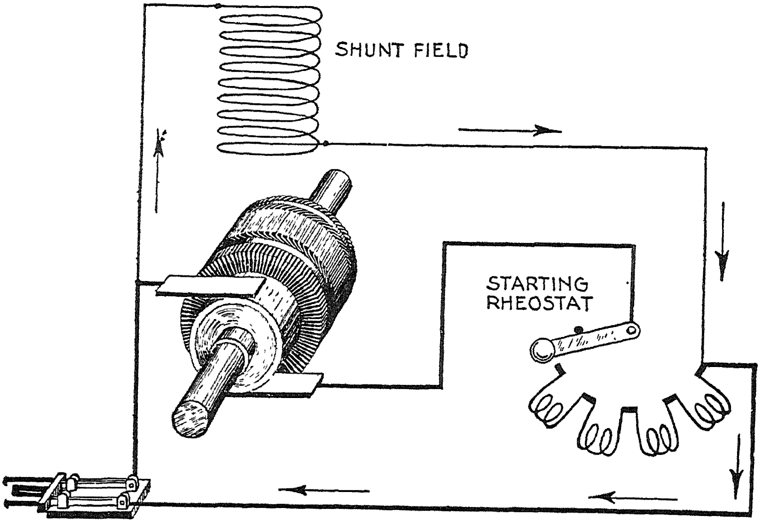


FIG. 1,081.—Speed regulation of shunt motor by variable resistance in the armature circuit.

This requires additional wire which increases the cost and line loss. The latter is avoided by magnetic remote control.

Regulation of Motor Speed.—Motors are generally run on constant voltage circuits. Under these conditions, the speed of series motors varies with the load and at light loads becomes excessive. Shunt motors run at nearly constant speeds.

For many purposes, particularly for traction, and for driving tools, it is desirable to have speed regulation, so that motors running on constant voltage circuits may be made to run at different speeds.

The following two methods are generally used for regulating the speed of motors operated on constant voltage circuits:

1. By inserting resistance in the armature circuit of a shunt wound motor;
2. By varying the field strength of series motors by switching sections of the field coils in or out of circuit.

Ques. Describe the first method.

Ans. This method is illustrated in fig. 1,081. When the main switch is closed, the field becomes excited, then by moving the lever of the starting rheostat to the various contacts more or less of the rheostat resistance is cut out of the armature circuit, thus varying the speed correspondingly.

This is the same as the method of starting a motor, that is, *by variation of resistance in armature circuit*, but it should be noted that when this method is used for speed regulation, *a speed regulating rheostat should be used instead of the ordinary starting box*, because the latter, not being designed for the purpose, *will overheat and probably burn out.*

Ques. Describe the second method.

Ans. This method of regulating the speed of a series motor is shown in fig. 1,082. The current through the armature will flow through all the field windings when the position of the switch lever S, is on contact 4, and the strength of the field will be the maximum. By moving the arm to contact 3, 2, etc., sections of the field winding are cut out, thus reducing the strength of field and varying the speed.

Ques. How does the speed vary with respect to variation of field strength?

Ans. Decreasing the field strength of a motor increases its speed, while increasing the field strength decreases the speed.

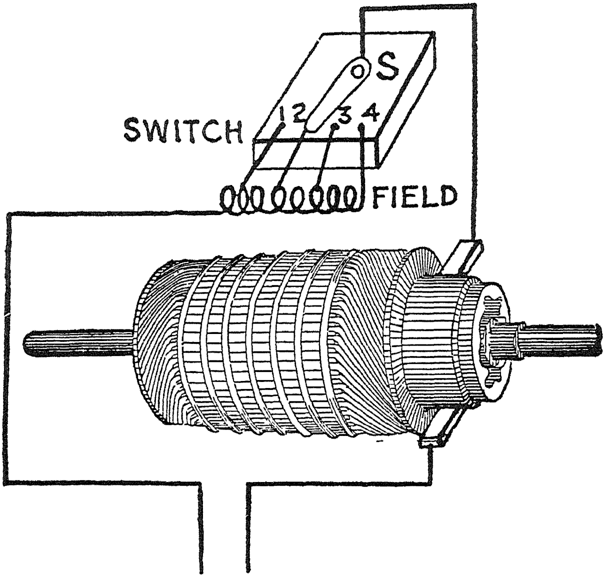


Fig. 1,082.—Speed regulation of series motor by cutting out sections of the field winding. In this method the field winding is tapped at several points, dividing the coil into sections and the leads from these points are connected to a multi-point switch of the type that would be used on a rheostat. By moving the lever S, to the left or right, the current will flow through one or more sections of the field winding, thus decreasing or increasing the ampere turns and thereby providing means of regulation.

Under the conditions of maximum field strength, as with switch S, on point 4, the torque will be greatest for any given current strength and the reverse voltage also greatest at any given speed. The current through the armature of the motor, to perform any given work, will thus be at a minimum, as well as the speed at which the motor has to run, in order to develop sufficient reverse voltage to permit this current to flow. Regulation of speed by varying the field strength is limited in range of action, since the field saturation point is soon reached, moreover, with too low a field strength, armature reaction produces excessive field distortion, sparking, etc.

Ques. How is the speed of shunt and compound motors varied with respect to the normal speed in the two methods?

Ans. The first method (variable resistance in armature circuit) reduces the speed *below* the normal or rated speed of the machine, while the second method increases the speed *above* the normal.

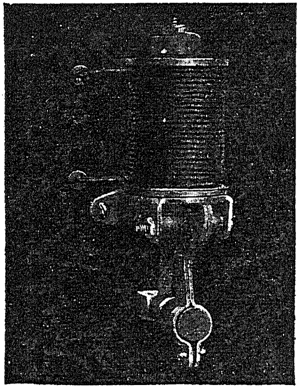


FIG. 1,083.—Monitor acceleration relay used to protect motors from excessive current inrush when the field rheostat is adjusted.

In the first method the amount of speed reduction depends partly upon the amount of resistance introduced into the armature circuit, and partly upon the load.

In the second method the amount of speed increase depends entirely upon the amount of resistance placed in the shunt winding circuit.

Eighty-five per cent. is about the maximum speed reduction obtainable by armature resistance but so great a reduction is seldom satisfactory since comparatively slight increases in the load will cause the motor to stall.

Shunt field regulation may be obtained up to any point for which the motor is suited, the only limitation in this case being the maximum speed at which the motor may be safely operated.

It should be remembered, however, that speed increase by shunt field weakening increases the current in proportion to the increase in speed, and care should be taken not to overload the armature.

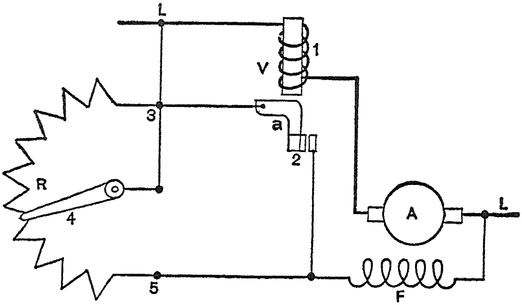


FIG. 1,084.—Wiring diagram of Monitor acceleration relay. The rise and fall of current in the relay winding which is connected in series with the motor armature actuates the armature of the relay cutting the field rheostat out and in respectively, and in this way preventing an excessive rush of current and at the same time allowing the motor to accelerate safely to whatever speed the field rheostat may be adjusted.

Ques. How is a wide range of speed regulation secured?

Ans. By a combination of the two methods.

Regulation by Armature Resistance.—Speed regulators for this method of regulation, are designed to carry the normal current on any contact without overheating and when all the resistance is in the circuit, they will reduce the speed of the motor about 50 per cent. provided the motor be taking the normal current. When operating without resistance in the armature circuit, shunt wound and compound wound motors will regulate to approximately constant speed regardless of load.

This characteristic of inherent regulation is lost, however, when armature resistance is employed to reduce the speed of the motor, fluctuations in load resulting in fluctuations in speed, which become more noticeable as the amount of resistance inserted in the armature circuit is increased. Accordingly, it becomes necessary to move the lever of the speed regulator forward or backward to again obtain the speed at which the machine was operating before the load changed.

When the speed of a motor driving a constant torque machine is reduced by inserting resistance in the armature circuit there is no corresponding reduction in current consumed. The motor runs more slowly

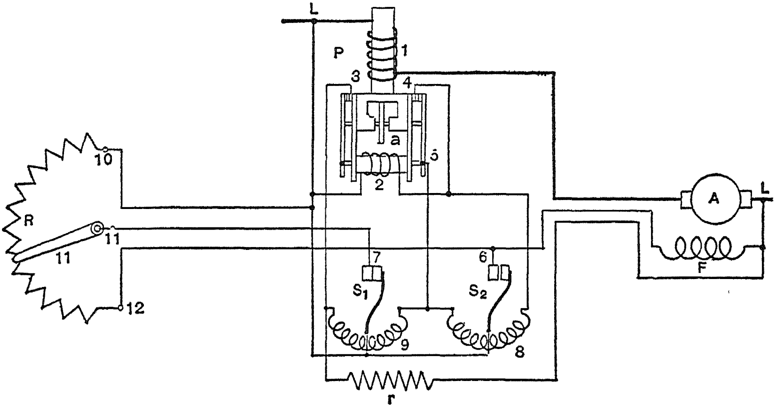


FIG. 1,085.—Circuit diagram of Monitor acceleration and deceleration relay. Coil 2, is wound on a fixed core of the relay, thus polarizing it. Current through the solenoid 1, which is in series with the armature A, in one direction closes contactor S_2, while current in the opposite direction opens contactor S_1. If it be assumed that the field rheostat R, has been suddenly adjusted to an increased value of resistance there will be an excessive current established through the armature A. The pull of solenoid 1, reacting with that of coil 2, causes armature a, to move to the right and through a sliding pin to open contacts 4, inserting coil 8, and closing contactor S_2, thus short circuiting the field rheostat. The instant the load drops, contacts 4, close, allowing contactor S_2, to open and so on. On the other hand, if the field rheostat be suddenly adjusted to a lower resistance an excessive reverse voltage will be generated which will tend to reverse the current through the motor armature. Such an action will cause solenoid 1, to react with coil 2, in such a way as to cause armature a, to move to the left, and through a sliding pin to open contacts 3, inserting coil 9, of the contactor. S_1, thus opening contacts 7, and connecting full field rheostat in series with the field winding. This action will be repeated until the change in speed has been accomplished.

simply because a part of the energy impelling it is shunted into the resistance and there dissipated in the form of heat. Hence, whether the motor be operating at full speed or half speed, the amount of current consumed is the same; the only difference being that in the one case all the energy taken from the line is expended in driving the motor while in the other case only one half is utilized for power, the other half being dissipated in the resistance.

Speed regulation by armature resistance only is therefore open to two objections: 1, the difficulty of maintaining constant speed under varying load conditions, and 2, the necessity of wasting energy to secure speed reduction. These objections are, in part, offset by the fact that speed reduction by armature resistance may be applied to any motor of standard design and requires nothing more than the simplest and least expensive speed regulating rheostat.

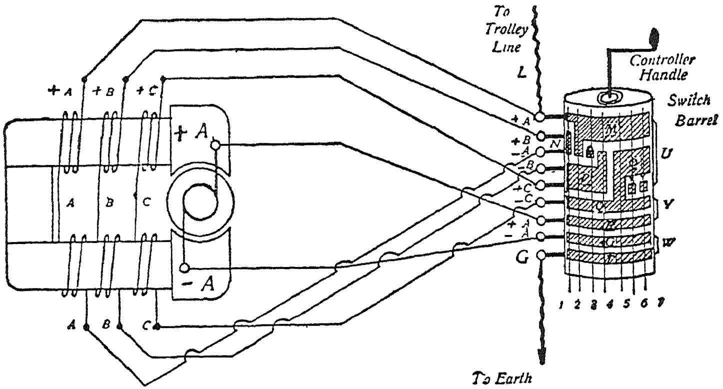
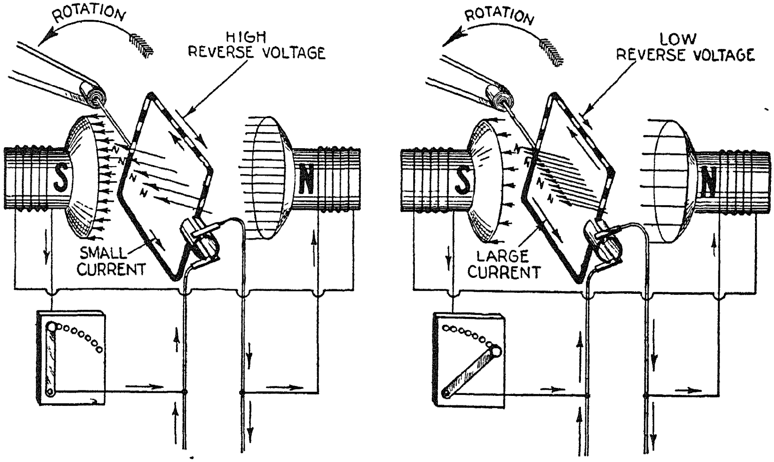


FIG. 1,086.—Speed regulation of a series motor by the method of short circuiting sections of the field winding. It will be seen that there are seven different positions for the contact springs on the barrel contacts. A, represents the armature and brushes, little A, B and C, the divided field magnet coils L, the line connection, and G, the earth connection. The diagram shows the connections for trolley car operation.

In cases where the motor will be operated nearly always at full speed, the difference in first cost of the installation may justify the use of the armature resistance method of control. As a rule, speed regulation by shunt field resistance is preferable.

Regulation by Shunt Field Resistance.—Since regulation by this method is for speeds above normal, a starter must be used to bring the motor up to its rated speed. Usually the starter is combined with the regulator, as shown in fig. 1,089, the device being called a *compound starter.*

The weakening of the shunt field of a motor by the insertion of resistance in the shunt field circuit causes the armature to revolve more rapidly. One advantage of this method of control



Figs. 1,087 and 1,088.—Motor speed regulation by shunt field resistance. Fig. 1,087, strong field; fig. 1,088, weak field. The amount of current flowing through the armature and resulting strength of armature flux depends upon the reverse voltage. The effect of cutting in resistance on the field circuit as in fig. 1,088, is to weaken the field with resulting drop in reverse voltage. This will cause an increase of current through the armature and strengthening of the armature flux. The motor will speed up until equilibrium is again established by the increasing reverse voltage.

NOTE.—***A compound motor*** may be made to run at constant speed, if the current in the series winding of the field be arranged to act in opposition to that of the shunt winding. In such case, an increase of load will weaken the fields and allow more current to flow through the armature without decreasing the speed of the armature, as would be necessary in a shunt motor. Such motors, however, are not very often used, since an overload would weaken the fields too much and cause trouble. If the current in the series field act in the same direction as that in the shunt field, the motor will slow up some when a heavy load comes on, but will take care of the load without much trouble.

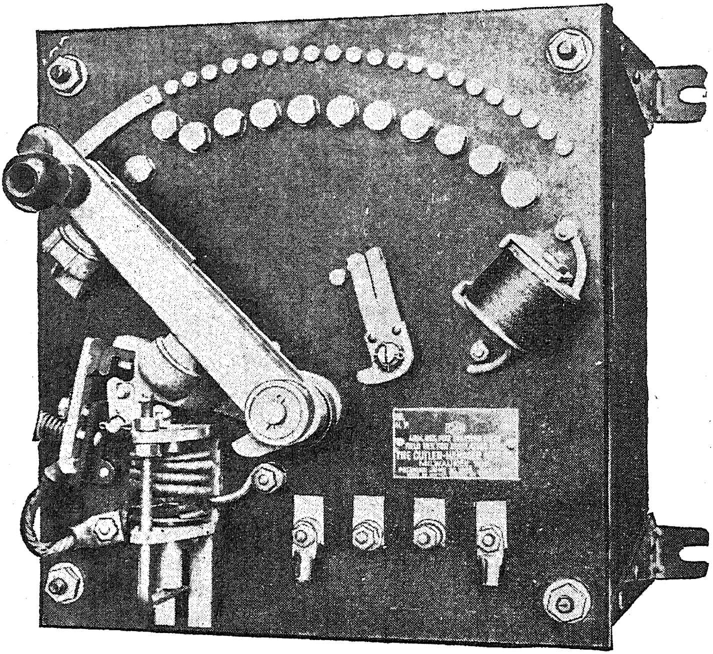


FIG. 1,089.—Cutler-Hammer enclosed compound motor starter and speed regulator with no-voltage protection and overload relay; view with cover removed. The starters are used to accelerate and regulate the speed of *d.c.* adjustable speed shunt motors. They combine in a single piece of apparatus a starting rheostat to bring the motor up to normal or full field speed, and a field rheostat to regulate the speed above normal. The armature or starting resistance and the field regulating resistance are under the control of a single operating handle. A double lever is used, one section having contacts which pass over the armature segments and the other section having contacts which pass over the field steps. The two parts of the lever are mounted one under the other and when the handle is moved from the off position to the starting position, the lower or starting lever is carried along by the upper or speed regulating lever until it comes in contact with the no voltage release magnet on the last armature point. The armature lever is held fast at this point by the magnet and the upper lever is now free to be moved backward over the field contacts thus weakening the shunt field little by little until the desired speed is obtained. During the operation of starting the motor and bringing it up to normal or full field speed the field resistance is short circuited by an auxiliary contact (the slotted metal strip shown near the center of the rheostat) just as soon as the starting lever touches the no voltage release magnet or in other words, when the motor has been accelerated to normal speed this short circuit is removed, and the field resistance becomes effective for speed regulation. The motor is accelerated from rest to normal speed by moving both levers from left to right while further increases in speed is that the motor will inherently regulate to approximately constant speed under widely varying load conditions.

Another advantage is found in the fact that all of the current taken from the line is utilized for power, the changes in speed being obtained, not by dissipating a portion of the effective energy in the resistance (as in the case of the armature resistance method of control) but by weakening the reverse voltage by inserting resistance in the shunt field circuit.

Speed increase by shunt field weakening is limited, however, to about 10 to 15 per cent. above the normal speed in motors of standard construction. Greater ranges of speed can be obtained from motors especially designed for shunt field control but should not be attempted with motors of standard design without first ascertaining from the manufacturer the maximum safe speed.

Combined Armature and Shunt Field Control.—Regulation by combined armature and shunt field resistance is by far the easiest way of obtaining a wide range of speeds. Rheostats embodying these methods are known as *compound speed regulators,* one form being shown in fig. 1,089. Standard regulators can be obtained giving a wide range of speed variation, and

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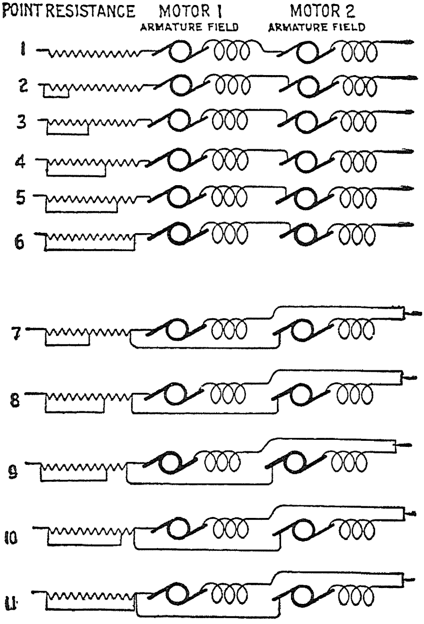
FIG. 1,089.—*Text continued.*

above normal are obtained by moving the upper lever from right to left. Only the lower or starting lever comes in contact with the no voltage release magnet. This lever is provided with a strong spring which tends to throw the lever back to off position. Therefore should the voltage fail and the no voltage release become de-energized, the starting lever is released and moves back to the off position opening the armature circuit of the motor. As it moves back it carries the speed regulating lever with it to the off position. The upper or speed regulating lever is not influenced directly by the spring and therefore when the starting lever is in contact with the no voltage release magnet the upper lever is free to move back and forth across the speed regulating button, thus giving speed regulation. If an overload should occur the overload release will trip and break the auxiliary fingers which are shown immediately above the overload coil. This breaks the circuit to the armature and disconnects the motor from the line. In order to reset the overload it is necessary to move the handle to the extreme left position where it is on the off position button so that the motor circuit is interrupted also at that point. The auxiliary contacts are then closed and the equipment is ready for restarting. With the arrangement used an overload will always open the circuit to the motor even though the operator should hold the handle in the full on position because the contacts which trip on overload are independent of the handle. It is also impossible to hold the motor circuit closed while the overload is being reset because the overload can only be reset when the starter handle is in the off position and the circuit broken on the main starting button.

special regulators may be constructed giving practically any desired range.

Two Motor Regulation.—With a two motor equipment, the controller becomes more complicated because it must be arranged to switch the motors in series or in parallel, so as to secure economy at half and full speed. The various connections of series-parallel regulation are shown in figs. 1,090 to 1,100.



Figs. 1,090 to 1,100.—Diagram of controller connections, illustrating the series parallel method of two motor control.

From these diagrams it is seen that the motors are first operated in series until all the resistance is cut out by the controller (figs. 1,090 to 1,095).

Starting and Speed Regulating Rheostats For Direct Current Motors

Face Plate Motor Starters.—Direct current motor face plate starters and controllers are manufactured in four principal types depending upon the control desired as:

1. For starting duty only.
2. For starting and speed regulating duty (speed control being obtained by varying a resistance inserted in the shunt field circuit).
3. For starting and speed regulating duty (speed control being obtained by inserting a resistance in the armature curcuit).
4. For starting and speed regulating duty (speed control being obtained by means of armature and field resistor).

The wiring diagram of a starter of the *first type* is shown in fig. 1,100-1, the operation of which is as follows: Connection is made from one of the line wires to a contact arm whose function is to carry the current over a series of stationary contact segments or buttons provided with graduated resistance steps to the motor winding. When the contact arm is moved towards the right, the first connection serves to put the shunt field circuit directly across the line.

When the contact arm is moved all the way to the right which is the "running position" it makes contact with a magnet coil (variously termed "holding coil" or no voltage release) whose purpose it is to hold the contact arm in position during normal conditions of the circuit.

If, however, the voltage fails, the magnet coil will be de-energized and the contact arm is carried back to its original position by spring action.

This action prevents the motor from the risk of being connected directly across the line when voltage is restored to the line.

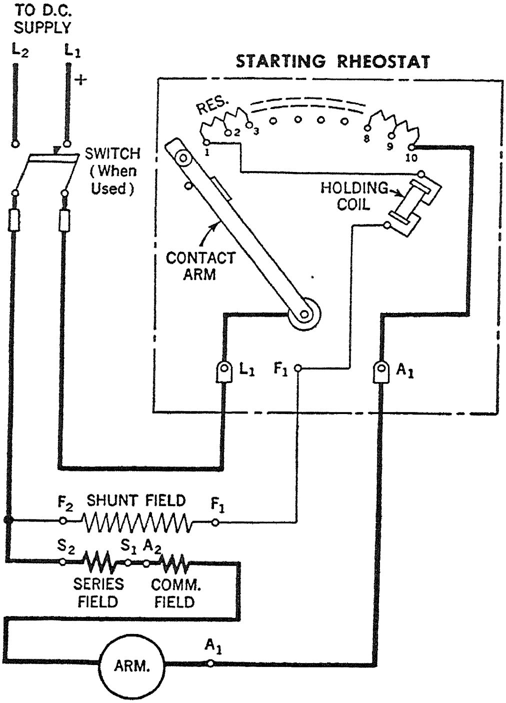


FIG. 1,100-1.—Wiring diagram of typical direct-current, face-plate starter having only three connections. Diagram is for compound-wound motors. For shunt-wound motors the series field coil is omitted.

When used with shunt motors, the common practice is to connect the holding coil in series with the field, so that in case of shunt field failure the contact arm will be released, thus stopping the motor.

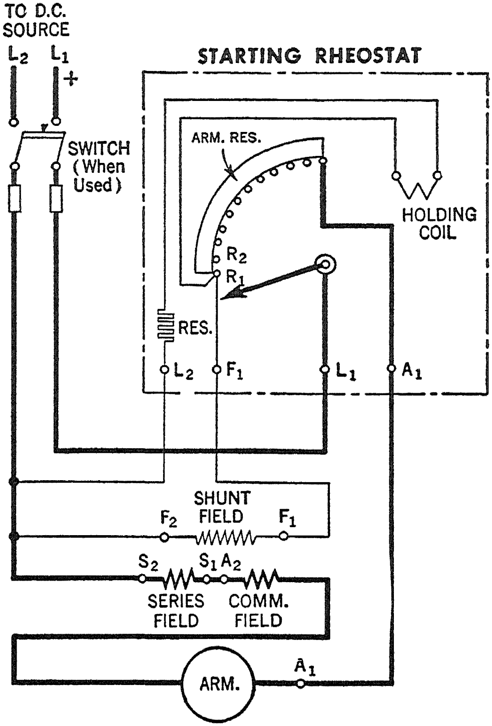


FIG. 1,100-2.—Wiring diagram of typical direct-current, face-plate starter for medium and small motors. Diagram is for compound wound motors. For shunt-wound motors the series field coil is omitted.

This type of direct current motor starter, provides a convenient and simple means for starting of series, shunt and compound motors that do not require more than 150 per cent full-load torque to start or longer than 30 seconds to attain full speed. It is manufactured for starting of motors up to 30 horsepower, 110 volts, and 50 horsepower, 230 and 550 volts.

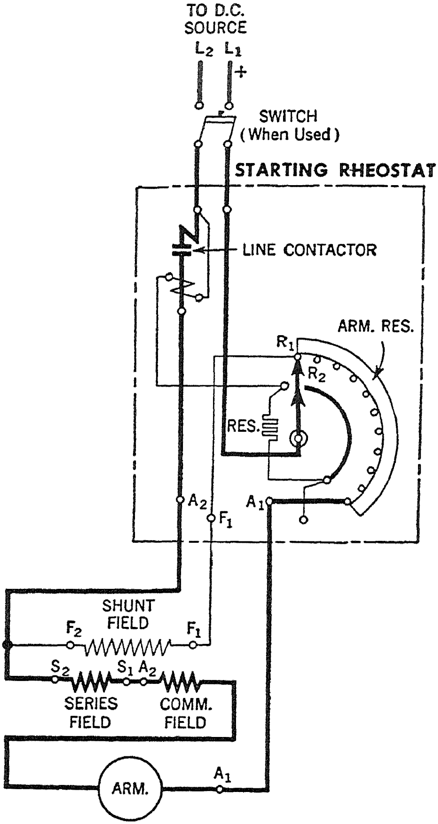


FIG. 1,100-3.—Wiring diagram of typical direct-current, face-plate starter for large motors. Diagram is for compound-wound motors. For shunt wound motors the series field coil is omitted.

Contact segments are easily renewable, except in starters of 5 horsepower, 115 volts, and 7½ horsepower, 230 volts, where the service does not warrant such provision.

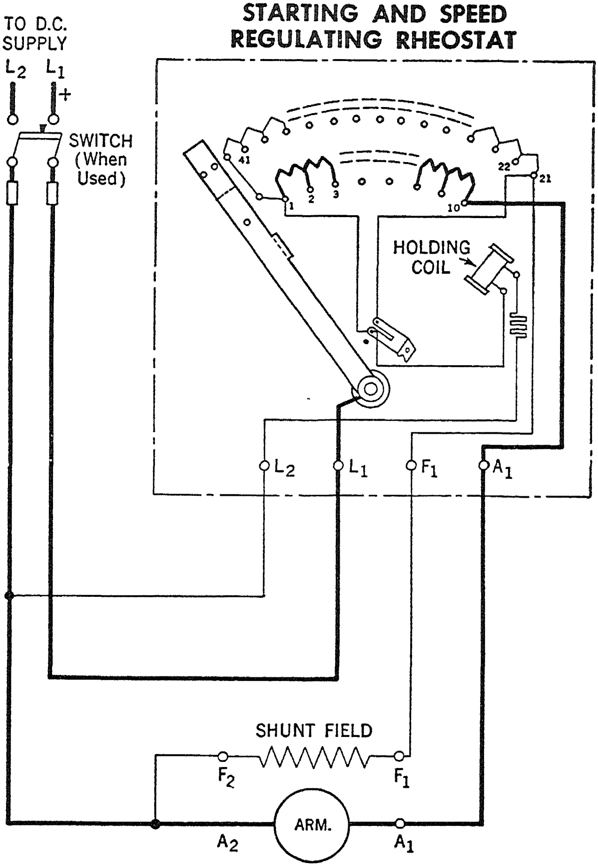


FIG. 1,100-4.—Wiring diagram of typical direct-current, face-plate starter. This type of starter combines the function of starting by armature resistor and speed regulating by resistance in the shunt field circuit. Diagram is for shunt-wound motors.

The contact arm may be of either cast steel or drawn steel. The contact shoe is made of brass and is backed up by springs providing constant pressure.

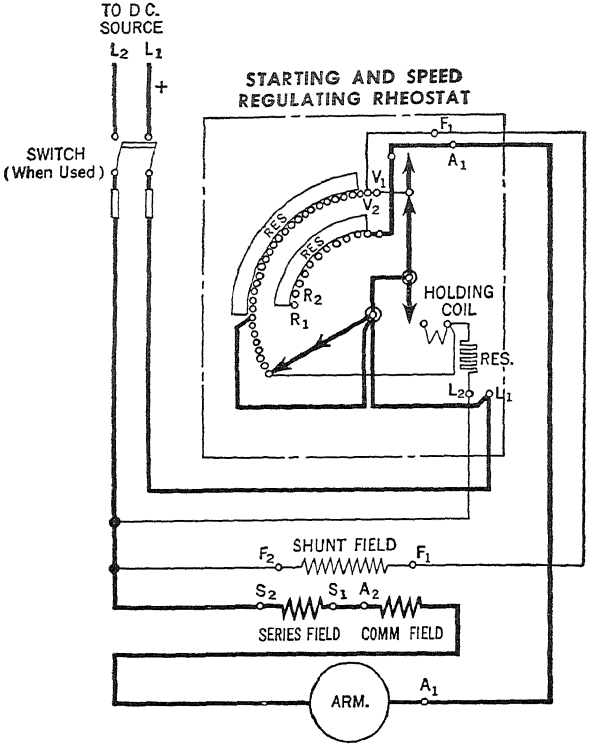


FIG. 1,100-5.—Wiring diagram of typical direct-current starting and speed regulating rheostat; speed control being obtained by varying a resistance inserted in the shunt field circuit Diagram is for compound-wound motors. For shunt-wound motors the series field circuit is omitted.

Starters of the *second type*, figs. 1,100-4 and 1,100-5 combine the functions of starting, by means of armature resistance and speed regulation, by means of field circuit resistance.

These are designed for starting and controlling the speed of adjustable speed direct current motors, speed control being obtained by varying a resistance inserted in the shunt field circuit.

The switch mechanism consists of a main arm, an auxiliary arm and two sets of segments or buttons, one set controlling the field resistor.

The auxiliary arm short circuits the entire field resistor while the motor is being started. After the running position is reached, the auxiliary arm is held by the magnet of an undervoltage coil and in turn, holds the main arm to be turned back toward the "off" position, thus inserting resistance into the field circuit by means of a sliding contact which bears on the field-resistor contact buttons.

The *third type* of direct current motor face plate starters shown in figs. 1,100-6 and 1,100-7 are used for speed regulation below normal speed of the motor by 50 per cent by insertion of resistance in the armature circuit. This type of face plate starter is very similar to that of type one, with the exception that all the starting buttons or segments must be dimensioned to carry the full load current continuously.

In this type of starter the no-voltage release is arranged to hold the movable contact arm at any desired point. This is accomplished by equipping the contact arm with a "pawl" and the magnet operates to hold the contact arm in any operating position. Ratings are usually limited to 10 horsepower at 115 volts, and 20 horsepower at 230 volts.

