PRACTICAL MANAGEMENT
OF
DYNAMOS AND MOTORS

CROCKER AND WHEELER

D. VAN NOSTRAND Co.

THE

PRACTICAL MANAGEMENT

OF

DYNAMOS AND MOTORS.

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PREFACE TO FIRST EDITION.

THE contents of this book appeared as a series of articles in the *Electrical Engineer* between September 1891 and May 1892. Its object is to give simple directions for the practical use and management of dynamos and motors.

The authors have taken special care to arrange the material so that the different subjects are treated separately and in the proper order, and the headings are printed in heavy type to facilitate ready reference to any subdivision.

The reader is recommended to familiarize himself at first with the plan and contents of the book, that he may when at work be able to turn readily to any part required.

The authors design the present volume to be simply the groundwork of a larger and more elaborate treatment of the subject which they contemplate preparing, and they will appreciate any suggestions.

NEW YORK, *May*, 1892.

PREFACE TO SECOND EDITION.

THE first edition of this book having been exhausted in less than one year, the authors have taken advantage of the opportunity for revision and enlargement presented by the issue of the second edition. A few corrections and many additions have been made. As many of the additions are in the chapter on examination and testing, and as this is properly a branch by itself, it has been separated as Part II.

Part IV has been added, giving special instructions for handling the Thomson-Houston, Brush, and other arc-light dynamos, since these machines have governors which require additional directions.

The statements are directly based upon actual experience, and most of them have been checked by the extensive use of the book by electrical teachers, engineers, students, and workmen, not only in college laboratories and the testing-rooms of factories, but also in the installation and management of dynamos and motors in commercial use.

The authors desire to acknowledge the kindness and assistance of several electric companies, and of Mr. Gano S. Dunn, Engineer of the Crocker-Wheeler Electric Company, who has carefully examined the proofs and made a number of valuable suggestions.

NEW YORK, *February*, 1894.

NOTE ON THIRD EDITION.

A NUMBER of corrections incidental to the introduction of much new matter in the second edition have been made, especially in the chapters on the T. H. dynamo, which have been carefully passed upon by Mr. E. E. Boyer, of Lynn, to whom the authors wish to express their thanks.

NEW YORK, *October*, 1894.

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THE
PRACTICAL MANAGEMENT
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PART I.

Definitions and Directions.

INTRODUCTION.

THE purpose of this book is to set forth the more important facts which present themselves in the actual handling of dynamo-electric machines and electric motors, as a guide for those who use or study these machines. The authors do not claim for this treatment of the subject much more than that it is a set of directions in which the various points are arranged under headings for convenience of reference.

Heretofore writers on the dynamo or motor have usually treated these machines entirely distinctly, and books or papers relating to the dynamo usually contain nothing about the motor, or merely consider it briefly in a few special chapters, and books on the motor refer to the dynamo only incidentally. The authors have found that there is no necessity for this separation; in fact, nine out of ten statements which apply to the dynamo are equally applicable to the motor, and if the word "machine" is used instead, the statement covers both and becomes doubly important and useful. Occasionally, of course, it is necessary to distinguish between the two machines, but, as a matter of fact, the difference in treatment required for dynamos and for motors is often less than for different kinds of dynamos; for example, a shunt dynamo and a shunt motor are much more similar in their construction and action than a shunt dynamo and a series dynamo. The following pages cover almost all types of dynamos and motors, except that certain dynamos with open-coil armatures, such as the Thomson-Houston and Brush, largely used for arc-lighting, require special directions to give all the peculiar actions which may occur, particularly in regard to sparking. But even with these machines the principal facts, precautions, etc., are included in the general directions.

Up to the present time the treatment of the dynamo and the motor has related almost entirely to theory, design and construction, and little has been written about their operation.

The theory and design of the dynamo is now one of the most interesting and perfect branches of applied science; but for every *one* person who *builds* dynamos there are a hundred who *use* them. The authors have therefore confined this book to *management*, giving only a few of the most important definitions and facts in the following chapter, and they refer the reader to existing works in which the principles, theory, design and construction of these machines are very ably and fully covered. The reader is also referred to some elementary work on the principles of electricity, including electrical laws, phenomena, units, methods of measurement, etc. These should be thoroughly learned before any one attempts to understand or handle electrical apparatus of any kind.

CHAPTER I.

GENERAL PRINCIPLES OF DYNAMOS AND MOTORS.

Definitions.—*A dynamo-electric machine is a machine for converting mechanical energy into electrical energy;* in other words, *it generates electric current when driven by mechanical*

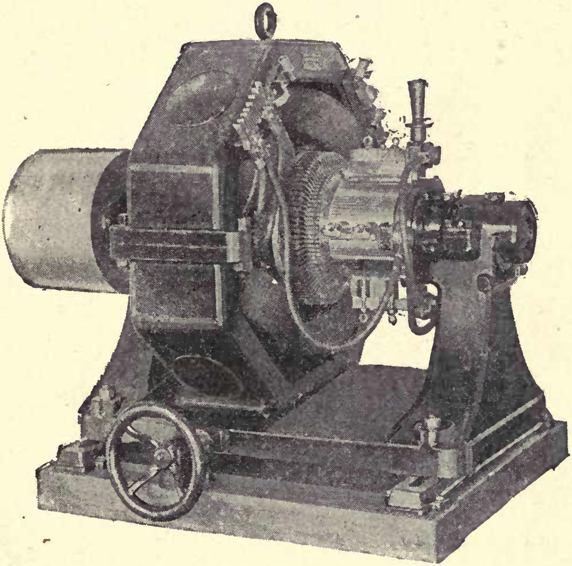


FIG. 1.—35-KILOWATT CROCKER-WHEELER DYNAMO. FOUR-POLE COMPOUND-WOUND. BAR-WOUND ARMATURE.

power. The term dynamo-electric machine is so long that it is usually and unavoidably shortened into "dynamo," which has exactly the same meaning. The name "electric generator," or simply "generator," is often applied to the dynamo, especially when used to produce current for electric railway or other motors; but this distinction is merely for convenience. An alternating-current dynamo is commonly called an "alternator."

An electric motor is a machine for converting electrical energy into mechanical energy; in other words, *it produces mechanical power when supplied with an electric current.* An electric motor is usually called simply a motor, and although motor might mean anything producing motion, it is very rarely used in any other sense, and is perfectly definite in connection with electrical matters.

A dynamotor, or motor-dynamo, is, as its name implies, a combination of the two machines, and consists of a motor and a dynamo, either directly coupled together or built as one machine. A dynamotor is commonly used to transform an electric current of a certain voltage into a current of either a higher or lower voltage, with a corresponding decrease or increase in the number of amperes. Since these machines are usually employed for direct currents they are called direct current transformers, but they are often used to convert direct into alternating currents, or the converse; they are also called rotary transformers.

Principles of Action.—The dynamo is based upon the discovery made by Faraday in 1831, that an electric current is generated in a conductor by moving the conductor in a magnetic field. The electric motor works on the principle that a conductor carrying a current in a magnetic field tends to move. Thus it will be seen that the dynamo and the motor are exactly the reverse of each other in their action.

Similarity of Dynamos and Motors.—The two machines are, however, very similar in their construction. In fact, the same machine can be used for either purpose equally well. In practice dynamos and motors are sometimes made slightly different, but this is only done to adapt a machine more perfectly to a certain purpose. Hence, as already stated in the introduction, the two machines will be treated as one, except where some distinction is specially stated.

General Form.—We have seen that both the dynamo and motor depend for their action upon the movement of conductors in magnetic fields. Now it has been found as a result of scientific experiment and practical experience during the 60 years since Faraday's discovery, that the best way to carry out this principle is to arrange the conductors in suitable form and rotate them between the poles of a magnet, or magnets. This rotating part is called the *armature* and the magnet is called the *field-magnet.* In alternating-current dynamos this plan is sometimes reversed, the field-magnets being made to rotate and the armature being fixed.

Armature.—This usually consists of an *armature core* of iron, on which are wound or fastened the conductors which carry the current. This iron core should be split up or *laminated;* that is, made of discs, tape, or wire, separated by paper, varnish, or rust, instead of one solid piece; otherwise it will have useless ("Foucault") currents generated in it, which would waste the power of the machine. This core is almost always made either in the form of a *drum* or a *ring*, and hence we have these as the two principal types of armature.

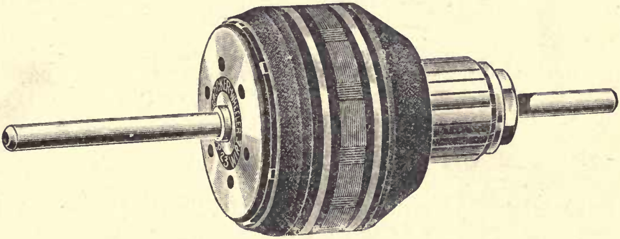


Fig. 2.—¼ H. P. 500-Volt Armature, Wire-wound.

Field-magnet.—This consists of one or more iron *cores*, on which are wound the field-*coils*. Attached to the field-cores are the *pole-pieces*, which give form to the magnetic field, or space in which the armature revolves.

CHAPTER II.

DIRECTIONS FOR SELECTING DYNAMOS AND MOTORS.

THE choice of a dynamo or motor will, of course, depend largely upon the circumstances in each particular instance. There are, however, certain general principles which apply to almost all cases.

Construction.—This should be of the most solid character and first-class in every respect, including material and workmanship, both of which should be of the best possible quality. All the parts should be of adequate size and strength to insure durability.

Finish.—A good finish is desirable—first, because it indicates good construction, both being secured by care and repeated improvements; second, because it stimulates the interest and pride of the attendant; and, third, because it shows the least dirt or neglect.

Simplicity.—The machine and all its parts should be as simple as possible, and any very peculiar or complicated part or attachment should be avoided. These are sometimes successful, but should be well tried and proved before being accepted.

Attention.—The amount of attention required by the machine should be small; for example, the brushes should be capable of being easily and securely adjusted, and the oiling devices should be effective and reliable, self-oiling bearings being very desirable. The screws, connections, and other small parts should be arranged so that they are not liable to become loose, and the delicate parts should not be particularly exposed or liable to injury. The machine should be made so as to be easily and thoroughly cleaned.

Handling.—The machine should be provided with an eye-bolt or other means by which it can be easily lifted or moved without injury. It should be possible to take out the armature conveniently by removing one of the bearings, or the top of the field-magnet.

Interchangeability.—Machines should be made with interchangeable parts, so that a new piece which will fit perfectly can be readily obtained (Fig. 3); for this reason regular and established types of machine are preferable to special or unsettled forms.

Regulation.—Some form of regulator should be provided by which the E. M. F. or current of a dynamo or the speed of a motor can be reliably and accurately governed.

Armature.—This should turn very freely in the bearings, and should be perfectly balanced, so as not to have any appreciable jar or vibration at full speed. There should be a uniform clearance of at least $\frac{1}{8}$ inch all around between the armature and pole-pieces. The armature should be capable of moving lengthwise in the bearings at least $\frac{1}{8}$ inch, except in the case of those types of machine in which the armature would strike the pole-pieces if it moved longitudinally. It is not usually desirable to have the speed of an armature at its circumference more than three thousand feet per minute. The ring form of armature is especially suited to high voltage, since the coils differing most in potential are at the greatest distance apart. A section can also be more easily rewound on a ring than on an ordinary drum armature.

Capacity.—This should be ample in all cases. It is a very common mistake to underestimate the work required of a given machine, and, even if the machine has sufficient power at first, the demands upon it are apt to increase and finally overload it. No one is ever likely to regret choosing a dynamo or motor with a considerable margin of capacity, since these machines only consume power in proportion to the work they are doing. For example, a 25 H. P. machine would probably run with a 20 H. P. load more economically

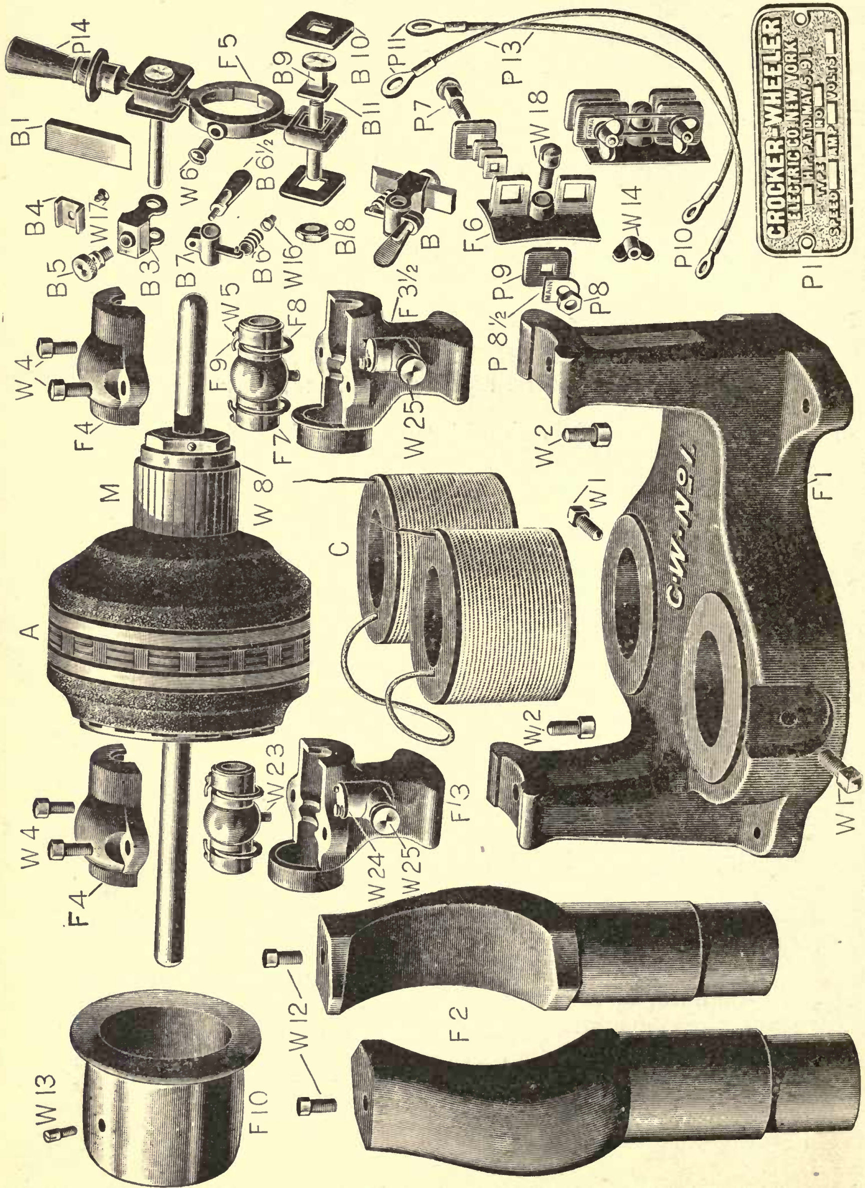


FIG 3.—INTERCHANGEABLE PARTS OF STANDARD MOTORS, $\frac{1}{6}$ TO 5 HORSE-POWER.

and satisfactorily than a 20 H. P. machine with the same load.

Commutator.—This should be large enough to radiate the heat produced by the current and by friction of the brushes, and it should have a sufficient number of bars so that the difference of potential between adjacent ones shall not be excessive. Nothing but mica insulation should be used between the bars except in the case of certain arc-lighting machines with very few segments, which have about $\frac{1}{4}$ inch air-space between the bars.

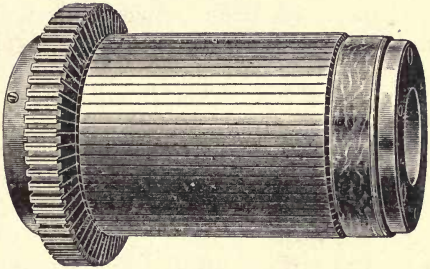


FIG. 4.—COMMUTATOR.

Form.—The machine should be symmetrical, well proportioned, compact and solid in form. If it is either very tall or very flat it is usually inconvenient and clumsy. No part of the machine should project excessively, or be awkwardly formed or arranged. The large and heavy portions of the machine should be placed as low as possible to give great stability. For the same reason the shaft should not be high above the base, nor should it be so low that there is not ample room for the pulley or other attachment. A horizontal belt, for example, will sag and strike the floor if the pulley is very low.

Weight.—The common idea that it is desirable to have a very light dynamo or motor is a mistake when it is for stationary use. There is no advantage in a light machine for stationary work, and it has the disadvantages of being less strong, less durable, and less steady in running. A sufficient weight to make the machine thoroughly substantial is obviously a great benefit.

Cost.—It is also a mistake to select a cheap machine, since both the materials and workmanship required in a high-quality dynamo or motor cost more than in almost any other machine of the same size and weight. It is an undeniable fact that there has been considerable trouble and loss with electrical machinery, owing to inferior construction.

These suggestions as to selecting a dynamo or motor may be followed when it is possible to make only a general examination of the machine, or even in cases where it is only possible to obtain a drawing or description of it. If it is desired to make a complete investigation of the machine, it is, of course, necessary to make a thorough test and measure exactly its various constants. This can be done as completely as may be required by following the "Directions for Testing," which are given in Part II.

A satisfactory test cannot usually be made, however, until after the machine is set up in place; and, moreover, it is not generally necessary if the machine is obtained from a reputable source.

CHAPTER III.

CIRCUITS AND WINDINGS.

The Various Kinds of Circuits on which motors and dynamos are commonly used, and the best type of machine in each case, are as follows:

DIRECT CURRENT, CONSTANT POTENTIAL.

(*Circuits on which potential or voltage is kept constant, machines, lamps, etc., being run in parallel.*)

Circuits intended for—	Potential.	Dynamo should be—	Motor should be—
Electrometallurgy	1 to 150 volts	Shunt wound.	Not used.
Incandescent lighting	110 volts (2-wire sys.) 220 volts (3-wire sys.)	Shunt or compound wound.	Shunt wound for constant speed. Sometimes series or compound wound for very variable speed.
Electric railway Electric power	500 volts.	Shunt or compound wound.	Series wound for railway. Shunt wound for stationary.

DIRECT, CONSTANT CURRENT.

(*Circuits on which current or amperes are kept constant, machines, lamps, etc., being run in series.*)

Circuits intended for—	Current in Amperes.	Dynamo should be—	Motor should be—
Arc-lighting Power circuits	6.8 9.5 or 18.	Series wound with current regulator.	Series wound with speed-regulator.

ALTERNATING CURRENT, SINGLE PHASE.

(*Almost always constant potential.*)

Circuits intended for—	Potential in Volts.		Dynamos should be—	Motor should be—
Incandescent lighting.......	Primary, 1000 or more.	Secondary, 50 or 100.	Separately excited. Also sometimes compound wound	Specially designed.
Arc-lighting..... Sometimes constant current Electric power...	Not in extensive use.			

ALTERNATING CURRENT, POLYPHASE.

(*Constant potential, two or three phase currents.*)

Circuits intended for—	Potential in Volts.		Dynamos should be—	Motor is—
Power transmission...........	On the line, 5000 to 20000	In the machines, 50 to 100.	Separately excited.	Either of synchronous or induction type (the latter has no commutator or other electrical connection to moving parts.

Kinds of Circuits.—There are really only five classes of electric circuits in very general use.

1. *Electrometallurgical Circuits*, on which the potential is usually very low, being only 3 to 6 volts for electroplating. In the electrolytic refining of copper the voltage is sometimes about 100 where there are a large number of vats in series. On the low-voltage circuits the current is usually very great, being often several thousand amperes.

The dynamos should be simple shunt wound to give a direct current of the required voltage, and regulated by means of a rheostat in the field-circuit. Motors are rarely used on these circuits, but a shunt or series wound motor could be run if desired in the same way as upon the circuits described in the following paragraph.

2. Low (Constant) Potential Direct Current Circuits for light and power are either two wire (Fig. 18) or three wire (Fig. 32). On the former the potential is kept constant and between 110 and 125 volts, the current being about one half ampere per 16 candle-power lamp and about 8 amperes per horse-power of motors in operation. (A standard of 80 volts is adopted in the navy.)

The voltage on the three-wire system is twice as great, or 220 to 250 volts, and the current one half. The two-wire system is almost universally used for light and power distribution, when the distance of the lamps or motors from the dynamos is not more than one-quarter to one-half mile. The three-wire system being employed where the average distance is greater, but not more than one to two miles.

Shunt or compound wound dynamos generating 115 to 125 volts are used on either the two or three wire systems, two dynamos being run in series in the latter case (Fig. 32). A single dynamo or pair of dynamos are used in small plants, and a dozen or more in large plants. It is always well to have one or more reserve machines.

Motors for the two-wire system should be plain shunt or compound wound for 115 to 120 volts (5 or 10 volts being lost on the line) and for the three wire they should be wound for 230 to 240 volts. Series-wound motors are sometimes used for elevator, fan, pump or other work, where there is no danger of the load being taken off (by the breaking of the belt, for example) which might allow them to "race" and destroy themselves. Compound-wound motors are adapted to work at variable speeds, such as is necessary in hoisting-apparatus, and they have the advantage that the shunt portions of their field-winding prevents them from racing.

Five-wire systems of about 450 volts are in use in Europe, but they are complicated, and have never been introduced in America.

3. Electric Railway Circuits are almost always operated at a nominally constant potential of 500 volts, but varying in practice between 450 and 550 volts. The average current is about 15 to 25 amperes per car. Stationary electric motors are very often supplied with current from electric-railway circuits. They should be shunt wound or "overwound series" for 500 volts nominal, but capable of standing at least 550, and should be particularly well made and insulated. Special "power circuits" of 500 volts are often used for supplying stationary motors only. These are similar to railway circuits, except that the current is steadier.