The *fourth type* of face plate starters fig. 1,100-8 are designed to reduce the speed of the motor 50 per cent when fully loaded at normal speed, by inserting a resistance in the armature circuit and increase the speed 25 per cent by regulating the resistance in the field circuit.

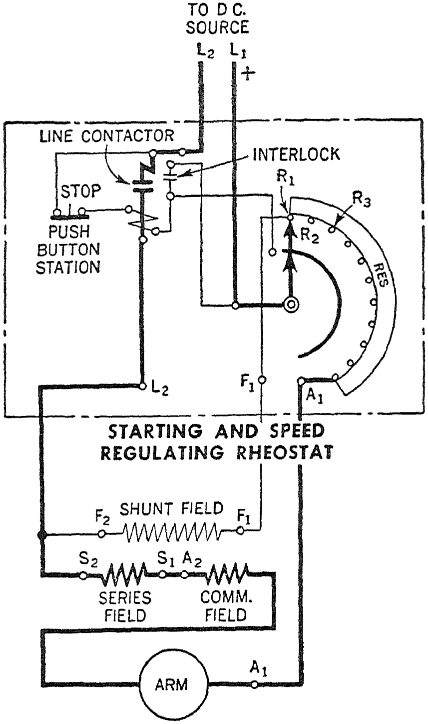


FIG. 1,100-6.—Wiring diagram of typical direct-current starting and speed-regulating rheostat equipped with magnetic contactor and push button control. Speed regulation permits a reduction in speed of 50 per cent by armature control. Diagram is for compound-wound, motors. For shunt-wound motors the series field circuit is omitted.

These controllers are designed in two types, one having a small number of field regulating steps, and the other a large number. Controllers equipped with a relatively small number of buttons (resistance steps) are used for standard constant speed motors where it is desired to increase the speed 25 per cent by weakening of the field current.

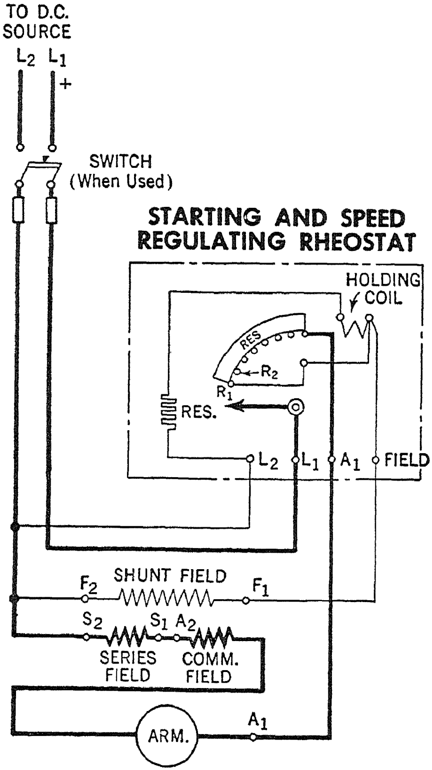


FIG. 1,100-7.—Wiring diagram of typical direct-current starting and speed-regulating rheostat. Speed regulation permits a reduction in speed by 50 per cent by armature control. Diagram is for compound-wound motors. For shunt-wound motors the series field coil is omitted.

A large number of buttons on the other hand, signifies controllers where a wide range of speed is desired by field control regulation.

Face plate starters and controllers of late designs are enclosed and arranged for operation by a lever arm outside the case. The enclosing case has conduit knockouts for the desired amount of control wires between the motor and its control elements. The case can be padlocked if desired, and is usually dustproof in the front and ventilated in the rear where the resistor is located.

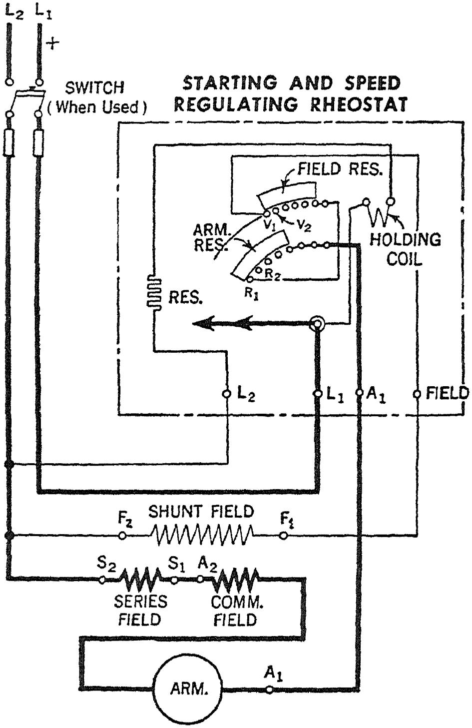


Fig. 1,100-8.—Wiring diagram of typical direct-current starting and speed-regulating rheostat. A controller of this type permits 50 per cent speed reduction by armature control and 25 per cent increase in normal speed by field control. Diagram is for compound-wound motors. For shunt-wound motors the series field coil is omitted.

The independent mounting of the starting resistor permits removal of the entire rheostat from the case for inspection or repair.

Overload protection as an additional feature is provided on some types of face plate starters. Here the overload relay has a series coil connected in the line circuit, thus carrying motor current. When this current exceeds the normal value a plunger acts to open an electrical contact, which in turn opens the circuit to release the magnet and permits the lever to return to the starting position. Some types are equipped with a magnetic type line contactor for remote control.

Self-contained knife switches with accompanied fuse protection are mounted outside of the case enclosure.

Maintenance of Face Plate Starters

To keep face plate starters in good operating condition, periodic inspection plus cleaning and smoothing the contacts with sandpaper is usually all that is needed.

Due to arcing and burning of contact making parts, which is unavoidable during normal operation, an occasional dressing with a file may be required.

Contacts should always be smooth. After each treatment with file or sandpaper (emery cloth should *not* be used) all parts should be thoroughly cleaned, including surfaces between contacts, and contacts should be very lightly greased.

Sometimes cutting of the metal is caused by sharp contact edges, or by abrasive matter in the air. If the latter, greasing should be omitted.

Reversing of Contacts.—Most types of face plate starters have movable and stationary contacts which can be turned over and used on the other side. This gives the contacts double life, but turning over should be done only when abnormal burning and subsequent dressing with a file has made adjacent contact surfaces uneven. The moving contact must bridge and be in firm contact with each adjacent stationary contact. If these points are not checked, irregular increments in speeds or voltage will be the result.

Spring Tension.—Firm pressure between contacts should be maintained by proper spring tension to minimize pitting, heating and oxidation which aggravates abnormal conditions. The recommended moving contact spring pressure for each type of rheostat may be checked with a hook spring balance, measuring the pull in pounds necessary to separate the contacts.

Resistor Replacement.—Abnormal starting or operating conditions may burn out a section of the rheostat resistor. In this case, the face plate, together with the resistors, can easily be removed from the box and the damaged units repaired or replaced.

If the resistor is of the wire wound Bobbin type, covered with a cement coating, a complete new set is recommended; if it is a suspension grid type, the burned out section should be replaced with one of the same pattern or style number; if it is a type "M" edge wound strap resistor, the break may be bridged with a clamp similar to the type furnished with the resistor. In most types of rheostats, the field resistors are removable from the resistor mounting without disconnecting the wiring.

Magnet Coil.—Practically all face plate starters of low horsepower rating have a magnet coil as part of the low voltage release. This coil is connected directly across the line. The release is adjusted to hold the operating handle in the last running position as long as the voltage is normal.

If it is desired to hold the starter in at slightly less than normal voltage, the holding power of the coil can be increased by filing down the little brass pin on the moving arm. However, this method should not be carried too far, nor should the operating arm be held in the running position by force. It is more economical to install a new magnet coil or spring than to take a chance on harming the motor by excessive starting current.

The rheostat should not be used to stop the motor. A safety switch or circuit breaker is provided for this purpose.

Checking Loose Connections.—After a face plate starter has been installed and in operation, all connections should be checked at least twice to make sure they remain tight when subject to heating. Loose connections are a considerable source of trouble causing many delays and they are difficult to find unless burning or failure of some other device occurs.

Means of checking are limited and in most cases restricted to mechanical inspection. This should be done periodically. One of the best devices for checking rheostats is an Ohm-meter. It is convenient, rugged in construction and small in size. Ohmic values are indicated on the dial. With this instrument and a record of normal resistance value, any change between two rheostats points can be determined readily. From the readings it will be obvious if the circuit is normal or not. Incidentally, burned out resistor tubes can be traced quickly in this manner.

TEST QUESTIONS

1. *What should be done before starting a motor!*
2. *How is a motor started?*
3. *Describe what occurs in starting a motor?*
4. *What is the difference between a starting box and a speed regulator?*
5. *What are the conditions at starting: 1, a series motor; 2, a shunt motor?*
6. *Mention some reasons for failure to start.*
7. *How can shunt motors be controlled from a distant point?*
8. *What precautions should be taken with shunt motors?*
9. *What provision is made so that the magnetizing current will have time to reach its normal value?*
10. *How are the connections arranged to avoid excessive voltage in the windings due to self-induction?*
11. *Mention two methods of regulating motor speed.*
12. *How does the speed vary with respect to variation of field strength?*
13. *How is the speed of shunt and compound motors varied with respect to the normal speed in two methods?*
14. *How is a wide range of speed regulation secured?*
15. *Describe the method of regulation by shunt field resistance?*
16. *Describe the methid of regulation by combined armature and shunt field control?*
17. *What is the method of two motor regulation?*

CHAPTER 34

D. C. Motor Control Apparatus

The various devices used in starting and speed regulation of motors may be classed as:

1. Rheostats, or starting boxes.
2. Regulators.
3. Controllers.

These devices are broadly speaking, various forms of rheostats, each being designed for the particular service for which it is intended.

In general, a rheostat may be defined as *a variable resistance box, so arranged that the amount of resistance in the circuit may be varied by moving a lever across a series of contacts which connect with the resistance at various points along its length.*

Resistor Material.—The resistance or resistor material used in starters and controllers varies widely according to requirements of the service. *For small size* motors a resistor with which a high ohmic value can be obtained is necessary, and at the

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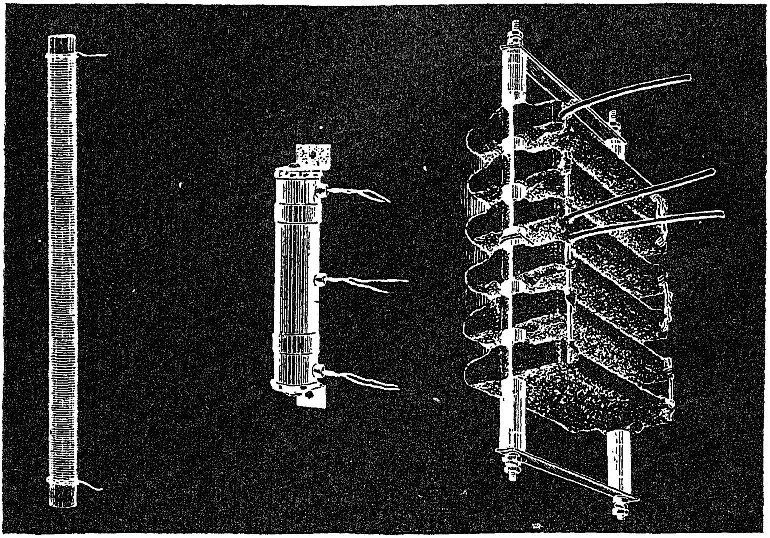
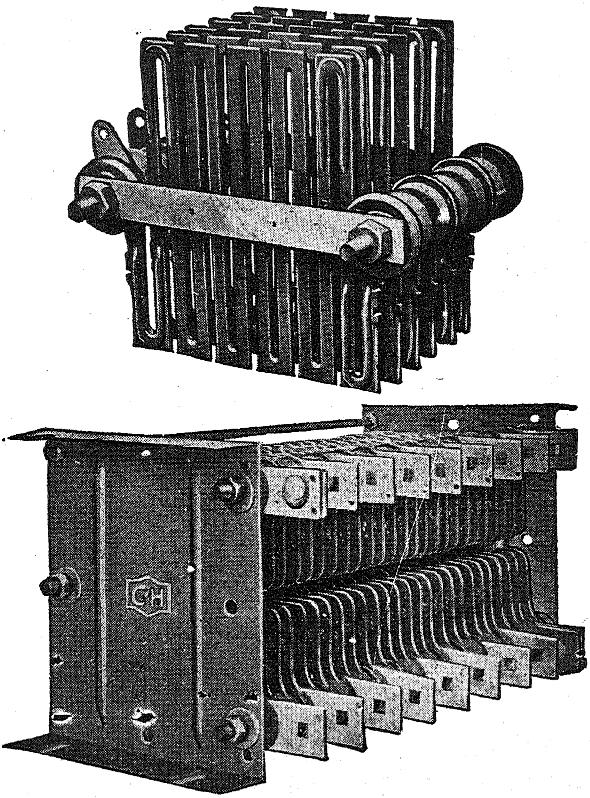
NOTE.—The most common form of resistor is the cast iron grid. Cast iron is admirably adapted for this purpose on account of its cheapness, high electrical resistance, freedom from corrosion, and small temperature coefficient. The resistance of cast iron increases about 15 per cent with a change of temperature of about 250 degrees. Its principal limitation is for small apparatus where a large ohmic value is required with a small capacity, requiring high resistance units of small size. Where a large ohmic value is required in a small space the embedded type resistor is used.

same time this resistor need not have capacity for carrying very heavy current.

For intermediate size motors the ohmic values required are lower and the current carrying capacity greater, while for *large motors* the ohmic values required are extremely low and the currents which must be carried are extremely heavy. Consequently for small motors resistors are ordinarily made of a special wire wound on porcelain or asbestos tubing or some form of suitable base. This wire is then covered over with a cement



Figs. 1,101 to 1,103.—Various Cutler-Hammer resistors, 1. Fig. 1,101, iron wire tube; fig. 1,102, iron clad resistor unit; fig. 1,103, assembly of units ready for mounting. The iron wire tube resistor, fig. 1,101, is used in small manual starters. Tinned iron wire is wound on an asbestos tube and these tubes are assembled in the frame of a starter. They are supported by porcelain nipples, the ends of which fit into the holes in the top and bottom of the enclosing case. The iron clad resistor fig. 1,102, has its wire cemented over and in addition a sheet metal covering is placed around the cement in order to protect the unit from injury. The assembly of units fig. 1,103 consists of special wire wound on a moulded core of vitreous material. The whole unit is then cemented over with a special cement. The units are mounted as shown and may be connected in series or parallel as occasion requires.



FIGS. 1,104 and 1,105.—Various Cutler-Hammer resistors, 2. Fig. 1,104, cast iron grid; fig. 1,105, assembly of cast iron grids. The grids are assembled on rods and connected in series or parallel to meet the required conditions. Boxes of this type consisting of various sizes of grids arranged in various groupings of series or parallel are built as a separate unit, and used in cases where it is not desirable to mount the resistor inside of the starter frame or where the starter is mounted on a switchboard type of frame which has no provision for resistor mounting.

NOTE.—The Electric Power Club defines a "resistor" as: "*An aggregation of one or more units possessing the property of resistance, used in an electric circuit for the purpose of operation, protection or control of that circuit.*" This term was coined to express properly the part of a controller often referred to as the "resistance." The word "resistance" expresses the property of a substance and should not be used to denote the material itself.

for protection purposes. The wire must have a negligible temperature coefficient of resistance and also a negligible expansion

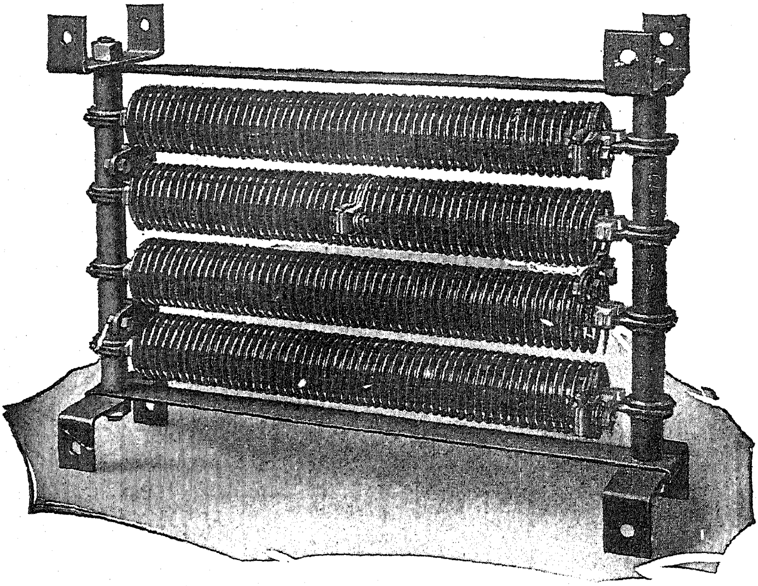


Fig. 1,106.—Monitor bank of four edgewound resistor units connected in series with one intermediate tap on second unit. There are only three joints in the whole bank.

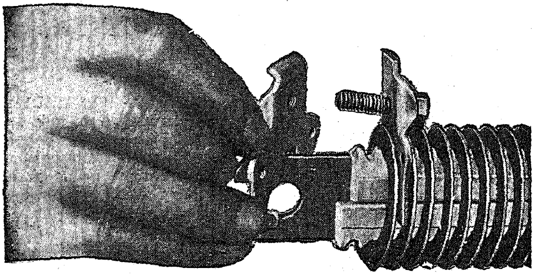


Fig. 1,107.—Method of making terminal connections on Monitor edgewound resistor by means of a two piece clamp. The porcelain support and lugs on the terminal clamp insure a rigid connectior.

coefficient as much expansion and contraction with heat would tend to break the cement coating. For intermediate sizes, ribbon resistor material or very fine cast iron grids are used, and for the heavy sizes heavier cast iron grids are used almost exclusively. For very large motors these grids are parallel, to obtain the necessary current carrying capacity.

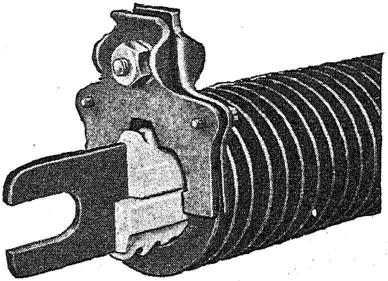


FIG. 1,108.—Terminal clamp for Monitor edgewound resistor in place. Clamp takes a firm grip on the ribbon and cannot work loose.

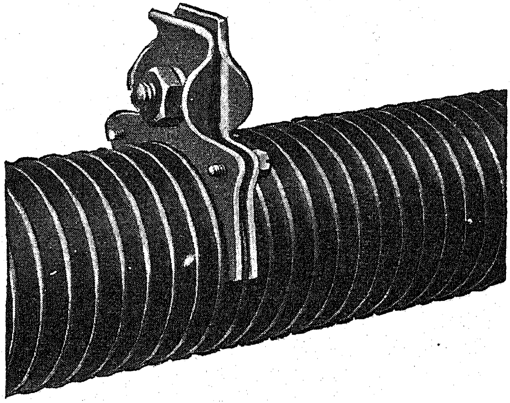


FIG. 1,109.—Monitor terminal clamp used for taking off a tap at an intermediate point on edgewound resistor unit. Right angle lug added for convenience in making wire connection.

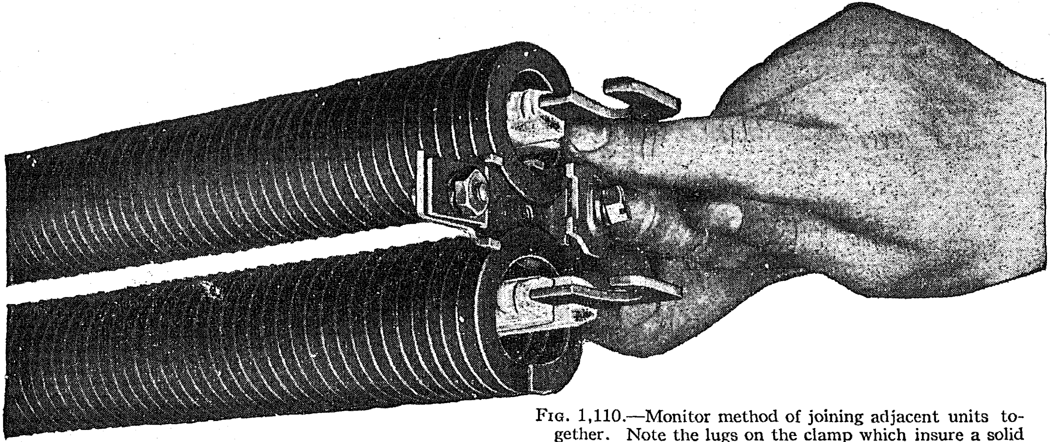


FIG. 1,110.—Monitor method of joining adjacent units together. Note the lugs on the clamp which insure a solid connection. Facilities are provided on the clamp for taking off a tap if desired.

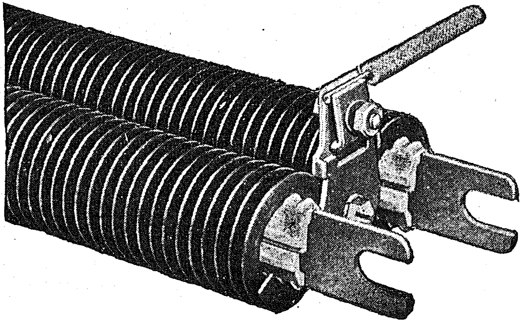


FIG. 1,111.—Monitor bridging clamp connecting adjacent edgewound resistor units. Also used for taking off intermediate taps when units are in parallel. Clamp takes a firm grip on the ribbon and cannot work loose.

Rheostats.—These devices consist of conductors inserted into a circuit for the purpose of diminishing, either constantly or in a variable degree, the amount of current flowing, or to develop heat by the passage of a current through them. Rheostats designed to be used in starting electric motors are frequently called "starting boxes."

Direct current motors up to ¼ *h.p.* may be started by throwing them directly upon the line, without an auxiliary switching or starting apparatus, or other than closing a switch.

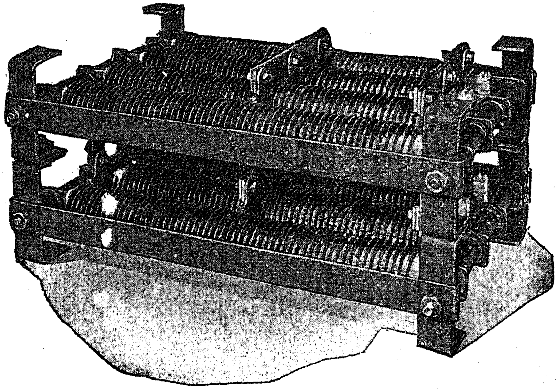


FIG. 1,112—Eight Monitor edgewound units connected four in parallel and two in series. Each bank of four units is tapped in the center, bridging clamps and a short lug being used for the purpose.

Starting rheostats are required for motors of ½ *h.p.* and larger and should be used on somewhat smaller motors when starts are frequent.

Qus. Describe the construction of a rheostat.

Ans. In fig. 1,113, resistance coils, A,B,C, etc., are mounted in a frame or box, and are connected at intervals to the contacts 1, 2, 3, etc. The rheostat arm or lever L, is pivoted at S, and when moved over the contacts, inserts more or less of the resistance in the circuit thus regulating the flow of the current. One terminal M, of the rheostat is connected to the last contact and the other terminal O, to the lever at S.

Ques. How is a starting box connected to a motor?

Ans. In series.

Ques. Why should a starting box be used with a motor?

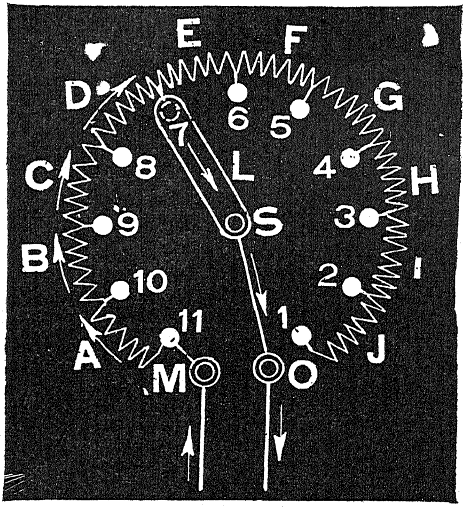
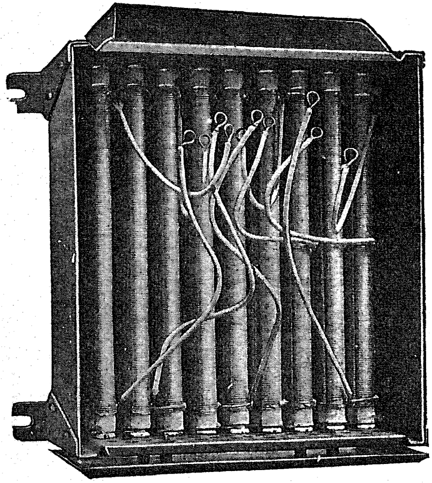


FIG. 1,113.—Diagram of plain rheostat. The rheostat is connected in series in the circuit that it is to control. *In operation,* when the lever is on contact 1, the current is opposed by all the resistance of the rheostat so that the flow is very small. As the lever is moved over contacts 1, 2, 3, etc., the coils are successively cut out, thus diminishing the resistance, and when contact 11 is reached all the resistance is short circuited allowing the full current to flow. M and O, are the terminals.

NOTE.—When an armature is in motion, there is an opposing magnetic field set up, due to the inductive effect of the armature. The effect of this is to induce a ***reverse pressure*** in the armature winding which opposes the applied voltage thus reducing the flow of current. Accordingly a rheostat is used to prevent too great initial rush of current before the armature begins to turn in starting.



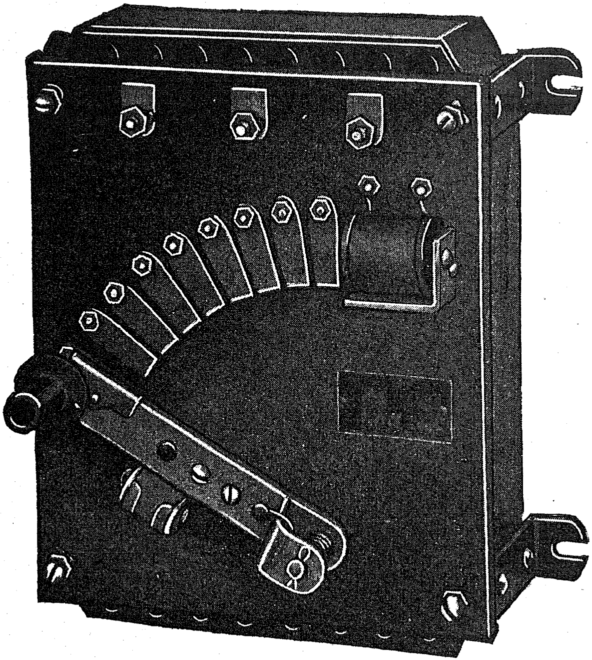


FIG. 1,114.—View of Cutler-Hammer starter with slate front removed showing open wire coil resistance. The type of resistance here used consists of tinned iron wire wound on asbestos tubes. The bottom of the casing is perforated to secure ventilation.

FIG. 1,115.—Union face plate non-reversing starter for bringing a general purpose series, shunt or compound wound *d. c.* motor from rest to full normal speed. The resistor is in the armature circuit. Low voltage protection is inherent.

Ans. If the line voltage should be applied directly to the terminals of the armature when not running, an excessive flow of current will result, on account of the low resistance of the armature.

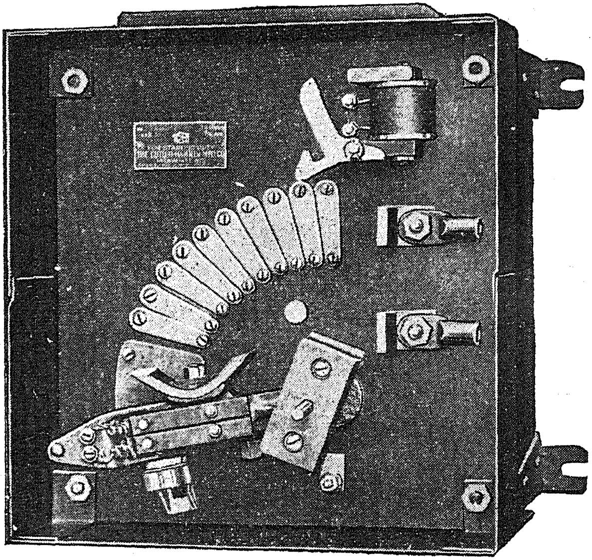


Fig. 1,116.—Cutler Hammer enclosed type motor starting rheostat with no voltage protection. The type starter here shown is provided with renewable segment contacts. This starter is used for starting up direct current motors under normal full load conditions. When the lever is moved to the first point the motor is connected to the line through the starting resistance and moving the lever to succeeding points cuts out one step after another of this starting resistance. When the lever reaches the final point the motor is connected directly on the line and the lever is held in this position by means of an electro-magnet operating latching device. The coil of this electro-magnet is generally connected in series with the shunt field of the motor so that a failure in the shunt field circuit will cause the release of the magnet and the starter handle will go back to the off position, disconnecting the motor from the line. Any failure in line voltage will also disconnect the motor. The starters are completely enclosed and operated from a lever on the outside of the enclosing cover. The resistor is mounted in the rear of the enclosing case

Ques. What attachments should be provided on a starting box?

Ans. An overload release, and a no voltage release.

NOTE.—*In starting,* the current flowing into the armature is greatly reduced owing to the high resistance of the rheostat coils, as the arm is moved across the contact buttons The speed of the armature increases because it is receiving more current The resistance being cut out gradually and the motor gradually attains its full speed.

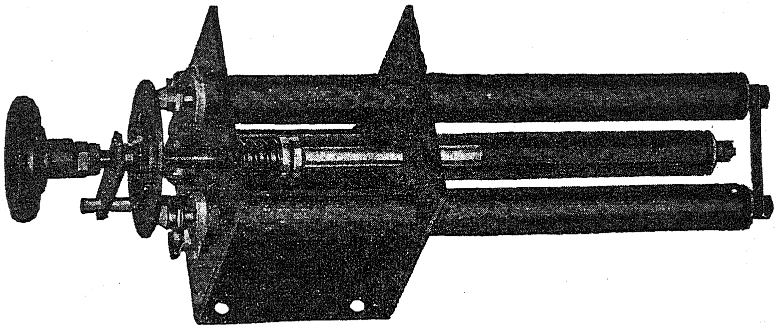
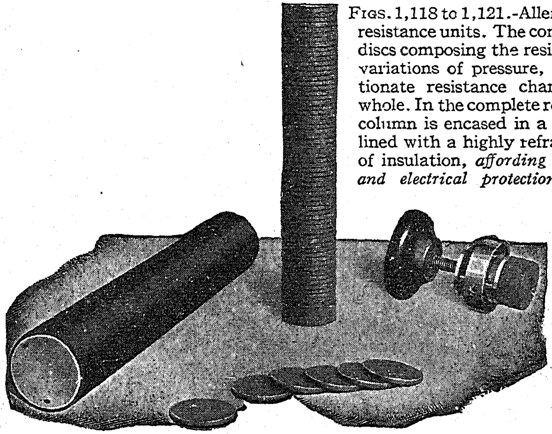
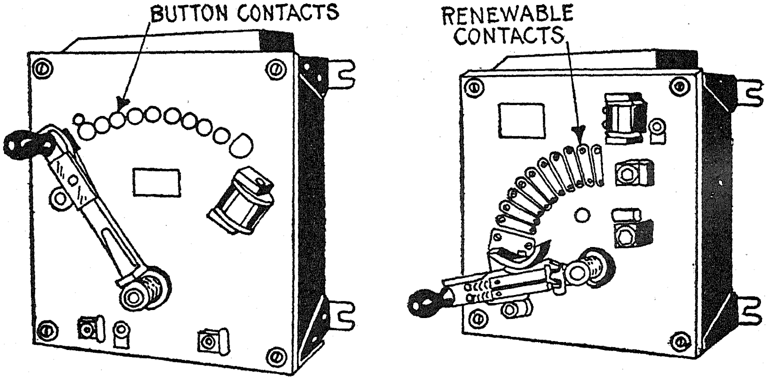


FIG. 1,117.—Allen Bradley multiple tube general purpose rheostat. ***It consists of,*** from one to twelve graphite disc compression resistor units, a compression screw, a handwheel, and provisions for various methods of mounting. The number of resistors depends upon the capacity required and, in cases of high voltage, the voltage drop across the rheostat helps to determine the number of resistors in the rheostat for the given application. ***In operation,*** the variation of resistance in the individual resistor is obtained by applying various degrees of pressure to the column of graphite discs enclosed in the refractory lined steel tube. Compression is applied to the column of discs by means of a handwheel which operates a compression screw. Turning the handwheel in a clock-wise direction increases the pressure on the graphite discs and decreases the resistance. Turning the handwheel in the opposite direction decreases the pressure and increases the resistance. In a single tube rheostat, the pressure is applied directly to a compression plug in the end of the resistance unit. In the multiple tube rhesotats the pressure is applied to an equalizing plate which in turn exerts an equal pressure on all the tubes. No matter how many resistance units in a rheostat, the resistance of all tubes is balanced at all times.