4. **Series Arc-lighting Circuits** are usually run at a constant current of about 10 amperes, the potential being about 50 volts per lamp on 10 ampere-circuits. The total voltage is usually 2000 or 3000, 40 or 60 lamps being connected in series, as shown in Fig. 19. Arc circuits of 7 and 20 amperes are sometimes used. The series system is used for arc-lighting where the lamps are very much scattered, the length of the circuits sometimes being as great as 10 or 15 miles. Formerly this system was almost invariably adopted for arc-lighting, but now arc-lamps are often put on the low-tension circuits, previously described, when the distances do not exceed those there stated.

Series-wound motors are operated on arc or constant current circuits, but they should be provided with an effective governor or cut-out, to prevent the speed from becoming excessive if the load is likely to be reduced or taken off. (See page 203.)

A great many types of these machines have been devised, but while there are a great many in use, they are not as extensively used as the plain, constant potential motors. Satisfactory results have been obtained, particularly in driving fans or other steady load; but a very variable load requires too much action on the part of the governor and tends to cause sparking. In short, motors on constant current circuits do not usually work as well as those on constant potential circuits, principally because it is difficult to govern the speed of the former, whereas a simple shunt motor runs at almost perfectly constant speed on a constant potential circuit, in spite of variations in load. Constant current or arc-dynamos, on the other hand, are thoroughly practical machines, and there are several very good types in exten-

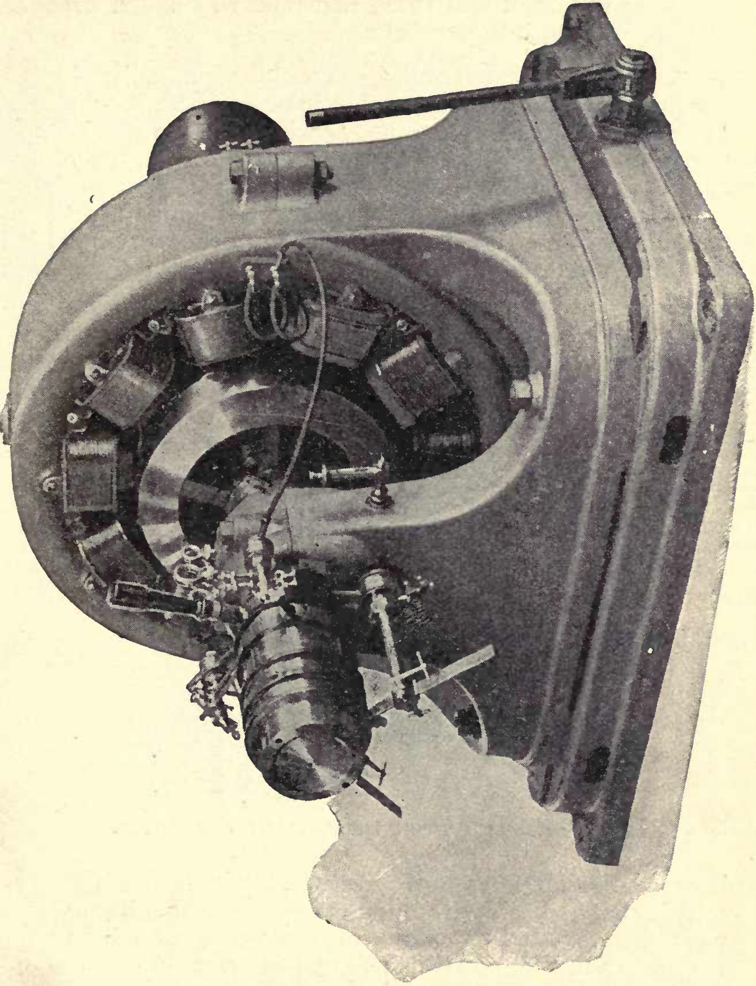


FIG. 5.—60-KILOWATT ALTERNATING CURRENT CONSTANT POTENTIAL GENERATOR, COMPOUND WOUND.

sive use; in fact, it was these machines which first brought electric-lighting into general use.

5. **Alternating-current Circuits** are generally adopted for supplying incandescent lights, in cases where the distance of the lamps exceeds one mile, or where the low-tension system is not applicable. The great advantage of the alternating current is that it can be transformed into a current of higher or lower pressure by a simple apparatus containing no moving parts. This makes it practical to distribute the current at high potential, usually 1000 volts, through wires which may be small because the amperes are correspondingly less. This current is changed at desired points by means of suitable transformers into currents of 50 or 100 volts, for feeding the lamps. (See Fig. 20.) The complication and cost of transformers, danger to life, and the difficulty of insulation of high-tension systems must, however, be considered.

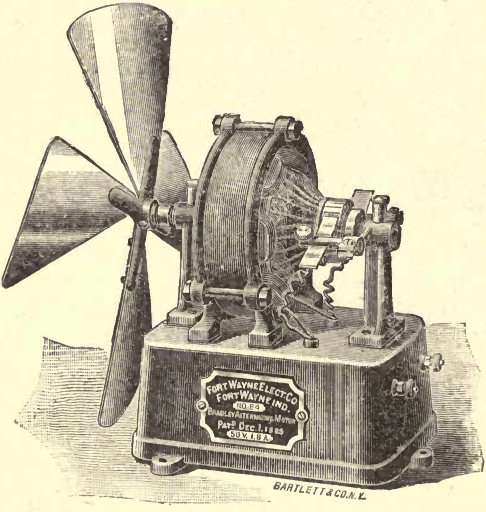


FIG. 6.—SMALL ALTERNATING-CURRENT FAN MOTOR.

An alternating-current dynamo (Fig. 5) possesses the advantage of having a pair of simple collecting rings instead of a commutator, and may thus be easily distinguished from a direct-current machine. An alternator usually requires a small direct-current dynamo to separately excite its field-magnets. Sometimes alternators are made self-exciting by having the current generated by a portion of their armature coils converted into a direct current by means of a commutator. These machines are also made compound wound or "composite" by rectifying by a commutator the main current or a current induced by it. Alternating-current motors have not yet been used in large numbers. Considerable difficulty has been found in constructing motors to operate well on the ordinary single-phase (two-wire) circuits. Small motors of this kind, however, are quite extensively used for driving fans, Fig. 6, and several types of larger motors have been brought out, but they are not yet in very general use.

Motors as well as dynamos, for two- and three-phase alternating currents, are very perfect machines; but at present the necessary circuits have not been widely introduced. The purpose to which these poly-phase currents are particularly applicable is the long-distance transmission of power. An enormous plant of this kind is now being installed at Niagara Falls.

CHAPTER IV.

DIRECTIONS FOR INSTALLING AND BELTING DYNAMOS AND MOTORS.

Setting up.—The place selected for a dynamo or motor should be dry, clean, cool, away from all pipes if possible, where the machine is in plain sight, and has plenty of room on all sides for easy access. It must be located so there is room enough to take out its armature. Avoid particularly any dusty, wet, or hot location. Any place near which grinding, filing, turning, or similar work is likely to be done is very undesirable for a dynamo or motor, as the dust and chips produced are liable to injure the bearings, commutator, and insulation of the machine. A firm and level foundation should be provided in any case, and machines of 20 H. P. or more should be set on solid stone, brick, or timber foundations (Fig. 7).

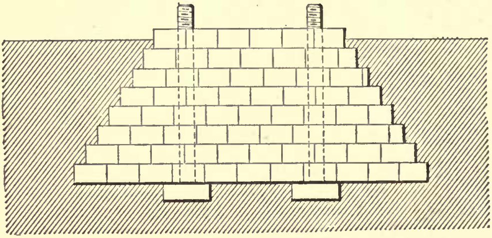


FIG. 7.—BRICK FOUNDATION.

Foundations for machinery should, if possible, be separate from the foundations or walls of the building, in order to avoid transmitting any vibration, which is sometimes very annoying. It is well, particularly in the case of high-voltage machines, to have them placed upon an insulating base-frame of wood, the pores of which should be filled with paraffine or well varnished to keep out moisture. If a wooden belt-tightening base is used, it will answer this purpose

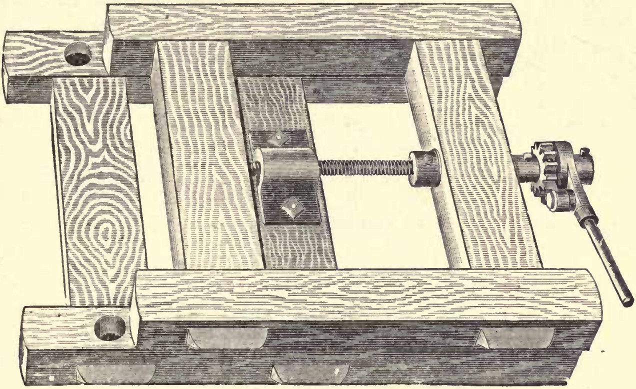


FIG. 8.—BELT-TIGHTENING WOODEN BASE-FRAME.

(Fig. 8); but if iron tracks are used, they should be placed on a wooden base.frame.

In unpacking and putting the machines together the greatest possible care should be used in *avoiding the least injury to any part*, in *scrupulously cleaning each part*, and in *putting the parts together in exactly the right way*. This care is particularly important with regard to the shaft, bearings, magnetic joints and electrical connections, from which every particle of grit, dust, chips of metal, etc., should be removed. It is very desirable to have machinery put together by a person thoroughly familiar with its construction, and in the absence of such a person no one should attempt it without at least a drawing or photograph of the complete machine as a guide. An exception may be made to this rule if the machine is very simple and the way to put it together is perfectly obvious, but in no event should the installation or management of machinery be left to guess-work. The armature should be handled with the greatest possible care, in order to avoid injury to the wires and their insulation, as well as to the commutator and shaft Handle and support the armature as far as possible by the shaft, and avoid any strain on the armature-body or commutator. If it is necessary to lay the armature on the ground interpose a pad of cloth; but it is much better to rest the shaft on two wooden horses or other supports. A convenient form of sling for handling armatures is shown in Fig. 9.

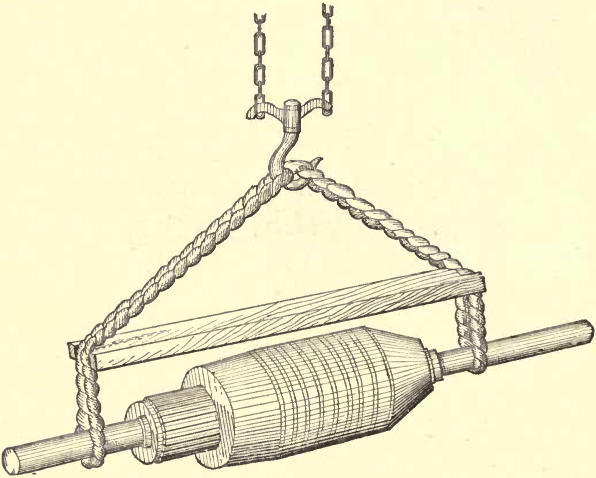


FIG. 9.—SLING FOR HOISTING ARMATURE.

The bearings should be very carefully cleaned, set in exactly the right position, and firmly screwed in place. The shaft should then revolve perfectly freely. The rings of self-oiling bearings and other oiling devices should be examined to see that they are adjusted to work properly (Fig. 10).

Pulleys.—A dynamo or motor usually has a pulley suited to it, furnished by the maker. In the case of a dynamo, do not use a smaller pulley, and with a motor do not use a larger one without consulting a competent electrical engineer, because either of these changes would increase the work of the machine. The size of pulley required on the other machine or counter-shaft, to which the given machine is to be connected, is found by multiplying the revolutions per minute of the dynamo or motor by the diameter of its pulley expressed in inches and dividing by the revolutions per minute of the other shaft, which gives diameter of pulley in inches. The proper speed for a dynamo or motor should always be obtained from its manufacturers, and this speed should not be departed from without their approval. It is commonly stamped on the name-plate of the machine or written on a card packed with it. A simple way of determining the sizes or speeds in any belt or gear transmission is to remember that the speed of either pulley or gear-wheel of a pair multiplied by its diameter is equal to the speed of the other multiplied by its diameter. An allowance should be made for two or three per cent loss of speed in the driven pulley owing to the slip of the belt. In fact, the usual result is that the speed actually obtained in practice is less than is expected, and this often makes a change of pulleys necessary.

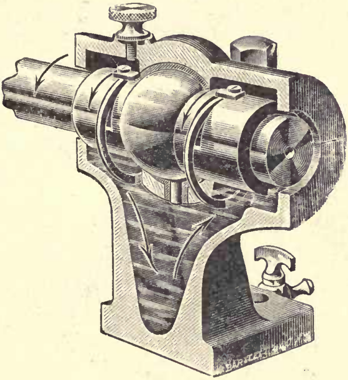


FIG. 10.—DETAIL OF SELF-OILING BEARING.

Belting.—The kind of belting to be selected is somewhat a matter of taste, but "light-double" leather belting is applicable to most cases, and is generally satisfactory. The width of belting is usually made about one inch less than the face of the pulley on the dynamo or motor. The common rule for determining width of belt is that "single" belt will transmit 1 H. P. for each inch in width at a speed of 1000 feet per minute. If the speed is greater or less, the power is correspondingly increased or decreased.

This is based upon the condition that the belt is in contact with the pulley around one half of its circumference or 180°, which is usually the case. If the arc of contact is less than half a circle the power transmitted is less in the following proportion: An arc of contact of 135° or three eighths of the whole circumference gives .84, while 90° or one quarter of the circle gives only .64 of the power derived from a belt-contact around one half of the circle.

If, on the other hand, the upper side of the belt sags downward, as should always be the case, and the belt is in contact with more than half of the circumference of the pulley, then the "grip" is considerably increased, the belt acting on the principle of a strap-brake. The greatly increased power that can be transmitted when the belt thus surrounds more than half of the pulley makes it very desirable to have the *loose side of the belt on top.* If the loose side is below, it sags away from the pulleys, and is also apt to strike the floor.

The complete formula is $\text{H. P.} = \frac{W \times S \times C}{1000}$; that is, the horse-power transmitted by a "single" belt is equal to the width of belt in inches (W) multiplied by the speed of belt in feet per minute (S), and by the figure depending upon the arc of contact (C), and divided by 1000. For example, a belt six inches wide travelling at 1500 feet per minute and touching three eighths of the circumference of the pulley will transmit:

$$\frac{6 \times 1500 \times .84}{1000} = \frac{7560}{1000} = 7.56 \text{ H. P.}$$

"Double" belting is expected to transmit one and one half, and "light double" one and one quarter times as much power as "single" belting. Another rule for calculating the power that a single belt will convey is that 75 sq. ft. per minute passing over the pulley transmits one H. P.

Rope-belting is employed more than leather in Europe, and is now used a little in America. Its advantages are lightness, cheapness, quietness, and large capacity in small space. It is particularly suited to cramped locations, a number of turns being used around both pulleys; and to very long distances, for example, between separate buildings, where a long single rope is used.

Cotton or hemp rope, from one to two inches in diameter, is used, running in V-grooves of about 45°, which wedges the rope and gives a good grip. A very long even splice is required. When several ropes running side by side are employed they may be entirely separate and complete belts, or one long one making several turns, in which case the rope is crossed over from the last groove to the first by a slanting idler pulley, which serves also as a belt-tightener. The capacity is from 5 to 10 H. P. per one-inch rope at 3000 feet per minute, which is the usual speed. The power of rope belting increases as the square of its diameter.

Rubber belt has 50 % more adhesion than leather. Rubber stretches continuously. For new leather allow one quarter to one half inch per foot for stretching. Belts slip or "creep" on the pulley about two per cent; hence in determining size of pulleys when speed must be accurate, arrange them to make the calculated speed two per cent too high.

The smooth side of a belt should be run against the pulley, as it transmits more power and wears better. An endless belt should be used for dynamos and motors, since they usually run at high speeds. When belts are joined or spliced while inposition on the pulleys, which is often necessary, some form of belt-clamp is required, such as is shown in Fig. 11.

The belt is stretched very tight with this, and the ends are held in position, overlapping each other by the clamp. Both ends are previously pared down with a sharp knife till they are the shape of a long, thin wedge, so that when laid together a long, uniform joint is formed of no greater thickness than the belt itself. The parts are then firmly joined by cement and rivets.

If an endless belt is not used the joint should be very carefully laced, so as to make it as *straight* and *smooth* as possible. In lacing-belts there must always be as many stitches of the lacer *slanting* to the left as there are to the right. Otherwise the ends of the belt will shift sideways, owing to the unequal strain, and the projecting corners will catch on something. Two good ways of doing this are shown in Fig. 12. In plan A 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.

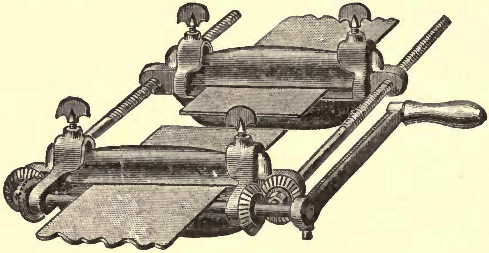


Fig. 11.—Clamp for Stretching Belt and Holding Ends while Making Joint.

In plan B the holes are all made in a row. This plan has the advantage of making the lacers 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 13A, which are additional holes for fastening the ends of the lacer.

A six-inch belt should have seven holes in each part, if there are two rows of holes; other widths in proportion; with one row the number is less. Be very careful to measure correctly the length of belt required, as it is very awkward to have it too short or even too long if it be an endless belt. If the machine has a belt-tightener, measure for the belt when the position of tightener makes the belt the *shortest*, in order to allow for stretch, which is considerable in some belts.

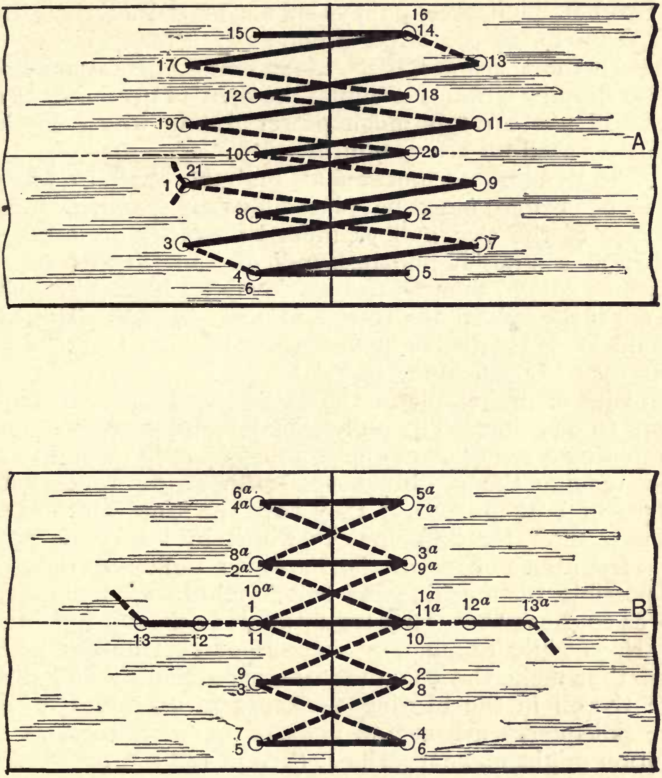


FIG. 12.—METHODS OF LACING A BELT.

The smooth side of the leather of the belt goes against the pulley. The dotted lines represent the lacing on the side away from pulley.

Avoid short or vertical belts, as they are much more apt to slip than long or horizontal ones. In connecting pulleys at different levels, make the belt as nearly horizontal as possible. The belt should make an angle of at least 45° with the vertical, if possible. The distance between the centres of two belt-connected pulleys should be at least three times the diameter of the larger pulley, and it may well be four times if the space permits. Make belt just tight enough to avoid slipping without straining the shaft or bearings. A new belt will not carry as much power as one which has been properly used for a few months.

The dynamo or motor shaft and the shaft to which it is to be belted must be placed exactly parallel, and the centres of the two pulleys must be exactly opposite each other in a straight line perpendicular to the shafts. The machine should then be turned slowly by hand with belt on to see if the belt tends to run to one side of pulley, which would show that it is not yet properly "lined up;" and in this case the machine should be slightly moved until the belt runs in the middle of the pulleys and does not tend to work to one side. The pulleys may be brought into line by stretching a string across both pulleys parallel with the belt, and moving the machines until the string touches both edges of both pulleys, if they have the same width of face. If not, allow for difference in width by measuring with a rule from both edges of the narrower pulley, to the string. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of side motion of belt, and thus make the commutator wear smoothly and distribute the oil in the bearings,—except in machines in which the pole-pieces are at the ends of the armature, as such motion might make it strike. (See p. 142.)

It is always desirable to have belts as pliable as possible; hence the use of some good belt-dressing is desirable. Rosin and other sticky substances are sometimes used to increase the adhesion of belts, but this is a practice which is only allowable in an emergency.

In places where they are liable to catch in the clothing or hair of any person, belts should be enclosed by boxing or railing.

CHAPTER V.

WIRING AND CONNECTIONS.

Electrical Connections.—As already stated, these should be very carefully cleaned, and this may well be carried to the extent of rubbing them vigorously with clean cloth or chamois-skin. Any of the metal surfaces used in making electrical contacts which are tarnished should be brightened with fine sand-paper or by scraping them; but all sand, metallic particles, etc., must be carefully removed afterwards. Particles of sand or dirt are often left accidentally between surfaces which should be in perfect contact.

Wiring.—It is very desirable to have a thoroughly competent lineman or electrician to connect a dynamo or motor to the circuit, see that everything is properly arranged, and start the machine the first time. The regulations of the local authorities, especially the Fire Underwriters, should be looked up and carefully followed, not only as a guide to good construction, but also to save trouble, expense, and delay which might result from ignoring them.

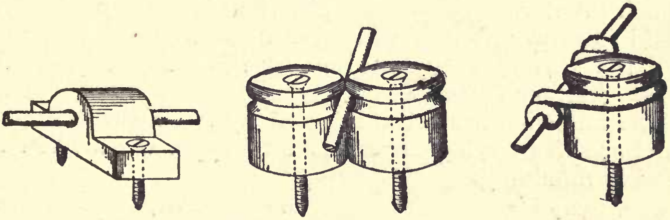


FIG. 13.—WIRES CARRIED ON PORCELAIN.

The connections should all be made in a substantial and permanent manner. Good quality of insulated wire, preferably rubber-covered, should be used, and should be properly arranged and laid.

Temporary, loose, or poorly insulated wires or connections are very objectionable. All circuits exposed to moisture should be supported on glass, porcelain, or other waterproof insulators. Circuits of over 250 volts, even where not exposed to moisture, should also be carried on porcelain or similar insulators, as shown in Fig. 13, and out of reach if possible.

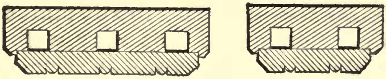


FIG. 14.—MOULDINGS.

Low-voltage circuits of 230 volts or under may be run in wooden moulding or cleats (Fig. 14), where entirely unexposed to moisture. Where wires pass through walls, floors, over pipes, or are otherwise liable to injury, they should be protected by hard-rubber tubing or other equally good covering. No wire smaller than No. 8 B. & S. gauge should be used for the arc current of 10 amperes.

The ordinary rule is that wires should have from 500 to 1000 circular mils per ampere. The former figure (500) is for small wires, in cool places; the latter figure (1000) is for wires carrying heavy currents or high voltage, and wires in hot places, such as ceilings of kitchens, etc., or for wires when wound in a coil, in which case the rise in temperature is much greater. No wire smaller than No. 16 should ever be laid to carry any current from a dynamo, no matter how small the current may be. Smaller wires may be used for primary-battery currents.

The following are recommended by the insurance companies as safe-carrying capacities for copper wires when inclosed in moulding:

Brown & Sharp Gauge No.	Amperes.	Brown & Sharp Gauge No.	Amperes.
0000	175	5	45
000	145	6	35
00	120	7	30
0	100	8	25
1	95	10	20
2	70	12	15
3	60	14	10
4	50	16	5

A micrometer screw caliper is extremely convenient, and better than any gauge for measuring wires.

It is wise to have an ample margin. Failure to allow a proper factor of safety has been the cause of most of the troubles in all branches of electrical work.

In addition to the above allowances for current capacity or the ability of wires to carry the current without overheating, it is also necessary to consider the fall of potential or "drop" on wires. This loss is usually about 5 per cent in isolated plants, 10 per cent in central-station systems, and 10 to 20 per cent in long-distance transmission—that is to say, the voltage at the most remote point on the system should not fall below the voltage at the dynamo by more than these percentages. "Wiring-tables" for determining the size of wire required in various cases are given in many electrical books—in fact, there are several entirely devoted to wiring, and the reader is referred to them. A simple rule derived from Ohm's law, applicable to all cases, except with alternating currents, is that the lost voltage or "drop" on any portion of a circuit is obtained by multiplying the maximum current in amperes in that portion by the resistance of that portion of the circuit in ohms. With alternating currents an additional "drop" occurs, due to "reactance," which, together with the ohmic loss, is called the impedence.

In the case of a branching circuit, where the current is not the same throughout, the separate parts should be treated separately, as indicated in the diagram.

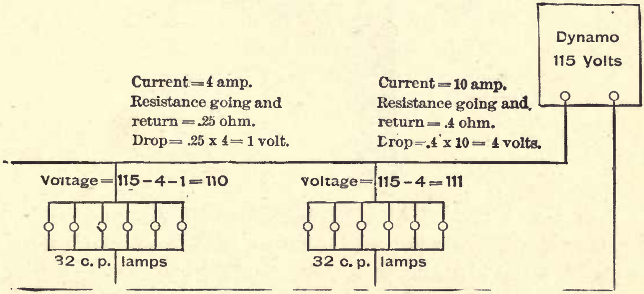


FIG. 15.—"DROP" ON BRANCHING CIRCUITS.

Switches and Cut-outs.—The bases of all switches, cut-outs, etc., should be of treated slate, porcelain, marble, or other fire-proof, non-porous insulating material. On all constant-potential or multiple arc circuits, double-pole fusible

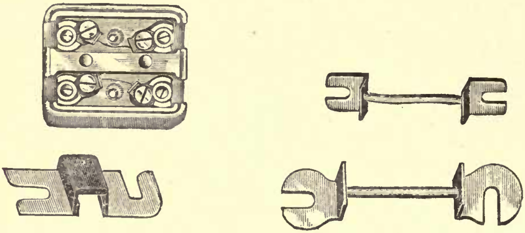


Fig. 16.—Double-pole Fusible Cut-out, and Safety Fuses, Link Pattern.

cut-outs should be put where each branch starts. On all constant current or arc-circuits, double-pole cut-out switches (see page 78) should be put where the circuit enters any building

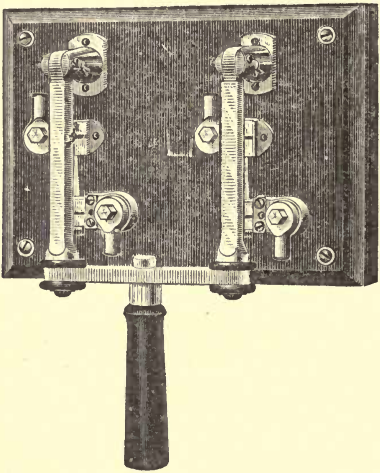


Fig. 17.—Double-pole "Quick-break" Knife-switch.

within reach of firemen, and also near any motor or group of lamps on such circuits (Fig. 38). All high voltage circuits and any low voltage circuit carrying more than three amperes should be controlled by double-pole "quick-break" switches or cut-outs, which will entirely disconnect both sides of the circuit. Fig. 17 shows a switch of this description for large currents.

The exceptions to this rule are, first, constant-potential dynamos, which usually have single-pole knife-switches, the other pole being permanently connected to the circuit; and, second, constant-potential motors, which generally have single-pole switches on the starting-boxes; the other pole being always connected to the circuit. In the latter case, however, it is recommended to put a double-pole quick-break switch (Fig. 17) in the circuit, also (see pages 63 and 79); in fact, this is required by the underwriters in most cities.

Diagrams of Connections are given for each important case to show the connections actually required. But when a machine is to be "connected up" a competent electrical engineer should be consulted, or an exact diagram should be obtained from the maker of the machine, as its connections may be peculiar, and cause serious trouble. Diagrams merely represent the path of the current in the simplest way, the important thing in electrical connections being to get these paths right, or to know which parts or wires are to be connected. Whether the path be straight or crooked, vertical or horizontal, etc., is not of much consequence, except that the crossing of wires should be avoided as much as possible; and where it occurs, one wire should be protected with a hard insulating-tube, or the upper wire should be bent away from the lower one so that there can be no danger of their touching each other. Diagrams of the three most important kinds of dynamo connections are given in Figs. 18, 19, and 20; in fact, nearly all plants are included in these three fundamental types, which are described in the three following paragraphs. The other diagrams of dynamo and motor connections are given hereafter.

Shunt Dynamo, supplying Constant-potential Circuit, is represented in Fig. 18, with the necessary connections. The brushes *B* and *B′* are connected to the two conductors forming the main circuit, also to the field-magnet coils *through* a resistance-box to regulate the strength of current, and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors to measure the voltage or electrical pressure between them. One of the main conductors is connected through an amperemeter, which measures the total current on the main circuit. The lamps or motors are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations, described on page 23.

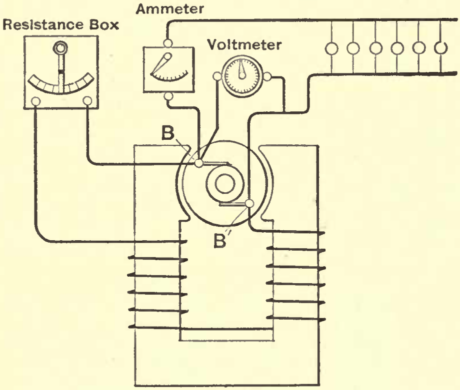


FIG. 18.—SHUNT DYNAMO, SUPPLYING CONSTANT-POTENTIAL CIRCUIT, WITH LAMPS IN PARALLEL.

Series Dynamo, supplying Constant-current Circuit.—The connections in this case are extremely simple, the armature, field-coils, amperemeter, main circuit, and lamps all being connected in one series (Fig. 19), and the current being kept constant. This system is the one commonly used for arc-lighting, as described on page 24.

Alternating-current Plant.—The proper connections in this case are shown in Fig. 20, in which the names of the different parts of the plant are given, and which therefore requires no explanation. This is the regular high-tension

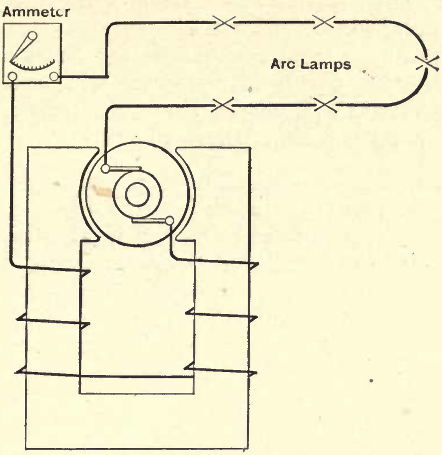


FIG. 19.—SERIES DYNAMO, SUPPLYING A CONSTANT-CURRENT CIRCUIT, WITH LAMPS IN SERIES.

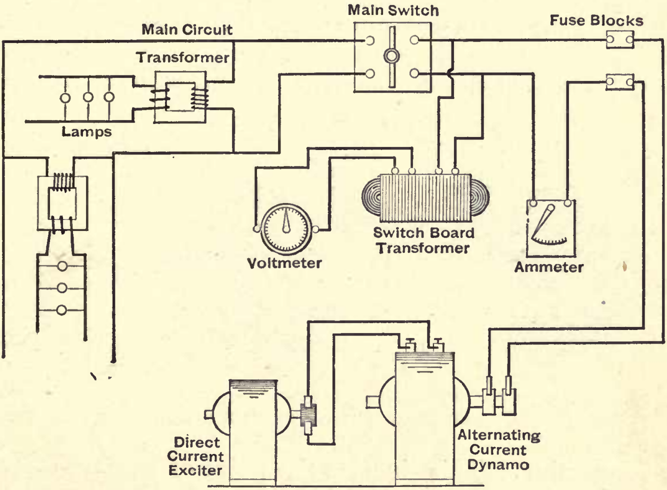


FIG. 20.—ALTERNATING-CURRENT PLANT.

alternating-current system extensively used for electric lighting, as explained on page 26.

The diagrams of connections of all cases of *dynamos coupled together* are given in Chapter VII, and of *electric motors* in Chapter VIII, where they are purposely put to accompany the explanations there given.

The Direction of Rotation of the various machines is sometimes a matter of doubt or trouble. Almost any dynamo or motor is intended to be run in a certain direction, that is, it is called right-handed or left-handed, according to whether the armature revolves right-handed, like the hands of a clock, when looked at from the pulley end; unfortunately some persons reverse this rule, and consider it from the commutator end. Dynamos and motors are usually designed to be right-handed, but the manufacturer will make them left-handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top (page 32), or to permit the machine to occupy a certain position where space is limited. To reverse the direction of rotation of an ordinary shunt, series, or compound wound direct-current, two-pole dynamo or motor, the brushes may simply be reversed as indicated in Fig. 21, without changing any connection. This changes the point of contact of each brush tip 180°. If the machine is multipolar, a similar

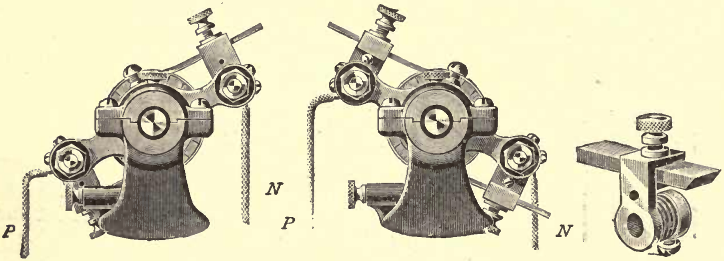


Fig. 21.—Reversing Position of Brushes to reverse Rotation, all Connections remaining the same.

change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc. The direction of the current and the polarity of the field-magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus. A separately excited alternating-current dynamo can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the commutator, and their tips moved through an angle as above if the rotation be reversed.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are perpendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current generated by a dynamo is opposite to that desired, the two wires leading out of it should exchange places in the terminals. Or if this is not desired, reverse the residual magnetism by a battery or other current.

Changing the direction of the current by reversing the main wires or otherwise does not reverse the direction of rotation of any motor, since it reverses *both* the armature and field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connections *alone*, leaving the other the same as before.

CHAPTER VI.

DIRECTIONS FOR STARTING DYNAMOS.

General.—Make sure that the machine is clean throughout, especially the commutator, brushes, electrical connections, etc. Remove any metal-dust, as it is very likely to make a ground or short circuit.

Examine the entire machine carefully, and see that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, and that the passages for the oil are clean and the feed is at the proper rate. In the case of self-oiling bearings see that the rings or other means for carrying the oil work freely. See that the belt is in place and has the proper tension. If it is the first time the machine is started, it should be turned a few times by hand, or very slowly, in order to see if the shaft revolves easily and the belt runs in centres of pulleys.

The brushes should now be carefully examined and adjusted to make good contact with the commutator and at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care and brought up to full speed, gradually if possible; and in any case the person who starts either a dynamo or a motor should closely watch the machine and everything connected with it and be ready to throw it out of circuit if it is connected, and shut down and stop it instantly if the least thing seems to be wrong, and should then be sure to find out and correct the trouble before starting again. (See Part III, "Locating and Remedying Troubles.")

Starting a Dynamo.—In the case of a dynamo it is usually brought up to speed either by starting up a steam-engine or by connecting the dynamo to a source of power already in motion. The former should of course only be attempted by a person competent to manage steam-engines and familiar with the particular type in question. This requires special knowledge acquired by experience, as there are many points to appreciate and attend to, the neglect of any of which might cause serious trouble. For example, the presence of water in the cylinder might knock out the cylinder-head; the failure to set the feed of the oil-cups properly might cause the piston-rod, shaft, or other part to cut. And other great or small damage might be done by ignorance or carelessness. The mere mechanical connecting of a dynamo to a source of power is usually not very difficult; nevertheless, it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from a loose pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high, and should not be tried except by a person who knows just how to do it. Even if a stick is used for this purpose it is apt to be caught and thrown around by the machinery, unless it is used in exactly the right way.

It has been customary to bring dynamos to full speed before the brushes are lowered into contact with the commutator; but this is not necessary, provided the dynamo is not allowed to turn backwards, which sometimes occurs from carelessness in starting, and might injure copper brushes by causing them to catch in the commutator. If the brushes are put in contact before starting they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine can be stopped, before any injury is done to it or to the system. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next chapter). If there are a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected an instant (see Dynamo Fails to Generate, Cause 3, page 157).

If one dynamo is to be connected to another or to a circuit having other dynamos or a storage battery working upon it, the greatest care should be taken. This coupling together of dynamos can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

CHAPTER VII.

SWITCHING DYNAMOS INTO CIRCUIT.

TWO or more machines are often connected to a common circuit. This is especially the case in electric-lighting, where the number of lamps required to be fed varies so much that one dynamo may be sufficient for certain hours, but two, three, or more machines may be required at other times. The various ways in which this is done depending upon the character of the machines and of the circuit and the precautions necessary in each case, make this a most important and interesting subject, which requires careful consideration.

Dynamos may be connected together either in parallel (multiple arc) or in series.

Dynamos in Parallel.—In this case the + terminals are connected together or to the same line and the — terminals are connected together or to the other line. The currents (i.e., amperes) of the machines are thereby added, but the E. M. F. (volts) are not increased. The chief condition for the running of dynamos in parallel is that their voltages shall be equal, but their current capacities may be different. For example: A dynamo producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working, is, therefore suited to constant potential circuits. A dynamo to be connected in parallel with others or with a storage battery must first be brought up to its proper speed, E. M. F., and other working conditions, otherwise it will short-circuit the system, and probably burn out its armature. Its field magnetism must therefore be at full strength owing to the fact that it generates no E. M. F. with no field magnetism. Hence it is well to find whether the pole-pieces are strongly magnetized by testing them with a piece of iron, and to make sure of the proper working of the machine in all other respects before connecting the armature to the circuit. It is a common accident for the field-circuit to be open at some point, and thus cause very serious results. In fact, a dynamo should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to or slightly (not over 1 or 2 per cent) greater than that of the circuit. If the voltage of the dynamo is less than that of the circuit the current will flow back into the dynamo and cause it to be run as a motor. The direction of rotation is the same, however, if it is shunt-wound, and no great harm results from a slight difference of potential. But a compound-wound machine requires more careful handling (see page 53).

Dynamos in Parallel are therefore always Shunt-wound (or Compound-wound).—The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or voltmeters connected to each may be compared (Fig. 22). Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer, and when the latter indicates no current it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp,"

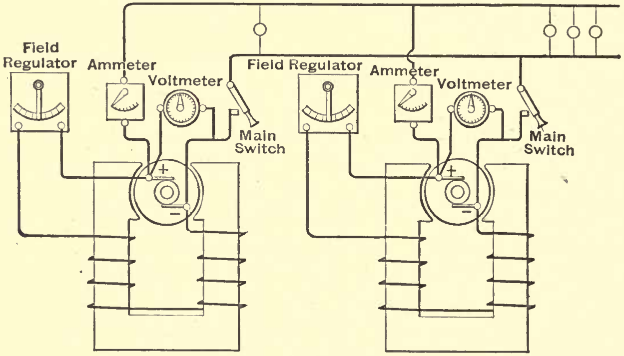


FIG. 22.—SHUNT DYNAMOS IN PARALLEL.

or other lamp fed by it, is fully as bright as the lamps on the circuit, and then connect the dynamo to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive wire, and the negative terminal to the negative wire (Fig. 22); otherwise there will be a very bad short-circuit.

When the dynamo is first connected in this way it should only supply a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

Series-wound Dynamos in Parallel not Used.—If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a short-circuit of double voltage, which is fatal. In fact, series dynamos in parallel are in very unstable equilibrium, because if either tends to generate too little current, that weakens its own field, which is in series, and thus still further reduces its current, and probably reverses the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome, is by causing each to excite the other's field-magnet, as shown in Fig. 23, so that if one generates too much current, it strengthens the field of the other, and thus counteracts its own excess of power.

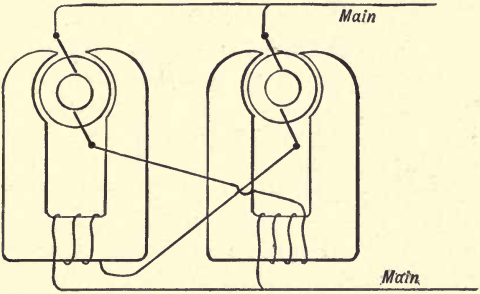


FIG. 23.—SERIES DYNAMOS IN PARALLEL, ARRANGED TO BALANCE.

Or both fields may be so connected as to be excited by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two — brushes respectively, by the line and by what is called an "equalizer" (Fig. 24). By this means the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is extremely important.

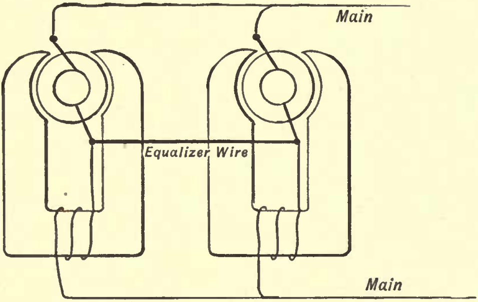


FIG. 24.—SERIES DYNAMOS IN PARALLEL, WITH FIELD CURRENTS "EQUALIZED."

Compound Dynamos in Parallel.—Since the field-magnets of these machines are wound with series as well as shunt coils, the coupling of them is a combination of the cases of the shunt and the series wound machines just described.

Fig. 25 represents in simplest outline two compound machines in parallel.

Assume that one machine is already running, that switches F¹ in the shunt circuit and S¹ in the main circuit are closed, and that armature No. 1 is generating its full current, and feeding the lamps on the main circuit, the shunt and series field-coils of the machine carrying their proper current. Now to throw on the other dynamo, its armature (No. 2) is brought up to normal speed, switch F² is closed, which excites its shunt-coil. Switch E, on the "equalizer" is then closed, which excites its series coil with part of the main current from No. 1. The voltage of the machine to be connected (No. 2) should then be compared with and made about one per cent higher than that of the circuit, and then it may be thrown in by closing the main switch S_2, as described for shunt machines on page 50. The machine should only generate a small current at first, but it may then be regulated by its rheostat to carry its share of the load. The "equalizer" should be closed before the main switch and before comparing the voltages, otherwise the machine will take too much load at first. Greater care and closer agreement in voltage is required with compound than with plain shunt dynamos both in coupling and in running.

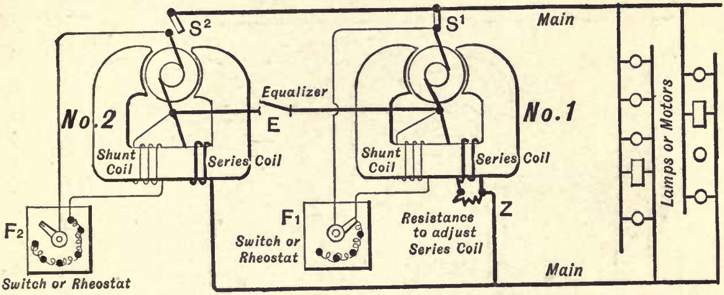


FIG. 25.—OUTLINE OF CONNECTIONS, COMPOUND DYNAMOS IN PARALLEL, WITH EQUALIZER BAR.