FIGS. 1,118 to 1,121.-Allen-Bradley compression type resistance units. The contact resistance between the discs composing the resistance column is subject to variations of pressure, thereby producing proportionate resistance changes in the column as a whole. In the complete resistance unit the resistance column is encased in a drawn steel tube, which is lined with a highly refractory cement, for purpose of insulation, *affording the column both mechanical and electrical protection* and excluding the air which effectually prevents any combustion should the column become red hot due to overload. The ends of the tube are closed by means of caps through which pass electrodes for making connections between the discs and exterior conductors. The steel tube, when necessary, is provided with ribs or fins for the dissipation of acquired heat.

Low Voltage Release.—The low voltage release consists of an electro-magnet sector on the pivot end of the rheostat operating arm, and a strong spring which tends to return the arm to the off position. The magnet is mounted directly below the pivot of the arm and its coil is connected in shunt across the line in series with a protecting resistance.



Figs. 1,122 and 1,123.—Sliding contact starters. Fig. 1,122, starter with button contacts; fig. 1,123, starter with renewable contacts. Motor starters in which the successive steps of resistance are cut out by a pivoted lever carrying a contact shoe which slides over button contacts or over contact segments, are known as sliding contact starters. Button contacts are usually furnished with motor starting rheostats of small size while contact segments are used on those of greater capacity. The contact segment being held in position by two screws, is readily renewable when worn by long service or damaged by arcing. The fixed button contact is not so easily renewed, but being used only on small size starters is never likely to be subjected to severe service. Some starters, however, have renewable button contacts.

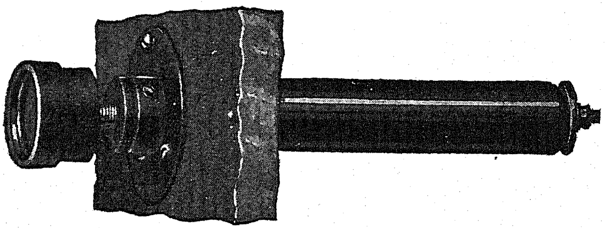


Fig. 1,124.—Allen Bradley single tube rheostat arranged for switchboard mounting.

When the magnet is energized its plunger rises and forces a steel ball into one of the series of depressions in the secto · on the arm with sufficient force to hold the arm against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned.

When the voltage fails, the magnet plunger falls, and the spring throws operating arm to off position.

If the electro-magnet does not become energized, it may be possible that its winding may be burnt out, in which case a jumper or a small piece of wire should be shunted across the magnet terminals.

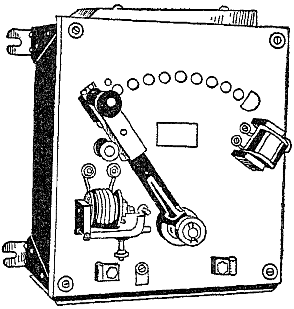


FIG. 1,125.—Starting rheostat with no voltage and overload release. The no voltage release permits the starting lever to fly to the "off position" should the voltage fail momentarily, thus protecting the motor against damage should the voltage suddenly return to the line. The movement of the lever is due to a spring. The overload device causes the lever to back to the off position should the current exceed a predetermined maximum for which the release is adjusted.

Overload Release.—This relay consists of an electro-magnet, the coil of which is connected in series with the motor armature circuit, and two contacts normally closed and connected in series with the low voltage release.

The overload relay magnet has a pivoted armature carrying an insulating wedge at its end.

When the motor armature current exceeds a predetermined value, the overload relay magnet armature rises and forces the insulating wedge between the contacts, thereby opening the low voltage release circuit, and allowing the operating arm to return to the off position.

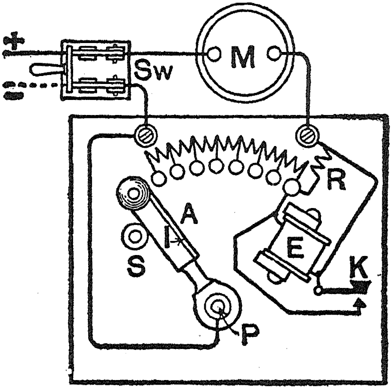
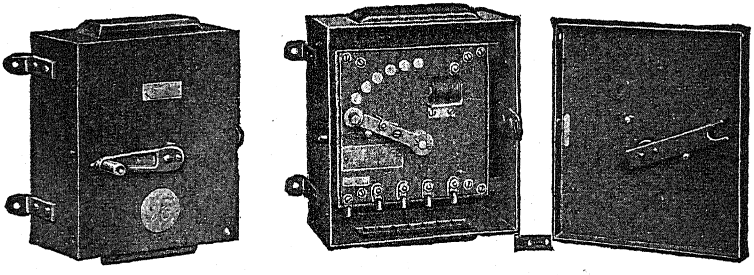


FIG. 1,126.—Starter with no voltage release for a series motor. A helical spring coiled around the lever pivot P, and acting on the lever A, tends to keep it in the off position against the stop S. This lever carries a soft iron armature I, which is held by the poles of the electro-magnet E, when, in starting the motor, the arm has been gradually forced over as far as it will go. Should anything happen to interrupt the current while the motor M, is running, E, will lose its magnetism and A, will be released, and will fly over to the off position. E, is usually shunted by a small resistance R, so that only a portion of the main current flows through it. This device constitutes the *no voltage release*, and ensures that all the resistance is in circuit every time the motor is started.



FIGS. 1,127 to 1,129.—General Electric enclosed heavy duty starting rheostat. ***Suitable for*** series, shunt or compound-wound *d. c.* motors that do not require more than 150 per cent full load torque to start or longer than 30 seconds to attain full speed. The retaining magnet coil is connected across the line. "Off" "Start" and "Run" markings on the cover correspond to the respective switch positions. The starter is operated by an external handle as shown in fig. 1,127 which shows starter complete with case and cover. The resistor units are mounted on supports fastened to the base of the rheostat independently of the box. This construction facilitates inspection and repairs by obviating the necessity of disconnecting a larger number of leads from the switch contacts.

Starting Rheostats for Series Wound Motors.—The speed of a series wound motor is regulated by a starting rheostat as shown in fig. 1,126, a resistance is inserted in series with the armature, the no voltage release is connected in series with the motor and the line, therefore its strength varies with the changes of current in the armature and field coils.

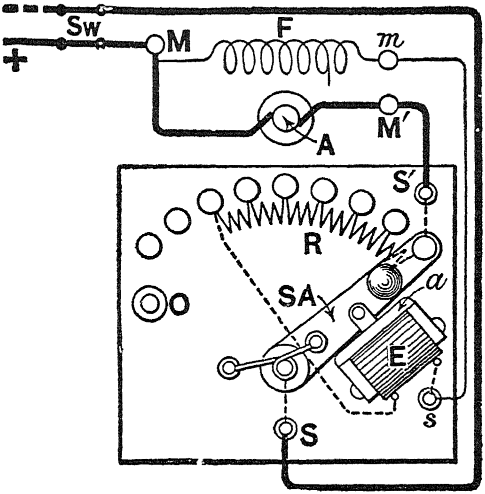


Fig. 1,130.—Starter with no voltage release for a shunt motor. The terminals of the motor are at M, M′, *m*, and those of the starter at S, S′, *s*. The lever SA, is shown in the "on" position. The current enters the motor at the terminal M, and there divides, part going through the field coil F, and the main current through the motor armature A. The armature current enters the starter at the terminal S′, and traversing the lever SA, leaves by the terminal S. The field current enters the starter at the terminal *s*, traverses the coil of the magnet E, (which holds up the armature *a*, linked to the lever) and thence completes its journey through the whole of the resistance R, and through the lever SA, to the terminal S. When the supply is cut off by opening Sw, or should the field circuit be accidentally broken, the magnet E, will release *a*, and the lever, which will thereupon fly to the "off" stop O. It should be noticed that when SA, is off, A and F, form a closed circuit with the resistance R and magnet E. The inductance of F, has consequently no chance of causing destructive sparking when the current is shut off. In starting the motor, Sw, is first closed, and then, as the lever is slowly moved, the resistance R, which at first is all in circuit with A, is gradually transferred from A, to F. The resistance of R, is too small to affect appreciably the current in F, which necessarily consists of a comparatively large number of turns of fine wire. The arrangement is adopted to render the breaking of the shunt circuit unnecessary and is rendered clearer by the diagram fig. 1,131. It should be noted that E, may be provided with a short circuiting key or push if required.

The disadvantage of this type of starting rheostat, is that if the no voltage release magnet winding should burn out, the motor will refuse to start, unless a wire or jumper be bridged across the terminals of the magnet.

Shunt and Compound Wound Motor Starting Rheostats.—These types of starters are similar to the series wound motor starting rheostats, except in the connections to the field circuit. The shunt field coils receive their current from the line through the no voltage release magnet as shown in fig. 1,132.

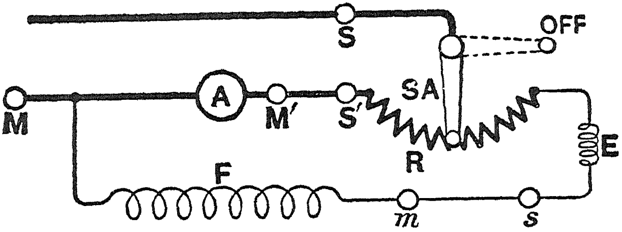


Fig. 1,131.—Simplified diagram of the connections of fig. 1,130.

Multi-Switch Starters.—These are used in connection with starting of large motors and moderate sized motors starting under heavy conditions where an ordinary starting rheostat would not be suitable, owing to the heavy currents that would be applied to the contacts.

Multi-switch starters consist of a set of separately mounted resistors and a panel carrying a group of switches and protective devices.

The switches are single pole, with heavy copper contact pieces bolted in place. Powerful coil springs are compressed when the switches are closed, so that the contacts are held firmly together.

The first switch of single-pole starters, and the first two switches of double pole starters, close and open the circuit; these switches are provided with arc shields and blowout coils. A mechanical interlocking device makes it impossible to close the switches in any way but the proper order.

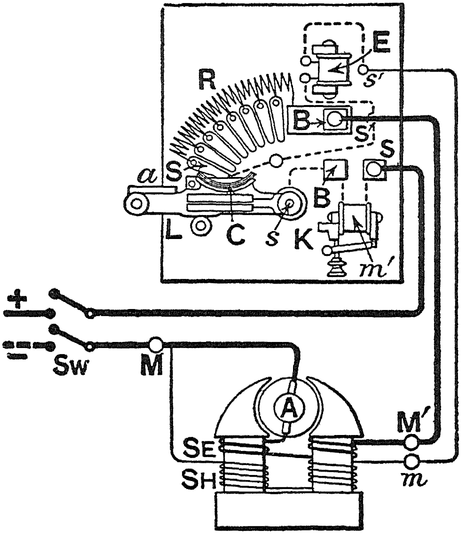


FIG. 1,132.—Starter with no voltage release and overload release connected to a compound motor. With a shunt motor, the only difference in the diagram would be that the series winding Se, would be absent, and the armature A, would then be connected straight across between the main terminals M and M'. When switch Sw, is closed, the current will enter the starter at its terminal S, and pass through the magnet coil *m'*, of the overload release to the switch lever L, which is shown in the off position. As soon as L, is moved up to make contact with the first contact S, the current divides; part going through the resistance R, and the terminals S' and M', to the series coil Se, (if a compound motor) and armature A; and part through the no voltage magnet E, to the shunt winding Sh. As the lever L, is moved up toward E, the effect is to take R, out of the armature circuit and put it into the shunt circuit. When the iron armature *a*, fixed on the switch lever, comes against the poles of E, the laminated copper brush C, bears against the blocks B, B, and so affords a better path for the current than through the spindle *s*. Should the supply voltage fail, either temporarily or permanently E, will release *a*, and L, will fly off under the tension of a helical spring coiled round *s*. If there should be an overload on the motor, tending to pull it up and cause an excess of current to flow through the armature; this excess current, passing through *m'*, will make it attract its armature, so bringing two contacts together at K, which will short circuit E, and allow the switch to fly off. The connections between E and *m'*, are not shown in the figure, but they are indicated at C, in fig. 1,135, which is a simplification of fig. 1,132, and which should be carefully compared therewith. When only the normal current is flowing, the attraction between *m'* and its armature is not sufficient to pull the latter up. The actual forms and arrangement of parts on the starters are well shown in some of the figures.

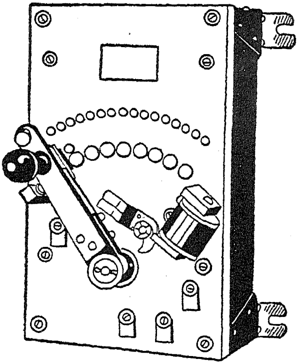


FIG. 1,133.—Compound starter. Designed for the double duty of starting a motor and regulating its speed, the resistance provided being a combination of armature resistance for starting duty and shunt field resistance for speed regulation.

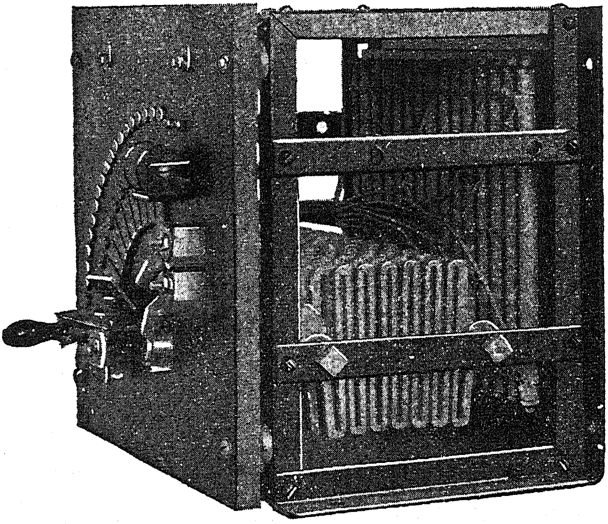


FIG. 1,134.—Union non-reversing compound starter and adjustable speed regulator for bringing a general purpose shunt or compound *d.c.* motor from rest to full normal speed by cutting out armature resistance, and for increasing the motor speed above normal by adding resistance to the shunt field circuit.

Each starter is equipped with an overload release and a low voltage release, which throw open all the switches in event of an overload or a failure of voltage. Both devices are effective while the motor is being started, and the tripping point of each is adjustable over a wide range. The overload release can be tripped by hand.

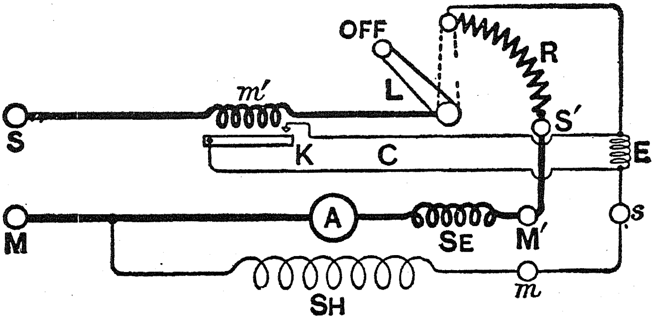
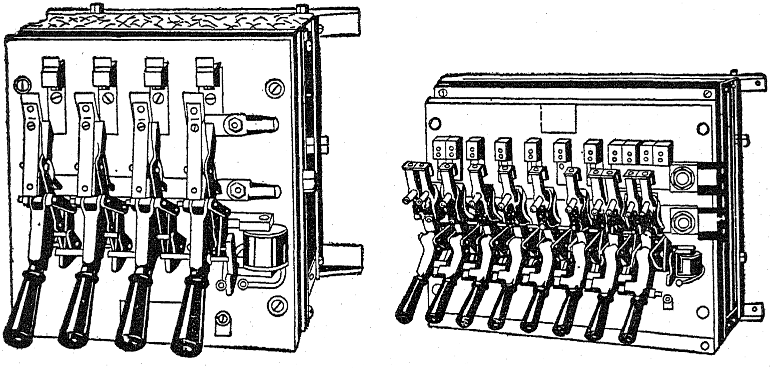


Fig. 1,135 —Simplified diagram of the connections of starter connected to compound motor as shown in fig. 1,132.



Figs. 1,136 and 1,137.—Multiple switch starters. Fig. 1,136, starter with no voltage release; fig. 1,137, starter with no voltage release and circuit breaker. The multiple switch type of starter is designed to overcome the arcing on sliding contacts which, in the case of large motors would be very severe. The cutting out of each step of resistance is accomplished in the multiple switch starter by a separate carbon contact switch which breaks the circuit with a quick snappy action.

In order to insure the closing of all the switches, a pendant switch in series with the low voltage release coil must be held closed until the last switch of the starter is closed; if this button is released before the last switch is closed, all the switches promptly open. The last switch automatically closes the release coil circuit.

The motor is started by closing the switches, one at a time, in regular consecutive order. In the single-pole type the first switch closes the armature circuit with all the resistance in series and connects the shunt field of shunt and compound wound motors directly across the line; each succeeding switch short circuits a section of resistance.

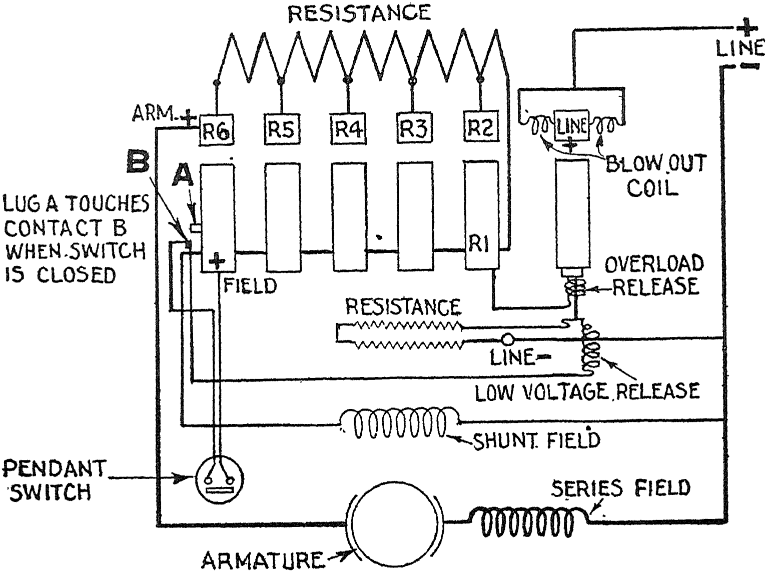


FIG. 1,138.—Connection diagram of single pole multiple switch starter.

In the double pole type the first two switches must be closed in order to admit current to the motor. With full load torque, the motor should be started in one minute; with fifty per cent. overload, in 30 seconds. The motor is stopped by tripping the overload release.

Speed Regulation of Traction Motors.—The speed regulator for motors of this class is called a *controller*, and being located in an exposed place is enclosed in a metal casing. Controllers are designed to be used for starting, stopping, reversing, and

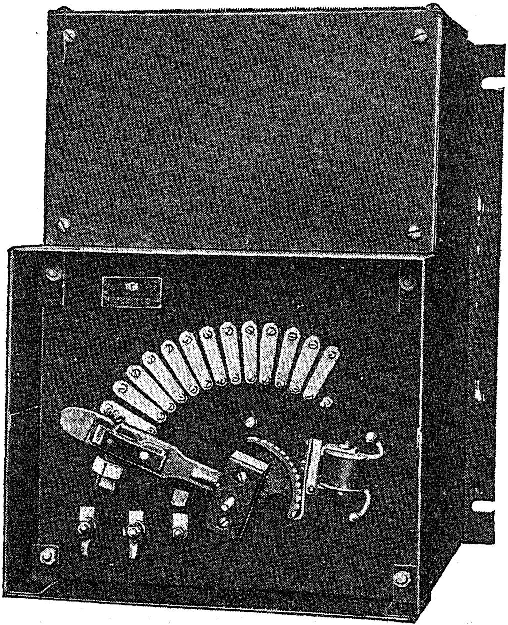


FIG. 1,139.—Cutler Hammer enclosed type manual speed regulator with no voltage protection. This device gives speed regulation by armature resistance only, reducing the speed of the motor below the normal running speed by means of resistance in the armature circuit. No provision is made in this type of regulator for increasing the speed of the motor above the normal speed by means of field resistance. The maximum speed obtainable with the controller is therefore the normal speed at which the motor is designed to operate with no resistance in circuit. With all resistance in circuit and the motor taking normal full load current the regulator will reduce the speed of the motor 50%. If the motor be taking less than normal current the percentage of speed reduction attainable will be correspondingly less. The operating lever is held in any given position by means of an electro-magnet which operates a latch. This latch engages with notches in the fan tail part of the operating lever. In case of failure of the line voltage the lever will be returned to the off position, disconnecting the motor from the line. The coil of the latching magnet is quite often connected in series with the shunt field of the motor so that a failure of the motor field will also disconnect the motor from the line. The regulating resistor is mounted in the rear of the enclosing case.

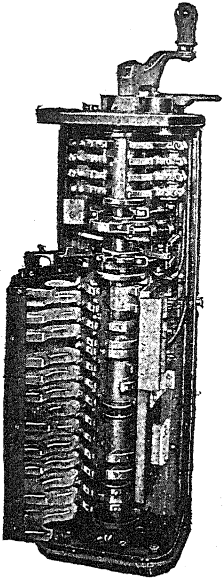


FIG. 1,140.—General Electric drum or platform type controller. The characteristic feature of this type is the series parallel combinations of motor connections. This controller is used principally for single car operation. Under certain conditions it can also be arranged to operate two cars in each train, using either two large or four small motors on each car. This adapts its use to city service where it is required to operate two cars in trains during rush hour periods.

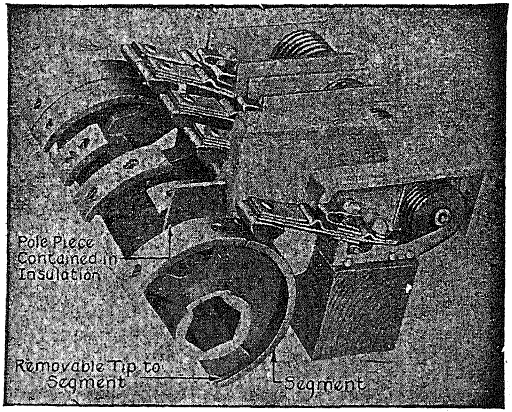
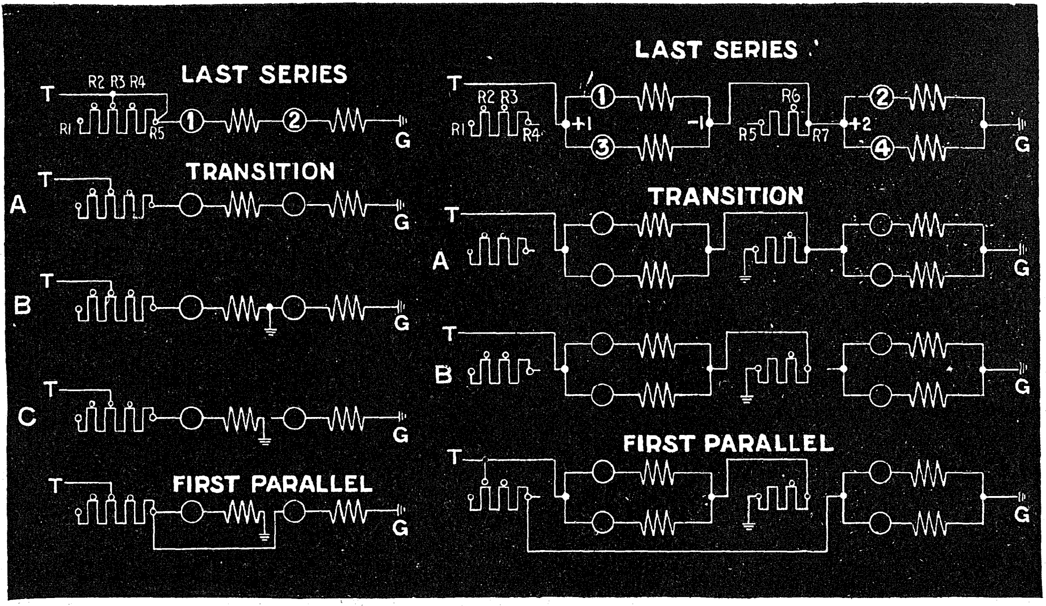


FIG. 1,141.—Detail of General Electric drum controller magnetic blowout. Individual magnetic blowouts are provided for each main finger or group of fingers. These are so located that the arc is blown outward.



FIGS. 1,142 to 1,150.—Transition connections of General Electric type K drum controller. The change from series to parallel connections of motors without cutting off power from both motors on a two motor equipment, or both pairs of motors on a four motor equipment, thus permitting a smooth acceleration. With controllers for small motors, the transfer of connections from series to parallel is effected by the K, method which consists of first grounding the low side of the first motor or pair of motors and opening the circuit of the second motor or pair, then connecting the second motor or pair in parallel with the first. With larger controllers the bridge method of transfer was originally used. This method, however, has been superseded by the T, or shunt resistance method, which gives substantially the same smoothness as the bridge method and with less burning of the contacts.

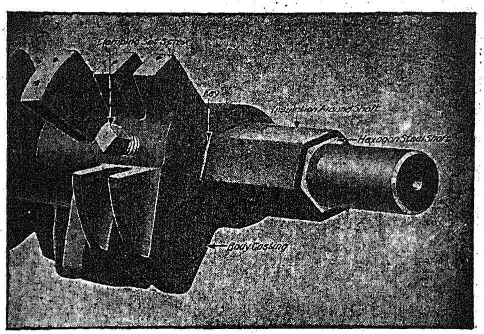


FIG. 1,151.—Detail of cylinder casting assembly for General Electric standard drum type controller.

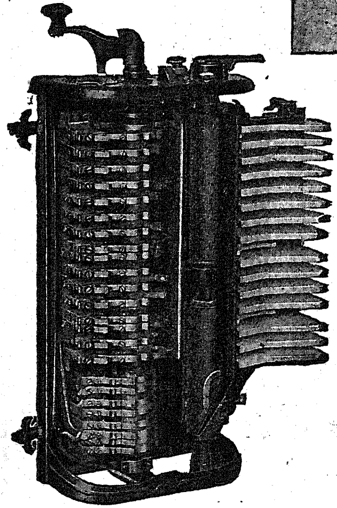
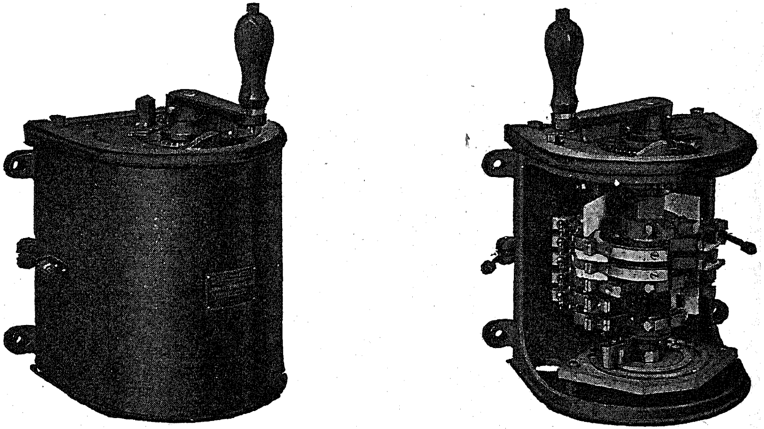


FIG. 1,152.—General Electric type B rheostatic braking controller. ***The fundamental principle*** on which the action of rheostatic braking is based is the conversion of the motors into dynamos, which derive their energy from the momentum of the car, and convert it into electrical energy which is absorbed in a set of resistors. The retardation of the car is, therefore, entirely independent of the current from the trolley and is proportional to the amount of energy absorbed in the resistors. Additional braking effort may be obtained by the use of magnetic brake shoes energized by the current thus generated. The controllers for this service are known as the B type and are essentially the same as the K type with additional contacts for establishing the circuits necessary for braking. Their operating handles may be turned forward through a number of notches, which gives series and parallel connections for power running, as in K controllers, and may also be turned in the reverse direction through a number of notches which establish the braking connections and vary the braking effort by varying the resistance in the circuit.

regulating the speed of motors where one or more of these operations have to be frequently repeated.

The controller used with a single motor equipment is practically the same as any other single motor starting box, excepting that the resistance has sufficient carrying capacity to be left in the circuit some time. When the motor is to operate at full speed all the resistance is cut out. To reverse, a reversing notch is placed in the armature or field circuit, but not in both.

Ques. What provision is made to overcome the arc when the circuit is opened?



Figs. 1,153 and 1,154.—Union general purpose drum controller. Fig. 1,153, controller with cover on; fig. 1,154, controller with cover off showing mechanism. This type controller is used for controlling motors on indoor service where the service is light, but where frequent starting and stopping or reversing is required. This service is found in most industrial plants, machine shops, printing plants, etc. in operating line shafts, fans, pumps, machine tools, etc. ***In operation,*** fingers and rotating cylinder control armature circuit. Flat plate and button contacts control the field, a pointer indicates the operating position of the drum. Cover is made of sheet steel enclosing all live parts.

Ans. A magnetic field is used with such polarity that it blows out the arc.

Magnetic blow out coils are used on all controllers designed for 500 volt circuits, and on types designed for lower voltages requiring more than 60 amperes normal capacity.

The coils are wound with either copper wire or flat strips of sufficient capacity to carry full load current continuously without undue heating, and after being wound they are treated with an insulating compound making them moisture proof.

Ques. What provision is made to prevent reversal before bringing the controller lever to the "off" position?

Ans. Controllers having separate reversing cylinders are fitted with mechanical interlocks making it necessary to place lever in off position before reversing.

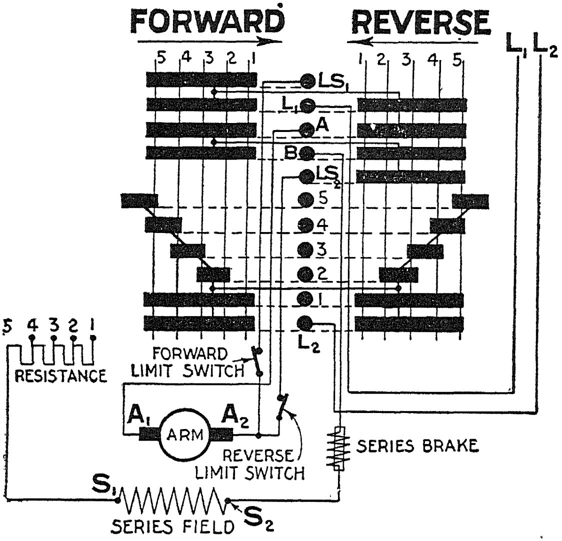


FIG. 1,155.—Connection diagram for Union small hoist duty controller designed for motors used on small traveling cranes, monorail hoists, portable hoists and any other similar equipment requiring a small intermittent duty controller. They are of the semi-weather proof design for indoor service, but may be used out of doors, if protected from the weather. This drum is designed for straight series motor control, is reversible and arranged for use with or without main line limit switches. In either case the standard controller is used. Limit switch protection is afforded in either one or both directions.

Selection of Starters and Regulators.—Unsatisfactory operation of these devices is, in nearly all cases, due to lack of precaution in selecting the proper piece of apparatus for the work to be done. One of the commonest errors is to select a rheostat of insufficient capacity. If the current required to operate the motor at full speed with no resistance in circuit be greater than the rated capacity of the rheostat, overheating of the resistance will result.

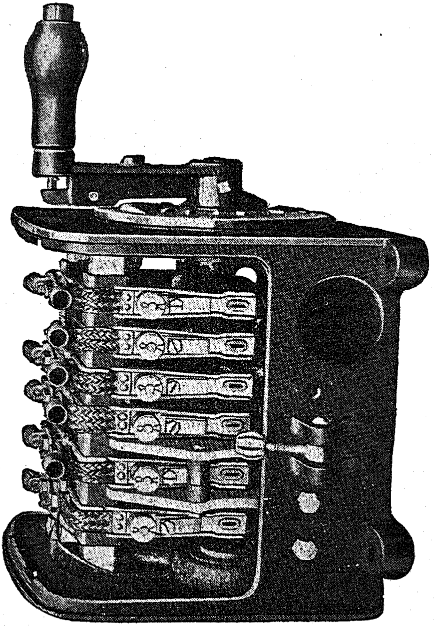


FIG. 1,156.—Cutler-Hammer drum controller with cover removed showing arc shield and finger board construction. This type controller is designed for use with series, shunt or compound motors on general reversing or non-reversing service, where plain starting or speed regulation is required. On regulating duty, the drum will carry full load current continuously on any point. They close only in the "off position" enabling the operator to control manually the magnetic switch panel. This also insures protection to the workmen and motor by preventing unexpected starts after stops caused by overload or voltage failures.

An increase in temperature even to a point where the hand cannot be held on the enclosing case need cause no apprehension, but should the resistance become red hot it indicates that the apparatus is being worked far beyond its capacity, and the load on the motor should be reduced or a regulator of greater capacity substituted.

If the current required to operate the motor at full speed with no resistance in circuit be less than the rated capacity of the rheostat no overheating will occur, but it will not be possible to secure the full 50 per cent speed reduction the rheostat is designed to give with all resistance in circuit.

In ordering a starter or regulator the manufacturer should be furnished with the following information:

1. Horse power of motor with which speed regulator will be used;
2. Voltage of motor;
3. Winding of motor, whether series, shunt, or compound wound;
4. Nature of the machine which motor is to operate;
5. Normal rated speed of motor to be used;
6. Maximum speed;
7. Minimum speed;
8. Whether controller will ever be required to reverse direction of motor or to operate it in one direction only;
9. If reversible controller be desired, whether or not full range of speed control is required in both directions;
10. Whether the regulator shall be equipped with any of the following devices: no voltage release, overload release, knife switch, fuses;
11. Whether button contacts or renewable contact segments are preferred;

12. Giving, also, if possible, the resistance of the shunt field coil, and the shunt field current at the maximum speed required. If this cannot be ascertained, give horse power, voltage, normal speed, maximum speed required, serial number of motor and name of manufacturer.

TEST QUESTIONS

1. *Name the various devices for motor control.*
2. *What kind of resistors are used in rheostats?*
3. *Describe the methods of connecting resistor units.*
4. *What is a rheostat?*
5. *Describe the construction of a rheostat.*
6. *How is a starting box connected to a motor?*
7. *Why should a starting box be used with a motor?*
8. *What attachments should be provided on a starting box?*
9. *Describe the connections for: 1, low voltage release; 2, overload release.*
10. *Describe the connections of a starter with no voltage release for a shunt motor.*
11. *Describe the connections for shunting compound motor starting rheostats.*
12. *For what service is a multi-switch starter used?*
13. *Describe the connections for a starter with no voltage release and overload release connected to a compound motor.*
14. *What form of rheostat is used to control the speed of traction motors?*

15. *What are the three functions performed by controllers?*
16. *How does a controller used with a single motor differ from an ordinary box?*
17. *How is the reversing switch arranged on controllers?*
18. *What provision is made to overcome the arc when the circuit is opened by a controller?*
19. *Describe a magnetic blow out coil.*
20. *What provision is made to prevent reversal before bringing the controller lever to the "off" position?*
21. *Give some points relating to the selection of starters and regulators.*
22. *What is the difference between a starter and a regulator?*

CHAPTER 35

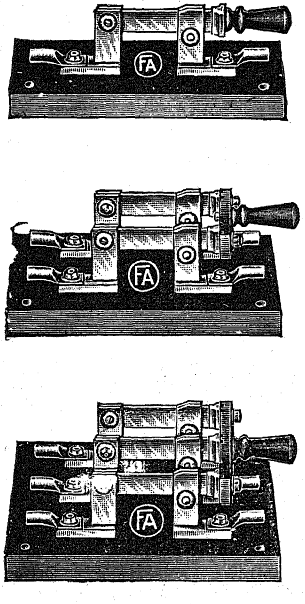
Auxiliary Apparatus

There are numerous devices that must be used in connection with dynamos and motors for proper control and safe operation. Among these may be mentioned:

1. Switches;
2. Fuses;
3. Circuit breakers;
4. Rheostats;
5. Switchboards;
6. Lightning Arresters.

Switches.—A switch is a device by means of which an electric circuit may be opened or closed. There are numerous types of switch; they may be either single or multi-pole, single or double throw and either of the "snap" or knife form.

Ques. What is the difference between a single and double pole switch?

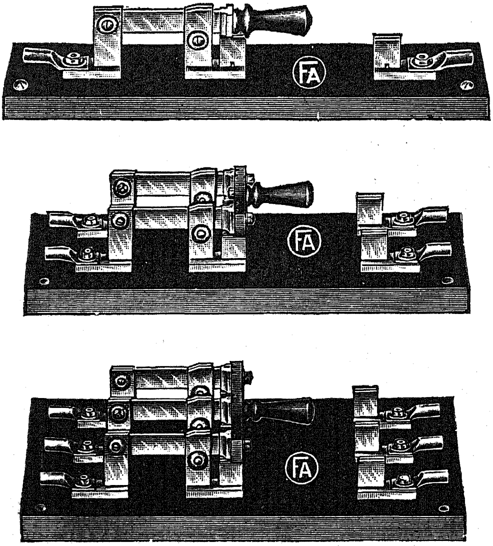


Figs. 1,157 to 1159.—Adam's single throw knife switches without fuse connections. Fig. 1,157, single pole switch; fig. 1,158, double-pole switch; fig. 1,159, three-pole switch.

Ans. A single pole switch controls only one of the wires of the circuit, while a double pole switch controls both.

Ques. What is the difference between a single break and a double break switch?

Ans. The distinction is that the one breaks the circuit at one point only, while the other breaks it at two points.



Figs. 1,160 to 1,162.—Adam's single throw knife switches with fuse connections at the handle end. Fig. 1,160, single pole switch; fig. 1,161, double pole switch; fig. 1,162, three pole switch.

Ques. What is the advantage of a double break?

Ans. If the circuit be opened at two points in series at the same instant, the voltage is divided between the two breaks and the length to which the current will maintain an arc at either break is reduced to one-half; thus there is less chance of burning the metal of the switch.

Another reason for providing two breaks is to avoid using the blade pivot as a conductor, the contact at this point being too poor for good conductivity.

Ques. When should a knife switch be used?

Ans. When the capacity of the circuit in which it is to be placed exceeds 10 amperes.

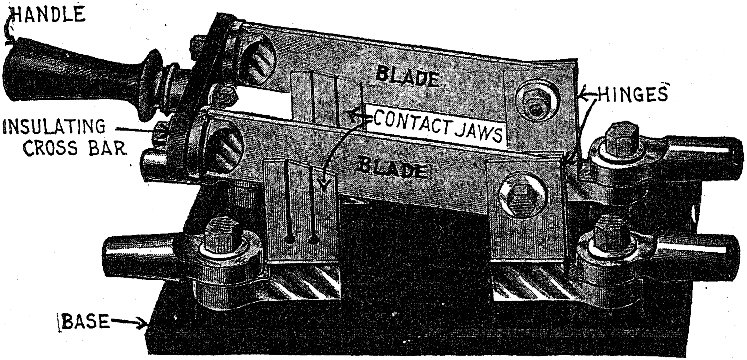


FIG. 1,163.—A single throw, two pole knife switch. As usually constructed it is made of hard drawn copper with cast terminal lugs and fibre cross bar.

Ques. Describe a knife switch.

Ans. Fig. 1,163 illustrates a knife switch of the double pole, single throw type. It consists of the following parts: base, hinges, blades, contact jaws, insulating cross bar, and handle, as shown.

Ques. How should knife switches be installed?

Ans. They should be placed so that *gravity tends to open them*.

Otherwise if the hinges become loose, the weight of the blades and handle would tend to close the switch, thus closing the circuit and possibly resulting in considerable damage.

Ques. How should switches be proportioned?

Ans. The minimum area of the contact surfaces should not be less than .01 sq. in. per ampere, and in those used on arc lighting or other high voltage circuits where the current is usually small, the area of the contact surfaces is usually from .02 to .05 inch per ampere. Since dirt or oxidation would prevent good contact under a simple pressure between the contact surfaces, the mechanism of a switch provides a sliding contact.

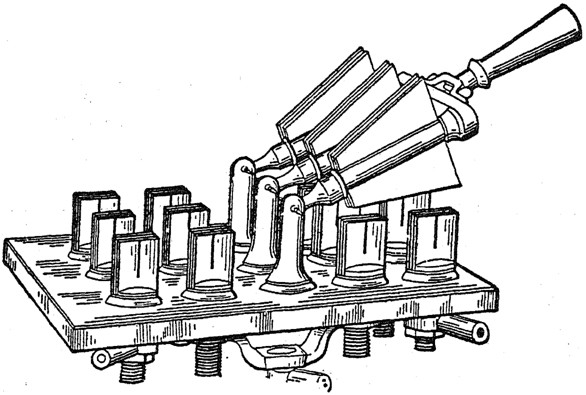
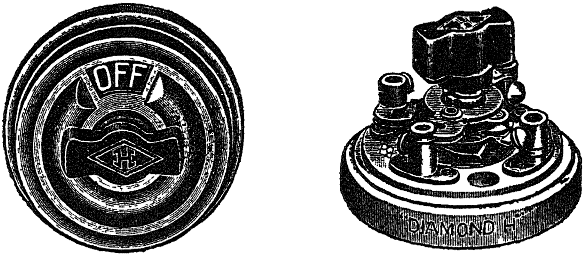


FIG. 1,164.—Triple pole, double break, double throw knife switch for very heavy current. The blades are made up of numerous strips to give adequate contact area. A double throw switch is used when it is desirable to open one circuit and immediately close another, or to transfer one or more connections from one circuit to another in the least possible interval of time, also, when one connection is to be broken, another closed and it is undesirable to allow both to be closed at the same time.

In the general design of switches, all parts which carry current are given a cross sectional area of at least one square inch per 1,000 amperes if they be made of copper, and about three times as much if made of brass, as the conductivity of the latter is only one-third that of the former. Furthermore, the current should never be permitted to pass through springs, as the heat generated will destroy their elasticity.

Ques. What difficulty is experienced in opening a circuit in which a heavy current is flowing?

Ans. It is impossible to instantly stop the current by opening the switch, consequently the current continues to flow and momentarily jumps the air gap, resulting in a more or less intense arc which tends to burn the metal of the switch.



FIGS. 1,165 and 1,166.—Snap switch; views showing switch with cover on, and exposed to show mechanism. The switch is provided with indicating dial which registers "on" and "off" positions.

Ques. How is this remedied to some extent?

Ans. The contact pieces are so shaped that they open along their whole length at the same time, so as to prevent the concentration of the arc at the last point of contact. This feature is clearly shown in fig. 1,163.

Ques. For what service are "snap" switches suitable?

Ans. They are used on circuits containing lamps in comparatively small groups, and other light duty service.

Ques. What is a quick break switch?

Ans. A form of switch in which the contact pieces are snapped apart by the action of the springs, as shown in fig. 1,168, so as to make the duration of the arc as short as possible.

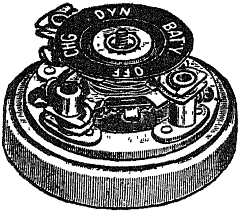


FIG. 1,167.—Gas engine snap switch. The first snap makes connection so that igniter is run from storage battery; second snap connections are changed so that igniter is supplied from dynamo; third snap makes connections so that dynamo supplies igniter and charges storage battery; fourth snap, all off.

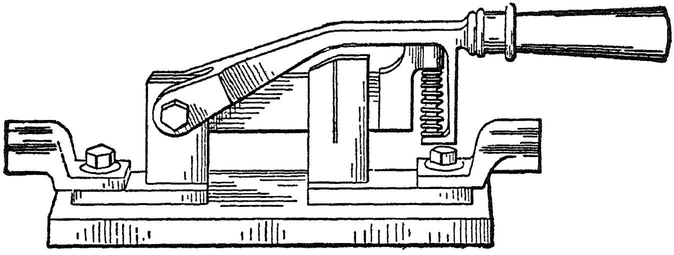


FIG. 1,168.—A "quick break" knife switch of the single throw, single break, one pole, type. The contact blade is held between the jaws by their clamping friction until the handle compresses the spring sufficiently to force the blade out. As soon as it breaks contact with the jaws, the spring expands and drives the blade away from the jaws with greater rapidity than could be done by hand. The object of this action is to break the arc as quickly as possible to prevent burning the metal of the switch.

The current allowed in each branch circuit of an electric lighting system is limited by the insurance rules to a maximum of 660 watts equivalent to 12 lamps of 16 c.p. each at 110 volts. They are also employed to control lamps in groups in theatres and other places where many lamps are turned on or off at about the same time.

Fuses.—All circuits subject to abnormal increase of current which might overheat the system, should be protected by fuses which will melt and thus open the circuit. A fuse is simply a strip of fusible metal, often consisting of lead with a small percentage of tin, connected in series in the circuit.

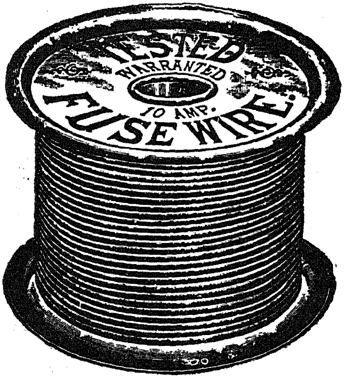


Fig. 1,169.—Spool of fuse wire usually made of an alloy of tin and lead, such as half and half solder. Bismuth is frequently added to the alloy to lower the melting point. For half and half solder the melting point is 370° Fahr. The current required to "blow" a fuse increases somewhat with the age of the fuse owing to oxidation and molecular changes. Fuses are sometimes rated according to the number of amperes to be taken normally by the circuit they are to protect. Open fuses are so unreliable that circuit breakers are preferable for large currents; when fuses are used, the enclosed type as shown in figs. 1,188 and 1,189 is usually the more desirable.

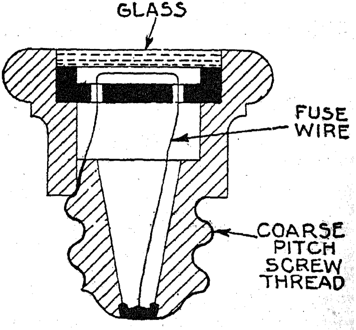
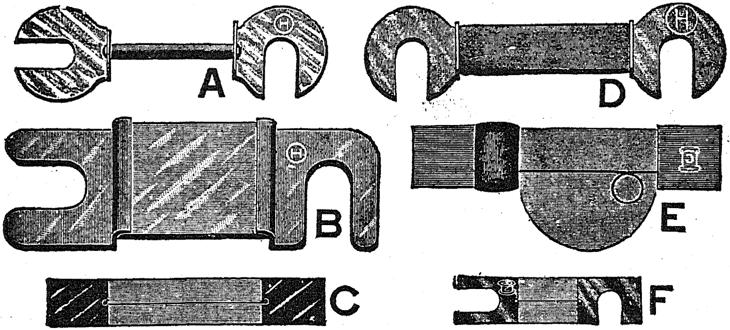


Fig. 1,170.—Cross section, through plug fuse. With this type of fuse it is impossible to place any except the correct size of plug in the socket.

Experiments have shown that for large fuses, a multiple fuse is more sensitive than a single one. A one hundred ampere fuse may be made by taking four wires of twenty-five amperes capacity. A fuse block may be overloaded, not because the metal of the terminals is not of sufficient cross section to carry the current, but because of insufficient area of contact, or loose contact of fuse and wires; the overload thus caused results in heating and frequently melts the fuse.

Ques. Where should fuses be placed?

Ans. They should be inserted wherever the size of wire changes or wherever there is a branch of smaller size wire connected, unless the next fuse on the main or larger wire be small enough to protect the branch or small wire.

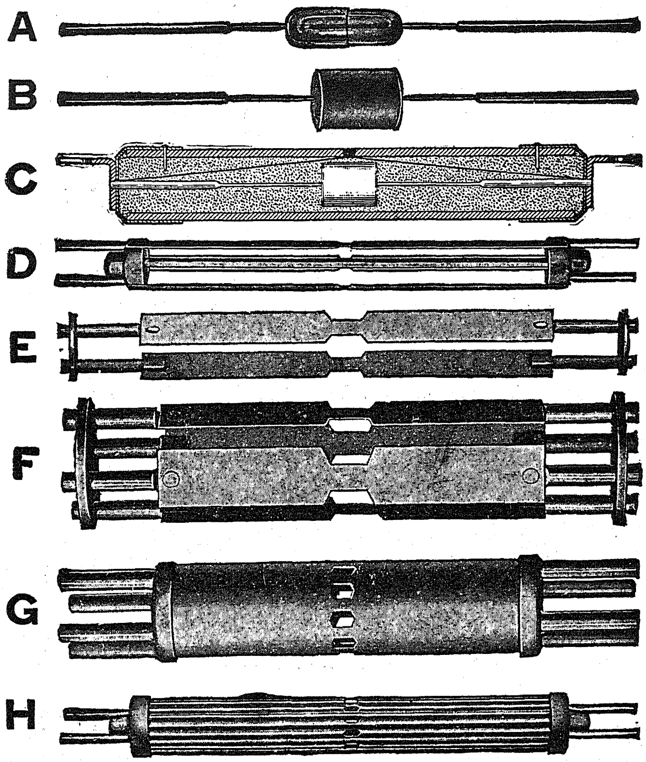


FIGS. 1,171 to 1,176.—Various open fuses. Fig. 1,171, fuse for main and branch blocks; fig. 1,172, standard railway fuse; fig. 1,173, Edison main style; fig. 1,174, sneak current fuse; fig. 1,175, W. U. pattern; fig. 1,176, Bell telephone style; When an open fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

Ques. How should fuses be mounted?

Ans. They should be placed on a base of slate, porcelain, marble, or other incombustible material.

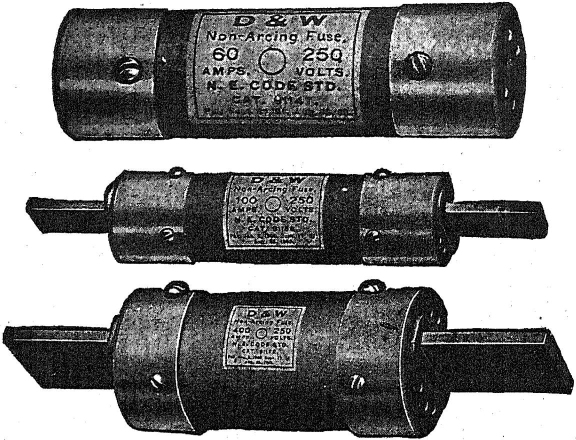
Ques. What is the objection to copper fuses?



FIGS. 1,177 to 1,184.—Interior construction of D. & W. fuses. ***In the manufacture*** of these fuses, four types of fuse link are used according to capacity of fuse, and classified as: 1, air drum link; 2, flat link; 3, multiple link; 4, cylinder link. In the air drum link, figs. **A** and **B,** a capsule provides an air space about the center of the link, the rate of heat conduction through the confined air being very slow, the temperature of that portion of the link rises rapidly with increasing current, rendering the blowing point practically constant; fig. **C,** shows a section through the complete fuse. In the flat link, fig. **D,** the section is reduced in the center, cutting down as far as possible the volume of metal to be fused. Figs. **E** to **G,** show various forms of multiple link construction. By subdividing the metal, increased radiating surface is obtained which permits a reduction in the volume of fusible metal necessary, and the metal vapor formed when the fuse blows on heavy over load is more readily dissipated. Figs. **F** and **G,** show two forms of cylinder link, the plain cylinder fig. **F,** being used for low voltage and large current, and fig. **G,** for certain high tension service. The corrugated cylinder presents more surface to the fuse filling than the plain type and secures a maximum radiating surface with resulting minimum volume of metal for a given current.

Ans. They heat perceptibly soon after their rated capacity is passed. The melting temperature is higher than lead alloy.

Ques. Upon what consideration does the choice between switches and circuit breakers depend?



FIGS. 1,185 to 1,187.—D & W. enclosed "cartridge" fuses. Fig. 1,185, type for 3 to 60 amperes; fig. 1,186, type for 61 to 100 amperes; fig. 1,187, type for 101 to 1,000 amperes.

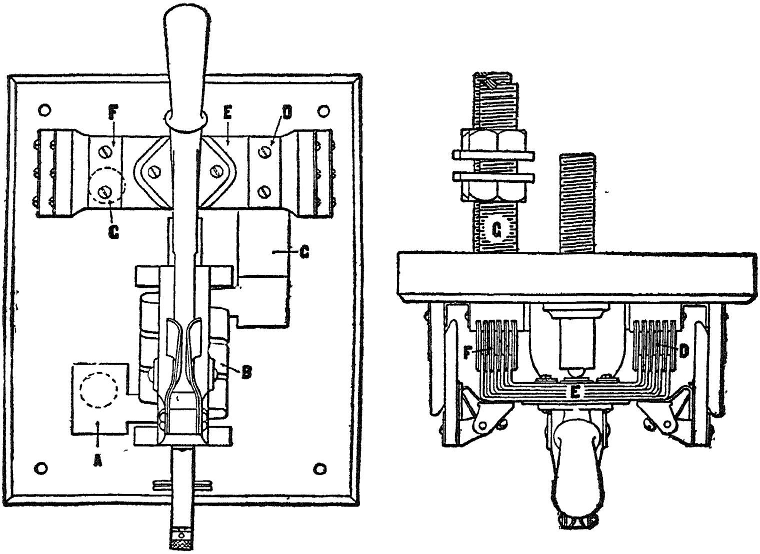
FIGS. 1,188 and 1,189.—D and W. enclosed or cartridge fuse showing blow indication. When the fuse blows, it is indicated by the appearance of a black spot within the circle on the label as in fig. 1,189. Fuses should be placed wherever the size of wire changes or wherever there is a branch of smaller size wire connected, unless the next fuse on the main or larger wire is small enough to protect the branch or small wire, but more lights may be added on the large wire, making it necessary to put in a larger one. Experiments have shown that for large fuses, a multiple fuse is more sensitive than a single one. A one hundred ampere fuse may be made by taking four wires of twenty-five amperes capacity.

Ans. Simple knife switches are suitable for use when the circuit is not liable to be opened while carrying large current.

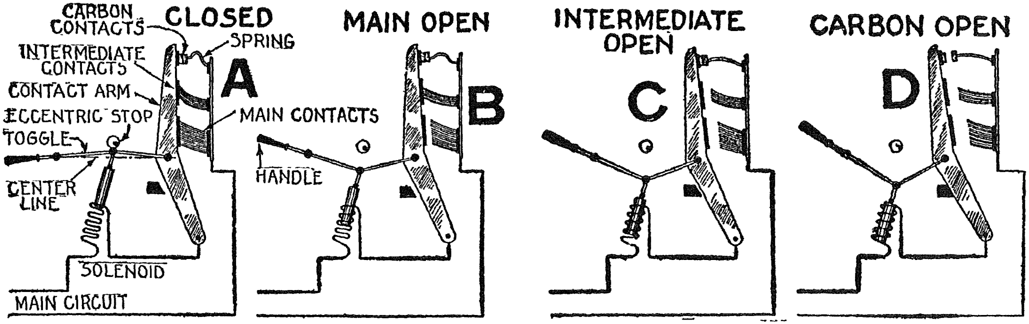
A circuit breaker, operated automatically or by hand should be used for interrupting heavy currents.

Circuit Breakers.—A circuit breaker is *a switch which is opened automatically when the current or the pressure exceeds or falls below a certain limit, or which can be tripped by hand.*

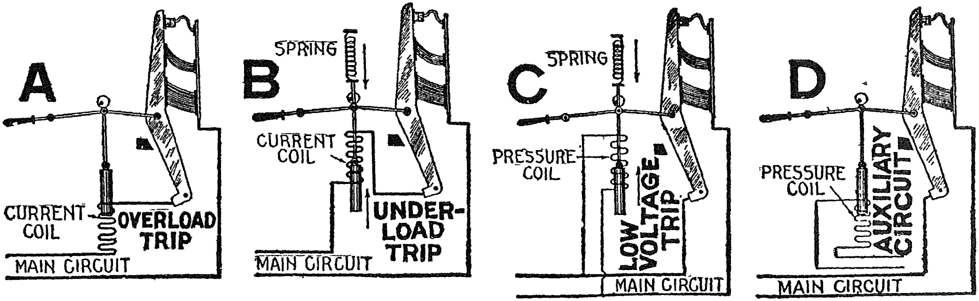
A circuit breaker consists of *a switch and a solenoid in the main circuit.*



Figs. 1,190 and 1,191.—Front and top views of I-T-E automatic overload circuit breaker. In fig. 1,190 the current in the circuit enters at A, passes through the solenoid coil B, (which in its iron jacket becomes a powerful magnet), through the copper terminal C, to the contact blades D, across the bridge at E, to the contact blades F, and out into the line at G. The path of the current as indicated above is more clearly indicated in the top view fig. 1,191. When the current in the solenoid coil produces sufficient magnetism to overcome the weight of the plunger, the latter is drawn up with constantly increasing velocity until it strikes a restraining latch or trigger which forces the arm out of the switch, thus automatically opening the circuit. The device is so constructed that in opening the circuit the arc is broken on the carbon contacts instead of the copper contacts.



Figs. 1,192 to 1,195.—Elementary diagrams illustrating the operation of a carbon circuit breaker of the overload type, showing the progressive opening of such device. Fig. 1,192, closed position; fig. 1,193, main contacts open; fig. 1,194, intermediate contacts open; fig. 1,195, carbon contacts open, circuit broken.



Figs. 1,196 to 1,199.—Elementary diagrams illustrating the various methods of electromagnetic control for circuit breakers. Fig. 1,196, overload trip; fig. 1,197, underload trip; fig. 1,198, low voltage trip; fig. 1,199, control from auxiliary circuit by means of a "relay."

When the current, flowing through the circuit, exceeds a certain value, the core of the solenoid is drawn in and trips a trigger which allows the switch to fly open under the action of a spring.

There are numerous kinds of circuit breaker to meet the varied conditions of service and they may be classified:

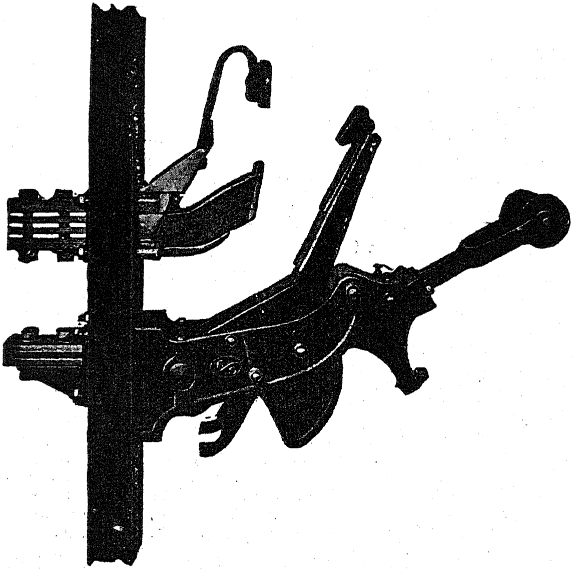
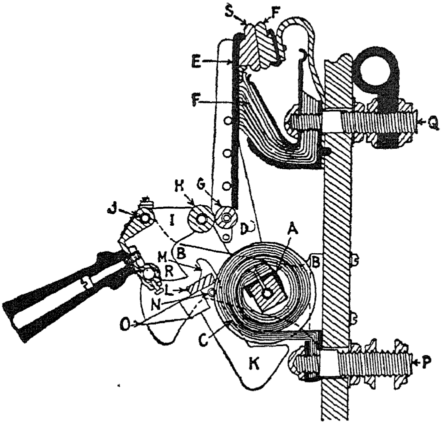


Fig. 1,200.—Roller-Smith, single pole, plain overload circuit breaker. As its name indicates, the function of the plain overload circuit breaker is to automatically interrupt the circuit in which it is placed when the flow of current through it exceeds the predetermined limit, for which the apparatus is set. It is the most common of all of the types and is utilized for the protection of dynamos and motors and all other electrical apparatus which, by reason of the conditions of operation, may become subject to loads in excess of the normal. The single pole type may be used separately for the protection of a single wire of a given circuit or grouped to protect the two or more wires of one circuit, becoming in the latter case the so called independent arm multiple apparatus. The action of this type of circuit breaker is fully explained in fig. 1,201.

1. With respect to kind of control

a. Maximum circuit breakers;



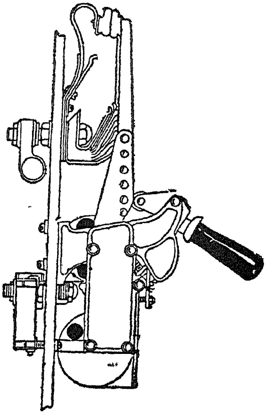


FIG. 1,201.—Roller-Smith "S.E." plain overload circuit braker. ***In operation,*** current entering through the lower studs flows through the laminated strap windings C, from this into the arm D, through the contact plate E, into the stationary brush F, and finally out through the upper stud Q. In its passage through the laminated windings C, the square core A, is of course magnetized to a degree dependent on the current strength. When this magnetization reaches a pre-determined value, the attraction exerted on the ends K, of the pivoted armature causes the same to rise with great and increasing velocity, finally bringing the finger D, which forms part of the armature into violent contact with the face R, of the corresponding projection on the housing which carries the handle and the roller H. This heavy blow causes H, in its rotation about the shaft J, to go over the center and consequently allows the strong outward pressure of the brush F, and the resilient coil C, to throw the arm outward with a high velocity and so break the circuit, first between the brush fingers and the contact plate and finally between the carbons S and F, the one of which is rigidly secured to the arm and the other of which is resiliently mounted on its supporting spring. To reset the breaker, the handle, which the act of opening has raised, is pulled down, thus bringing roller H, into engagement with roller G, once more and in that way forcing the arm back into its initial position.