In disconnecting a machine the same steps are taken, only in exactly the reverse order. More than two compound machines may be run in parallel in this way by connecting them in a precisely similar manner.

Compounding is most extensively used in the large modern types of dynamos, which are nearly all multipolar, four poles being the most common. In these (Fig. 26) there are as many spools as fields, and as each contains both series and shunt coils the connections become complicated. Fig. 27 represents the connections of a standard four-pole compounded generator and of a shunt-wound generator. If the four coils are taken as one, it will be seen that they are the same as Figs. 25 and 18, respectively.

Compound dynamos of different size or current capacity may also be coupled as described, provided of course their voltages are equal, and provided also that the resistances of

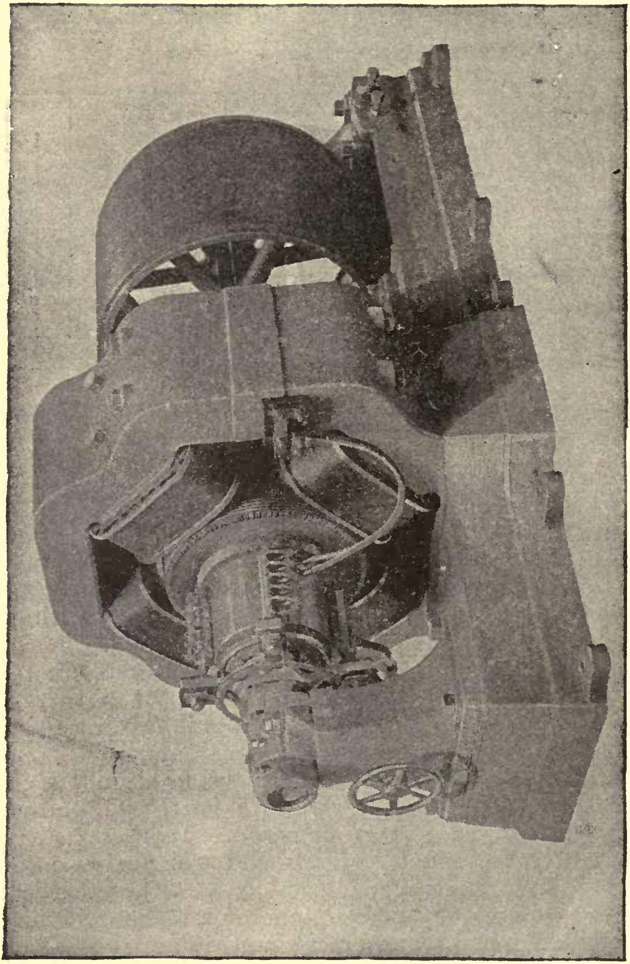
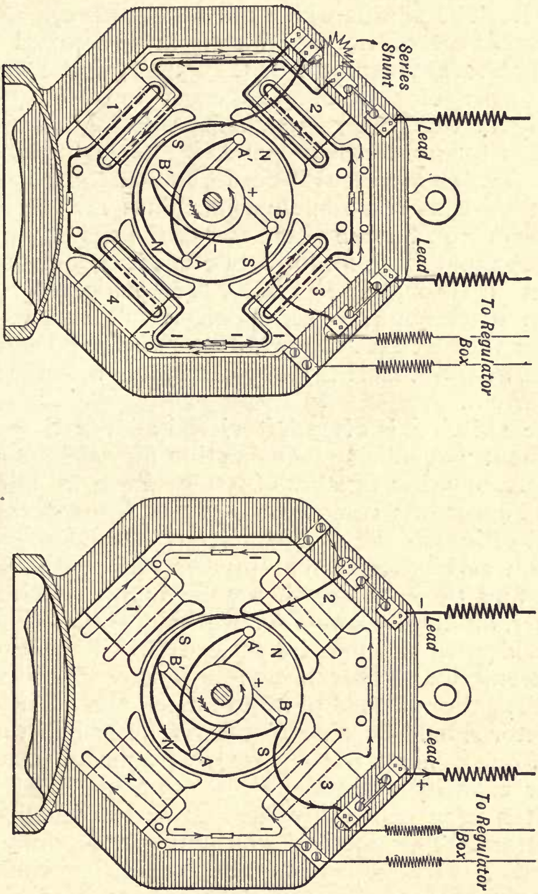


Fig. 26.—600-H.P. Generator for Electric Railways.

the series field-coils are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series-coil should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages. If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series-

CONNECTIONS FOR COMPOUND WOUND GENERATORS.

CONNECTIONS FOR SHUNT WOUND GENERATORS.



O, OUTSIDE TERMINAL OF COIL. I, INSIDE TERMINAL OF COIL.

FIG. 27.

coil of the machine, which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series-coil between the latter and the main conductor or 'bus bar. The shunts which are almost always used to adjust the effect of the series-coils in compound dynamos (shown at *Z* in machine No. 1, Fig. 25; and at upper left-hand corner of compound dynamo in Fig. 27) operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series-coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for the shunt makes the compounding effect in the dynamo more uniform, because its resistance rising as the current through it increases, throws a greater *portion* of the current through the series-coils at full load, and compensates for the fact that the field-magnetism, and consequently voltage, does not increase proportionately with the increasing load current.

The switch *E* is often left closed all the time; in fact a permanent "equalizing" connection may be made between the corresponding brushes of two or more machines. This has the effect of "compounding" the dynamos collectively instead of individually. For example, when only one dynamo is working, its current divides among the series-coils of all, and these coils will not be highly excited; when, however, all the dynamos are working, the whole current of each will pass through its series-coil. Thus the greatest field strength, and therefore voltage, is produced when most needed, at the full load of all the machines. The equalizing conductor should be able to carry at least half the full current of one dynamo in the case of two machines, and of still greater capacity when there are more machines. Trouble has often been caused by the use of too small equalizing conductors. This method of running compound dynamos in parallel, without opening the equalizing connection, is important, because it makes the effect of the series-coil proportional to the total load, instead of the load on each machine. This is particularly desirable in central stations, or where dynamos are "overcompounded." Shunt-wound dynamos run in parallel tend to steady each other, for if one happens to run too fast it has to do more work, which opposes the increase of speed, and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series-coil, and it is necessary that their speeds, voltages, etc., should agree much more exactly than with simple shunt machines. It is not uncommon for them to work badly together, owing to carelessness or imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

Alternators in Parallel.—Since the alternating current consists of waves, it is necessary, in order to properly connect alternators together, that they should agree, not only in *voltage*, but also in two other respects: first, in *frequency*, or the number of waves produced per second; and, second, in *phase*, that is, their current waves should be at corresponding points at the same instant. The case is precisely similar to that of two persons walking together: they should not only have the same *speed* and *length of step*, but they should also be *in step*. If an alternator is thrown into circuit with others when not exactly in phase, it will cause severe fluctuations in the lamps.

Even the highest authorities do not agree in regard to the best conditions for parallel running of alternators, but it is certainly a fact that there is quite a strong tendency for alternators working in parallel to remain in phase after they have once been brought exactly into unison, for the same reason that alternating-current motors tend to run synchronously with the generator, the action being similar to that of two cog-wheels.

In a number of European stations alternators are regularly and successfully operated in parallel, but in America this practice is not common. This difference is probably due chiefly to the fact that the frequency usual in this country is higher than in Europe, which necessitates an exceedingly close agreement in order that machines may work well together. For example, an alternator with 16 poles and 1000 revolutions per minute would be entirely thrown out of phase if it differed $\frac{1}{16}$ of a revolution from the other machine. Nevertheless, this running in parallel can be and is done successfully, provided the engines as well as dynamos are properly adjusted to each other. A sudden change in the number of lamps in circuit might produce a different effect on the dynamos or engines, and would throw them out of synchronism. For example, the governor of one engine might act more slowly than that of the other, and cause the former engine to fall behind. Other similar differences in action have made it difficult or impossible to run alternators in parallel in many cases but if the conditions are favorable there is no trouble, and the actual operation is as follows:

To throw an alternator into circuit with others, bring its speed up to the proper point, regulate the field-exciting current to make the voltage of the machine equal to that of the circuit. The phase may then be determined by connecting two lamps in series to the secondary circuits of two transformers at the same time, the primary circuits being fed respectively by the machine to be switched in and by the others, or the main circuit.

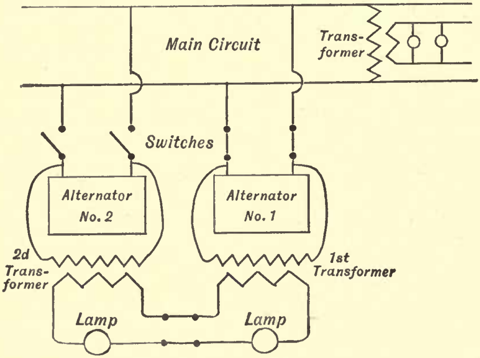


FIG. 28.—METHOD OF BRINGING ALTERNATORS INTO SYNCHRONISM.

The secondaries of, say, 50 volts each should be connected in series with each other and to two 50-volt lamps.

When the phases of the currents of the two machines are opposed the lamps are dim, and *vice versa.* If the lamps flicker badly the phase is not right; but if the lamps are steady at full brightness, the machine is in phase, and it may be connected without disturbing the circuit by closing its main switch.

If dynamos are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

Dynamos in Series.—This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which are very successful. (See Part IV.) The conditions are exactly opposite to those in the preceding group—dynamos in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. If dynamos are in series, each of them must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together, and therefore danger to persons, insulation, etc., is increased in proportion.

Series-wound Dynamos in Series are connected in the simple way represented in Fig. 29, but, usually, machines connected in series are for arc-lighting,—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one

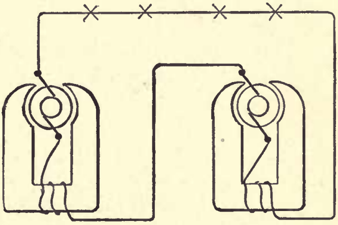


Fig. 29.—Series-wound Dynamos in Series.

regulator to give full E. M. F. and let the other alone control the current. This latter plan can only be followed when the variation in load does not exceed the power of

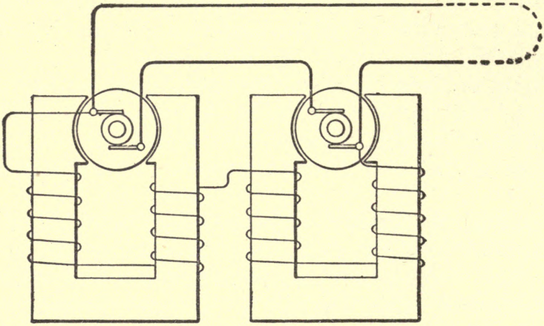


FIG. 30.—SHUNT DYNAMOS IN SERIES. FIELDS JOINED AND FED BY BOTH ARMATURES.

one machine. Constant-current or "series" dynamos having regulators with little inertia in the moving parts or tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

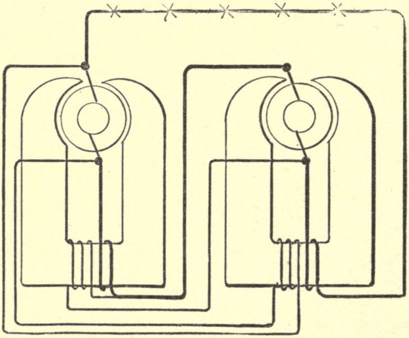


FIG. 31.—COMPOUND DYNAMOS IN SERIES, SHUNT COILS OF EACH EXCITED BY ARMATURE OF THE OTHER.

Shunt or Compound Dynamos in Series may be run well, provided the shunt field-coils are connected together to form one shunt across both machines, as indicated in Fig. 30. If the machine is compound, the series-coils must be connected in series in the main circuit. Or each shunt field may be connected so that it is fed only by the armature of the other machine (Fig. 31). Or both the shunt-coils may be connected so as to be fed by one armature, the series-coils being in the main circuit, as before.

Alternators in Series.—The synchronizing tendency which makes it possible under certain circumstances to run alternators in parallel (page 57) causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected together so they must run exactly in phase, and add their waves of current, instead of counteracting each other. This is a case that rarely arises in practice.

Dynamos on the Three-wire System (Direct Current).—In the ordinary three-wire system for incandescent-lighting, as represented in Fig. 32, no particular precautions are required in starting or connecting dynamos. As a matter of fact, the two dynamos are almost independent of each other, and work on practically separate circuits. Dynamo 1 feeds the circuit formed by the mains marked + and *N*, and dynamo 2 feeds the circuit formed by mains *N* and —. The "neutral" wire *N* merely acts as a common conductor for both circuits. There is, however, a tendency for one of the dynamos to be reversed by the other in starting up, shutting down, or in case of a bad short circuit. This may be avoided by exciting all the field coils from one dynamo or "side" of the system. (See page 52.) This and other difficulties on three-wire circuits are treated on page 154. The E. M. F on each circuit should be kept constant at the precribed voltage, and the current on the two circuits or "sides" of the system should be kept as nearly equal as possible by distributing the lamps equally between them. Any difference in current either way is carried by *N*. One dynamo may be run alone on one side of the system, and the only effect of throwing on the other dynamo is to reduce the "drop" or fall of potential on the wire *N*. In fact, if the load is equal on both sides there is practically no current or drop in *N*. If additional dynamos are put on the circuit in parallel—for example, two in parallel on each side of the system, making four dynamos in all—the machines on each side are managed simply as dynamos in parallel, as previously described, and they may be thrown in singly or in pairs (i.e., one on each "side"). This applies not only to the first dynamos, but also to those added in parallel afterward.

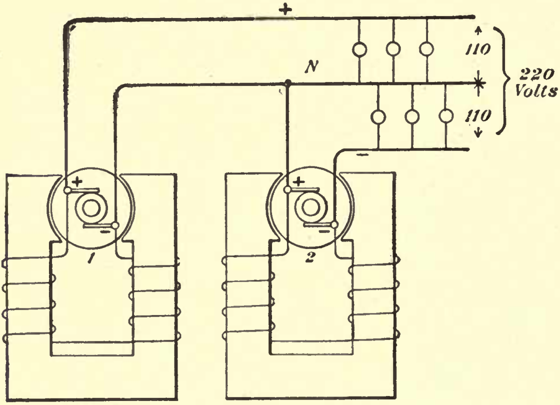


FIG. 32.—THREE-WIRE SYSTEM.

When only one dynamo is running, the lamps, etc., on both sides can be kept going by converting the system into a two-wire system temporarily by joining the two outside wires together by a "breakdown switch." But if there are chemical meters on the circuit that is thus reversed, they will be run backward. Besides, the middle wire has to carry as much current as the two outside wires combined, which might be very excessive; therefore this arrangement should not be employed with heavy loads.

CHAPTER VIII.

KINDS OF MOTORS AND METHODS OF STARTING.

THE general instructions relating to adjustment of brushes, screws, belt, oil-cups, etc., given in the chapter on starting dynamos, should be carefully followed preparatory to starting a motor.

The actual starting of a motor is usually a simple matter, since it consists merely in operating a switch, but in each case there are one or more important points to consider.

For Constant-potential Circuit, *Shunt-wound Motor.*—A motor, to run at constant speed on a constant-potential circuit (a 110-volt incandescent-lighting circuit, for example), is usually plain shunt-wound. This is the commonest form of stationary motor. The field-coils are wound with the right size of wire to have sufficient resistance, so that they will take the proper magnetizing current, as in the case of a shunt dynamo, and, since the potential is constant, the field strength is constant. Shunt-coils should be rewound or exchanged for those having the proper size and resistance of wire, if the potential is more than 10 per cent higher, or 20 per cent lower than that for which they are intended.

In starting shunt motors, throwing the field into circuit is simple. The difficulty is in taking care of the current in the armature, because the resistance of the armature is very low, in order to get high efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To prevent this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance-coils (Fig. 34).

The main wires are connected through a branch cut-out (with safety-fuses), and preferably also a double-pole quick-break switch *Q*, to the motor and box, as indicated in Fig.

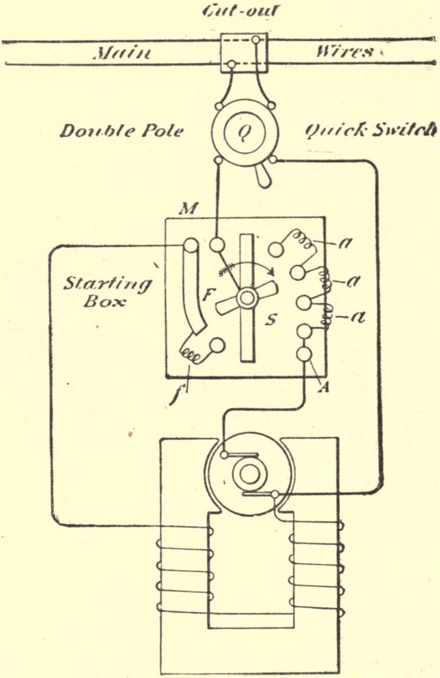


FIG. 33.—SHUNT MOTOR ON CONSTANT-POTENTIAL CIRCUIT

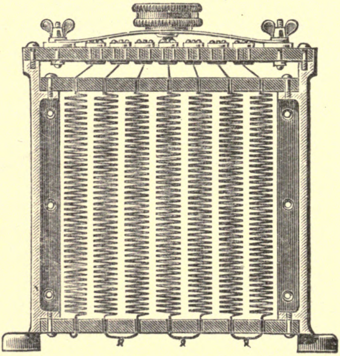


FIG. 34.—RESISTANCE-COILS.

33. When the switch *Q* is closed and the arm *S* is turned to the right, the field circuit is closed through the contact strip *F*, and the armature circuit is closed through the resistance-coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as its speed rises it generates a counter E. M. F., so that the arm *S* can be turned further until all the resistance-coils *a*, *a*, *a* are cut out, and the motor is directly connected to the circuit and running at full speed. The arm *S* should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm *S* should positively close the field circuit first, so that the magnetism reaches its full strength (which takes several seconds) before the armature is connected.

The object of the resistance *f* is to gradually decrease the current and thereby reduce the spark, which occurs when the field circuit is opened. But this resistance is not essential, and some boxes have a number of strips which merely subdivide the spark, and others have no connection at all between the field-coils and the starting or regulating box, the circuit being led directly from the switch *Q* to the field, the armature alone being connected through the resistance-box. The coils *a*, *a*, *a* are made of comparatively fine wire, which can only carry the current for a few seconds in a "starting-box;" but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm *S* may be left so that some of the resistances *a*, *a*, *a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator does not have to control a heavy current, but a special circuit of unvaried pressure has to be provided to keep the field of the motor constant.

For Constant-potential Circuit, *Series-wound Motor.*— The ordinary electric railway motor on the 500-volt trolley system is the chief example of this class (Fig. 35). Motors for electric elevators and hoists are either of this kind or the previous one. A rush of current tends to occur when this type of motor is started, similar to that in the case just described; but it is somewhat less, because the field-coils are in series, and their resistance and self-induction reduce the excess.

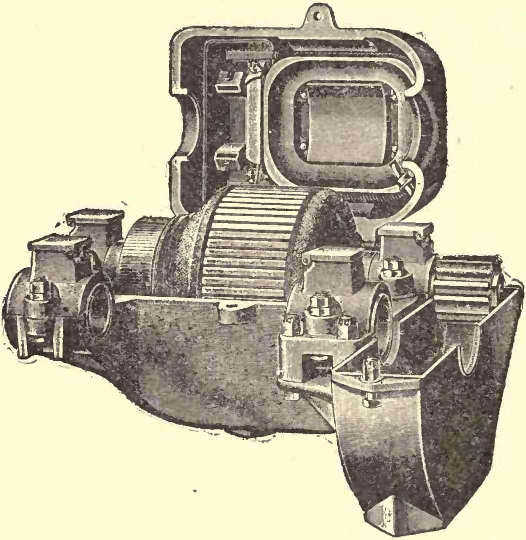


FIG. 35.—STANDARD STREET-CAR MOTOR, WITH ONE SET OF GEARS OR "SINGLE REDUCTION" OF SPEED.

The connections as indicated in Fig. 36 are very simple, the armature, field-coils *F F*, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at constant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore only suited to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. They are also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly.

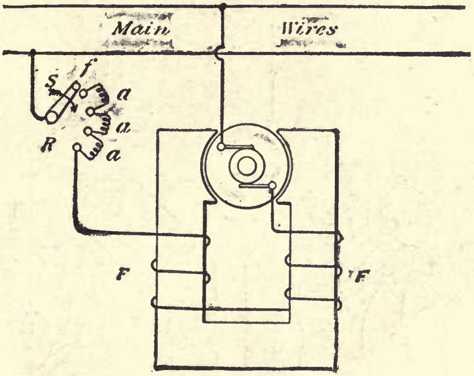


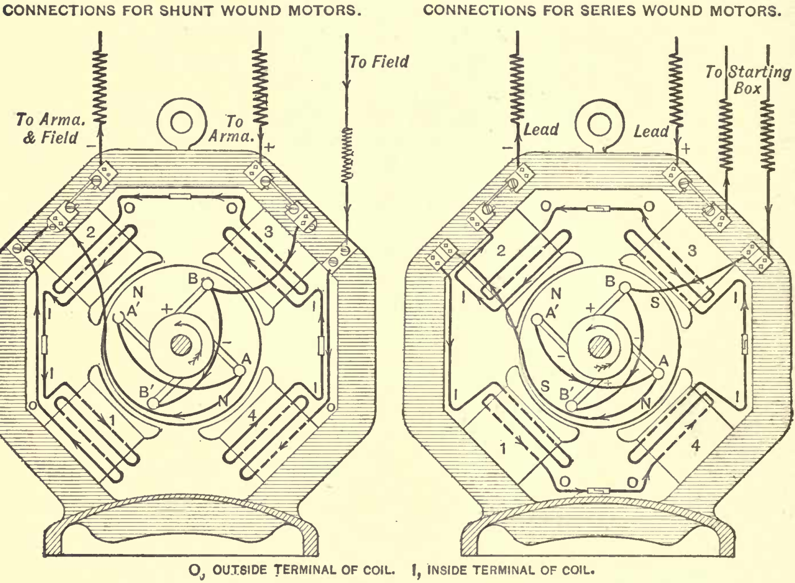
Fig. 36.—Series-wound Motor and Controller on Constant-potential Circuit.