FIG. 1,202.—Roller-Smith "S.E." combination overload and underload circuit breaker. Attached to the supporting frame is the extension, which is of non-magnetic material and carries a rectangular magnetic core around which there are wrapped laminated copper conductors. Hinged is a heavy cup shaped mass of magnetic material, and also hinged is a flat lever which bears against the extension, secured to the housing which carries the operating handle. The circuit through the breaker conveys the current around the windings of this underload coil and passes from it to the regular overload winding from which it pursues the same course and exercises the same function as in a plain overload breaker. The core being thus magnetized, the cup-shaped member is held in firm contact therewith and the lever hangs free. Should, however, the current fall below the minimum value, the under load armature is no longer sustained by the magnetic attraction but drops away, swinging on its hinge until the projection on the heel thereof strikes the lever which blow is transmitted to the handle and thus trips the breaker. When closing to reset the breaker, the handle,

b. Minimum circuit breakers.
c. Reverse current circuit breakers.
d. Maximum and reverse current circuit breakers.
e. No voltage circuit breakers.

Of these the maximum, reverse, and maximum and reverse current types are the more important.

A maximum circuit breaker is equivalent to a fuse, but has the advantage that it can be at once reset, whereas a fuse must be replaced.

A reverse breaker is used in connection with dynamos in parallel, to automatically cut out a machine if it take more than say, 10 per cent. motor current.

Maximum and reverse circuit breakers are frequently used on dynamo panels.

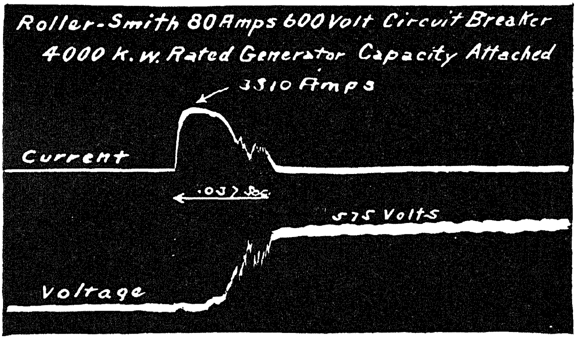


FIG. 1,203.—Oscillogram showing test of Roller-Smith 80 ampere standard type circuit breaker opening a circuit of 3310 amperes at 575 volts in .037 second.

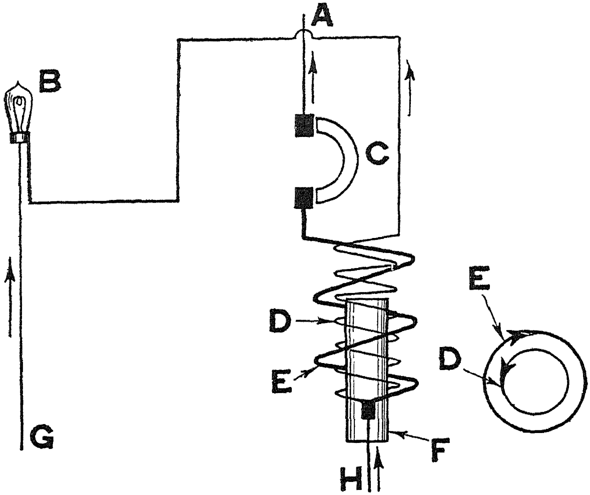
2. With respect to method of breaking the arc, as

a. Air circuit breakers;
b. Oil circuit breakers.

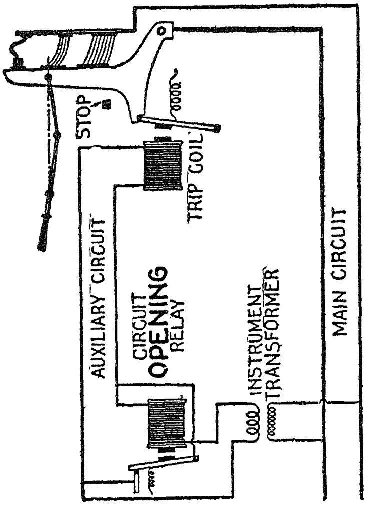
FIG. 1,202.—*Text continued.*
is manipulated just as in the case of a plain overload breaker, that is, it is pulled down, thus not only closing and locking the breaker as before but through the pressure exerted, putting the latter into contact with its rectangular core to which it will adhere if the necessary current be present.

Ques. Describe a reverse current circuit breaker or discriminating cut out.

Ans. This type of circuit breaker is arranged to open a circuit in the event of current flowing in the circuit in a direction reverse to the normal. This is sometimes effected by winding the electromagnet of the circuit breaker with two coils, one connected as a shunt across the main circuit and the other in series with the main circuit, the two coils being so arranged that when the main current flows in the normal direction their effects assist one another, whereas, when the main current reverses, the effects of the coils are neutralized and the breaker opens.



Figs. 1,204 and 1,205.—Reverse current circuit breaker; fig. 1,205, view looking at end of coils of cut out, showing direction of current. A, to + bus bar; B, resistance lamp; C, brush of cut out; D, shunt coil; E, series coil; F, core that trips cut out; G, to − bus bar; H, to + pole of dynamo.



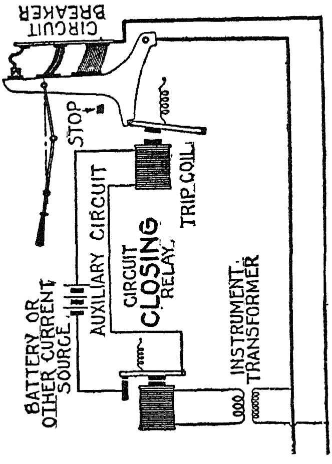
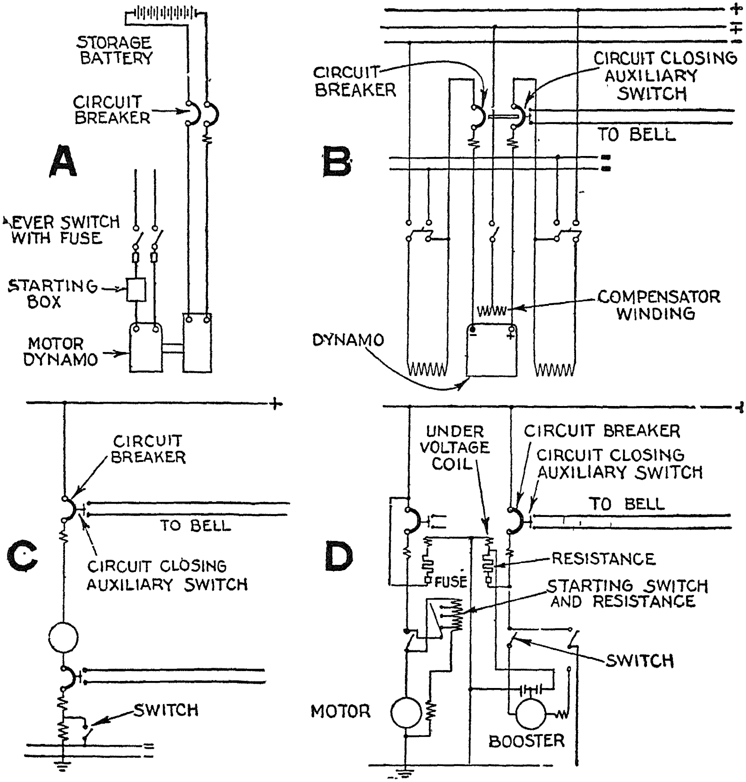


Fig. 1,206.—Diagram illustrating the operation of a *circuit closing relay*. When the predetermined abnormal condition is reached in the main circuit, the relay closes the auxiliary circuit, thus energizing the trip coil and opening the breaker.

Fig. 1,207.—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.

Ques. State some disadvantages of a discriminating cut out.

Ans. If one current reverse very rapidly, and soon reach a large value in the opposite direction, it is possible the cut out may not open at the desired instant, and thereafter the effect of the heavy reverse current will be so great that the breaker will be held in more and more strongly; a second disadvantage is that should the supply fail, the breaker will open in any case, and have to be reset before the supply can be resumed, though in certain cases, as, for instance where there is a motor load, this feature is an advantage and not a disadvantage, since the breaker acts as a no-voltage cut out as well as a reverse current cut out.

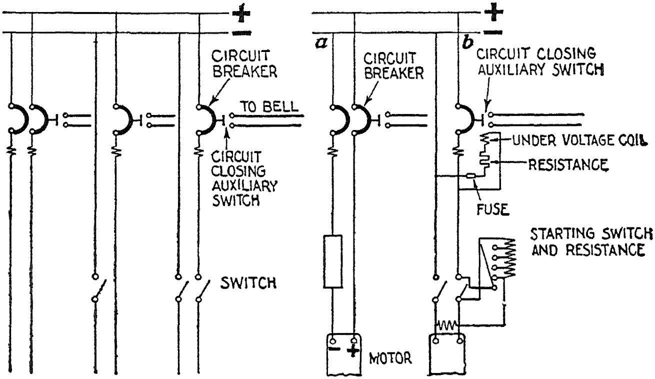


Figs. 1,208 to 1,211.—Common applications of air circuit breakers. **A**, storage battery and charging dynamo protected by double pole single coil under current breaker (breaker disconnects battery when fully charged). **B**, three wire dynamo protected by double pole double coil over current breaker with bell alarm switch (complete protection is secured as breaker is connected between armature and series field). **C**, engine driven railway dynamo protected by two single pole over current breakers with bell alarm switches. Either breaker takes care of over currents and external troubles. The breaker on negative side at the machine takes care of grounds not only in the dynamo but anywhere in the leads from positive breaker to machine armature. **D**, motor booster set (series wound booster) protected by two single pole over current breakers with under voltage device and bell alarm switches. The under voltage device on the motor circuit releases only in case of failure of bus voltage, but the device on the booster circuit releases on under voltage, also when the speed limit device operates because of over speeding of the machine.

Reverse breakers, however, can be made positive in their action; that is, they can be so arranged that a reverse current exerts a positive pull on the tripping gear, so that the greater the reverse current, the greater the tripping effect.

Ques. What are time limit attachments?

Ans. Devices which are fitted to circuit breakers and which act as dampers and prevent the too sudden operation of the breakers on what may be only a temporary overload or reverse current.



FIGS. 1,212 and 1,213.—Common applications of air circuit breakers. Fig. 1,212 two wire *d.c.* feeder circuits protected by over current breakers with bell alarm switches; fig. 1,213 *d.c.* motors protected by over current breakers with bell alarm switches; *a*, double pole single coil breaker, no switch required, under voltage device is on the starting rheostat; *b*, single pole breaker in series lever switch, under voltage device on the breaker.

By having different time limits on feeder and dynamo breakers it can be insured that the former operate before the latter, and suitably in other cases where it is desired that one breaker shall operate before another.

Ques. Describe a time limit attachment.

Ans. There are numerous types. It may consist of a clockwork device, a weight acting on a small drum or pulley, a

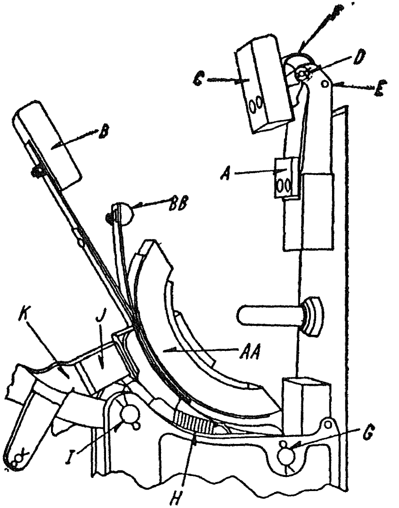


FIG. 1,214 —Westinghouse circuit breaker construction. 1, ***Parts:*** AA, main brush; BB, arcing tip; A, copper arcing plate; B, moving carbon; C, stationary carbon; D, pin; E, carbon holder; F, copper shunt; G, pivot rod; H, springs; I, phosphor-bronze pin; J, phosphor-bronze clip; K, projection on toggle mechanism for large breakers.

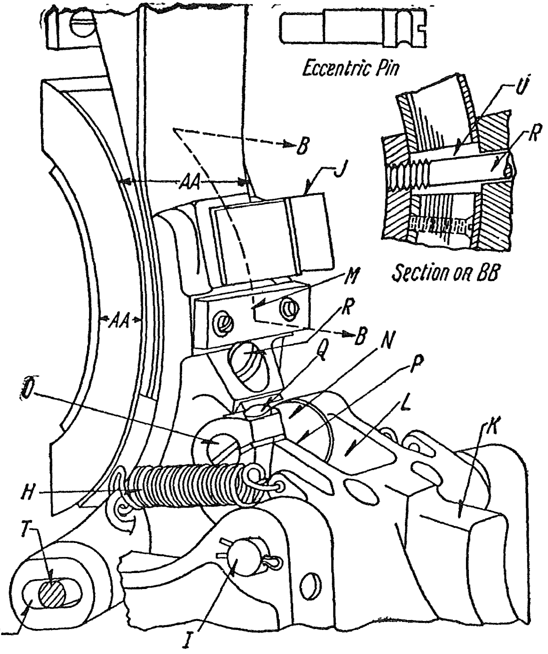
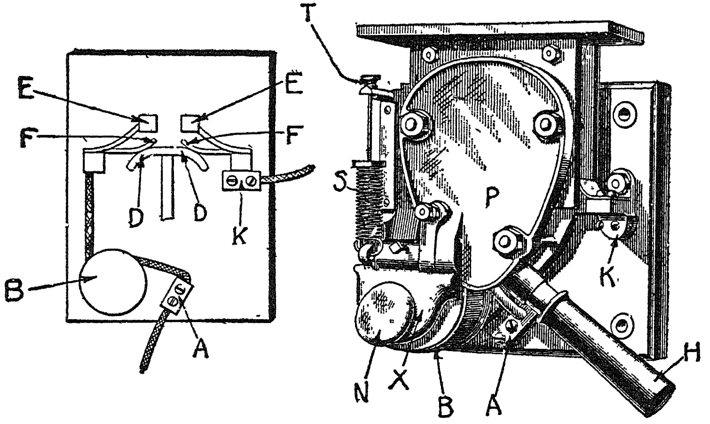


FIG. 1,215 —Westinghouse circuit breaker construction. 2, ***Parts:*** AA, main brush, width and thickness, H, springs; I, phosphor-bronze pin; J, phosphor-bronze clip; K, projection on toggle mechanism for large capacity breakers; L, clip opening for small capacity breakers; M, bumper; N, roller; O, eccentric pin; P, lever; Q, screw for tightening pin on lever; R, screw for fastening brush to carbon arm.

modified dash pot arrangement, or a device operating by the expansion of a conductor due to the heat generated by a current passing through it.

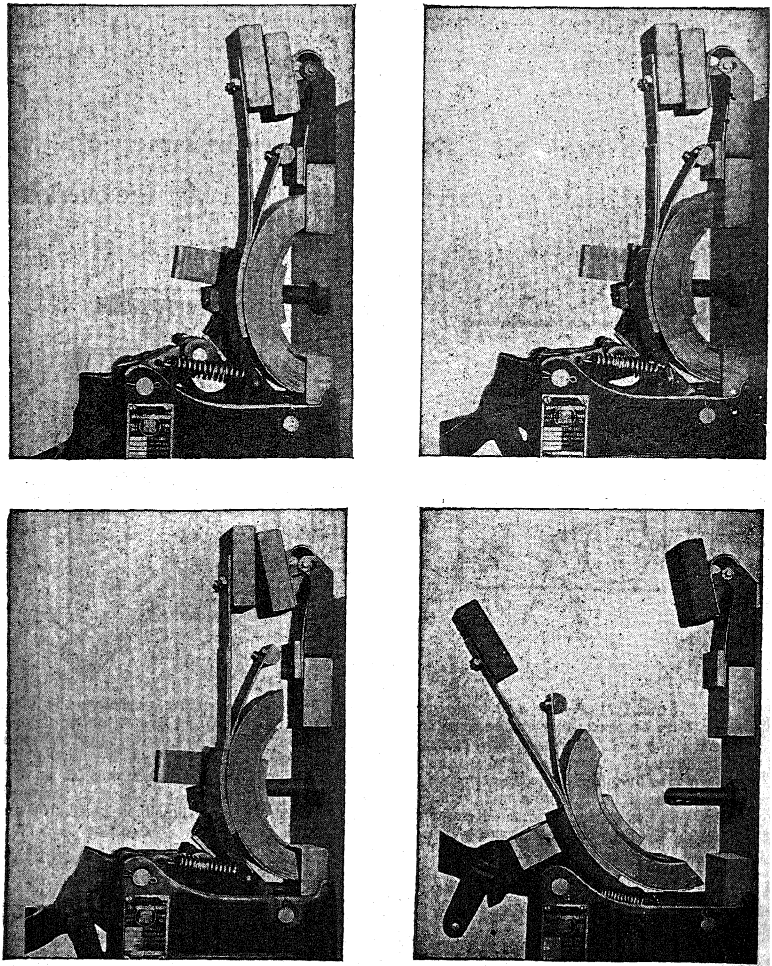
Ques. How should a time limit device be arranged?

Ans. It should be so arranged that the heavier the overload the quicker the device acts, until with a short circuit the device is almost instantaneous in its action.



Figs. 1,216 and 1,217.—*Magnetic blow out circuit breaker.* ***Its operation*** is based on the principle that a *conductor carrying a current in a magnetic field will tend to move in a direction at right angles to the field.* ***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 upward, 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.

Air Circuit Breakers.—By definition an air circuit breaker



FIGS. 1,218 to 1,221.—Moving picture of ***Westinghouse air circuit breaker.*** Fig. 1,218 breaker in closed position. This is the position of the breaker when ready to carry current. Details is a type of switch designed *to break the circuit in the open air or in an enclosed air space.*

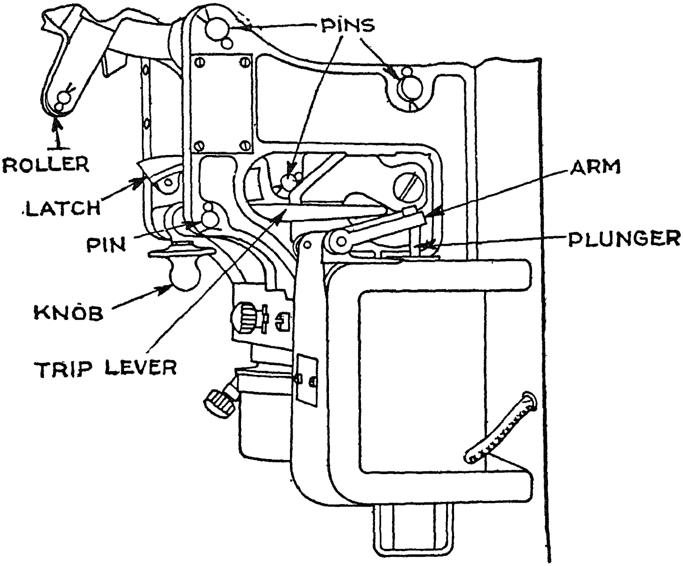
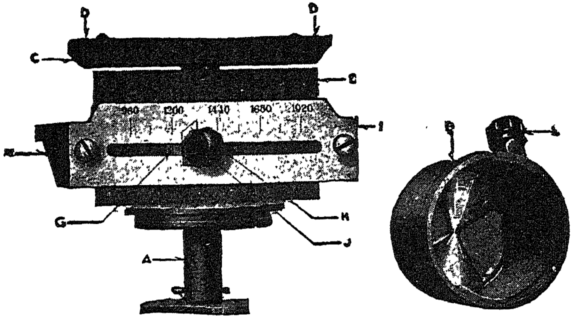


FIG. 1,222.—Westinghouse circuit breaker construction. 3, Detail of inverse time limit, and shunt trip attachments. ***In operation.*** When the shunt trip attachment operates, the plunger raises the arm which engages the trip lever and trips the breaker. The under voltage release attachment is added at the left hand side of the breaker in the same manner. To trip the breaker by hand it is necessary only to force the knob toward the breaker unit. This movement lifts the latching device and releases the toggle mechanism.

FIGS. 1,218 to 1,221.—*Text continued.*

of main, arcing and carbon contacts and the laminated form of main brush are clearly visible; fig. 1,219, as the overload causes the breaker to open the main contact moves from the upper contact block leaving a small gap; the heel of the brush leaves the lower block; the secondary arcing tip is in contact with the arcing plate; the carbons are in contact but due to lessened pressure, the pin has moved in its slot; fig. 1,220, the gap between the main brush and the contacts has widened considerably. The arcing tip is no longer in contact with the arcing plate, the toe of the lower end of the brush is still touching the contact block. The carbons are about to separate. The stationary contact has tilted about the pin; fig. 1,221, the breaker is here shown fully opened. The brush is entirely separated from the contact block. A flexible shunt at the lower end of the main contact prevents arcing.

The air circuit breaker is a simple piece of electrical apparatus. The straight over current type consists of one or more current carrying parts bridging across contact studs, and an electro-magnet so arranged that on the occurrence of a current greater than that which the breaker is "set" to guard against, the circuit is opened. By this arrangement, valuable electrical machinery is protected against the injurious effects caused by over current, short circuits or other abnormal conditions.



FIGS. 1,223 and 1,224.—Detail of inverse time limit attachment of Westinghouse circuit breaker. Parts: A, plunger; B, plunger cylinder or dashpot; C, moving magnet; D, moving magnet; E, metal plate; G, rectangular block; H, frame with slot for block G; I, scale plate; J, thumbscrew; K, pointer; L, thumbscrew. ***In construction*** the plunger is attached to a horizontal bar, which forms the overload armature. The stationary portion of the overload magnet is in the form of a yoke, and air gaps are formed between the two ends of this yoke and the ends of C, at D, and D. Guiding the plunger is a metal plate E, with a diagonal tongue which fits into the diagonal slot in the metal plate. The thumbscrew J, is threaded into the rectangular block. In moving the rectangular block to the left, by means of the thumbscrew, the metal plate and the moving magnet are raised, thus decreasing the length of the air gap between the armature and the magnet. A movement to the right reverses this operation. When the desired overload adjustment has been made, the rectangular block and pointer K, are clamped to opposite sides of the scale plate by the thumbscrew. With the knob at the left, the air gap is the shortest and therefore, the minimum calibration of 80% of the normal 30° rating of the breaker is obtained. The maximum air gap is secured with the knob at the right. This arrangement will require greater current to close the air gap, as it is the maximum point of calibration, namely, 160% of the normal 30° rating. The dashpot is of an adjustable type. The bottom of the plunger cylinder B, shows two raised and two depressed portions. At the end of the plunger is a plate. the bottom of which has two opposite quadrant surfaces that match the similar surfaces in the bottom of the plunger cylinder, when the device is set at 100% time limit. Adjustment for shorter time is obtained by rotating the plunger cylinder relative to the quadrant plate. A 90° rotation produces practically zero time limit. The time limit is approximately porportional to the area of the quadrant surfaces in contact with each other, in the oil, in the bottom of the pot. When the desired time limit in seconds is secured, thumbscrew L, is tightened and clamps the dashpot to the flange on the metal plate.

By variation of design, the breaker can be used to guard against momentary or continued over current, under voltage, high voltage, reverse current and numerous other conditions which may arise singly or in combination.

For satisfactory operation the circuit breaker should be so designed as to possess characteristics which make it suitable for the service requirements.

The preferable location for the air circuit breaker is at the top of the panel; otherwise placed, the automatic opening of the breaker might damage apparatus mounted above it; or cause the operator to be injured by being struck by the handle of the large capacity breakers or burnt by the arc. The top of the secondary contacts should project slightly above the panel. When this is not possible on circuits of over 300 volts *d. c.* (or 500 volts *a. c.*) arc deflectors should be used to prevent the panel being burnt by the arc.

Lightning Arresters.—These devices *are designed to provide paths by which lightning disturbances or other static discharges may pass to the earth.*

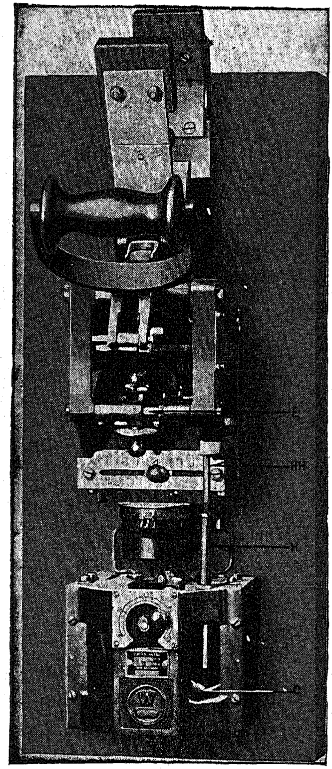


FIG. 1,225.—Westinghouse circuit breaker equipped with the reverse current attachment. Located directly above HH, is the plunger hole through which plunger H, operates. The reverse current attachment raises arm C, which action actuates the plunger and trips the breaker.

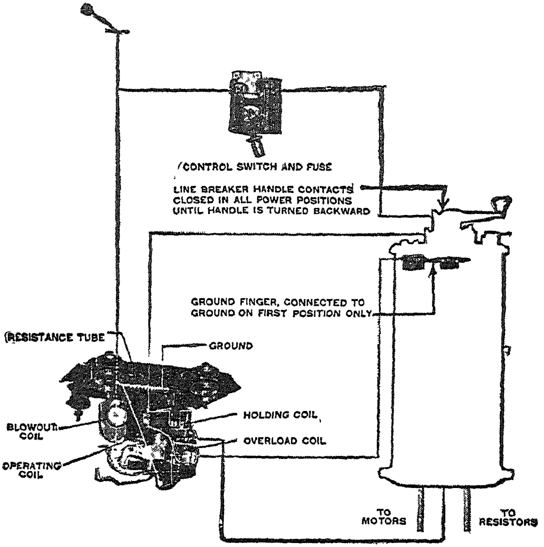


Fig. 1 226.—Connections of General Electric auxiliary apparatus for use with drum controllers. The line breaker used is of the magnetically operated type and is provided with contact tips, which may be easily renewed at small expense, when necessary. A powerful magnetic blowout coil with large arc chute insured the rupturing of the arc under all service conditions. The overload relay can be adjusted to open over a wide range of overload current. The compact line breaker permits its installation on cars having small wheels. Porcelain insulators are provided for insulating the box from the car body. The line breaker equipment may also be used with rheostatic braking controllers with slight modifications of the control handle. With a braking controller, the line breaker protects the motors in the power positions of the controller only; that is, accelerating and running. In the braking positions of the controller, the line breaker is made inoperative so that the motors may be used for braking, even though the power supply at the car be interrupted.

NOTE.—***Direct and remote control.*** With respect to location there are two methods of controlling motors: 1, ***direct*** or ***manual*** operation of the starting box or controller which controls the main motor circuits; 2, ***remote*** in which the operator handles only a push button or master switch carrying pilot circuits. The main motor circuits are handled by a device remote from the operator. Some remote starters or controllers are built to be operated pneumatically by means of switches closed by air operated mechanisms. Much more commonly the remote controllers are operated by means of electro-magnets or solenoids. These controllers are commonly called magnetic controllers.

In general, their construction comprises an assembly of air gaps, resistances, inductances and arc suppression devices. A lightning arrester must prevent excessive pressure differences between line and ground, and between conductor turns in the electrical apparatus.

An *air gap* is frequently used to form the necessary high resistance which must be interposed between the ground and the conductor. The resistance 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

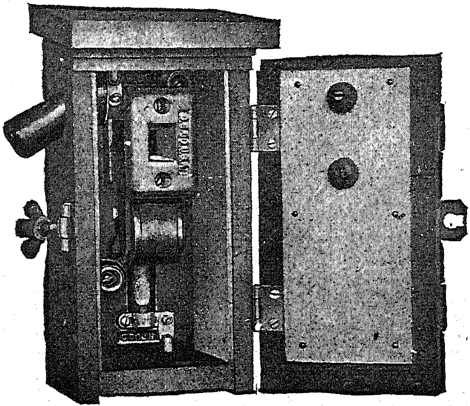


Fig. 1,227.—General Electric magnetic blow out arrester. ***It consists of*** an adjustable spark gap in series with a resistance. Part of the resistance is in shunt with a blowout coil, between the poles of which is the spark gap. The parts are mounted on a porcelain base. The spark gap is mounted on a small porcelain block which can be readily removed for inspection of the gap. This porcelain block also forms the arc chute and the magnetism of the field is always such as to forcibly blow the arc through the chute. ***In operation,*** when lightning induces a pressure on a line, thus putting an excess strain on the insulation, it causes the spark gap to break down, whereupon a discharge occurs through the gap and the resistance rod to ground. This current discharge lowers the lightning potential and thereby prevents damage to the insulation. Part of the current shunts through the blow out coil, producing across the spark gap a strong magnetic field which acts on the arc in the gap like a strong blast of air on an open flame; it blows out the arc and thus prevents the line current continuing to flow and causing a ground. The magnetic blow out acts immediately after the discharge and, hence, restores the arrester to its normal condition for taking care of a second discharge. The blow out coil is not in the main circuit, but merely shunts it. There is therefore, no danger of the coil being damaged by the lightning discharge. It is firmly fixed in position with the spark gap mounted between the poles of the magnet so that the arc is blown out of the arc chute.

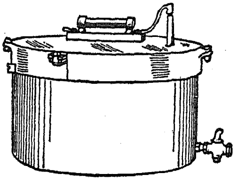


FIG. 1,128.—Westinghouse ***electrolytic station lightning arrester*** for direct current up to 1,500 volts consists of a tank of oil in which are placed, on properly insulated supports, a nest of cup shaped aluminum trays. The spaces between the trays are filled with electrolyte, a sufficient quantity 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 termperature appreciably. The immersed area of each tray is 100 square inches. The shape and the arrangement of the trays are such that any gases generated by the discharge can pass out readily without disturbing the electrolyte between the trays.

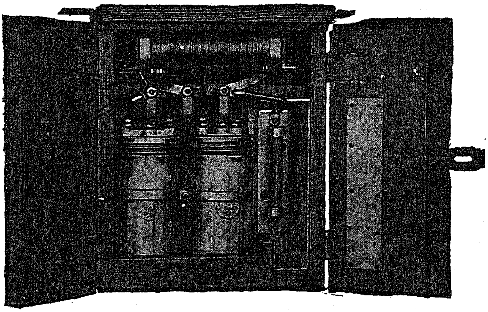


FIG. 1,129.—General Electric aluminum arrester for *d. c.* railway circuits. ***It consists of*** two or more aluminum plates on which has been formed by chemical and electro-chemical processes, a film of hydroxide of aluminum the plates being immersed in a suitable electrolyte. The 600 volt arrester consists of two of these cells in series; the aluminum is in the form of hollow concentric cylinders held in glass jars filled with electrolyte. The aluminum cylinders are supported rigidly from porcelain covers in such a way as to prevent short circuiting against one another through vibration. When this arrester is connected to a 600 volt circuit a small leakage current flows through the arrester keeping the film formed on the plates. If an excess voltage be suddenly put on the line, as from a lightning disturbance, the film opens, and a discharge current limited only by the internal resistance of the cells, which is very low, flows through the arrester to ground. No discharge current is caused to flow by the normal voltage of the line as this is prevented by the films which are kept formed to the normal voltage by the leakage current. It is only the voltage in excess of the normal that causes a discharge through the arrester, and the slightest rise over normal will produce a discharge. The action is very similar to that of a steam boiler safety valve by which steam is confined until the pressure rises to a certain value when the valve opens and the steam escapes freely until the pressure again drops to normal.

air gap arresters. There may be one gap or many in series, and the gap may be in air or in vacuum. Other methods are: electrolytic, magnetic blow out, choke coils, static interrupters, etc.