The fields of series motors are sometimes "overwound;" that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The object of this is to secure constant speed with varying load, as with a shunt motor. Also in railway motors to enable them to run at high economy when drawing small currents and to prevent sparking at heavy load.

In multipolar motors having more than two field-coils the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated, however, it is sometimes necessary to trace out the connections. Fig. 37 represents all the connections of a four-pole motor, shunt-wound and series-wound.

For Constant-potential Circuit, *Differentially-wound Motor.*—This is a shunt-wound motor with the addition of a coil of large wire on the field connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt-winding, weaken the field, and thus cause the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly much used to obtain very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor has the great disadvantage that, if overloaded, the current in the opposing (series) field-coil becomes so great as to kill the field-magnetism, and instead of increasing or keeping up its speed, the armature slows down or stops, and is liable to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.


CONNECTIONS FOR SHUNT WOUND MOTORS. CONNECTIONS FOR SERIES WOUND MOTORS.

O, OUTSIDE TERMINAL OF COIL. I, INSIDE TERMINAL OF COIL.

FIG. 37.

For Constant-current Circuit, *Series-wound Motor.*—The commonest example is a series-wound motor on the arc circuit. The connections are shown in Fig. 38. The switch I is to entirely disconnect the circuit from the building in case of fire or other emergency. By simply turning the other switch 2 the motor is started or stopped; and since the current is constant, the motor may be overloaded

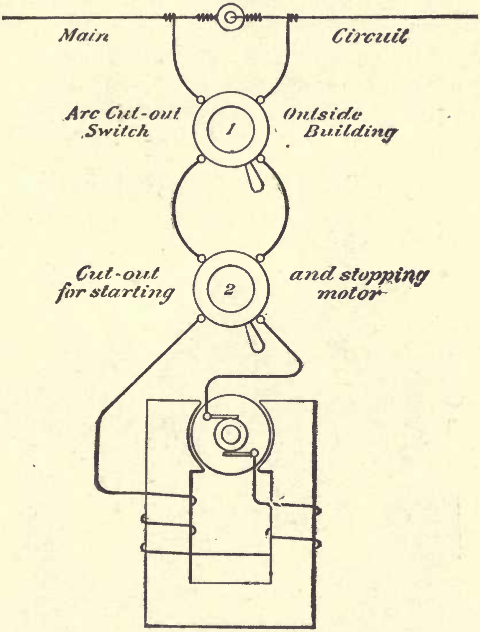


Fig. 38.—Series Motor on Constant-current Circuit.

or held still without injury, except loss of ventilation, whereas a constant-potential motor would burn out.

The precaution necessary is, *never touch the machine when the current is on*, as the E. M. F. is probably high and very dangerous. Turn off the switch to fix the machine. A constant-current motor should be provided with an effective centrifugal governor for controlling the speed (see Chapter XXXIII); otherwise it will run away and burst when the load is taken off, being very much worse than a series motor on a constant-potential circuit, because the latter reduces the current as it speeds up, while the former cannot.

Battery Motors.—These are nearly always series-wound, like the last, so as to get the most economical effect in the field when current is weak, as this current is expensive and difficult to maintain when obtained from a primary battery. For same reasons, primary-battery motors are always for small power only, usually not exceeding one-quarter horsepower. If a storage-battery is used to furnish the current it is cheaper and gives more power, but it requires frequent recharging.

Dynamotors (Fig. 39) are started in the same way as motors; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain

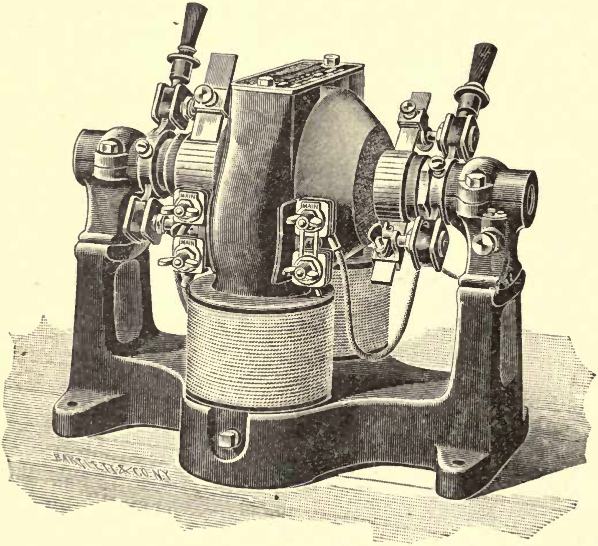


Fig. 39.—2-H.P. 110-Volt Incandescent Electric-light-circuit Motor-Dynamo.
To furnish 5000 volts for testing insulation.

shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 64.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field-magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, then the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter will be apt to cause sparking.

Alternating-Current Motors.—These have not been very extensively used up to the present time, although a great variety of forms have been tried or suggested. Alternating motors are required to run on constant-potential circuits, since almost all alternating-current systems are of this kind. There are several types of these motors, the simplest of which is a plain series or shunt machine, the same as for direct current, except that the field-magnet is laminated as well as the armature (Fig. 6). The trouble with this type, which has been used commercially in small sizes, is that bad sparking is apt to occur when the brush passes from one commutator-bar to the next, and short-circuits a coil which has alternating currents generated in it by the reversals of the field-magnetism. Various arrangements have been devised to overcome this difficulty, but it is unlikely that this type will be practical in any but small sizes. An ordinary alternating-current dynamo can be used as a motor, but it must be started and driven by some other motor or engine until its speed is in synchronism, that is, agrees precisely with the current alternations in order to make it run at all, and then if it loses this exact speed it stops, and is therefore unpractical except for large plants.

Synchronous motors of this kind are sometimes employed in the long-distance transmission of power or in other special cases. Auxiliary devices have been applied to these motors to start them and bring them up to synchronism. Many other forms of alternating-current motors have been brought out. So far, motors are not used to any great extent on the ordinary (two-wire) alternating circuits, except the small motors referred to above.

The Tesla and other types of polyphase (two or three phase) motors (Fig. 40) are operated by the rotation of magnetic polarity or the so-called "rotary current." But all of these require special circuits of three or four wires, which have not yet been introduced except for the long-distance transmission of power. In fact, it is to this purpose that polyphase motors are particularly applicable. (See page 27.) Some of the smaller Tesla induction motors obtain a rotary current from a single circuit by "splitting the phase."

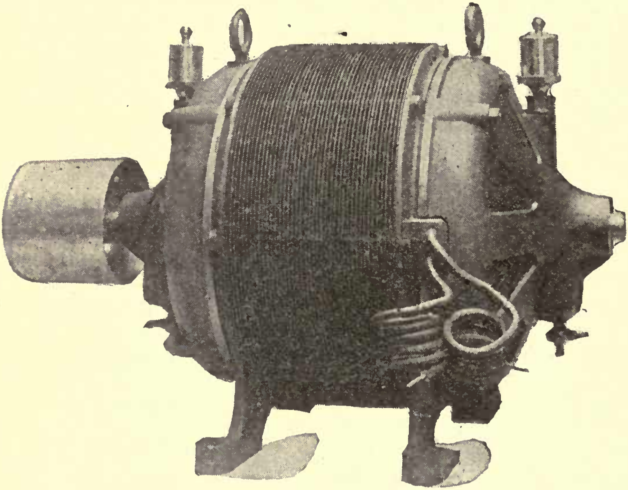


FIG. 40.—TESLA TWO-PHASE MOTOR.

Three-phase motors both of synchronous and induction types are self-starting. In the latter, to get a good torque in starting or at low speeds, or to start with considerable load, it is necessary to have added resistance in series with the armature winding, which consists merely of coils or bars that can be short-circuited when the machine has reached normal speed. This resistance is gradually cut out by a special device, as the speed increases to its full value. The motor tends to run almost synchronously at a certain speed, only falling a few per cent from no load to full load. But if the motor is overloaded even for an instant, the normal speed is lost and the motor runs very slowly or stops entirely, unless the load is taken off or greatly reduced, since the torque falls from its full amount down to about one third. To start again with the load on the motor the operation just described must be repeated. When a polyphase motor becomes stalled in this way, it is liable to become overheated or burnt out.

CHAPTER IX.

DIRECTIONS FOR RUNNING DYNAMOS AND MOTORS.

After any one of these machines has been properly started, as described in the previous chapters, it usually requires very little attention while running; in fact, a dynamo or motor frequently runs well all day without any care whatever.

In the case of a machine which has not been run before or has been changed in any way, it is of course wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it, and to run the belt rather slack until the bearings and belt have gotten into easy working condition. If possible, a new machine should be run without load or with a light one for an hour or two, or several hours in the case of a large machine; and it is always wrong to start a new machine with its full load or even a large fraction of it.

This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance which would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A dynamo requires that its voltage or current should be observed and regulated if it varies. The person in charge should always be ready and sure to detect the beginning of any trouble, such as sparking, the heating of any part of machine, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it by following the directions given in Part III. Those directions should be pretty thoroughly committed to mind in order to facilitate the prompt detection and remedy of any trouble when it suddenly occurs, as is apt to be the case. If possible the machine should be shut down instantly when any trouble or indication of one appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, and perhaps get between the armature and pole-pieces and ruin the machine. For this reason use a zinc, brass, or copper oil-can instead of iron or "tin" (tinned iron).

Particular attention and care should be given to the commutator and brushes to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See SPARKING, p. 120.)

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator.

Touch the bearings and field-coils occasionally to see that they are not hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a dynamo or motor to avoid *overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety.—Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of body in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves (Fig. 41) or rubber shoes, or both, should be used in handling circuits of over 500 volts. The safest plan is not to touch any conductor while the current is on, and it should be remembered that the current may be present when not expected, due to an accidental contact with some other wire or to a change of connections. Tools

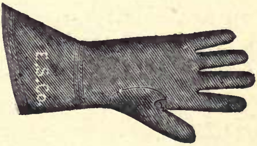


FIG. 41.—INSULATING RUBBER GLOVE.

with insulated handles (Fig. 41*a*) or a dry stick of wood should be used instead of the bare hand.

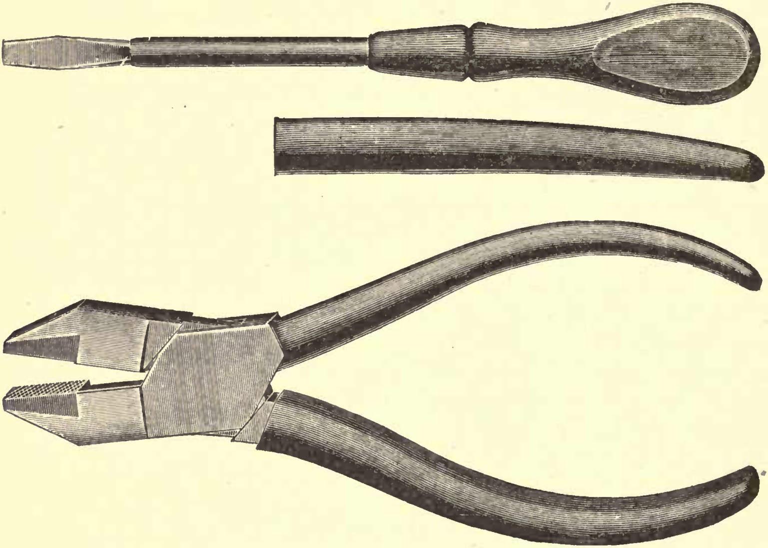


FIG. 41*a*.—TOOLS WITH INSULATED HANDLES.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the full current right through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless by familiarity with dangerous currents. The result of this has been that *almost all the persons accidentally killed by electricity have been experienced electric linemen or stationmen.*

CHAPTER X.

DIRECTIONS FOR STOPPING DYNAMOS AND MOTORS.

THIS is accomplished by following substantially the same rules as those given for starting dynamos and motors in Chapters VI, VII, and VIII, only in the reverse order. But there are certain peculiar points to be observed in each case; so, in order to avoid any possible mistake, the matter of stopping is treated in this separate chapter. After any machine is stopped it should be thoroughly cleaned of dirt, copper dust, and oil, and put in perfect order for the next run. This can be done much more easily while the machine is still warm. Switches, brushes, etc., should be fixed so that they will not accidentally close the circuit.

One Constant-potential Dynamo (Shunt, or Compound Wound) running *alone* on a circuit, with no danger of receiving current from any other dynamo or battery, should be slowed down and stopped without touching the switches, brushes, etc., in which case the E. M. F. and current decrease gradually to zero as the speed goes down. The switches may then be opened and the brushes lifted without any spark. In the case of copper brushes they should be raised just before the machine stops entirely, in order to avoid any injury to them if the machine turns back a little, as it sometimes does. Never switch out or disconnect a dynamo at full or even partial load except in extreme emergency, and never raise the brushes while the fields are strongly magnetized, as the discharge of the magnetism may break lamps or pierce the insulation.

Dynamos in Parallel.—To stop a dynamo running in parallel with one or more others or with a storage-battery on the same circuit (usually constant-potential), regulate its E. M. F. until it is equal to or only slightly greater than that of the circuit, and its amperemeter shows that it is producing little or no current; then open quickly the switch connecting its armature to the circuit. Under no circumstances, however, should a dynamo in parallel with others or with a battery be stopped, slowed down, or have its field-magnetism discharged or weakened (i.e., more than enough to regulate its E. M. F., as stated) until its armature is completely disconnected from the circuit, as it might be burnt out or driven as a motor if its E. M. F. decreased more than a few per cent.

A dynamo should, of course, only be thrown out of circuit when the remaining machines are fully able to carry the load. Allowance should also be made for any possible increase in load.

Compound-wound Dynamos in Parallel may be stopped by exactly reversing the method for starting (Fig. 25); but if, as there suggested, the "equalizer" is left closed all the time, the machines may then be stopped like simple shunt machines in parallel, as just described.

Dynamos on the Three-wire (Direct) System are also stopped like dynamos on any constant-potential circuit, as explained in the chapter on starting.

Constant-current Dynamos and Motors in series may be cut out of, or into, the circuit without trouble, and may be slowed down or stopped without disconnecting them from the circuit, as the current is limited. If desired, the armature or field-coils may be short-circuited to stop the action of the machine. The only precaution, and that is absolutely imperative, is to maintain the *continuity* of the circuit and never attempt to open it at any point, as it would cause a dangerous arc. Hence to stop a constant current motor it must be *cut out* by first closing the main circuit around or past the machine, and then entirely disconnecting both its wires or terminals from the circuit. This entire operation is accomplished by any arc-circuit cut-out switch (Fig. 42).

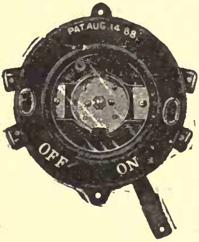


FIG. 42.—ARC CUT-OUT SWITCH.

One Alternator running *alone* on a circuit may be stopped or the field current shut off without trouble.

Alternators in Parallel may be thrown out of circuit by disconnecting them one at a time, the E. M. F. of the particular dynamo having been previously regulated so that it is supplying only a little current to the circuit.

A Constant-potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 33), or if there is a switch *Q* connecting the motor to the circuit it should be opened, after which the starting-box handle should be turned back to be ready for starting again.

A constant-potential motor, like the corresponding dynamos when in parallel, should never be stopped by overload or much reduced in speed, or have its field discharged or weakened, until it is disconnected from the circuit; otherwise its counter E. M. F. is not enough to prevent an excessive current from rushing through its armature.

Thus it will be seen that the constant-potential machine is exactly the opposite of the constant current. The former is safest when the circuit is open, and it is very bad to short-circuit or stop it with the current on, whereas the circuit of the latter should always be kept closed, and the machine may be stopped or short-circuited while in circuit. But the dynamo supplying the circuit should have an effective regulator to maintain the current at constant strength when lamps or motors are cut into or out of the circuit.

Waterproof Covers of oiled canvas or enamel cloth should be placed upon any machine when not running, it having been previously cleaned, and all dirt, copper dust, and superfluous oil removed.

PART II.

Examination, Measurement, and Testing.

Directions for Inspecting and Testing Dynamos and Motors Critically.

CHAPTER XI.

INTRODUCTION AND CLASSIFICATION.

THE matter of testing dynamos and motors critically is of special importance, since it is only by a thorough test that either the manufacturer or the user can determine whether a machine is up to the standard. Nevertheless it is difficult, if not impossible, to find in books or journals anything like a complete and practical system for this purpose. Each electrical manufacturer or engineer has collected by experience certain methods, but these usually apply to particular forms of machine or testing apparatus, and, moreover, are often guarded as trade secrets.

The following methods cover the various points about dynamos and motors which one is likely to want to test. Under each heading exact methods are given, which should, of course, always be preferred. Wherever possible, we have also given simple, rough methods for emergencies or cases in which dynamos or motors may have to be tested without the accurate and expensive instruments required for the more refined methods.

This subject differs from that which is treated in Part III, "Locating and Remedying Troubles in Dynamos or Motors," in that the latter relates to actual faults which are already apparent, whereas testing applies to any machine whether in perfect working condition or containing some latent fault which a test brings out or anticipates. The testing methods here given can also be used as supplementary to the methods for locating troubles in cases where a more complete investigation may be desirable. In testing any machine it is well to follow as nearly as possible the directions given by its maker and try it under the conditions for which it is intended, in regard to voltage, current, speed, etc. Tests of dynamos and motors may cover any or all of the following points:

CHAPTER XII.

1. **Adjustment** and fit of parts.
2. **Mechanical Strength** of parts against breaking or displacement.
3. **Friction** of bearings and brushes.
4. **Balance** of armature and pulley.
5. **Noise.**
6. **Heating** of armature, commutator, field-magnets, bearings, etc.
7. **Sparking** at commutator.

CHAPTER XIII.

8. **Electrical Resistance** of conductors and insulation of machine.
9. **Line** or **Circuit** testing for conductivity, insulation, faults, etc.

CHAPTER XIV.

10. **Voltage,** E. M. F., "drop," or fall of potential, etc.
11. **Current** in field and in armature, free and loaded.

CHAPTER XV.

12. **Speed** of armature, free and loaded.
13. **Torque** or **pull,** standing or running.

CHAPTER XVI.

14. **Power,** electrical and mechanical.
15. **Efficiency,** electrical and commercial.

CHAPTER XVII.

16. **Magnetism,**—total flux, intensity, leakage, and distribution.
17. **Separation** of **losses** which occur in a dynamo or motor. Friction, resistance, field excitation, hysteresis, Foucault currents, etc.

CHAPTER XII.

ADJUSTMENT, MECHANICAL STRENGTH, FRICTION, BALANCE, NOISE, HEATING, AND SPARKING.

1. **Adjustment** and the other points which depend merely upon mechanical construction are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test, and a poorly fitted bearing, brush-holder, etc., might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts in order to be sure to get them together in exactly the same position as before. In taking a machine apart or putting it together only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or rawhide mallet (Fig. 43) is preferable to an iron hammer, since it does not bruise or mar the parts so much. Usually screws, nuts, and other parts should be set up fairly tight, but not

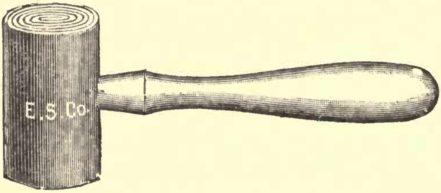


FIG. 43.—RAWHIDE MALLET.

tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver will almost always show whether any of them are too loose, or otherwise out of adjustment.

2. **Mechanical Strength** of a dynamo or motor is best specified by stating that it should be above question. The base, bearings, shaft, armature, field-magnets, and other main parts of the machine should not spring even one one-hundredth of an inch with any reasonable force that may be applied to them. There has long existed a craze for very light dynamos and motors, as a result of which, strength, rigidity, durability, and satisfactory qualities in general have been sacrificed to reduce weight. There is certainly no sense in this. For stationary machines, and even for ship dynamos or railway motors, good solid frames, bearings, etc., are much better than light ones.

The magnetic attraction between the field and armature is often very great, and amounts to hundreds, or even thousands of pounds. This tends to draw the pole-pieces against the armature, or to spring the armature shaft if the armature is even slightly nearer one pole-piece than the other. It is well to magnetize the field by putting the proper current through its coils and see if it produces any reduction of the clearance or any displacement that is appreciable to the eye, or even to ordinary measurement. The effect of the maximum pull of the belt or of any other legitimate stress may be tested in the same way.

In addition to this, all the parts of the machine should be scrutinized to see if they are of adequate size and proper proportion.

3. **Friction.**—The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to cause the armature to revolve by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near

full speed will continue to run for one or more minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and turn the armature without current is then determined by known weights or, more conveniently, by an ordinary spring-balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. (See No. 13, " Torque.") The friction of the bearings alone—that is, the pull required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should then not exceed about 3 per cent, that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first with brushes lifted off, and second with brushes on the commutator with the usual pressure. The torque or force exerted by the driving-machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque ; care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques which were exerted by the driving-machine to overcome friction in each of the first two tests are determined, and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for the maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the centre of the space between the pole-pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized, and occurs to a certain extent in all cases, but it should be corrected if it be comes excessive. (See " Remedy, Heating of Bearings,' Cause 9.) This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 4 or 5%.