Switchboards.—A switchboard consists of a panel or series of panels or slate, marble, soapstone or brick tile erected in an electric plant for the purpose of mounting in a convenient group the instruments for controlling and distributing the current and safeguarding the system. Switchboards may be divided according to operation into two classes:

1. Direct control;
2. Remote control.

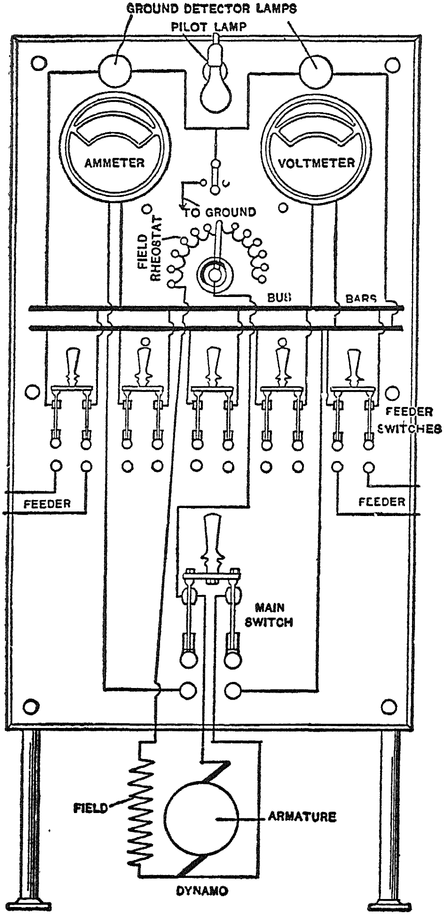
A direct control switchboard has all its apparatus mounted directly on the board and controlled by hand, while in the remote control type, the main current carrying parts are at some distance from the operating board, the control being effected by mechanical devices or by electric motors or solenoids.

When the control system of a plant is very extensive, it sometimes occupies a separate building known as the *switch house*.

Ques. What may be said with respect to the material for switchboards?

Ans. In order to avoid danger of fire from short circuits, the panel should be made of some non-combustible material, such as marble, slate, glass plates or earthenware tiles. If slate be used, care should be taken to have it free from conducting veins, or it should be marbleized, that is, subjected to a treatment that will fill up the pores of the veins and thus prevent the absorption of moisture.

Wood is seldom used, except in cases where the switches, fuse blocks, wire supports, etc., are all mounted on porcelain or other incombustible material.



Ques. How should the instruments and connections be arranged on a switchboard?

Ans. They should be arranged so as to provide the shortest possible path for the current, and preferably always in the same direction, that is, from right to left or from top to bottom, the connecting wires being brought in on one side and out on the other, and the crossing of wires avoided as far as possible.

All wires and current carrying parts should be kept far enough apart at all points to prevent accidental contact or the jumping across of the current where there is a great difference of voltage. Such wires should be also kept at a sufficient distance from screw heads, metal brackets, gas pipes, water pipes, and other conducting bodies, in order to prevent accidental grounds or short circuits.

Fig. 1,230,.—View showing general arrangement of a switchboard. The wires are shown to illustrate the various connections, but in actual construction these wires are connected on the back of the switchboard.

All instruments and switches should be placed so as to be conveniently accessible for observation and operation, and sufficiently out of reach of accidental contact by persons; otherwise they should be protected by some form of insulating shield.

Ques. What type of switch is used on switchboards?

Ans. The "knife" switch.

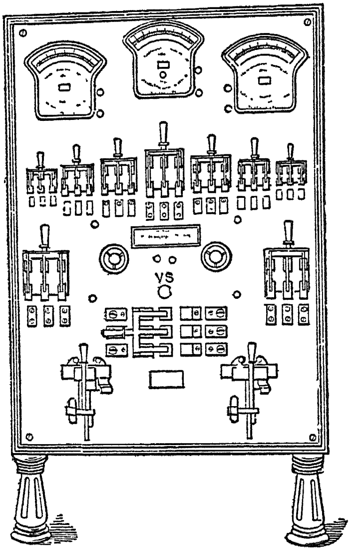


FIG. 1,231.—Small switchboard suitable for two dynamos; view showing ammeters and voltmeters, switches, circuit breakers, etc.

Ques. Describe a small switchboard.

Ans. Fig. 1,231 shows one suitable for two dynamos. At the top is a voltmeter and two ammeters. Immediately below is a row of feeder switches serving to connect and disconnect the various feeders with and from the bus bars which are mounted behind the board. Below are two rheostat hand wheels, and two large switches connecting the dynamos with the bus bars. V S, is a voltmeter switch connecting the voltmeter with various parts of the system. Below the voltmeter switch is a double throw switch to transfer the bus bars from connection with the dynamo switches to one with some other source of current such as a street circuit, in the event of a breakdown. At the bottom are two circuit breakers.

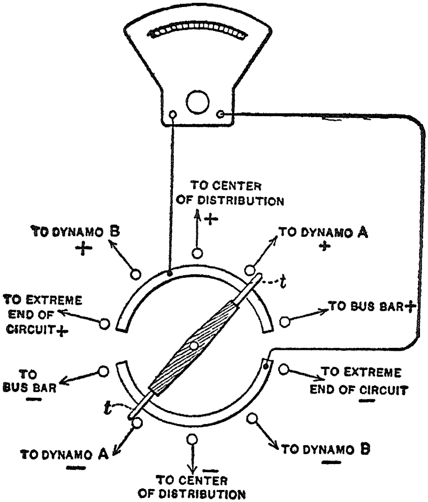


FIG. 1,232.—Diagram showing various connections of voltmeter switch of the small switchboard shown in fig. 1,231.

Ques. Describe the voltmeter switch.

Ans. Fig. 1,232 shows the connections, from which it can be seen that the voltmeter can be connected with the terminals of either dynamo or with the bus bars, or with either a central or remote part in the lamp circuits.

Under ordinary conditions it remains connected to the circuit at the central point of distribution. When one dynamo is already in circuit, however, and it becomes necessary to connect up the other one, the voltage of the latter must be the same as that at the bus bars. Accordingly, connections are provided to the voltmeter switch such that the attendant can compare the voltages at the dynamo terminals and bus bars before closing the dynamo switch. All the positive connections are on one side of the circle swept by the switch and all the negative connections on the other side.

Oil Circuit Breaker.—By definition an oil circuit breaker is *a type of switch in which the circuit is broken under oil.* This type of breaker is described in a later chapter.

Connection for Parallel Operation of Two Shunt-Wound D.C. Generators

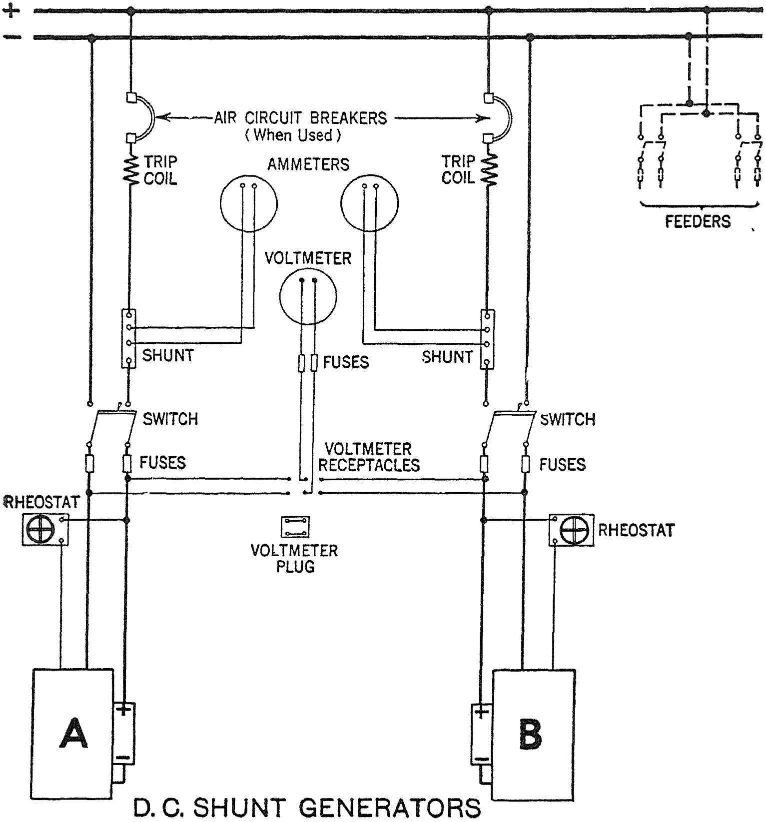


Fig. 1,232A.—Detail connection diagram for parallel operation of two shunt-wound generators. It is customary to employ only one voltmeter with the addition of receptacles and a plug as shown. Sometimes a rotary switch arrangement similar to that shown on page 866 is employed, in which case the receptacles and plug be omitted. The voltmeter may in either case be connected at will, to read the voltage across the terminals of any one of two or more generators. Occasionally voltage readings across the bus-bars (load) may be included in the voltmeter-switch arrangement. The method for operating the two generators in parallel are as follows: Assume that generator **B**, by means of its prime mover has been brought up to normal speed and is already connected to the bus-bars. Then with the switch and circuit breaker of **A** open, start the prime mover of **A**, and bring it up to speed. Now adjust the field rheostat of **A**, and note the voltmeter reading on this machine. Finally close the circuit breaker and switch of generator **A**.

Connection for Parallel Operation of Two Compound-Wound D.C. Generators

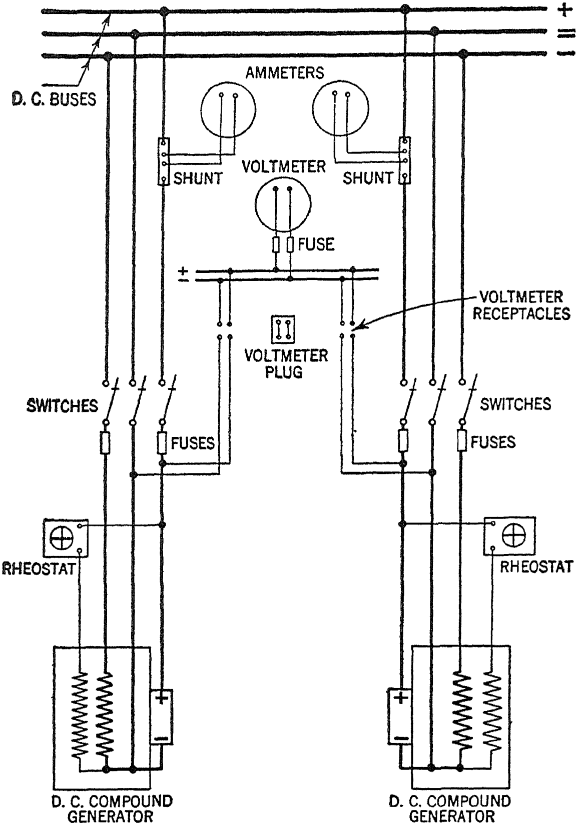


Fig. 1,232B.—Detail of connections for two compound generators in parallel. When two over-compounded generators are to be operated in parallel, it is necessary for a satisfactory division of loads, to parallel their respective series field. This is accomplished by connecting their negatives together as indicated, and this common connector is usually referred to as the *equalizer*. The instruments and switches shown are connected in the usual manner, which are similar to those used for connection of shunt generators in parallel, the only addition being the equalizer and connections thereto. It should, however, be noted, that the ammeter for each machine should be connected in the lead from the armature to the main bus, and not in the lead from the series field, because if the ammeter be placed in the latter it will read the series field current which may be quite different from the current supplied by the generator to the load connected to the buses.

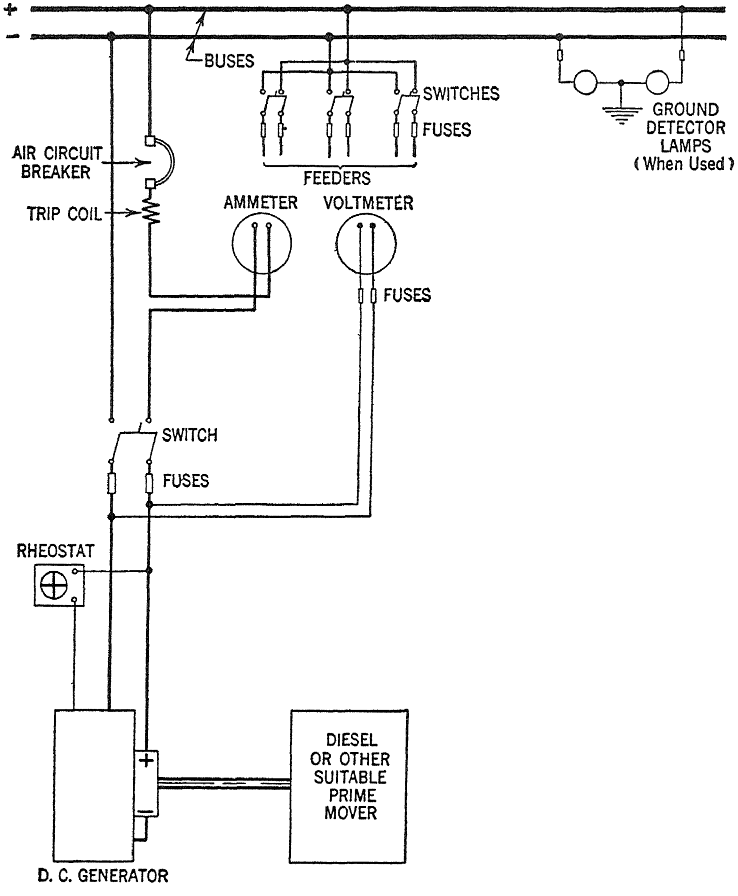


FIG. 1,232C.—Connection of a shunt wound direct current generator. The connections are largely self-explanatory, the voltmeter being connected across the main leads at the generator side of the double-pole knife switch. This will enable the operator to read the voltage of the machine at all times, regardless of the position of the main switches. The current indicator (ammeter) is connected in series with the positive lead connecting the machine to the load. The purpose of the over-load coil on the circuit breaker is to prevent the current from reaching dangerous proportions, that is, when the current exceeds the calibrated settings of the coil, the breaker trips, disconnecting the generator from its load.

Connection for D.C. Operated Solenoid Used for Control of D.C. Oil Circuit Breaker

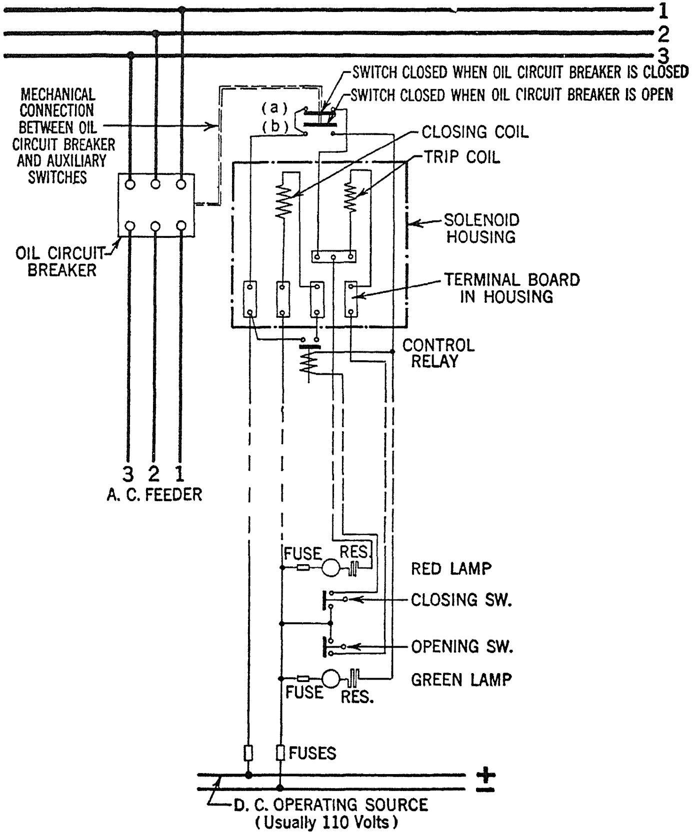


Fig. 1,232D.—Typical connection diagram for a remote controlled oil circuit breaker. In this method of operation, it is necessary, however, that an unfailing supply of direct current be available. The operation of the breaker is accomplished as follows: Assume the breaker is open and the condition for its closing has been established. When the main breaker is open, auxiliary switch marked (b) is closed, and the green lamp on the instrument board is lighted. When the closing switch is operated, the coil of the control relay. Whose contacts are normally open, becomes energized and closes its contact which in turn actuates the closing coil (which is mechanically connected with the breaker contacts) closing the breaker. This closing of the breaker simultaneously reverses the position of the auxiliary switches, opening the previously closed switch marked (b) and closes switch marked (a), which in turn extinguishes the green lamp and lights the red. The breaker may be opened in a similar manner by operating the lower of the two switches on the control board.

Electrolytic Generator with Polarity-Directional Protection

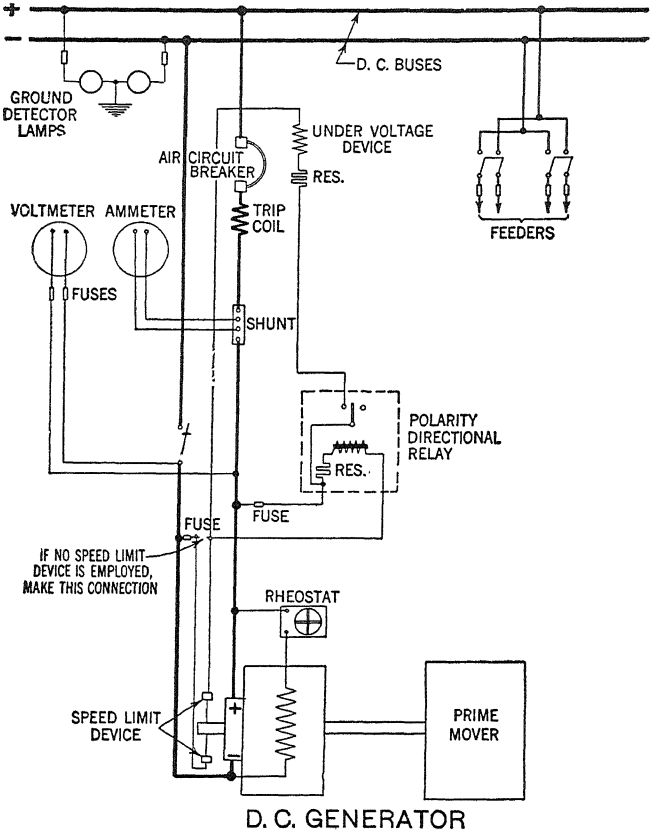


Fig. 1,232E.—Polarity directional protection such as that which may be used, where protection against sparks is of the utmost importance, for example, where hydrogen or other high explosive materials are manufactured. In such cases it is of the utmost importance that the polarity be not inverted, as the explosion resulting from such a condition might endanger both life and property. The polarity-directional relay consists essentially of a pair of stationary permanent magnets, a rotable soft iron armature pivoted within a stationary coil and a double throw set of contacts. The winding of the coil is of such direction that when potential is applied, connected with the proper polarity, the armature tends to rotate in a direction to keep the contacts closed to one side. A spring, in tension, tends to pull the armature back, open the closed contacts and close the contacts on the other side. When an invertion of the polarity occurs, the spring overcomes the action of the magnet which opens the circuit breaker.

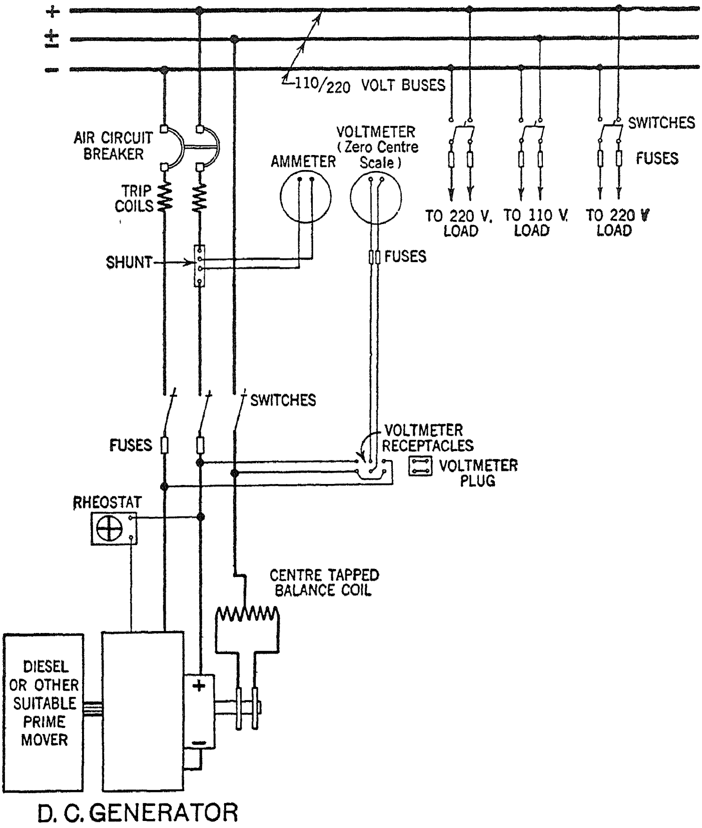
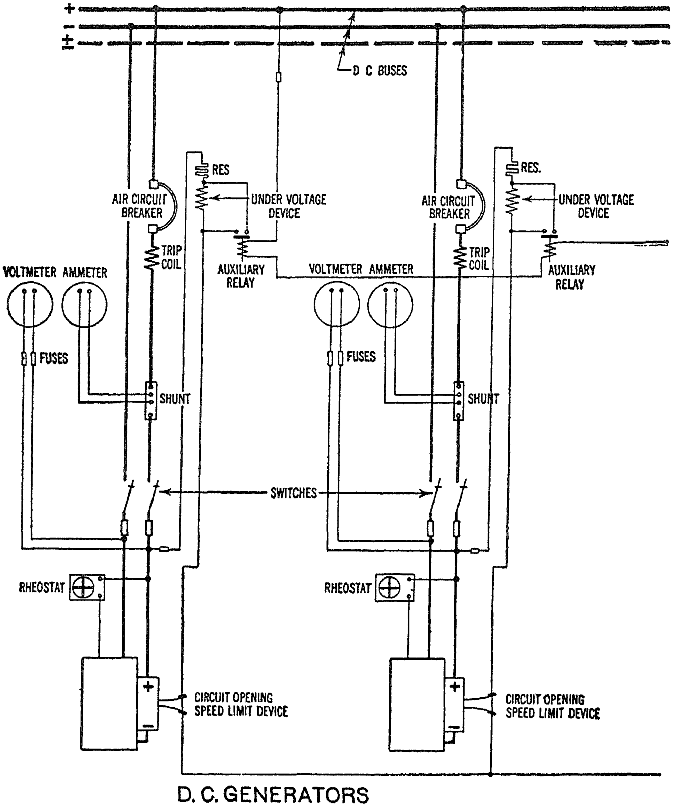
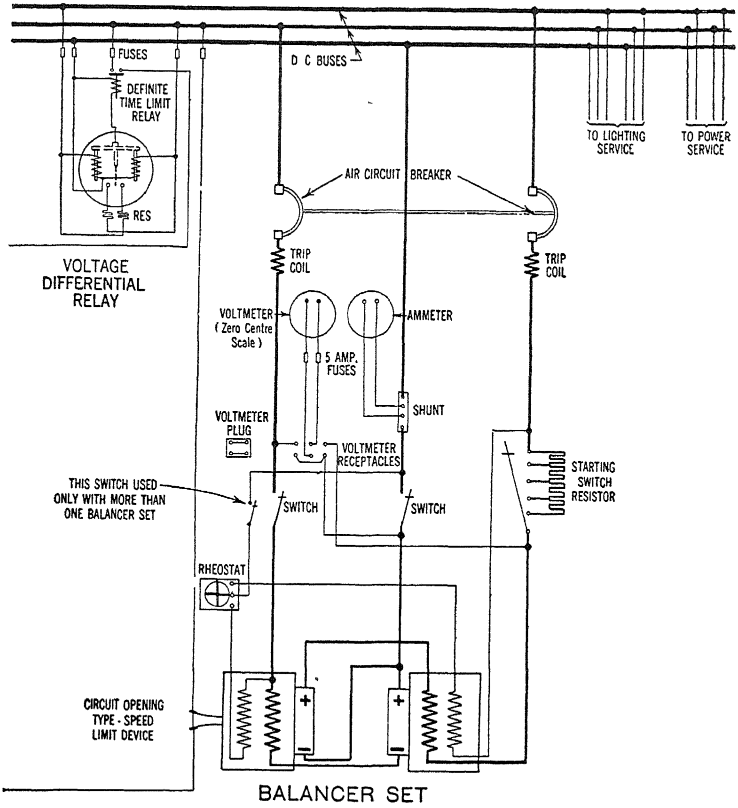


Fig. 1,232F.—The three-wire generator with external balance coil is often resorted to when it is desired to obtain a three-wire system with a minimum of rotating machinery. The third wire (sometimes misleadingly called *neutral*) is obtained as follows: To an ordinary generator designed to give a terminal voltage equal to that between the two main wires, are added two slip rings as shown; from these slip rings two leads are brought out and connected to armature points located 180 electrical degrees apart (this connection is not shown in the diagram). Collectors from the slip rings are connected from the two ends of the balance coil wound on an iron core, and the middle point of this coil is finally connected to the third wire. It should be observed that in a system of this kind it is necessary to balance the load between the two main wires and the wire leading from the balance coil as closely as possible. The amount of unbalance allowed for a properly designed system (usually specified by the manufacturers) should not exceed 10% approximately of the total current.



Figs. 1,232G and 1,232H.—Common method of obtaining three-wire service by means of a small motor-generator of identical size, usually identified as a balancer set. The additional wire or the so-called *neutral* is obtained and brought out from the common lead in the balancer set connecting the positive of one machine with the negative of the other. By the employment of a system of this kind, it is possible to establish better economy, in that the higher potential between the main generators, positive and negative leads can be utilized for power service. The amount of this saving in copper may best be understood by the fact that the weight of the conductors (and therefore the cost) required to transmit a given amount of power at a given efficiency is inversely proportional to the square of the line voltage. When establishing such a system, however, it is necessary to employ some protective scheme to guard against the unbalance of voltage in case the balancer set should become disconnected. The voltage differential relay shown, will protect against unbalanced voltage, and as this relay is practically instantaneous in action, and to protect against false operation, therefore, upon transitory disturbances, definite time limit relays are utilized in the contact circuits.



Figs. 1,232G and 1,232H.—*continued.*

The voltage differential relay functions principally as follows: The relay consists essentially of a pair of solenoids of equal characteristics, and each with a plunger core connected to a balanced lever which actuates the contacts. One winding is connected across one circuit and the other winding across the other circuit of the two circuits to be differentially protected. As long as the voltages are equal, the balance lever is in equilibrium and the contacts remains open. When for any reason the voltage becomes unequal, the unequal pull of the two solenoids tends to close the contacts and when this difference in voltage reaches the value at which the relay is calibrated, the contacts close instantaneously energizing the definite time limit and auxiliary relays which in turn shorts the coil of undervoltage device on the circuit breakers, tripping the breakers and disconnects the generators from the buses.

TEST QUESTIONS

1. *Mention some devices used in connection with dynamos and motors.*
2. *What is the difference between a single and double pole switch?*
3. *What is the difference between a single break and a double break switch?*
4. *When should a knife switch be used?*
5. *How should switches be proportioned?*
6. *What difficulty is experienced in opening a circuit in which a heavy current is flowing?*
7. *For what service are "snap" switches suitable?*
8. *What is a quick break switch?*
9. *What are fuses used for?*
10. *Where should fuses be placed?*
11. *Upon what does the choice between switches and circuit breakers depend?*
12. *Define a circuit breaker.*
13. *What are the various types of circuit breaker used?*
14. *Describe a reverse current circuit breaker or discriminating cut out.*
15. *What are time limit attachments?*
16. *How should a time limit device be arranged?*
17. *Describe the various trips.*
18. *Name some types of lightning arrester used on d. c. lines.*
19. *Describe a magnetic blow out.*
20. *What kind of material is used for switchboards?*
21. *How should the instruments and connections be arranged on a switchboard?*
22. *Describe a small switchboard.*

CHAPTER 36

Installation of Electrical Machinery

General Conditions Governing Selection.—In any particular case, the voltage, current capacity, and type of dynamo selected will depend upon the system of transmission or distribution to which it is to be connected, and the character of the work which it is required to perform. The suitability of the different types of dynamo for various kinds of work has already been considered to some extent, but there are certain general conditions which are applicable to almost all cases, such as:

1. Construction;
2. Operation;
3. Form;
4. Cost;
5. Number and size of units.

Construction.—This should be as *simple* as possible and of the most solid character. All parts should be interchangeable, and have a good finish.

All machines should be provided with eye bolts or other means by which they can be lifted or moved, as a whole or in parts, easily and without injury. These features are so carefully attended to and guaranteed by the manufacturers as to leave little choice in this direction.

Operation.—The considerations relating to the operation of a machine involve an examination of the details of its construction, in order to determine the amount of attention it will require, the character of its regulating device, its *capacity*, *form*, and *weight*.

Ques. What may be said regarding capacity?

Ans. Dynamos and motors should not be overloaded, because the efficiency is greater when the working load does not exceed the rated capacity of the machine.

Form.—As a rule, there is not much choice in the matter of form between standard machines, as they are uniformly symmetrical, well proportioned and compact. It is a mistake however, to select a light machine for stationary use, as the weight of a machine increases its strength, stability and durability.

Cost.—In some cases, the matter of first cost is important and deserves careful consideration. It should be remembered, however, that high grade electric machinery cannot be built out of low grade materials and with poor workmen; therefore, when necessity compels the selection of a cheap machine, it should not be expected that its service will be as satisfactory as that of a first class machine.

Number and Size of Units.—The best number and size of units for an electrical plant are usually governed by the requirements of the driving engines. As a rule, dynamos and motors are not much less efficient at quarter load than at full load, and the smaller dynamos are fully equal to the larger machines in this respect, therefore, a generating plant can be subdivided, and if so desired, without any detrimental results except those due to a multiplicity of units.

Ques. What is the important consideration with respect to efficiency?

Ans. Efficiency at maximum load is not so important as efficiency at average load.

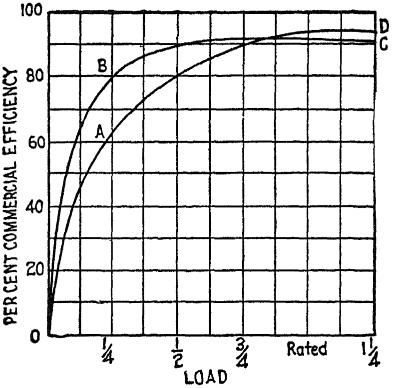


FIG. 1,233.—Efficiency curves for 110 K. W. dynamos. *The efficiency* of a dynamo at maximum load is not so important as at average load. For instance, if in the figure the curve OBC, represents the efficiency of a 110 K. W. dynamo and OAD, that of another machine, it would be in accordance with common practice to compare them at rated load, at which the efficiency of the first is only 91%, while the other is 93%. The first machine, however, is far better than the second, since its average efficiency is much higher, being nearly 91% between half load and 25% overload. It should be noted that full load is a limit which should be but occasionally reached, and then only for short periods of time.

For instance, in the diagram, fig. 1,233 the rated efficiency of one dynamo as shown by the curve A, is 93 per cent., and that of another, as shown by curve B, is 91 per cent., but it will be observed that the average efficiency of B, is much higher, being 75 per cent. at quarter-load, 89 per cent. at half-load, and 91 per cent. at three-quarter load, to 55, 77 and

89 per cent. of A, at the corresponding loads. In this case, A, is higher than B, only at full load, and as full load is a limit which should not be reached except in special cases, and then only for short intervals of time, the service rendered by B, would be much more satisfactory in the long run. In order to avoid the difficulties possible under these conditions, a guarantee to carry 25 per cent. overload for two hours without injury should be required, and either this or the rated load be taken as the full load, so as to give a factor of safety of 25 per cent.

Ques. Upon what does the choice of field winding of a dynamo depend?

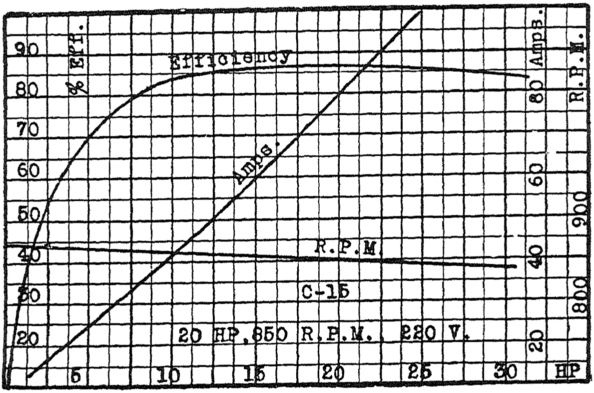


Fig. 1,234—Performance curves of a 20 H.P. motor, showing efficiency, speed regulation, and amperes input.

Ans. The series dynamo is used where a constant current at variable voltage is desired. A shunt dynamo is used on constant voltage circuits, where the distance from the machine to the load is not great, that is, where there is small line loss. With a compound dynamo there is compensation for line loss, that is, it can be constructed so that the voltage at its terminals, or at the load can be maintained constant or allowed to increase or decrease with a change in load.

It can thus operate lamps at constant voltage though they be located at some distance, or the voltage at the end of the line can be made to increase with an increase of load, as is frequently the case in railway work.

Ques. For what conditions of service are series motors adapted?

Ans. They are used on constant current circuits, and also on constant voltage circuits as in railway work and similar purposes where an attendant is always at hand to regulate the speed.

Ques. Name some advantages and disadvantages of series motors.

Ans. They are easily started even under heavy loads, the winding is cheaper than the other types and the speed is nearer constant than shunt motors when operated on constant current circuits. When used on constant pressure circuits, such as is employed for incandescent lighting, the speed will depend on the load.

Ques. What kind of circuit is suitable for shunt motors?

Ans. Constant voltage circuits.

Ques. What are the advantages of shunt motors?

Ans. The speed remains nearly constant for variable load.

Ques. State the disadvantages.

Ans. They start less easily under a heavy load than do series motors, and the speed cannot be varied through any wide range without considerable loss. The shunt motor requires more attention than the series type and is more liable to burn out.

Location.—The place chosen for the dynamo or motor should be dry, free from dust, and preferably where a cool current of air can be had. It should allow sufficient room for a belt of proper length when a belt drive is used.

Foundations.—It is most important to secure a good foundation for every dynamo, and great care should be taken to have them entirely separate from those of the walls of the building in which the machine is installed, and if the dynamo be directly driven, but not on the same bed plate as the engine, a foundation large enough for both together should be laid down.

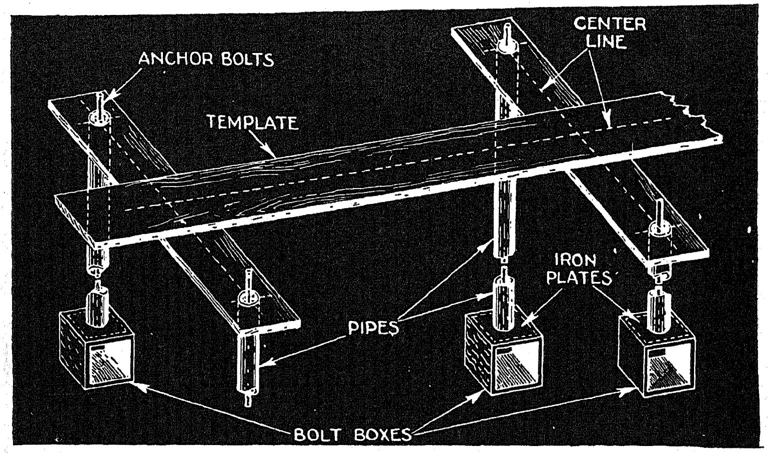


Fig. 1,235.—View showing part of template for locating anchor bolt centers, pipes through which the bolts pass and bolt boxes at lower end of bolts. The completed foundation is shown in fig. 1,236, with template removed. The template is made of plain boards upon which the center lines are drawn, and bolt center located. Holes are bored at the bolt centers to permit insertion of the pipes as shown.

Stone or concrete may be used, or brick built with cement, having a large thick stone bedded at the top.

For small machines the holding down bolts may be set with lead or sulphur in holes in the stone top, but for large machines the bolts should be long enough to pass down to the bottom, where they should be anchored with iron plates.

Setting up of Dynamos and Motors.—In unpacking the machines care should be taken to avoid injury to any part, and in putting the parts together, each part should be carefully cleaned, and all the parts put together in exactly the right way. The shafts, bearings, magnetic joints, and electrical connections should receive special attention and be thoroughly cleaned of every particle of dirt, grit, dust, metal clippings, etc.

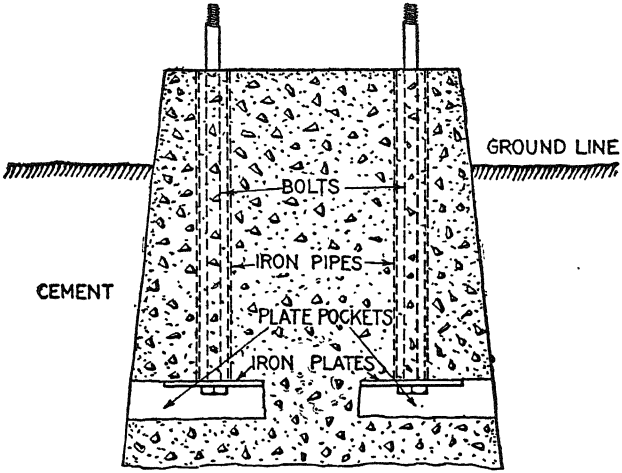


FIG. 1,236.—Concrete foundation, showing method of installing the anchor bolts.

The improper leveling of machines is a common cause of heating. so when machines are installed great care should be taken that base of machine sets level on its foundation.

After a machine has been erected it should be leveled with a high grade spirit level, and care should be taken that end play should be removed.

End play can be easily located by the unusual amount of noise created by the armature hitting the lower bearing.

If the pole pieces be not set evenly around the frame, it will cause end thrust, due to the magnetic pull, the armature being "sucked" into the field because it extends beyond the field poles further at one end than the other.

Ques. Who should preferably assemble the machines?

Ans. Whenever possible, they should be assembled by someone thoroughly familiar with the construction; but if the services of such a person cannot be had, no one should attempt to put a machine together unless he has a drawing or photograph of the same for a general guide.

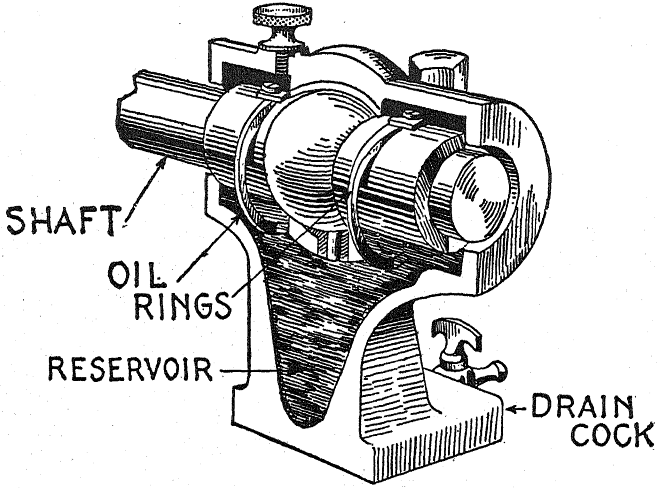


Fig. 1,237.—Sectiona lview showing a ring oiler or self-oiling bearing. As shown the pedestal or bearing standard is cored out to form a reservoir for the oil. The rings are in rolling contact with the shaft, and dip at their lower part into the oil. In operation, oil is brought up by the rings which revolve because of the frictional contacts with the shaft. The oil is in this way brought up to the top of the bearing and distributed along the shaft gradually descending by gravity to the reservoir, being thus used over and over. A drain cock is provided in the base so that the oil may be periodically removed from the reservoir and strained to remove the accumulation of foreign matter. This should be frequently done to minimize the wear of the bearing.

Ques. What precaution should be taken with the armature?

Ans. It should be handled carefully to avoid any injury to the wires of the winding and their insulation.

If it become necessary to lay the armature on the ground it should be laid on clean paper or cloth, but it is better to support it by the shaft on

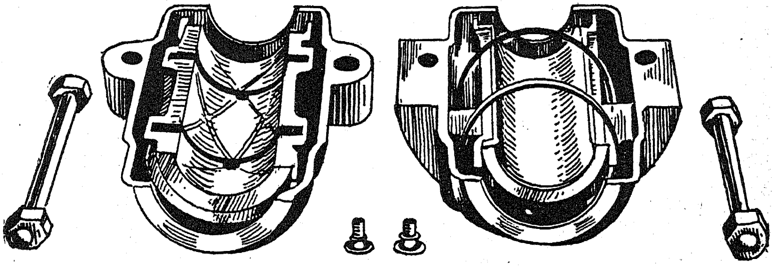


FIG. 1,238 to 1,243.—Self-oiling, self-aligning, bearing open. View showing oil grooves, rings, bolts, etc.

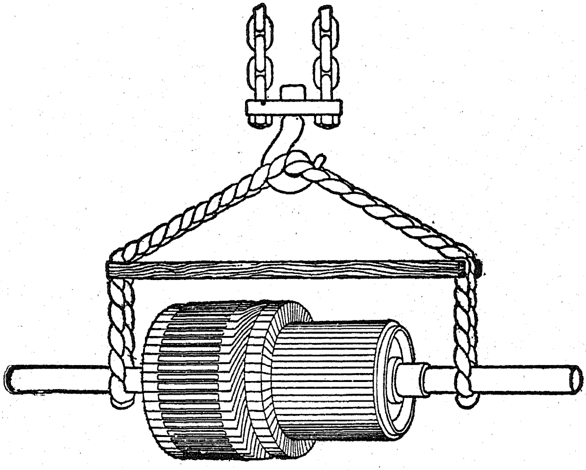


FIG. 1,244.—Sling for handling armatures. In raising an armature it should be supported by the shaft to avoid any strain on the armature body or commutator.

two wooden horses or other supports, and thus avoid any strain on the armature body or commutator.

Connecting Up Dynamos.—The manner in which the connections of the field magnet coils, brushes, and terminals, are connected to one another depends entirely upon the type of machine.

The field magnet shunt coils of shunt and compound wound dynamos are invariably arranged in series with one another, and then connected as a shunt to the brushes or terminals of the machine.

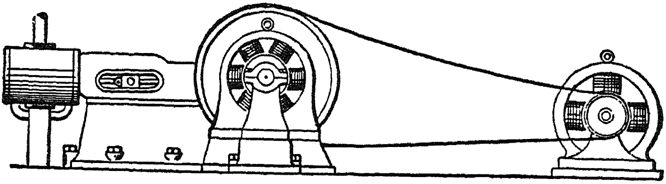


Fig. 1,245.—Comparison of space occupied by direct and belt connected dynamos. In office buildings space is of value and the room required by belt connected dynamos can always be put to profitable use. For this reason the direct connected unit has become generally adopted in the best type of office buildings. In large factories the direct connected unit is generally adopted also to save space. Where these conditions do not obtain, belted type of dynamo can be used to advantage, as a given output can be obtained with a smaller size machine than where it is direct connected to the engine. This is due to the limited rotative speeds at which engines can be run. The illustration shows the relative space required by the two types.

The series coils of series and compound wound machines are arranged either in series or in parallel with one another, according to conditions of operation, and then connected in series to the armature and external circuit.

Coupling Up Field Magnet Coils.—In coupling up the coils of either salient or consequent pole field magnets, assume each of the pole pieces to have a certain polarity (in bipolar dynamos two poles only, a north and south pole respectively, are required; in multipolar dynamos the poles must be arranged in alternate order around the armature, the number of

N and S poles being equal), then apply Fleming's rule as given in figs. 330 and 331, to each of the coils, and ascertain the direction in which the magnetizing current must flow in each in order to produce the assumed polarity in each of the pole pieces. Having marked these directions on the coils, they can

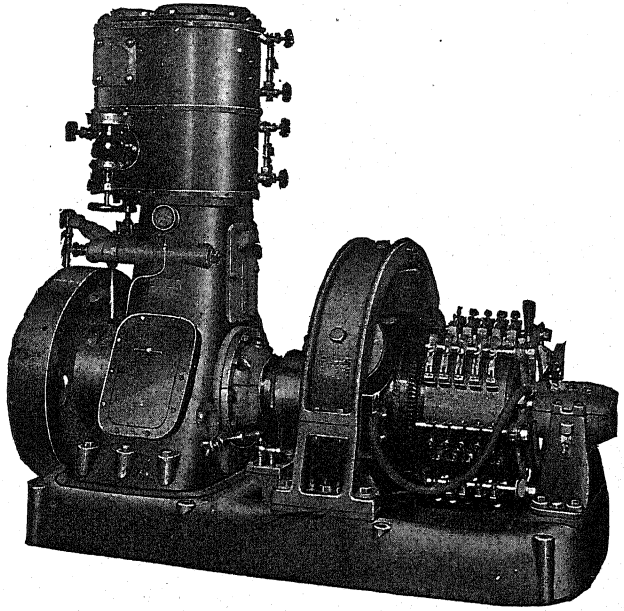


FIG. 1,246.—General Electric type M P, marine generating set with tandem compound engine. The requirements of such units are compactness, light weight, simplicity, freedom from vibration and noise at high speed, perfect regulation and durability. By adopting a short stroke for the engines and a special armature winding for the dynamo, the height and length of the sets have been reduced. The bed is carried out to the full width of the dynamo frame, making an ample base surface for foundation without increasing the floor space required. While the construction gives a massive appearance, the bed has been cored out and the various parts so designed that the complete sets have an approximate capacity of 3½ watts per pound. All of the moving parts are enclosed by the engine column, excluding dust and reducing wear and attention to a minimum. The bearings are oiled automatically under pressure. These sets are made in sizes from 25 K. W. to 75 K. W., the cylinder dimensions for the smallest size being 6½ and 10½ by 5, and for the largest size 10½ and 18 by 8. Single cylinder sets are made in sizes ranging from 2½ K. W. to 50 K. W., the cylinder dimensions ranging from 3½ x 3 to 12 x 11.

be coupled up in either series or parallel connection according to requirements, so that the current flows in the proper direction in each.

The Drive.—Various means are employed to connect the engine or other prime mover with the dynamo, or the motor with the machinery to driver. Among these may be mentioned the following:

1. Direct drive;

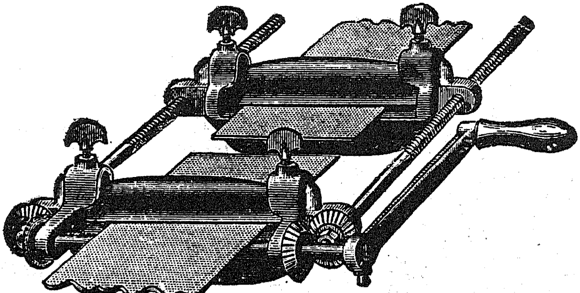


FIG. 1,247.—Belt clamp for stretching belt and holding the ends while making joint. It consists of a *stretching frame*, the two ends of which are coupled by screwed bars; used for pulling the ends of a belt together with the proper tension, when lacing or joining the ends.

2. Belt drive;
3. Rope drive;
4. Gear drive;
5. Friction drive.

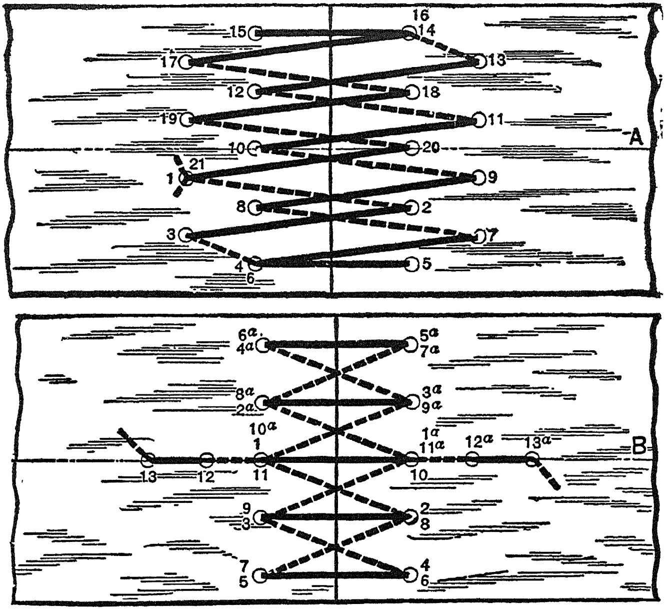
Ques. What is a direct drive?

Ans. One in which the driving member is connected direct to the driven member, without any interposed gearing.

Fig. 1,246 shows a direct connected unit, which is an example of direct drive.

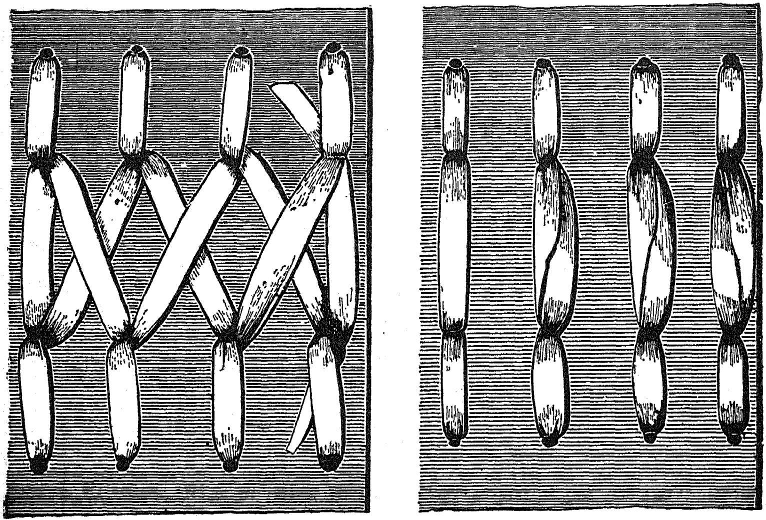
Ques. What may be said with respect to direct drive?

Ans. It is the simplest method and the space required is less than with belt drive. With direct drive the engine and dynamo must run at the same speed; this is a disadvantage because the most desirable speeds of the two machines may not agree.



FIGS. 1,248 and 1,249.—Two methods of lacing a belt. In fig. 1,248 two rows of oval holes should be made with a punch, as indicated. The nearest hole should be ¾ inch from the side, and the first row ⅞ inch from the end, and the second row 1¾ inches from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing (a strong, pliable strip of leather) should be used, beginning at hole No. 1, and passing consecutively through all the holes as numbered. In fig. 1,249 the holes are all made in a row. This method has the advantage of making the lacing lie parallel with the motion on the pulley side. The lacing is doubled to find its middle, and the two ends are passed through the two holes marked "1," and "1*a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes in the order in which they are numbered, 2,3,4, etc., and 2*a*, 3*a*,4*a*, etc., finishing at 13, and 13*a*, which are additional holes for fastening the ends of the lacer.

Since the usual engine speeds are slower than dynamo speeds, direct drive involves the use of a larger dynamo for a given output than would be necessary with belt connection, and involves a corresponding increase



FIGS. 1,250 and 1,251.—A good method of lacing a 4 in. belt. Fig. 1,250 outside; fig. 1,251, inside. ***The lacing used*** is 5/16 inch oil tanned leather, and the first row of holes is punched 1″ from the end of the belt, the second row 1⅛″ back of these, while the holes on the side are ⅜″ from the edge. The number of holes across are equal to the number of inches in the width of belt. ***In lacing,*** commence to lace from the side of the belt, the ends being passed from the inside, each end is then passed through the hole in the opposite end of the belt, making two thicknesses of lacing on the inner side. Each lacing end is then passed through the hole in the back row and again through the same hole as before in the first row, thus filling the four holes at the side and leaving the lacing straight with the length of the belt. Both ends of the lacing now being on the inside of the belt, they must be put through the second hole in the first row on the opposite end, thus causing the lacing to cross on the back or inside of the belt. The ends are now put through these same holes again, opposite end through opposite hole, making two strands of lacing between this set of holes on the face side, the strands being straight with the length of the belt. The ends again being on the back of the belt are now to be put through the second row of holes and again through the corresponding holes in the first row, which brings the ends again to the back side of the belt ready to be crossed as they are put through the next set of holes, and so on until all the holes are filled. This makes a lacing double on the outside and smooth single strands crossing on the back and a straight pull on each strand on the face as it is passed through each of the four holes in line. As the lacing is drawn through each of the four holes, the ends will be found securely fastened, and will bear a strand or two being cut. It is necessary to use pliers to draw the laces through the holes.

in cost and greater friction loss due to the rotation of larger and heavier parts.

Ques. Mention some of the features of belt drive.

Ans. Greater flexibility in the original design of a plant is possible and new arrangements of old apparatus can be made at any time. It gives conveniently any desired speed ratio and permits the use of high speed dynamos and motors.

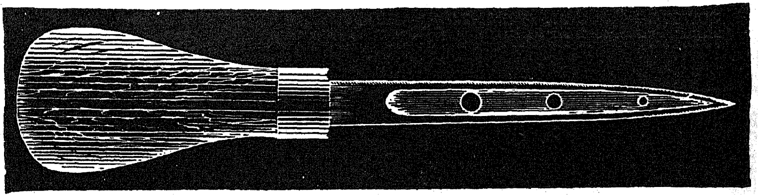
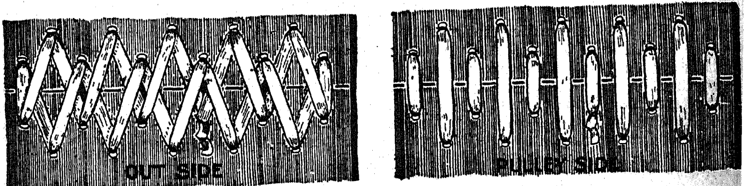


FIG. 1,252.—Belt awl. With this awl no punch is required for single belting. It is, however, advisable to use a small drive punch with double or rubber belts **In using,** the awl is thrust through from either side, until the first, second or third hole (according to the size of lace demanded) is visible on the opposite side of the belt. The end of the lace is inserted, *from the point of the awl,* through this hole; in pulling the awl back, the lace is drawn through the belt. ***In making butt joints,*** the holes should be one inch apart, and about five-eighths of an inch from the edges of the belt. If placed zig-zag, each row of holes across the belt should be half an inch behind the next. ***The groove*** in the awl is provided with one cutting edge, so that, twisting it to the right, it will cut the hole, but on turning it to the left, the hole in the belt is simply expanded without cutting.



FIGS. 1,253 and 1,254.—A simple and reliable method of lacing a belt joint for rubber belt. Fig. 1,253, outside view; fig. 1254, inside view.

Ques. State some of the disadvantages of belt drive.

Ans. Considerable space is required and the action is not positive. Belts exert a side pull on the bearings which results in wear, also loss of power by friction.

Ques. Give a rule for determining the proper size of belt.

Ans. *A single belt traveling* 1,000 *feet per minute will transmit one horse power per inch of width; a double belt will transmit twice this amount.*

> ***Example.***—What size of double belt is required to transmit 50 horse power at 4,000 ft. speed, and what diameter pulley must be used for 954 revolutions per minute at 4,000 ft. speed of belt?

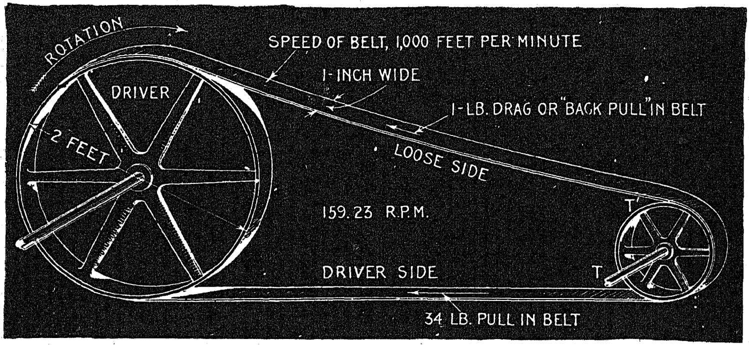


FIG. 1,255.—One horse power transmitted by belt illustrating the ***rule: A single belt one inch wide and traveling* 1,000 *feet per minute will transmit one horse power: a double belt under the same conditions will transmit two horse power.*** A pulley is driven by a belt by means of the friction between the surfaces in contact. Let T, be the tension on the driving side of the belt, and T′, the tension on the loose side; then the driving force=T−T′. In the figure T, is taken at 34 lbs. and T′, at 1 lb.; hence driving force =34−1=33 lbs. Since the belt is traveling at a velocity of 1,000 feet per minute the power transmitted=33 lbs.×1,000 ft. =33,000 ft. lbs. per minute=1 horse power.

The horse power transmitted per inch is

$$\frac{4,000}{1,000}\times 2=8$$

accordingly, the width of belt required to transmit 50 horse power is

$$50\div 8=6.25, \text{ say } 6''.$$

For 4,000 ft. per minute belt speed, the distance *in inches* traveled by the belt *per revolution* of the pulley.

$$\frac{4{,}000\times 12}{954}=50.31 \text{ inches}$$

This is equal to the circumference of the pulley, and the corresponding diameter is

$$\frac{50.31}{3.1416}=16.1, \text{ say } 16 \text{ inches.}$$

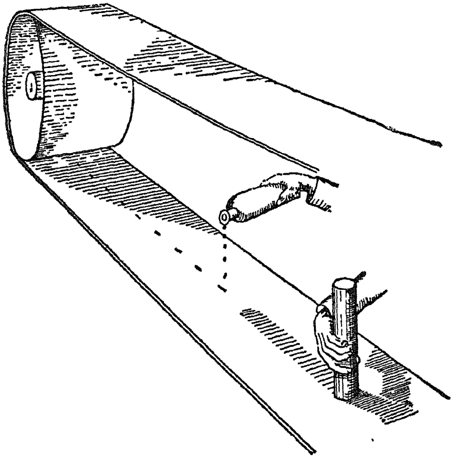
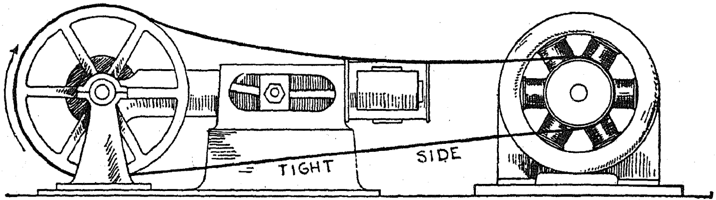


Fig. 1,256.—Method of applying dressing to a running belt. Sometimes the application of dressing to a running belt causes additional trouble. This is due to improper application. Dressing, whether liquid, paste or so called stick variety, should be applied sparingly, and at the center of the belt first, as shown, gradually working out to the edges, first applying the dressing a little to one side of the center, then a little to the other side. Treating all of one side of a belt first usually causes trouble. Such applications are efficacious in stopping slipping temporarily, while the thorough rubbing in of dressing after cleaning the surface is by all means the most satisfactory and durable treatment. Of the home made preparations probably neatsfoot oil comes first for softening very dry belts which are so hard as to begin to crack. It is not desirable to attempt to get a belt into prime condition with one treatment. This results in the use of too much oil or other dressing. It is better to treat it several times and bring it to condition gradually. For this reason all dressing should be used sparingly at each application, but applied often enough to keep the belt in the same condition after once put in order. The addition of from ½ to 1 pound of beeswax to the gallon of oil improves the latter as a dressing. First melt the wax and heat the oil, mixing the two while warm. Tallow frequently is used by first heating it until it can be rubbed into the belt. When belts run in damp basements, the addition of ½ ounce of rosin to the pound of tallow aids in eliminating the effects of moisture

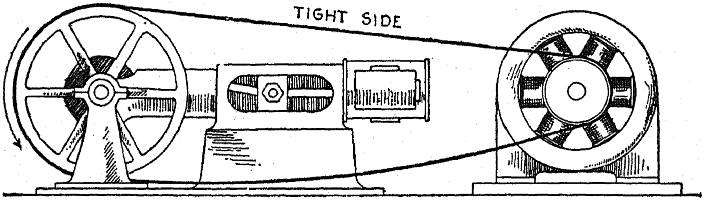
Ques. How should belts be run?

Ans. Whenever possible belts should be run with the right side on the bottom, the upper or loose side will then form a concave arc, which increases the arc of contact on both pulleys; a belt put on in this manner may be kept much slacker than a belt put on the reverse way.

Ques. What is a quarter turn belt?



RIGHT WAY



WRONG WAY

FIGS. 1,257 and 1,258.—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, a *better grip* is in this way obtained.

Ans. A quarter turn belt is used to drive a shaft that is at right angles to the driving shaft; as, for example, a vertical shaft driving a horizontal shaft.

Ques. What is a cross belt?

Ans. A cross belt is used to drive a shaft in the reverse direction of the driver.

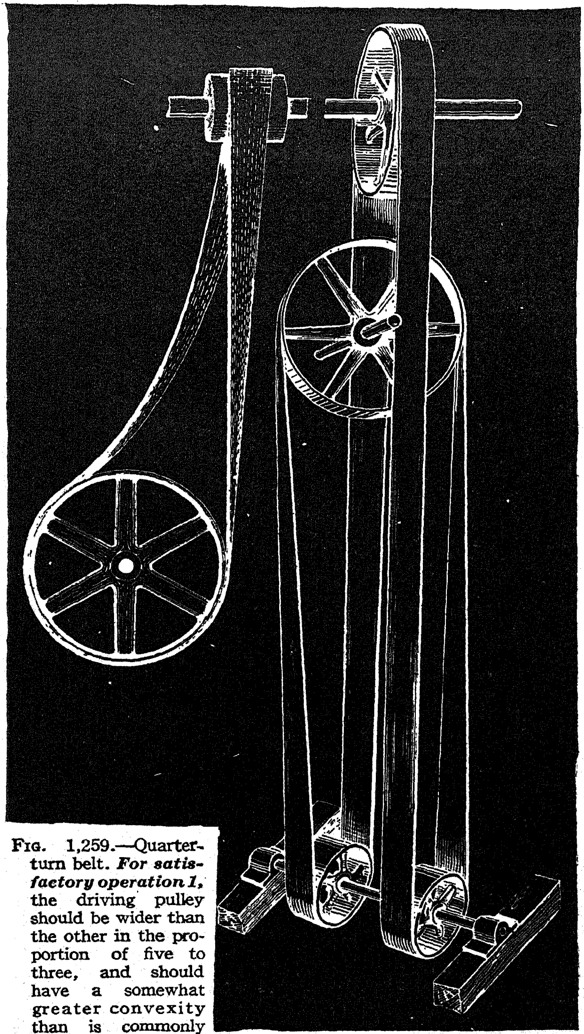


Fig. 1,259.—Quarter-turn belt. ***For satisfactory operation 1,*** the driving pulley should be wider than the other in the proportion of five to three, and should have a somewhat greater convexity than is commonly given to the face of a pulley; 2, both pulleys should be as small as possible, in view of the power to be transmitted, and ought to be nearly the same size; 3, the position in which they are placed relative to each other must be such that *the belt leads from the face of one to the center of the face of the other.*

Fig. 1,260. —Cross belt. ***In this arrangement,*** the belt passes around a small guide pulley on an idler shaft before passing to the driven pulley, returning around another idler on the same shaft before returning to the driver pulley. Here the same side of the belt is always in contact with the various pulleys, and the area enveloping the pulley is much as it would be with a plain drive. The idler shaft must bisect the angle made by the two shafts, that is, it should lie at an angle of 45° with each, when viewed from above. Its plane should be parallel with the planes of the other shafts, and the position of the small pulleys should be determined by lines led from the face of one pulley to the center of the face of the other as before.