Tests for friction alone should be made at a low speed, because at high speeds the effect of Foucault currents and hysteresis enter and materially increase the apparent friction. (See No. 17, "Separation of Losses.")

4. **Balance.**—The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at its normal speed and noting if these parts are sufficiently well balanced not to cause any objectionable vibration. Of course practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested and the extent of the vibration measured by suspending the machine or mounting it on wheels and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a dynamo, in order to make it produce its own motion, so to speak, and avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 44 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt, indicated by a dotted line. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

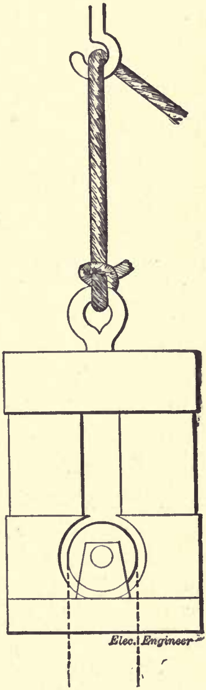


Fig. 44. — Arrangement for Testing Balance of Armature.

5. **Noise.**—This cannot be well tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by the various causes given in Chapter XXV, "Noise." The machine should be run at full speed, and any noise and its cause carefully noted. A machine will nearly always run quieter after it has been in use a week or more, and has worn smooth, especially the commutator. (See "Noise," Cause 5.)

6. **Heating.**—This is measured by applying a thermometer to the various parts of the machine after it has run at full load for one or two hours, unless it is a very large machine, which will not reach its maximum temperature until it has run for three or four hours. The bulb of the thermometer is applied directly to the surface of the field-coil or other part. To test the armature it must, of course, be stopped. The thermometer bulb should be covered over with a bunch of waste or cloth to keep in the heat. The temperature of the armature, field-coils, bearings, etc., should not rise more than 45° C. or 81° F. above that of the surrounding air. A very simple test of heating is to apply the hand to the armature, etc., and if it can be kept on without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that on account of its heat-conductivity bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures, but this apparent difference is much less if the hand is kept on for 10 or 20 seconds. (See "Heating," Chapter XX.)

7. **Sparking** at the commutator cannot be accurately measured, but it is very ojectionable, and in a machine in good order it should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not, and if so, to what it is due. (See "Sparking," Chapter XIX.)

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In most machines the brushes must be shifted to follow the armature reaction as the load increases, but one should always be able to find a place where sparking ceases. A first-class machine should be able to run with 20% overload before sparking is serious. If machine begins to spark at 75% of its load, it is clearly only three quarters as useful, and this may be taken in a sense as a measure of sparking. Finely adjusted copper brushes are sometimes preferred in observing sparking.

CHAPTER XIII.

ELECTRICAL RESISTANCE AND INSULATION.

8. **Electrical Resistance.**—There are two principal classes of resistance tests that have to be made in connection with dynamos and motors. First, the resistance of the wires or conductors themselves, which might be called the *metallic* resistance; and, second, the resistance of the insulation of the wires, which is called the *insulation* resistance. The former should usually be as low as possible; the latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field-coils, is commonly tested either by the Wheatstone bridge or the "drop" (fall-of-potential) method.

The Wheatstone bridge is simply a number of branch circuits connected as indicated in Fig. 45. *A*, *B*, and *C* are resistances the values of which are known. *D* is the resistance which is being measured. *G* is a galvanometer, and *E* is a battery of one or two cells controlled by a key *K*, all

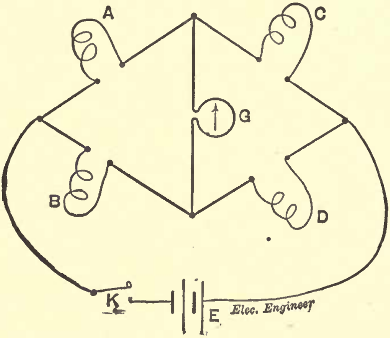


FIG. 45.

being connected exactly as shown. The resistance C is varied until the galvanometer shows no deflection, when the key K is closed. The value of the resistance D is then found by multiplying together resistances C and B, and dividing by A; that is, $D = \frac{C \times B}{A}$. A very convenient form of this apparatus is what is known as the portable bridge (Fig. 46).

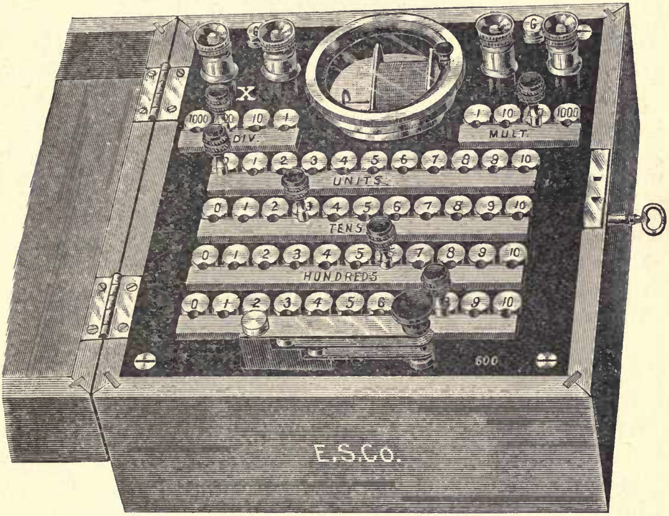


FIG. 46.—WHEATSTONE'S PORTABLE BRIDGE WITH GALVANOMETER.

This consists of a box containing the three sets of known resistances A, B, and C controlled by plugs; also the galvanometer G and key K, all connected in the proper way. In some cases the perfection of convenience is reached by including the battery E in the box also; but ordinarily this is not done and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance care should be taken to make the connections clean and tight. The ordinary bridge will not measure above 100,000 ohms, because if the resistance in the arm *B* is 100 ohms, 1 ohm in *A*, and 1000 ohms in *C*, then *D* is 100,000. Sometimes the arms *A* and *B* are provided with 1000-ohm coils in addition to the usual 1, 10, and 100 ohm coils; or sometimes the arm *C* contains more than 1000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1000:1 or even 100:1 is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other, except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistance of almost any field-coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos or motors vary from about 1 to 20 ohms. In measuring field resistances with the bridge care must be taken to wait a considerable time after pressing the battery key before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may also be used for testing the armature resistance of most machines. But 110-volt shunt machines above 10 H. P. usually have resistances below $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. Higher voltage dynamos and motors have proportionally higher resistance armatures. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The "drop" or fall-of-potential method is well adapted to locating faults quickly, and to testing the armature resistance of large incandescent dynamos or the resistance of contact between commutator and brushes or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections, and a known resistance of, say, $\frac{1}{100}$ ohm connected in series with each other, as represented in Fig. 47. The " drop " or fall of potential in the armature and in the known resistance are then compared by connecting a galvanometer first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted galvanometer terminals at M, N, O, Q, R, and S, so as to include successively all parts which are to be tested. The deflections of the needle in all cases are proportional to the resistances included between the points touched by the terminals of the galvanometer. The current needed depends upon the sensitiveness of the galvanometer, but in any station the simplest way is to take the current from the mains or from a dynamo, but then a bank of lamps or a liquid resistance (see page 102) must be used to limit the current, as otherwise the parts being tested would short-circuit the dynamo.

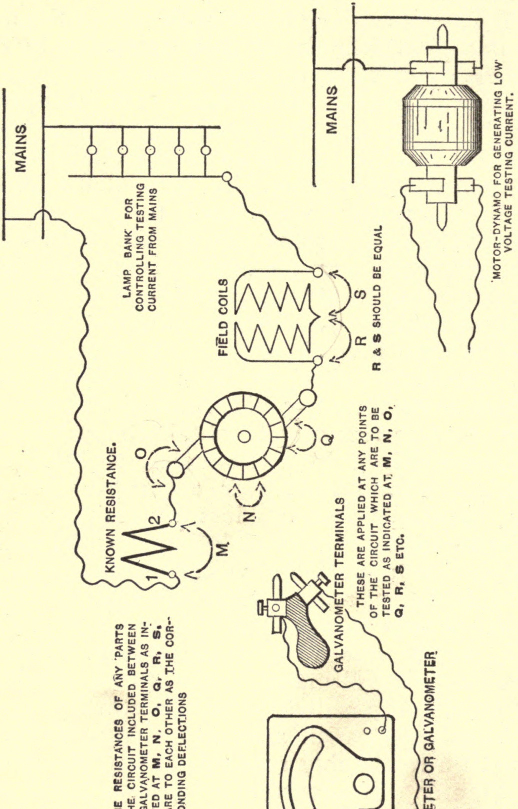
A much more perfect way to obtain the current is to use a motor-dynamo driven from the mains, as shown in corner of diagram, and wound to deliver a current at, say, 6 volts for testing. There is then no loss by resistances, and the current may be nicely regulated by moving the rocker-arm.

A " station " or a portable voltmeter (page 99) may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a voltmeter reading to a single volt or fraction of a volt are needed for low resistances.

It is wise to start with a small testing current and increase it until a reasonably readable deflection is obtained on the voltmeter. If a current of a number of amperes cannot be had, a few cells of storage-battery or some strong primary battery, such as a Bunsen, a bichromate or a plunge battery, can be used with a galvanometer.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance, while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is very useful in locating any fault. The two wires leading from the galvanometer are



R & S SHOULD BE EQUAL

MOTOR-DYNAMO FOR GENERATING LOW VOLTAGE TESTING CURRENT.

THESE ARE APPLIED AT ANY POINTS OF THE CIRCUIT WHICH ARE TO BE TESTED AS INDICATED AT **M, N, O, Q, R, S** ETC.

THE RESISTANCES OF ANY PARTS OF THE CIRCUIT INCLUDED BETWEEN THE GALVANOMETER TERMINALS AS INDICATED AT **M, N, O, Q, R, S,** ETC., ARE TO EACH OTHER AS THE CORRESPONDING DEFLECTIONS

Fig. 47.—Drop Method for Comparing Resistances.

applied to any two points of the circuit, as indicated by the dotted points,—for instance, to two adjacent commutator-bars or to a brush tip and the commutator,—and any break or poor contact will be immediately indicated by a corresponding increase in the deflection of the galvanometer. This shows that the fault is between the two points to which the galvanometer wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, a short circuit, or an extra resistance, can be found.

The insulation resistance of a dynamo or motor, that is, the resistance between its wires and its frame, should be at least one megohm per hundred volts E. M. F., and it is of course better if it is much higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests, but there are two good methods which are applicable—the "direct-deflection" method and the voltmeter method.

The direct-deflection method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer (tripod or square pattern), in series with a known high-resistance, usually a 100,000-ohm rheostat, a battery, and a key, as shown in Fig. 48. The galvanometer should be shunted with the $\frac{1}{999}$-coil of the shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The key is closed and the steady deflection noted. It is well to use only one cell of battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at *A* and connected by wires to the binding-post or commutator of the dynamo or motor and to the frame or shaft of the machine, as indicated by dotted lines, so that the insulation resistance is included directly in the circuit with the galvanometer and battery. The key is

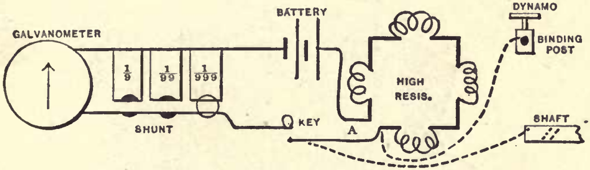


FIG. 48.—DIRECT-DEFLECTION METHOD OF MEASURING INSULATION RESISTANCE.

closed and the deflection noted. Probably there will be little or no deflection on account of the high insulation resistance, and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula: Insulation resistance $= \frac{D \times R \times S}{d}$, in which D is the first deflection without the machine connected and d the deflection with the insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test and $\frac{1}{9}$ in the second, then S is 100, and if the shunt is out entirely in the second test S is 1000. It is safer to leave the high resistance in circuit in the second test to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation itself.

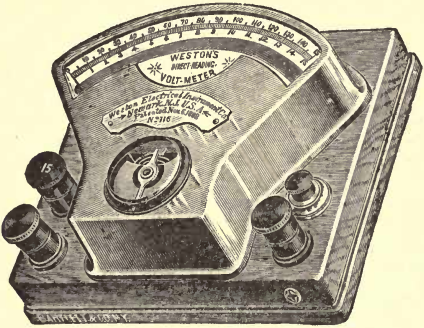


FIG. 49.—WESTON VOLTMETER.

By the above method it is possible to measure 1000 megohms, or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. This test may be checked by placing one finger on the shaft or frame and one on the binding-post of the machine, thereby making enough leakage to affect the galvanometer and show that the connections are right, and that any poor insulation will be indicated if it exists.

The voltmeter test for insulation resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 49, which usually has about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible; say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 50. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

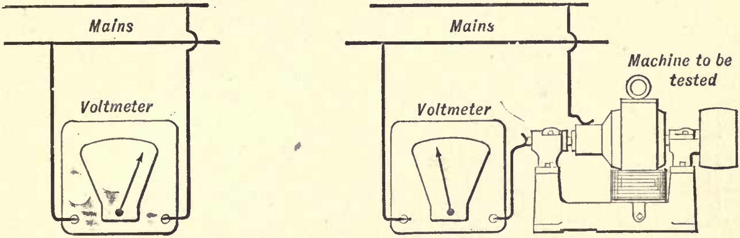


FIG. 50.—CONNECTIONS FOR TESTING INSULATION WITH VOLTMETER.

The insulation is then found by the equation: Insulation resistance $= \frac{D \times R}{d} - R$, in which D is the first and d the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, then D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, then the insulation is $(100 \times 15{,}000) - 15{,}000 = 1{,}485{,}000$ ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. The dynamo should then be regulated, when making measurements, to the E. M. F. assumed in preparing this scale (say, 115 volts). To calculate the scale, use this formula: $d = \frac{115R}{X + R}$, in which X is the resistance of insulation (1 megohm, $\frac{1}{2}$ meg ohm, etc.), and *d* is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances, but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms,—which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine and the other to the frame or shaft.

A magneto bell is rated to ring through from 10,000 to 30,000 ohms, and if it does not ring, it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case, and therefore this test is rough, and really only shows whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A motor-dynamo wound to give a very high voltage is convenient for this.

Tests of the resistances of dynamos or motors should properly be made when the machines are as *warm* as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values better than a test made when the machine is cold.

9. **Line or Circuit Testing** for conductor resistance and insulation resistance is performed by exactly the same methods as those just described for making the corresponding tests on dynamos and motors. For example, in testing the insulation resistance of a line or circuit one wire is connected to the line and the other to the ground (a gas or water pipe is convenient for this purpose), instead of connecting one

wire to the commutator and the other to the frame of the machine, as described for testing the insulation resistance of a dynamo; otherwise the test is exactly the same. The "electrical capacity" of a line will cause current to flow into it for some seconds after the key is closed, even though the line is well insulated. Therefore one must wait till the galvanometer needle comes to rest before taking the reading. The testing of circuits for current, voltage, etc., is also done in the same manner as described in the following chapter for dynamos and motors.

CHAPTER XIV.

VOLTAGE AND CURRENT.

10. **Voltage.**—Unfortunately a really satisfactory voltmeter is rather expensive, because it is required to be very accurate, an error of one per cent in the voltage of an incandescent circuit being objectionable, whereas the same error would be insignificant in almost any other practical measurement. A voltmeter should have as high a resistance as possible—at least several hundreds or thousands of ohms—in order not to take too much current, which might lower its reading on a high-resistance circuit. It should not be affected by the magnetism of a dynamo or motor at any

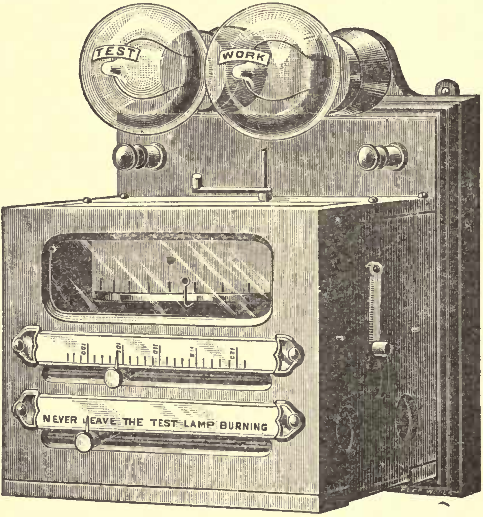


FIG. 51.—PRESSURE-INDICATOR FOR CENTRAL STATIONS.

distance over four or five feet. There are two kinds of voltmeters: those which simply indicate whether the E. M. F. is *at* or a little above or below the standard (110 volts, for example),—such instruments (Fig. 51) are generally used in central stations, and are called pressure-indicators,—and those which measure from a single volt or fraction up to the full capacity of the scale, such as the Weston (Fig. 49). These often have two scales, one reading one tenth of the other.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. In the case of a dynamo or motor the voltmeter is usually applied to the two main binding-posts or brushes of the machine to get the external voltage of the machine. This external voltage is what a dynamo supplies to the circuit, and it is what a motor receives from the circuit. This is called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A dynamo for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the loss of voltage in the resistance of the armature, which in turn weakens the field current and magnetism; armature reaction and reduction in speed usually occur also, and still further lower the external voltage. This variation is very undesirable, and is usually avoided by regulating the field-magnetism (by varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "overcompounded" it should rise 3 to 10 per cent in voltage to make up for loss on the wiring.

The voltage of a constant-current dynamo or motor is not important. The current should be carefully measured by an amperemeter, but little or no attention is paid to the voltage in practical working; in fact it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one third and a bright red at one half its full voltage. Voltages higher than that of one lamp can be tested in this way by using lamps in series. Thus 1000 volts can be measured by using 10 lamps in series, and so on.

11. **Current.**—This is, of course, measured by an amperemeter (Fig. 52), which is usually cheaper than a voltmeter, because it contains a comparatively small amount of wire, and does not ordinarily require to be so accurate. In testing the current of a dynamo or motor, it is only necessary to connect an amperemeter of the proper range in series with the machine to be tested, so that the whole current to be measured passes through the instrument. To test the current in the armature or the field alone, the amperemeter is connected in series with the particular part. In the case of a shunt-wound dynamo, it is well to open the external circuit entirely in testing the current used in

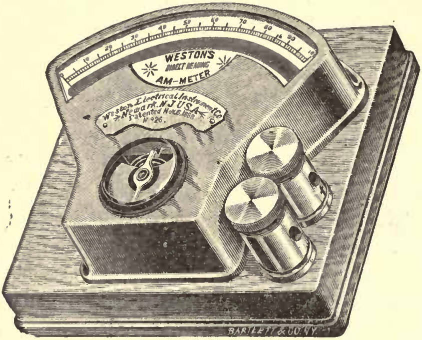


Fig. 52.—Weston Ammeter.

the field-coils in order to avoid mistake; for the same reason the brushes of a shunt motor should be raised while testing the current taken by the field. In a constant-current (series-wound) dynamo or motor the same current flows through all parts of the machine and the circuit, consequently the measurement of current is very simple.

On constant-current circuits, instruments are often used which simply indicate whether the amperes are at or near the standard current of, say, 10 amperes, precisely as with "station pressure-indicators" (Fig. 51). The Brush Ammeter (Chapter XXXI, Fig. 92) is of this kind.

If an ammeter cannot be had, current may be measured by a voltmeter by inserting a known resistance in the circuit and measuring the difference of potential between its ends with the voltmeter. The volts so indicated, divided by the resistance in ohms, give the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be computed from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires.

Or the resistance may be measured by a Wheatstone bridge (Fig. 46), or by putting an ammeter, sometime when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes give the resistance in ohms between the points to which the voltmeter is connected. Or two connections can be attached permanently to two points on the circuit and an ammeter temporarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, but allows for the increase of resistance when the current and heating increase. In any case, it is convenient to use a length of wire, or a distance between contacts which will give an even amount of resistance, say $\frac{1}{10}$ or $\frac{1}{100}$ ohm. And as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc. Current may also be very roughly judged by the temperature of the wire, or by the size of wire necessary to carry it without exceeding a certain temperature.

As the pressure of the circuit is constant in most cases where ammeters are used to indicate the current drawn, a definite number of amperes represents 1 H. P. and the dial may be graduated in H. P. as well as amperes.

Thus on 115-volt circuits 6.48 amperes is 1 H. P. of current (or 746 watts), 12.96 amperes is 2 H. P., etc. On 500-volt circuits 1.49 amperes is 1 H. P., etc. (See section 14, "Power.")

In testing the output of a dynamo, it is often quite a problem to dispose of the current produced. A bank of lamps, for example, to use the whole current generated by a dynamo of 110 volts and 200 amperes would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to use its current to drive a motor which is belted back to the dynamo. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a solution of carbonate of soda (common washing-soda) which is much better than almost any other solution, because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid and the strength of the solution. The energy may be sufficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

CHAPTER XV.

SPEED AND TORQUE.

12. **Speed.**—This is usually measured by the well-known speed-counter (Fig. 53), which consists of a little spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the centre of the shaft of the dynamo or motor for a certain time, say one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

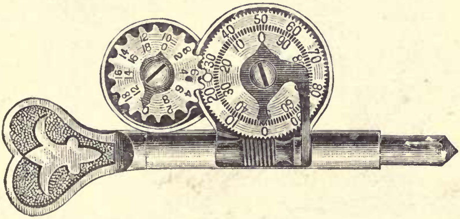


FIG. 53.—SPEED-COUNTER.