Ques. Which will pull more, an open belt or a cross belt?

Ans. A cross belt will pull more, as crossing increases the arc of contact (belt surface on pulley).

Ques. What is the proper speed for a belt?

Ans. From 3,000 to 5,000 feet per minute, depending on conditions.

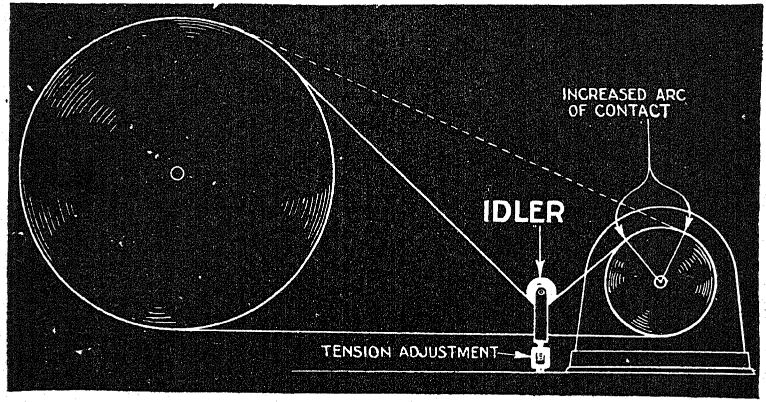
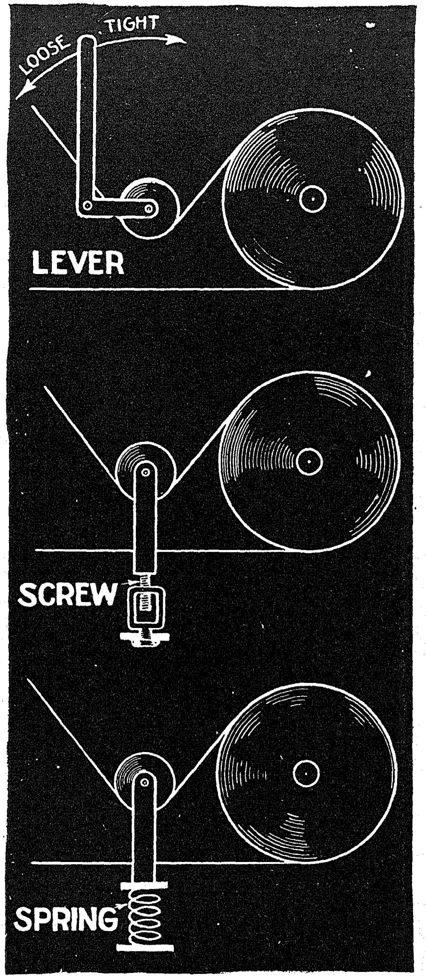


FIG. 1,261.—Idler pulley or intermediate gear, used: 1, to increase the arc of contact and thus secure better adhesion, and 2, as a means of adjusting the belt to the proper tension as here shown and also in figs. 1,262 to 1,264.

Points Relating to Belts.

1. The amount of power that a belt of given size can transmit is not a very definite quantity. The rule given on page 884 is conservative and will give an amply large belt for ordinary conditions.

2. A belt should make a straight run through the air and over the pulleys without wabbling; it should maintain an even and perfect contact with that part of the pulley with which it comes in contact. In order



to do this it should be kept soft, pliable, and have no abrasions or rough places.

3. When belt fasteners give way there is too much strain upon the belt. The greatest amount of slack in a belt is found where it leaves the driving pulley, hence the tightener should be near the driving pulley, as it takes up the slack, prevents vibration and diminishes strain on belts and bearings. More than 100 degrees of heat is injurious to belts.

4. Double belts should always run with the splices, and not against them. Quarter turn belts should be made of two ply leather, so as to diminish the side strain.

5. Friction is greatest when the pulleys are covered with leather. Friction depends upon pressure, but adhesion depends upon surface contact; the more a belt adheres to pulley surface without straining, through too much tightening, the better the driving power. Slipping occurs on wet days because the leather absorbs dampness.

6. A leather covered pulley will produce more resistance than polished or rough iron ones. A good belt dressing makes a smooth, resisting surface, and as it contains

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NOTE.—If regular belt dressing be not available use beef tallow at blood temperature. Apply and dry in sun. The addition of beeswax will help when belts are run in wet or damp places.

Figs. 1,262 to 1,264.—Three methods of idler pulley adjustment. Fig. 1,262, lever; fig. 1,263, screw; fig. 1.264, spring.

no oils which create a slippery surface to belts, it increases belt adhesion. The friction of leather upon leather is five times greater than leather upon iron.

7. Moisture and water distend the fibres, change the properties of the tanner's grease and softening compounds. Repeated saturation and drying will soon destroy leather. Leather well filled with tanner's grease or animal oil, if allowed to hang in a warm room for several months without handling, will dry out, become harsh, and will readily crack.

8. A running belt is stretched and relaxed at different times and unless there be perfect elasticity in all its parts there will not be uniform distension.

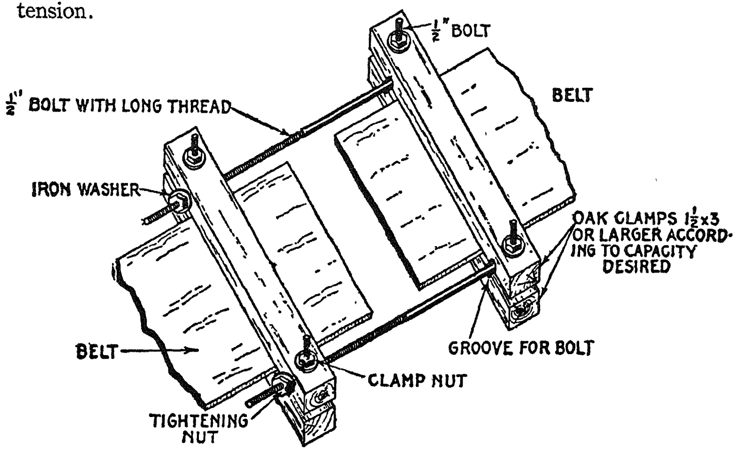
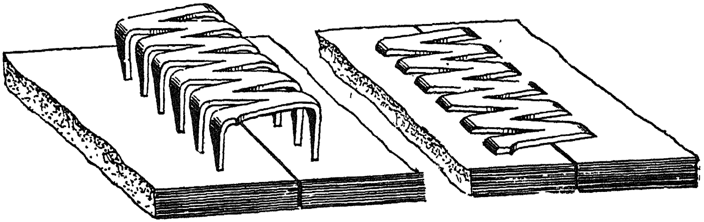


FIG. 1,265.—Home made belt clamp. It is made with four pieces of oak of ample size to firmly grip the belt ends where the bolts are tightened. The figure shows the clamp complete and in position on the belt and clearly illustrates the details of construction. In making the long bolts the thread should be cut about three-quarter length of bolt and deep enough so that the nuts will easily screw on.

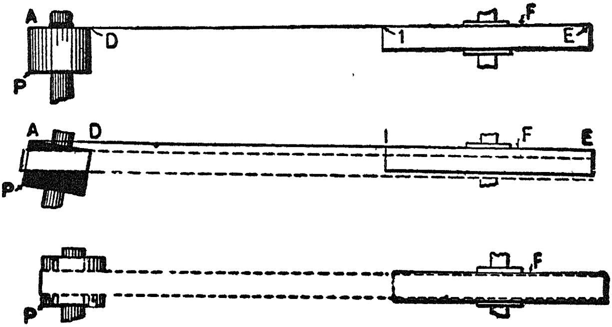


FIGS. 1,266 and 1,267.—Metallic belt fastener.

9. There should be 25 per cent margin allowed for adhesion before a belt begins to slip.

Rules for Calculating Speed and Sizes of Pulley.—When two pulleys are working together connected by a belt, the one which communicates the motion is called the *driver* and the other which receives it, the *driven pulley.*

To Find the Size of the Driver Pulley: Multiply the diameter of the driven pulley by its required number of revolutions, and divide the product by the revolutions of the driver. The quotient will be the diameter of the driver.



FIGS. 1,268 to 1,270.—Method of aligning engine and dynamo. In fig. 1,268, a line is stretched from A, to E, and the dynamo shifted until the line contacts with points A, D, I, and E. In a small dynamo, the pulley may be loosened and set back on the shaft as in fig. 1,269, while lining up the faces, and then moved back to its original position as in fig. 1,270. When the pulley is not easily shifted the distances at A and D (fig. 1,268) may be measured.

To Find the Number of Revolutions of the Driven Pulley: Multiply the diameter of the driver by its number of revolutions, and divide by diameter of the driven. The quotient will be the number of revolutions of the driven.

To Find the Diameter of the Driven that Shall Make a Given Number of Revolutions, the Diameter and Revolutions of the Driver Being Given: Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven pulley. The quotient will be the diameter of the driven pulley.

Four problems arise

Problem 1. To find diameter of driver.
Problem 2. To find speed of driver.
Problem 3. To find diameter of driven pulley.
Problem 4. To find speed of driven pulley.

The practice of memorizing rules is worse than ridiculous. If the principle upon which the speeds and sizes of pulleys depend, be understood, a formula expressing the relationship may be easily constructed and solved for any one of the four items desired.

According to the rules of proportion.

Diam. driver: diam. driven pulley = rev. driven pulley: rev. driver . . (1)

Let

D = diameter of driver.
d = diameter of driven pulley.
R = revolutions of driver.
r = revolutions of driven pulley.

Substituting these symbols equation (1) becomes

$$D : d = r : R \qquad (2)$$

Problem 1—What size engine pulley must be used to drive a dynamo at a speed of 2,000 revolutions per minute (*r.p.m.*) if the dynamo have a 4 in. pulley and the speed of the engine be 500 *r.p.m.*? Here $d = 4$; $R = 500$ and $r = 2{,}000$.

Solving equation (2) for D,

$$DR = dr \qquad (3)$$

$$D = \frac{dr}{R} \qquad (4)$$

Substituting the given values in (4).

$$D = \frac{4 \times 2{,}000}{500} = \frac{8{,}000}{500} = 16 \text{ ins.}$$

Problem 2—At what speed must an engine run to drive a dynamo at a speed of 2,000 *r.p.m.*; if the dynamo have a 4 in. pulley, and the diameter of engine pulley be 16 ins.? Here $d = 4$; $r = 2{,}000$ and $D = 16$.

Solving equation (3) for R,

$$R = \frac{dr}{D} \qquad \text{(5)}$$

Substituting the given values in (5)

$$R = \frac{4 \times 2{,}000}{16} = \frac{8{,}000}{16} = 500 \; r.p.m.$$

Problem 3.—What size pulley must be used on a dynamo for a speed of 2,000 *r.p.m.* if the engine have a 16 in. pulley running 500 *r.p.m.*? Here $D = 16$; $R = 500$ and $r = 2{,}000$.

Solving equation (3) for *d*.

$$d = \frac{DR}{r} \qquad \text{(6)}$$

Substituting the given values in (6),

$$d = \frac{16 \times 500}{2{,}000} = 4 \text{ in.}$$

Problem 4—At what speed will a dynamo run if it have a 4 in. pulley and be driven by an engine having a 16 in. pulley turning 500 *r.p.m.* Here $D = 16$; $R = 500$ and $d = 4$.

Solving equation (3) for *r*

$$r = \frac{DR}{d} \qquad \text{(7)}$$

Substituting the given values in (7)

$$r = \frac{16 \times 500}{4} = 2{,}000 \; r.p.m.$$

Rope Drive.—In this method of power transmission, rope is run in V-shaped grooves in the rims of the pulleys; this form of drive, in some cases, is more desirable than in others.

Ques. What are some of the advantages of rope drive?

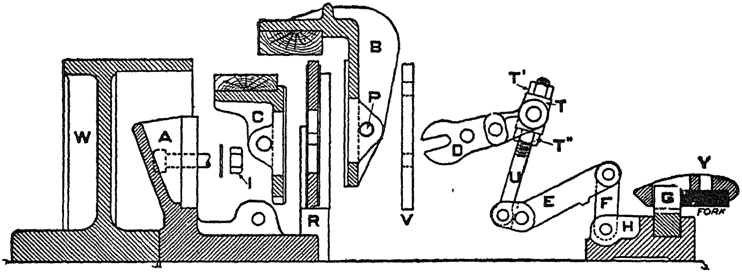


Fig. 1,271.—Sectional view of Hill clutch mechanism. In every case the mechanism hub A, and in a clutch coupling the ring W, is permanently and rigidly secured to the shaft and need not be disturbed when removing the wearing parts. When erected, the adjustment should be verified, and always with the 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. Oil the moving parts of the clutch. Keep it clean. Examine at regular intervals.

Ans. More power can be transmitted with a given diameter and width of pulley, on account of the increased grip in the grooves. Rope drive can be employed for long or short distances by reason of its lightness and the action of the grooves.

Gear Drive.—This method is used where a positive drive is desired, as for elevator or railway motors. It admits of any degree of speed reduction without attending difficulties as would be encountered with belt drive.

Thus, with the worm type of gear as used on elevator motors a great reduction in velocity can be made without incurring the expense of countershaft as with a belt.

Friction Drive.—This is a very simple mode of transmitting power and has the advantages of simplicity and compactness.

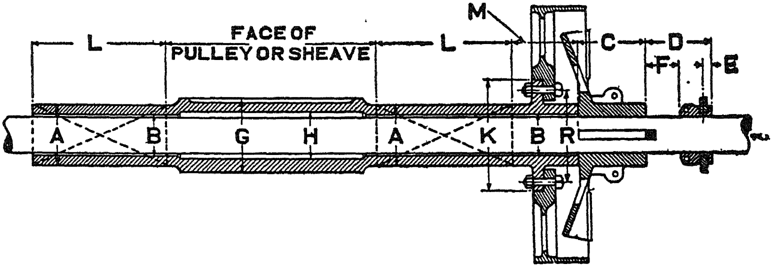


FIG. 1,272.—Quill drive. This is the proper transmission arrangement as substitute for heavy service, requiring large pulleys, sheaves, gears, etc. It is a hollow shaft supported by independent bearings. The main driving shaft running through the quill is thus relieved of all transverse stresses. The power is transmitted to the quill by means of a friction or jaw clutch. When the clutch is thrown out, the pulley or sheave stands idle and the driving shaft revolves freely within the quill. As there is no contact between moving parts there is no wear. Jaw clutches should be used for drives demanding positive angular displacement. They can only be thrown in and out of engagement when at rest. All very large clutch pulleys, sheaves, or gears designed to run loose on the line shaft are preferably mounted on quills. The letters A, B, C, etc., indicate the dimensions to be specified in ordering a quill.

In operation, the driving wheel is pressed against the wheel to be driven, transmitting motion to the latter by the frictional grip. The drive is thrown out of gear by slightly moving the machine on its sliding base. In construction, the friction may be increased by making one wheel of the pair, of wood, compressed paper, or leather.

Electrical Connections.—Circuits for dynamos and motors should be carefully planned so as to secure the simplest system and to avoid unnecessary expense and delay, the wiring should be installed in accordance with the requirements of the National Electrical Code.

Ques. What may be said with respect to exposed and concealed wiring?

Ans. Exposed wiring is cheap and accessible; a short circuit or ground is easily located and repaired. Concealed wiring, especially when placed under the floor, has the advantage of being out of the way, and thus protected from injury.

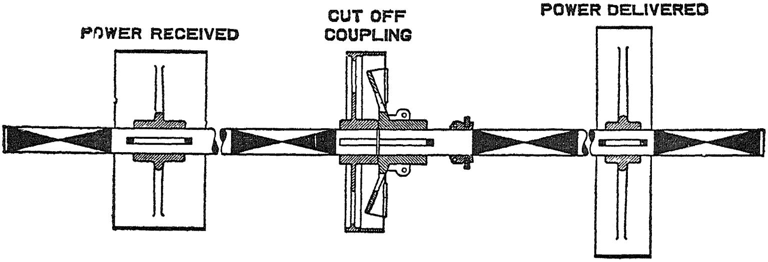


FIG. 1,273—Cut off coupling for power transmission by line shafting It is used to cut off a driving shaft from a driven shaft. Its use obviates the use of a *quill*, such as is shown in fig. 1,272.

Ques. In wiring a dynamo what are the considerations with respect to size of wire?

Ans. All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the dynamo and switchboard should not exceed one-half per cent. at full load, because it interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

Chain Drive.—Mount the motor so that the chain may be tightened. Secure accurate alignment. Avoid vertical drives if possible.

Safety Regulations.—All belts, chains, gears, couplings and machines should be properly housed or suitably guarded in accordance with the National, State or Local Safety Regulations in effect.

Floor, Wall or Ceiling Mounting.—All standard grease lubricated machines will usually operate successfully mounted on floor, wall or ceiling without changing the position of the end shield. Standard oil lubricated motors are assembled for floor installation unless otherwise desired. For wall or ceiling mounting, block armature, mark position of brushes on commutator, loosen yoke, rotate end shield so that the oil well cover will be horizontal in new operating position, see that the brushes have not moved from marked position on commutator, tighten yoke and unblock armature; in other words, maintain the same relative position between brushes and field coils.

Position of Terminal Plate.—It is standard practice to locate the terminal plate on the right hand side of the frame for motors when viewed from the commutator end.

Starting and Control Devices.—Instructions regarding proper installation, connections and operation should accompany each control device.

Protection.—Suitable thermal overload protection (if not incorporated in the control apparatus) should be installed to guard the motor against excessive overloads of long duration.

NOTE.—Whenever the end shields are removed, or rotated, make sure that the joints between end shields and stator frame are clean before the shields are replaced. Be sure that the grease in the V-grooves is renewed. The V-grooves are located at both ends of the bearing housings and are filled with a fibrous grease to keep out dust and dirt. Check the air gap and see that the armature revolves freely. Be sure to fill the oil wells after the motor is re-assembled.

External Wiring.—All motor and control wiring should be carefully installed in accordance with the National Electric Code and any local requirements, and should be of ample capacity based on a maximum drop of 2 per cent of line voltage at full load current.

OPERATION

Before Starting the Motor for the First Time.—1. Dry out all moisture. If the motor has been exposed to moist atmosphere for long periods while in transit or storage (or has remained idle for long periods after installing in moist atmosphere) it should always be dried out thoroughly before being placed in service. If possible, place the motor in an oven and bake at a temperature not exceeding 85° C. Fair results can be obtained by enclosing the motor with canvas or other covering, inserting some heating units or incandescent lamps to raise the temperature and leaving a hole at the top of the enclosure to permit the escape of moisture. The motor may also be dried out by passing a current at a low voltage (motor at rest) through the field windings that will raise the temperature to not over 85° C.

Increase the temperature gradually to this value, keeping the whole winding as nearly uniform in temperature as possible.

2. See that the voltage on motor and control name plates corresponds with the power supply.

3. Check all connections to the motor and control with the wiring diagrams.

4. Make sure that the drain plugs are tight and that the bearings are lubricated properly.

5. If oil ring bearings are used, make sure that the oil rings turn freely.

6. Remove all external load if possible and turn armature by hand to see that it rotates freely.

Before putting the motor in service, it is desirable to operate without load long enough to determine that there is no unusual localized heating.

Starting and Stopping.—The motor should come up to speed in about 5 to 20 seconds.

NOTE.—This does not apply to series motors. Series motors should not be operated without load.

CHAPTER 36A

Motor Calculations

The following simple motor circuit calculations will serve to acquaint the student with methods used in compiling voltage drops, currents and efficiency of direct and alternating current motors.

Example.—*A* 115 *volt D.C. motor which draws a current of* 200 *amperes is located* 1,000 *ft. from the supply source. If the copper transmission line wire has a diameter of* 0.45 *inch, what is the voltage of the supply source?*

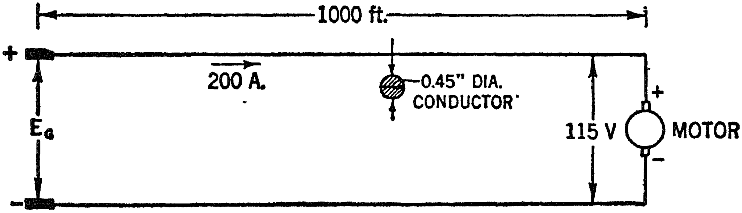


FIG. 1.—Voltage drop calculation in motor feeder.

Solution.—Resistance of the line,

$$R = \frac{10.4 \times 2{,}000}{450^2} = 0.103 \text{ ohm}$$

and $E_G = E_R + I_L R = 115 + 200 \times 0.103 = 135.6$ volts. *Ans.*

Example.—*A* 10 *horsepower* 230 *volt D.C. motor of* 84% *full load efficiency is located* 500 *ft. from the supply mains. If the motor starting current is* 1.5 *times the full load current, what is the smallest cross-section area of copper wire required when the allowable voltage drop in feeder at starting is* 24 *volts?*

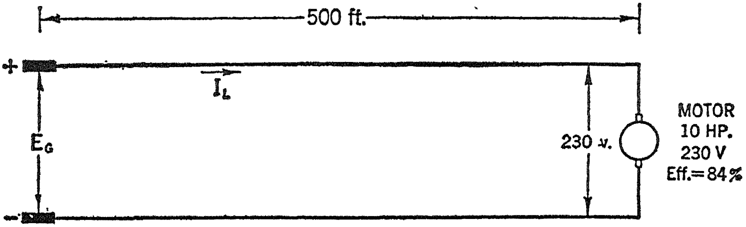


Fig. 2.—Calculation of feeder cross-section area for a 10 HP. motor.

Solution.—The motor full load current

$$I_L=\frac{HP\times746}{E\times\text{efficiency}}=\frac{10\times746}{230\times0.84}=38.6\text{ amperes}$$

Motor starting current

$$I_S=38.6\times1.5=57.9\text{ amperes}$$

Since the voltage drop in the feeder at starting is 24 volts, then according to ohm's law

$$24=57.9\times R\text{ and }R=\frac{24}{57.9}=0.415\text{ ohm}$$

The minimum cross-section area is therefore

$$A=\frac{10.4\times2\times500}{0.415}=25{,}000\text{ C.M. (approximately). }\textit{Ans.}$$

Example.—*In circuit fig.* 3 , *with loads* L_1, L_2 *and* L_3 *drawing currents of* 25, 8 *and* 40 *amperes respectively*:

Calculate

(*a*) *Power supplied by each generator*

(*b*) *Voltages* E_1, E_2 *and* E_3.

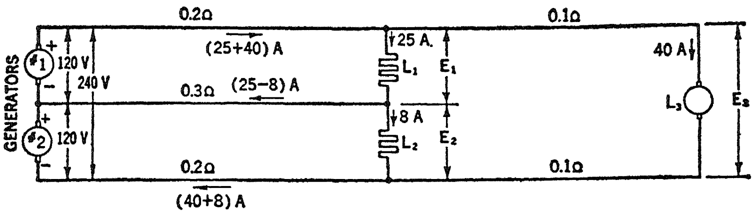


Fig. 3.—Three-wire system supplying three loads.

Solution.—By inspection the currents supplied by generators Nos. 1 and 2 are 65 and 48 amperes respectively.

(*a*) and

$$P_{G1}=120\times 65=7{,}800 \text{ watts.} \quad \textit{Ans.}$$

$$P_{G2}=120\times 48=5{,}760 \text{ watts.} \quad \textit{Ans.}$$

(*b*) According to Kirchhoff's law

$$E_1=120-65\times 0.2-17\times 0.3=101.9 \text{ volts.} \quad \textit{Ans.}$$

$$E_2=120+17\times 0.3-48\times 0.2=115.5 \text{ volts.} \quad \textit{Ans.}$$

and

$$E_1+E_2=217.4 \text{ volts}$$

Similarly

$$E_3=217.4-0.2\times 40=209.4 \text{ volts.} \quad \textit{Ans.}$$

Example.—*A three-wire system supplies the load shown in fig. 4. If the resistance of each lamp be* 110 *ohms and the motor takes a current of* 25 *amperes, calculate the voltage across each group of lamps.*

(*a*) *When the motor is disconnected.*

(*b*) *When the motor is operating.*

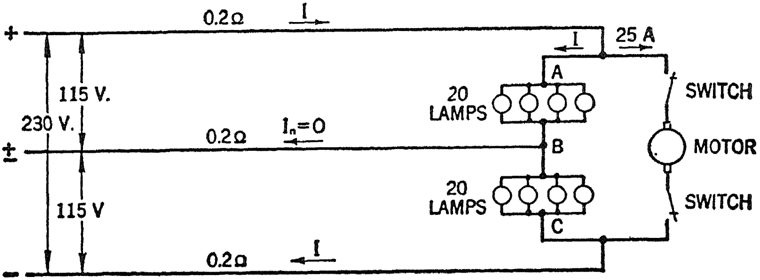


FIG. 4.—Three-wire system supplying lamp and motor load.

Solution.—The combined resistance of a group of 20 lamps each having a resistance of 110 ohms gives

$$R=\frac{110}{20}=5.5 \text{ ohms}$$

Since the load is a balanced one, it is evident that the current in the neutral is zero.

The current through the lamps with the motor disconnected:

$$I=\frac{230}{11.4}=20.2 \text{ amperes}$$

(*a*) Voltage $E_{AB}=E_{BC}=\frac{20.2\times 11}{2}=111.1$ volts. *Ans.*

The current through the lamps with motor operating and drawing 25 amperes, can be obtained if Kirchhoff's law be applied to the circuit, remembering that the current flowing in the line is now $(I+25)$ amperes.

$$230=0.4(I+25)+11I=11.4I+10$$

and

$$I=\frac{220}{11.4}=19.3 \text{ amperes}$$

(*b*) Voltage $E_{AB}=E_{BC}=\frac{19.3\times 11}{2}=106.15$ volts. *Ans.*

Thus, when the motor is thrown on the line the voltage across the lamps will fall from 111.10 to 106.15 volts.

Example.—*An electric range has a rating of* 3 *horsepower. What is* (*a*) *the amount of calories generated per minute;* (*b*) *the cost per hour of usage when the cost of electricity is* 2 *cents per kilowatt-hour?*

Solution.—

(a) $W=0.24EIt=0.24\times 3\times 746\times 60=32{,}227$ gr. cal. *Ans.*

(b) Cost per hour $=3\times 0.746\times 2=4.476$ cents. *Ans.*

Example.—*The field winding of a shunt motor has a resistance of* 110 *ohms, and the e.m.f. applied to it is* 220 *volts. What is the amount of power expanded in the field excitation?*

Solution.—The current through the field

$$I_f=\frac{V_t}{R_f}=\frac{220}{110}=2 \text{ amperes}$$

Power expanded $= V_tI_f=220\times2=440$ watts. *Ans.*

The same results will of course be obtained direct by using equation

$$\frac{V_t^2}{R_f}=P_f=\frac{220^2}{110}=440 \text{ watts (check)}$$

Example.—*A shunt motor whose armature resistance is* 0.2 *ohm and whose terminal voltage is* 220 *volts takes an armature current of* 50 *amperes and runs at* 1,500 *r.p.m. when the field is fully excited. If the field be decreased and the armature current increased both by* 50%, *at what speed will the motor run?*

Solution.—The expression for the counter e.m.f. of the motor is

$$E_a=V_t-I_aR_a$$

and $E_{a1}=220-50\times0.2'=210$ volts

Similarly $E_{a2}=220-75\times0.2=205$ volts

also $E_a=N\phi K$

and $\frac{E_{a1}}{E_{a2}}=\frac{N_1\phi_1K_1}{N_2\phi_2K_2}$

Since the field is decreased by 50%, then

$$\phi_1 = 1.5\phi_2, \text{ and } Z_1 = Z_2$$

It follows that

$$\frac{210}{205} = \frac{1{,}500 \times 1.5}{N_2} \text{ and } N_2 = \frac{1{,}500 \times 205 \times 1.5}{210} = 2{,}196 \text{ r.p.m. } \textit{Ans.}$$

Example.—*A* 7.5 *hp.* 220 *volt interpole motor has armature and shunt field resistances of* 0.5 *ohm and* 200 *ohms, respectively. The current input at* 1,800 *r.p.m. and no-load is* 3.5 *amperes. Calculate the current and electromagnetic torque for a speed of* 1,700 *r.p.m.*

Solution.—At no load

$$I_a = I_L - I_f = 3.5 - \frac{220}{200} = 2.4 \text{ amperes}$$

$$\text{and } \phi K_{NL} = \frac{V_t - I_a R_a}{N} = \frac{220 - 2.4 \times 0.5}{1{,}800} = 0.1216$$

$$\phi K_{NL} = \phi K_{FL}$$

(at 1,700 r.p.m.)

$$I_a = \frac{V_t - N\phi K}{R_a} = \frac{220 - 1{,}700 \times 0.1216}{0.5} = 26.6 \text{ amperes}$$

$$I_L = I_a + I_f = 26.6 + 1.1 = 27.7 \text{ amperes. } \textit{Ans.}$$

$$T_e = 7.05\phi K I_a = 7.05 \times 0.1216 \times 26.6 = 22.8 \text{ ft. lbs. } \textit{Ans.}$$

Example.—*A* 220 *volt,* 60 *cycle,* 10 *horsepower, single phase induction motor operates at an efficiency of* 86% *and a power factor of* 90%. *What capacity should be placed in parallel with the motor so that the feeder supplying the motor will operate at unity power factor?*

Solution.—The current taken by the motor

$$I = \frac{10 \times 746}{220 \times 0.9 \times 0.86} = 43.75 \text{ amperes (lagging)}$$

Current taken by the condenser

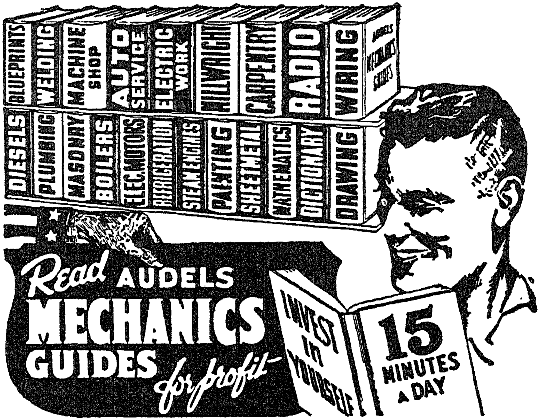
$$I_C = 43.75 \times \sin \phi$$

$$I_C = 43.75 \times 0.4352 = 19 \text{ amperes}$$

The capacitive reactance of the condenser

$$X_C = \frac{220}{19} = 11.58 \text{ ohms}$$

$$\text{Capacitance } C = \frac{10^6}{2\pi \times 60 \times 11.58} = 229 \text{ microfarads.} \quad \textit{Ans.}$$



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