Another instrument for testing the number of revolutions per minute is the tachometer. The stationary form of this instrument is shown in Fig. 54. This requires to be belted by a string, tape, or light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 55) is applied directly to the end of the shaft of the machine, like the speed-counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1000, or 2000 revolutions. These instruments possess the great advantage over the speed-counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

A simple way to test revolutions per minute is to make a large black or white mark on the belt of a machine and note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the

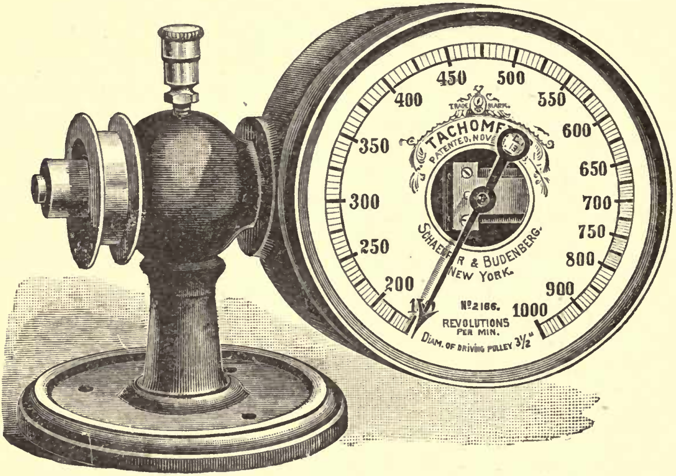


FIG. 54.—STATIONARY TACHOMETER.

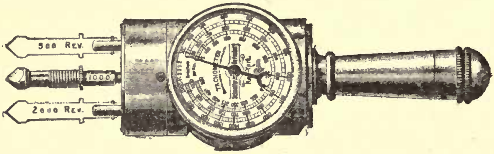


FIG. 55.—PORTABLE TACHOMETER.

revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink-mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip; for example, in the case of the tape belt just referred to, it should pass around the pulley of the machine, and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

13. **Torque or Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever *LL* of wood clamped on to the pulley or shaft of the machine to be tested, as indicated in Fig. 56. The pressure of the screws *S S* is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current and run at a given speed. Usually the maximum torque or pull is the most important to test, and this is obtained in the case of a constant-potential motor by tightening the screws *S S* until the motor draws its full current as indicated by an amperemeter. What the full current should be, is usually marked on the name plate; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and $1\frac{3}{4}$

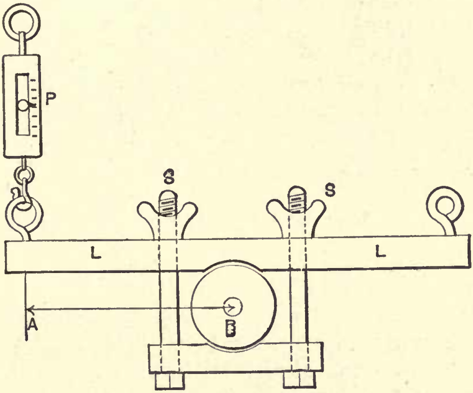


FIG. 56.—PRONY BRAKE FOR MEASURING TORQUE OR PULL.

amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1000, and dividing by the voltage of the machine. The torque or pull is measured by known weights, or more conveniently by a spring balance *P*. If desired, the test may also be made at three quarters, one half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained may also be calculated from the power at which the machine is rated by the formula

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times S},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius. 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1000 requires a pull of 5.252 lbs. at end of 1-ft. lever; at 500 revolutions, twice as much; at 2000 revolutions, half as much; and so on. If lever is 4 feet long, the pull is one fourth as much, etc.

The torque of a constant-current motor is found by adjusting the screws *S S* until the armature runs at its normal speed.

The Torque of a Dynamo, that is, the force required to drive it, is tested by a **transmission dynamometer.** This is a machine which measures the pull on the belt or the turning power of the shaft, without interfering with the motion. There are several forms of this apparatus, but none of them are very satisfactory. In the cradle dynamometer the dynamo is placed on a platform, which is hung on a pivot or fulcrum. The axis of the shaft of the dynamo is adjusted so that it exactly coincides with the axis of the pivot. When the dynamo is run by a vertical belt, the pull or torque tends to cause the dynamo to turn about its axis of suspension, and the force of this torque is measured by the amount of weights required to keep the dynamo and platform horizontal. In a modified form of the cradle dynamometer the dynamo is placed in a water-tight box which floats in another box filled with water instead of being hung on a pivot. A simple testing-room dynamometer is shown in Fig. 57. The belt from the motor passes around two idlers, and then around the driven pulley, which carries a large fan, or may be connected to other work. The idlers are on a beam pivoted on the shaft of the driven pulley. As they are equidistant from this pivot, the only force to move the beam is that imparted to the belt by the motor. This is measured by the spring balance which is attached to a right-angle lever, to which is also connected a dash-pot to check the vibration of the spring balance while the belt is in motion. For further information on this subject, the reader is referred to "Dynamometers, and the Measurement of Power," by J. J. Flather.

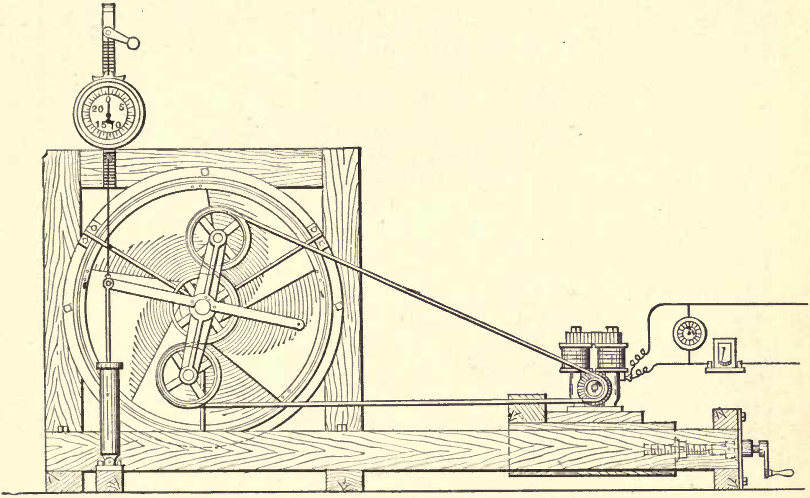


FIG. 57.—WHEELER TRANSMISSION DYNAMOMETER.

It is usually much easier to test the torque of a dynamo by running it as a motor and testing it by the Prony brake method described above.

The torque of a dynamo is practically equal to that of a motor under identical conditions.

CHAPTER XVI.

POWER AND EFFICIENCY.

14. **Power.**—The electrical power of a dynamo or motor is found by testing the voltage and current at the terminals of the machine, as described in sections 10 and 11, and multiplying the two together, which gives the electrical power of the machine in watts. Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1000.

The mechanical power of a dynamo or motor, that is, the power required for or developed by it, is found by multiplying its pull, determined as described in section 13, by its speed, determined as described in section 12, and by the circumference of the circle on which the pull is measured, and dividing by 33,000. That is,

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33{,}000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

15. **Efficiency.**—This is determined in the case of a dynamo by comparing the mechanical power required to drive it by the electrical power generated by it; that is,

$$\text{Efficiency of dynamo} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the *actual* or *commercial* efficiencies of these machines, and should be about 90 per cent in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as described in the last section.

AMPERES REQUIRED TO GIVE DIFFERENT POWERS, ON THE VARIOUS CONSTANT-POTENTIAL CIRCUITS, ALLOWING FOR THE EFFICIENCY OF THE ORDINARY MOTOR.

Horse-power of Motor.	Effi-ciency of Motor.	Electrical H. P. Required.	On 8-volt Battery Circuit.	On 75-volt Circuit.	On 110-volt Circuit.	On 220-volt Circuit.	On 500-volt Circuit.
			Ampere.	Amperes.	Amperes.	Amperes.	Amperes.
$\frac{1}{16}$	40%	.16	14	1.6	1.1	.53	.23
$\frac{1}{8}$	55	.23	21	2.2	1.5	.76	.34
$\frac{1}{6}$	60	.28	26	2.8	1.9	.95	.41
$\frac{1}{4}$	62	.40	38	4.0	2.7	1.4	.60
$\frac{1}{2}$	66	.76	71	7.5	5.1	2.6	1.13
1	72	1.4	130	13.8	9.4	4.7	2.07
2	75	2.7		26.6	18.1	9.1	3.98
3	78	3.8		38.2	26.	13.0	5.73
4	79	5.0		50.3	34.3	17.2	7.55
5	80	6.2		62.2	42.4	21.2	9.33
7½	82	9.1		90.9	62.	31.0	13.6
10	84	12.		118.	80.7	40.4	17.8
15	85	17.6		176.	120.	60.	26.3
20	86	23.		231.	158.	79.	34.7
25	88	28.		283.	193.	96.	42.4
30	88	34.		339.	231.	116.	50.7
35	89	40.		391.	266.	133.	59.
40	89	45.		447.	305.	153.	67.
50	90	55.5		553.	377.	188.	83.
75	90	83.		828.	565.	283.	124.
100	90	111.		1107.	754.	377.	166.

It is usually more convenient to test the efficiency of a dynamo by testing it as a motor with a Prony brake. But the efficiency of a dynamo may be determined very nicely by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known (section 14). Then it is only necessary to measure the watts generated by the dynamo when the motor is running at a certain power, and the efficiency of the dynamo is the watts divided by the known power. Another method is to employ two identical machines, one used as a motor driving the other as a dynamo. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a small loss. The watts generated by the dynamo divided by the watts consumed by the motor is the combined efficiency of the two machines, and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each is .90, since $.90 \times .90 = .81$. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current generated by the dynamo may be used to help feed the motor, and then only the difference in current need be supplied by another dynamo or other source. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in multiple-arc with the source of current, belt them together, and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a larger pulley on it. In this way the motor will consume current from the circuit while the dynamo yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a dynamotor or direct-current transformer is very easily determined by simply measuring the input and output in watts (by wattmeters or by ampere and voltmeters) and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical ones, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts. Mechanical measurements of power by dynamometer or other means are difficult, and not, usually, very accurate.

CHAPTER XVII.

MAGNETISM AND SEPARATION OF LOSSES.

16. **Magnetism.**—Magnetic measurements are difficult to make with the ordinary apparatus used in practical work. The proper method requires the ballistic galvanometer. To test the magnetic leakage in a dynamo or motor, for example, a coil of wire of any convenient size connected with the galvanometer is put around the field-magnet and the current in the field is stopped, the deflection of the galvanometer needle being noted. A coil of the same number of turns is then put around the armature, and the swing of the galvanometer when the field circuit is opened is again noted. The first deflection is to the second as the number of lines of magnetic force in the field is to that in the armature, provided the angles of deflection are only a few degrees. If the field current is reversed the effects of residual magnetism are eliminated, and hence this is better than merely opening the circuit.

An ordinary detector galvanometer can be used for this work if it is not damped by wings to prevent its swinging freely. A low-voltage Weston voltmeter or the calibration coil of a high-reading one can also be used very conveniently for magnetic measurements in place of the galvanometer.* In a similar manner the relative number of magnetic lines passing through or leaking out of any portion of the machine may be tested and the distribution of the magnetism determined. The actual number of lines in any magnetic circuit, or portion of circuit, may be determined either absolutely by finding the constant of the ballistic galvanometer† or by comparison with a standard magnet having a known number of lines of force. It may also be calculated from the magneto-motive force and reluctance,‡ or may be measured by

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* Paper by A. S. Ives in the *Electrical World*, Jan. 2, 1892.

† Thompson's "Dynamo-electric Machinery," 4th Ed., p. 134.

‡ Thompson's "Dynamo-electric Machinery," 4th Ed., pp. 406 to 421.

an exploring coil of bismuth, as the resistance of this metal is affected by magnetism.

17. **Separation of Losses.**—The total losses in a dynamo or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run it free as a motor. In a machine of 90% efficiency this cannot amount to more than about 8% of the current required to give the full power. Consequently running free is the easiest way of testing a machine. The various losses of power which occur in a dynamo or motor may be determined and separated from each other as follows:

Take a dynamo, for example, and drive it with another machine used as a motor in the manner described for testing friction (see No. 3, "Friction"). The motor should be calibrated previously—that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency (see No. 15, "Efficiency"). A simple shunt-wound motor on a constant-potential circuit is best suited to the purpose. The dynamo is first driven at normal speed with no field-magnetism and with the brushes lifted; then the actual power developed by the motor (as shown by the voltmeter and ammeter) equals the power lost in the dynamo by the friction of the bearings and belt. The brushes are then adjusted in contact with the commutator with the usual pressure. The increase in the power of the motor (as shown by the current it then draws) is equal to the brush friction.

Finally, excite the field-magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to Foucault currents and hysteresis in the iron core of the armature, provided there is no considerable magnetic side pull on the armature (see No. 3, "Friction"). The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

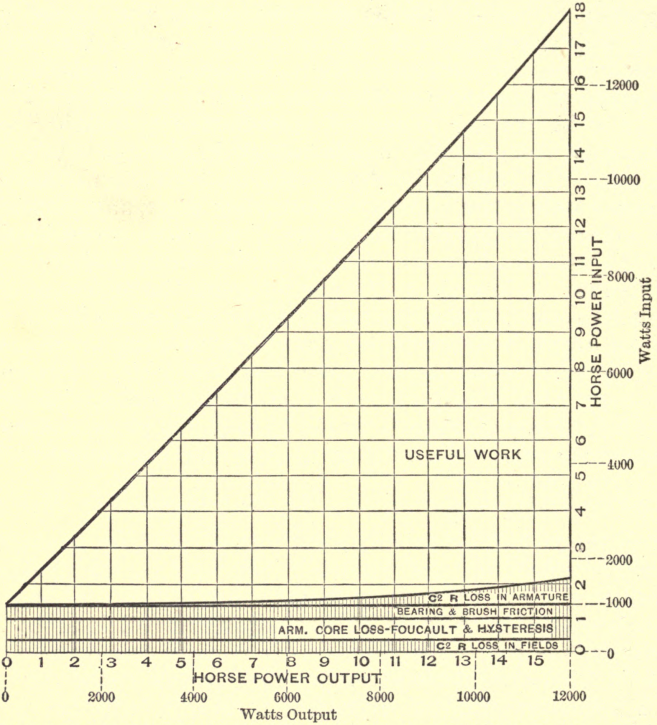
For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed, A the power consumed by both at full speed, and B that consumed at half speed. Then $A = x + y$ and $B = \frac{x}{2} + \frac{y}{4}$, and by eliminating x we have $y = 2A - 4B$. That is, the Foucault loss is twice the power consumed by both at full speed minus four times the power lost by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could only be done before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents do not amount to much unless the conductors are very large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss, but it usually causes only a very small loss and is almost impossible to separate except by running the machine in a vacuum, which is of course impracticable. The other losses are quite easily measured and separated, as follows:

The number of watts used in the field can be measured by a voltmeter and amperemeter, or it can be calculated by the formula watts $= \frac{E^2}{R} = C^2R = EC$, in which E is E. M. F., R is resistance, and C is the current. It is sufficient if any two of these quantities are known. The loss in the armature conductors due to resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the "C^2R loss." This should not be more than one to three per cent in a constant-potential dynamo or motor, whether it be alternating or direct current. The sum of all the losses makes up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good dynamo or motor of 25 H. P. or more are approximately as follows:

Useful power developed..................	about 90	per cent
Used in magnetizing field...............	" 1 to 3	"
Loss in armature resistance (C^2R).......	" 1 to 3	"
Friction of bearings.....................	" 2	"
" of brushes..................	" $\frac{1}{2}$	"
" of air.......................	" $\frac{1}{2}$	"
Hysteresis in armature core............	" 1$\frac{1}{2}$	"
Foucault currents in armature core......	" 1$\frac{1}{2}$	"



ANALYSIS OF LOSSES IN 15 HORSE POWER MOTOR AT DIFFERENT LOADS, AND PROPORTION OF USEFUL WORK.

FIG. 58.

The diagram (Fig. 58) shows the distribution of losses from every cause in a standard shunt-wound motor of 15

H. P. on constant-potential circuit. As the field strength and speed are the same at all loads, the losses due to field current, friction, and effects of reversal of magnetism in armature core are the same at all times. The armature-current loss, "C^2R loss," or loss due to the resistance of the armature winding, increases as the load and current increase.

The power consumed (see scale at side of diagram), corresponding to any given power produced (scale at bottom of diagram), is found by following the straight line from either to the slanting line, and then following at right angles a corresponding line, to the scale at the other margin. Or by following the line upward from any given power and comparing its total length, which represents the power consumed, with the length through the white part, which represents useful work. The ratio of loss to useful work at every load can be seen by following the vertical line up from the horse-power in question and comparing the length through the shaded part, representing loss, with the length through the white part, representing useful work. An examination in this way shows that as the motor's load decreases from the maximum the *percentage* of useful work decreases.

PART III.

The Localization and Remedy of Troubles in Dynamos or Motors.

CHAPTER XVIII.

INTRODUCTION.

THE promptness and ease with which any accident or difficulty with electrical machinery may be dealt with, whether by the inspector of construction or by the operator in charge of running, will always have much to do with the success of the plant and of those dependent upon it. It is therefore likely that any method to eliminate or reduce these troubles would be very welcome to those handling dynamos and motors. With the object of obtaining such a method, we have prepared a list of troubles, symptoms, and remedies, based upon quite an extensive experience with the various types and sizes of dynamos and motors in common use.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others. Nevertheless, it is quite remarkable how much can be covered by a systematic and reasonably simple statement of the matter, and we feel confident that nearly all of the cases of trouble most likely to occur are covered by the table, and that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not as easily detected, are of frequent occurrence. In such cases a very slight knowledge on the part of the man having the machine in charge, guided by a correct set of rules, will enable him to overcome the difficulty immediately, and save much time, trouble, and expense.

It must not be supposed that this method for treating dynamo and motor troubles is given because these machines are particularly liable to such difficulties. On the contrary, no machine in existence is mechanically simpler than the dynamo or motor. The only wearing parts about the machine are the commutator, brushes, and the bearings, all of which are made to stand almost unlimited use. In this respect, therefore, the dynamo or motor is as simple as an ordinary grindstone, and infinitely simpler than a steam-engine, which often has a dozen or more oil-cups and several dozen wearing parts. Even a sewing-machine is far more complicated mechanically than any dynamo or motor. In fact, it would be useless to attempt to give a method for detecting and curing dynamo and motor troubles if it were not for the fact that these machines consist of very few parts, which makes it reasonably possible to locate the trouble.

The rules are made, as far as possible, self-explanatory, but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table the principal object should always be to separate clearly the various causes and effects from each other. A careful and thorough examination should first be made, and as far as possible one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course general precautions and preventive measures should be taken *before* any troubles occur, if possible, rather than wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort.

The general plan of the table is to divide *all* troubles which may occur to dynamos or motors, into nine classes, the headings of which are the nine most important and obvious bad effects ever produced in these machines, viz.:

Chap. XIX. Sparking at Commutator.
XXI. Heating of Commutator and Brushes.
XXII. Heating of Armature.
XXIII. Heating of Field-magnets.
XXIV. Heating of Bearings.
XXV. Noise.
XXVI. Speed Too High or Too Low.
XXVII. Motor Stops or Fails to Start.
XXVIII. Dynamo Fails to Generate.

Any one of these general effects is very evident, even to the casual observer, and still more so to any person making a careful examination, and every one of them is perfectly distinguishable from any of the others without the least difficulty. Hence this classification is perfectly definite, and makes it easy to tell, almost at the first glance, under which one of these heads any trouble belongs, thereby eliminating about eight ninths of the possible cases. The next step is to find out which particular one of the eight or ten causes *in* this class is responsible for the trouble. This, of course, requires more careful examination, but nevertheless can be done with comparative ease in most cases. Of course one cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a very complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; then proceed to pick out the particular one by following the directions, which show how each case may be distinguished from any other. Any dynamo or motor may have almost any of the various troubles, but in each instance the particular kind of machine most liable to it is specified, and special directions are given for special types. It should be remembered by those in charge, that it is usually better to STOP the machine when any trouble manifests itself, even though the difficulty does not seem to be very serious, because it is very likely to develop into something worse. There are, of course, many cases, particularly in electric-lighting, when it is almost impossible to shut down. But even then spare machines should always be ready to be quickly substituted for the defective one. Of course, one must use his judgment and do what is best under the circumstances. The continued use of faulty apparatus is too common, and is often inexcusable.

The table is intended for the use of those who build, test, install, own, or operate electrical machinery, and all statements apply equally well to both dynamos and motors, unless otherwise especially noted.

CHAPTER XIX.

SPARKING AT COMMUTATOR.

THIS is one of the most common troubles, the objection to it being that it wears or may even destroy the commutator and brushes, and produces heat, which may injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. Alternating-current machines have continuous collecting rings which are not likely to spark, but self-exciting or compound-wound alternators require a supplementary continuous-current commutator which may spark. This trouble can be prevented in most cases, however, by proper construction and care. Of all the troubles which may occur, sparking is the only one which is very different in the different types of machine. In some its occurrence is practically impossible. In others it may result from a number of causes. The following cases of sparking apply to nearly all machines, and they cover closed-coil dynamos and motors completely.

The very peculiar cases which may arise in particular types of open-coil armatures can only be reached by special directions for each. (See Part IV.) A certain amount of sparking occurs normally in most constant-current dynamos for arc-lighting, where it is not very objectionable, since they are designed to stand it, and the current is small.

1. **Cause.**—*Armature carrying too much current*, due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by constant-potential motor); a bad short-circuit, leak, or ground on the line may also have the effect of overloading a dynamo; (*b*) excessive voltage on a constant-potential circuit or excessive amperes on a constant-current circuit. In the case of a motor on a constant-potential circuit, any friction, such as armature striking pole-pieces, or shaft not turning freely, will of course have

the same effect as overload in producing excessive current. The armature of a motor on a constant-current circuit does not tend to heat more when overloaded, because the current and the heat it produces in the armature ($C^2 R$) are constant. In fact the armature can be stopped with full current on without injury except loss of ventilation.

Symptom.—Whole armature becomes overheated, and belt very tight on tension side, and sometimes squeaks, due to slipping on pulley. Overload due to friction is detected by stopping machine and then turning it slowly by hand. (See "Heating of Bearings" and "Noise," Cause 2.)

Remedy.—(*c*) Reduce the load, or eliminate the short-circuit, leak, or ground on the line; (*d*) decrease the size of driving-pulley, or (*e*) increase the size of driven pulley; (*f*) decrease magnetic strength of the field in the case of a dynamo or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will probably be necessary to change the machine or its winding. Overload due to friction is eliminated as described under "Heating of Bearings" and "Noise," Cause 2, page 146.

If the starting or regulating box of a motor on a constant potential circuit, has too little resistance, it will cause the motor to start too suddenly and spark badly at first. The only remedy is more resistance in the box.

2. Cause.—*Brushes not set at the neutral point.*

Symptom.—Sparking varied by shifting the brushes with rocker-arm.

Remedy.—Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This may be done by simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite, or in a four-pole machine 90° apart, they should be made so, the proper points of contact being determined by counting the commutator-bars or measuring with a string or paper. The brushes should also be carefully adjusted in line with each other. If one is ahead or behind the others they may span too much of the commutator.

The usual position for brushes in two-pole machines is opposite the spaces between the pole-pieces, but in Edison, Sprague, and some other machines they must be set at right angles to this position, and in the T. H. motors about 45° to this position, because the armature wires are carried around a portion of a circle before reaching the commutator. If the brushes are set very far wrong, namely, half-way toward the proper position for the other brush, it will cause a dynamo to fail to generate and a motor to fail to start, and in the latter case burn out or "blow" the fuse.

See "Dynamo Fails to Generate," Cause 6.

3. **Cause.**—*Commutator rough, eccentric, or has one or more "high bars"* projecting beyond the others, or one or more flat bars, commonly called "flats," or projecting mica, any one of which causes brush to vibrate or to be actually thrown out of contact with commutator (Figs. 59,

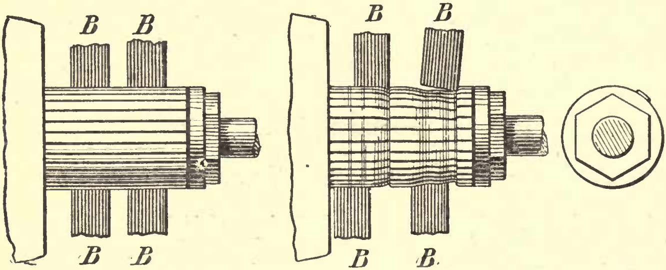


FIG. 59.—COMMUTATOR IN GOOD CONDITION. FIG. 60.—COMMUTATOR IN BAD CONDITION. FIG. 61.—HIGH BAR ON COMMUTATOR.

60, and 61). The effect of eccentricity may be produced by the shaft being *loose* in bearings while commutator is perfectly true on shaft. This will allow whole armature to chatter when running at full speed. Hard mica between the bars which does not wear as rapidly as the copper will throw brushes off.

Symptom.—Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger-nail and the least roughness is perceptible, or feel of brushes to see if there is any jar. If the machine runs at high voltage (over 250) the commutator or brushes should be touched with a small stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when commutator turns slowly, or a chattering of brush when running fast. Sometimes by sighting in line with brush contact one can see clear daylight between commutator and brush, owing to brush jumping up and down.

Remedy.—Smooth the commutator with a fine file or fine sand-paper, which should be applied by a block of wood which exactly fits the commutator (in latter case be careful to remove any sand remaining afterward; *and never use emery*). If bearing is loose, put in new one. If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines sometimes have a slide-rest attach-

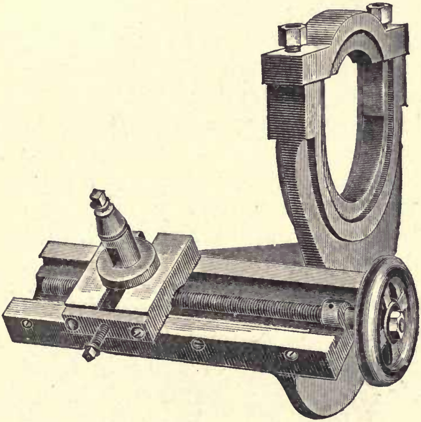


FIG. 62.—SLIDE-REST FOR TURNING OFF COMMUTATOR WHICH CLAMPS ON PILLOW-BLOCK IN PLACE OF ROCKER-ARM.

ment (Fig. 62), so that the commutator can be turned off without removing the armature. This is clamped on the pillow-block after removing the rocker-arm.

In turning a commutator in the lathe, a diamond-pointed tool should be used, this being better than either a round or square end. The tool should have a very sharp and smooth edge, and only an exceedingly fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

In order to have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about a sixteenth or an eighth of an inch in the bearings. The position of the bearings, pulley, collars, and shoulders on the shaft and of the machine with respect to the belt should be such as to cause this to take place of itself—except in the case of types of machines in which the pole-pieces surround the ends of the armature (see Part IV). It is desirable for the commutator to have a dull glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a *very little* vaseline or a drop of oil may be applied to a commutator which is rough. Too much oil is very bad, and causes the following trouble.

4. **Cause.**—*Brushes make poor contact with commutator.*

Symptom.—Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will only touch in one or two points, and should be discarded.

Remedy.—File, bend, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but light pressure. Copper brushes require a regular brush jig (Fig. 63). Carbon brushes may be fitted perfectly by drawing a strip of sand-paper back and forth between them and the commutator while they are pressing down, which cuts them to the shape of the commutator. A band of sand-paper may be pasted or tied around the commutator, and if the armature is then slowly revolved by hand or by power and the brushes are pressed upon it, they will be very effectively, rapidly, and perfectly shaped to the commutator.

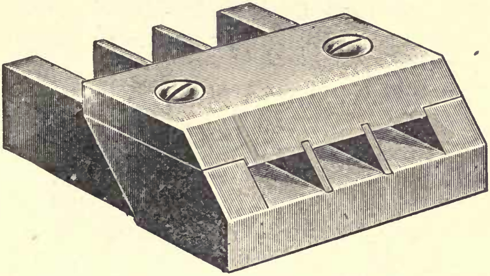


FIG. 63.—JIG FOR FILING BRUSHES TO THE CORRECT BEVEL.

It sometimes happens that the brushes make poor contact, because the brush-holders do not turn or work freely.

5. **Cause.**—*Short-circuited coil in armature or reversed coil.*

Symptom.—A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil see "Heating of armature," Cause 6.

The short-circuited coil is heated much more than the others, and is very apt to be burnt out entirely; therefore stop machine immediately. If necessary to run machine to locate the short-circuit, one or two minutes is long enough, but it may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field-magnets near the revolving armature vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it, but a short-circuit produces a much stronger effect only *once* per revolution. Be very careful not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when armature turns rather slowly. If a large portion of the armature is short-circuited the heating is distributed and harder to locate. In this case a motor runs very slowly giving little power, but having full field-magnetism. A short-circuited coil can also be detected by the drop-of-potential method. (For dynamos, see "Dynamo Fails to Generate," Cause 3.)

Remedy.—A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature, and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short-circuit is in the coil itself, the only real cure is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short-circuit. (See Cause 7.)

6. **Cause.**—*Broken circuit in armature.*

Symptom.—Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in this case no particular armature coil will be heated, as in the last case (Cause 5), and the flashing will be very much worse, even when turning slowly. This trouble which might also be confounded with a bad case of "high bar" or eccentricity in commutator ("Sparking," Cause 3), is distinguished from it by slowly turning the armature, when violent flashing will continue if circuit is broken, but not with eccentric commutator or even with "high bar," unless the latter is very bad, in which case it is easily felt or seen. A very bad contact would have almost the same effect as a break in the circuit.

Remedy.—A break or bad contact may be located by the "drop" method (page 92), or by a continuity test (page 96). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire may be resoldered or screwed back in place. If the trouble is due to a broken commutator connection, and it cannot be fixed, then connect the disconnected bar to the next by solder, or "stagger" the brushes; that is, put one a little forward and the other back so as to bridge over the break (Fig. 64). If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator-bars connected together, or other makeshifts resorted to, but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator-bars is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible, but if it has to be done in an emergency it can afterwards be picked out and smoothed over. In carrying out any of these methods care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

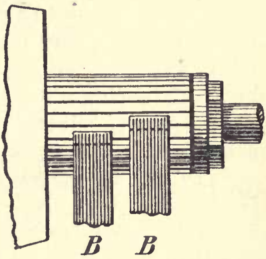


FIG. 64.—STAGGERED BRUSHES.

7. **Cause.**—*Ground in armature.*

Symptom.—Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short-circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric railway ("trolley") or other circuit which employs the earth as the return conductor one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a very variable torque at different parts of a revolution.

Remedy.—A ground is detected by testing with a magneto bell (page 96). It may be located by the drop-of-potential method (page 92). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass-needle when slowly moved around the surface of the armature. The current may be obtained from a storage-battery or from the circuit, but then it should be regulated by lamps or a resistance-box so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others have to be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt; in fact, a belt usually gives off electric sparks while running. If the frame of the machine is connected to the ground the static charge will pass off to the ground, but this grounding is not generally considered allowable. The frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static change that is of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current, which might cause trouble.

8. **Cause.**—*Weak field-magnetism.*

Symptom.—Pole-pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, due to relatively strong distorting effect of armature magnetism. Speed of a constant-potential motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards. A dynamo fails to generate the full E. M. F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care to first disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field-coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short-circuit is confined to one magnet, and will therefore weaken that one more than the others, and a piece of iron held half-way between the pole-pieces will be attracted to one more than the other. It may be found by the drop-of-potential method by testing from the splice between the field-coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. Then we have a double ground, through which the current finds a complete circuit, which is equivalent to a short-circuit. In the ordinary "trolley" electric-railway system a ground return is used, and one ground may therefore be sufficient to cut out one or more field-coils. This is, however, almost the only case in which a grounded circuit is used.

If a field-coil is reversed and opposed to the others, it will weaken the field-magnetism, and cause bad sparking. This may be detected by examining the field-coils to see if they are all connected in the right way, or by testing with a compass needle. (See "Dynamo Fails to Generate," Cause 4.) The series-coil of a compound-wound dynamo is quite often connected wrongly, and will have the effect of forcing down the voltage the more the load is increased instead of raising it.

Remedy.—A broken or a short circuit or a ground is easily repaired if it is external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the starting-box connects the armature before the field. This may be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it is likely to cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised the resistance of the field-circuit should be reduced by unwinding a few layers of wire or by substituting other coils.

(See "Speed Too High or Too Low," "Motor Stops or Fails to Start," "Dynamo Fails to Generate.")

9. **Cause.**—*Unequal distribution of magnetism.* One pole-tip very much weaker than the other.

Symptom.—One brush sparks more than the other.

Remedy.—Reshape pole-pieces, or strengthen weak tip.

10. **Cause.**—*Very high resistance brush.*—A carbon brush of abnormally high resistance may cause sparking by being unable to make good conducting contact with commutator. In that case its end will burn off slowly, as with any bad connection.

Symptom.—Measurement shows high resistance and the brush is very hot.

Remedy.—Use new brush.

11. **Cause.**—*Vibration of machine.*

Symptom.—Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

Remedy.—The vibration is usually due to an imperfectly balanced armature or pulley (see "Noise," Cause 1), a bad belt (see "Noise," Cause 6), or to unsteady foundations, and the remedies described for these troubles should be applied.

Any considerable vibration is almost sure to produce sparking, of which it is a common cause. This sparking may be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome by the remedies referred to above.

12. **Cause.**—*Chatter of brushes.*—The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similarly to the action of a violin-bow.

Symptom.—Slight tingling or jarring is felt in brushes.

Remedy.—Clean commutator and oil slightly. This stops it at once.

13. **Cause.**—*Pulsations of current*, which are common in arc-lighting circuits, will cause sparking in motors on such circuit.

Symptom.—An ammeter in the circuit will show that the current is constantly fluctuating if slow; if rapid, humming can be heard.

Remedy.—Steady the current by better adjustment of the regulator on the generator, or stop the throwing of lamps or motors on and off the circuit too suddenly.

14. **Cause.**—*Flying break in armature conductor.*

Symptom.—No break shown by test when armature standing still, but break shown when running by flashing of brushes.

Remedy.—Tighten connections to commutator, or repair broken wire, etc.

CHAPTER XX.

HEATING IN DYNAMO OR MOTOR.

GENERAL INSTRUCTIONS.

THE degree of heat that is injurious or objectionable in any part of a dynamo or motor is easily determined by feeling the various parts. If the heat is bearable for a few moments it is entirely harmless. But if the heat is unbearable for more than a few seconds the safe limit of temperature has been passed, except in the case of commutators in which solder is not used; and it should be reduced in some of the ways that are given below. In testing with the hand, allowance should always be made for the fact that bare metal feels much hotter than cotton, etc. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off and the machine stopped immediately, as this indicates a serious trouble, such as a short-circuited coil or a tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines, where it can be applied without danger of wetting the other parts.

Feeling for heat will answer in ordinary cases, but, of course, the sensitiveness of the hand differs, and it makes a very great difference whether the surface is a good or bad conductor of heat. The back of the hand is more sensitive and less variable than the palm for this test. But for accurate results a thermometer should be applied and covered with waste or cloth to keep in the heat. In proper working the temperature of no parts of the machine should rise more than 45° C. or 81° F. *above* the temperature of the surrounding air. If the actual temperature of the machine is near the boiling-point, 100° C. or 212° F., it is seriously high.

It is very important in all cases of heating to locate correctly the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine which is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa.* In every case all parts of the machine should be felt to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is generally much surer and easier in the end to make observations for heating by starting with the whole machine perfectly cool, which is done by letting it stand for one or more hours, or over night, before making the examination. When ready to try it, run it fast for three to five minutes, with the field-magnets charged; then stop, and feel all parts immediately. The heat will be found in the right place, as it will not have had time to diffuse from the heated to the cool parts of the machine. Whereas, after the machine has run some time any heating effect will spread until all parts are nearly equal in temperature, and it will then be almost impossible to locate the trouble.

Excessive heating of commutator, armature, field-magnets, or bearings may occur in *any* type of dynamo or motor, but it can almost always be avoided by proper care and working conditions.

CHAPTER XXI.

HEATING OF COMMUTATOR AND BRUSHES.

1. **Cause.**—*Heat spread from another part of machine.*

Symptom.—Start with the machine cool and run for a short time, so that heat will not have time to spread. The real seat of trouble will then be the part that heats first.

Remedy. (See Heating of Armature, Fields, or Bearings, respectively.)

2. **Cause.**—*Sparking.*—Any of the causes of sparking will cause heating, which may be slight or serious.

Symptom and **Remedy.** (See "Sparking.")

3. **Cause.**—*Tendency to spark* or slight sparking not visible. Sometimes before sparking appears serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

Symptom.—Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

Remedy. (See "Sparking.")—Apply the remedies with extra care.

4. **Cause.**—*Overheated commutator will decompose carbon brush* and cover commutator with a black film, which offers resistance and aggravates the heat.

Symptom.—Commutator covered with dark coating; commutator brushes and holders show marks of extreme heat.

Remedy.—Clean off and polish commutator, reset brushes, start over again, and watch carefully.

5. **Cause.**—*Bad connections in brush-holder, cable*, etc.

Symptom.—Holder, cable, etc., feels hottest; unusual resistance found in these parts by "drop method," p. 92.

Remedy.—Improve the connections.

6. **Cause.**—"*Arcing*" *or short-circuit in commutator* across mica, or insulation between bars or nuts.

Symptom.—Burnt spot between parts; spark appears in the insulation when current is put on.

Remedy.—Pick out the charred particles, take commutator apart and remedy, or put on new commutator.

7. **Cause.**—*Carbon brushes heated by the current.*

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance prevents the development of sparking, but this higher resistance causes them to heat up more than copper brushes.

Symptom.—Brushes hotter than other parts. Machine runs much cooler with copper brushes.

Remedy.—Use higher conductivity carbon. Let the brush-holder grip brush closer to commutator so as to reduce the length of brush through which the current has to pass. Reinforce the brush with copper gauze, sheet copper, or wires run through it, or use some form of the combined metal and carbon brushes that are on the market. Use larger brushes or a greater number of them.

CHAPTER XXII.

HEATING OF ARMATURE.

NOTE.—Any excess of current taken by an armature when running FREE, whatever the cause, must be converted into heat by some defect in the motor, hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of a machine.

1. **Cause.**—*Excessive current in armature coils.*—Symptom and Remedy the same as "Sparking," Cause 1.

2. **Cause.**—*Short-circuited armature coils.*—Symptom and Remedy the same as "Sparking," Cause 5. See also Cause 7.

3. **Cause.**—*Moisture in armature coils.*

Symptom.—Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation of armature, which would be much lowered by moisture.

Remedy.—Bake the armature for five hours in an oven or other place which is sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A very neat way to do this is to pass a current through the armature, which should be regulated so as to be about three quarters of the full armature current, the armature being held still and turned over only once or twice to prevent the shellac running to one side when hot. If weather is damp armature should be baked all day or all night, and in any case until its insulation measures at least 1 megohm.

4. **Cause.**—*Foucault currents in armature core.*

Symptom.—Iron of armature core hotter than coils after a short run, and considerable power required to run armature when field is magnetized and there is no load on armature. This may be distinguished from Cause 2, by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See Part II, 17, "Separation of Losses.")

Remedy.—Armature core should be laminated more perfectly, which is a matter of first construction.

5. **Cause.**—*Eddy currents in armature conductors.*

Symptom.—The same as Cause 4, except that armature conductors are hotter than core even without any load.

Remedy.—This trouble is due to one side of each armature conductor having E. M. F. generated in it before the other side; it is, therefore, found in machines with large armature conductors or bars. It is overcome by reducing the thickness of the conductors or by splitting them up into a number of strips or strands, which should be twisted to equalize them. Rounding or bevelling off the edges of the pole pieces will also reduce the trouble, as will also sinking the conductors in slots in the armature core. Fig. 72*a*. (See Part II, 17, "Separation of Losses.")

6. **Cause.**—*One or more reversed coils on one side of armature*, which will cause a local current to circulate around armature.

Symptom.—Excessive current when running free, but no coil heated more than others. If current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

Remedy.—Reconnect the coil to agree with the others.

7. **Cause.**—*Heat conveyed from other parts.*

Symptom.—Other parts hotter than armature. Start with machine cool and see if other parts heat first.

Remedy. (See Heating of Bearings, Field, Commutator, etc., as the case may be.)

8. **Cause.**—*Flying cross in armature conductor.*

Symptom and **Remedy.**—Similar to sparking (Cause 14), except that it refers to the insulation of the conductors.

CHAPTER XXIII.

HEATING OF FIELD-MAGNETS.

1. **Cause.**—*Excessive current in field circuit.*

Symptom.—Field-coils too hot to keep the hand on.

Remedy.—In the case of a shunt-wound machine decrease the voltage at terminals of field-coils, or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field, or take a layer or more of wire off the field-coils, or rewind with coarser wire. This trouble might be due to a short-circuit in field-coils in the case of a shunt-wound dynamo or motor, and would be indicated by one pole-piece with the short-circuited coil being weaker than the other; one of the coils would also probably be hotter than the other; but this can only be remedied by rewinding short-circuited coil. Measure resistance of field coils to see if they are nearly equal. (See "drop method," page 92.) If the difference is considerable (i.e., more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded. *If one field coil is much hotter than the other, the trouble probably lies in the cooler coil, as it is short-circuited and allows the other to carry excessive current and become heated.*

2. **Cause.**—*Foucault currents in pole-pieces.*

Symptom.—The pole-pieces hotter than the coils after a short run. When making the comparison it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole-pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

Remedy.—This trouble is either due to faulty design and construction, which can only be corrected by rebuilding, or else it is caused by fluctuations in the current. The latter can be detected if the variations are not too rapid, by putting an ammeter in circuit, or rapid variations may be felt by holding a piece of iron near the pole-pieces and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating, and the ordinary arc currents fluctuate enough to cause some trouble in this way. In fact, the currents generated by the open-coil armatures used in arc-lighting (Thomson-Houston and Brush, for example)* are pulsating in character, and are apt to cause Foucault currents and heating in the field-magnets of motors fed by such currents.

3. **Cause.**—*Moisture in field-coils.*

Symptom.—Field-circuit tests lower in resistance than normal in that type of machine, and in the case of shunt-wound machines the field takes more than the ordinary current. Field-coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

Remedy.—The same as for moisture in armature, page 136.

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* A Study of an Open-coil Arc Dynamo, by M. E. Thompson, *Electrical Engineer*, May 27, 1891.

CHAPTER XXIV.

HEATING OF BEARINGS.

THIS may arise in any machine. The cause should be found and removed promptly, but heating of the bearings may be reduced temporarily by applying cold water or ice to them. This is only allowable when it is absolutely necessary to keep running, and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly, as it might "freeze" or stick fast if stopped entirely.

1. **Cause.**—*Lack of oil.*

Symptom.—Oil cup or reservoir empty. Oil passages clogged. Self-oiling rings stuck fast. Shaft and bearing look dry. The shaft does not turn freely.

Remedy.—Supply oil, and make sure that oil-passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. Good quality of oil should always be used, as poor oil might be as bad as no oil.

2. **Cause.**—*Grit or other foreign matter in bearings.*

Symptom.—Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also scratch the shaft.

Remedy.—Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft the dirt might be washed out with kerosene or water, but these should not be allowed to get on the commutator, armature, or field-coils.

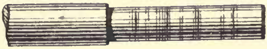


FIG. 65.—SHAFT ROUGH OR CUT.

3. **Cause.**—*Shaft rough or cut.* (Fig. 65.)

Symptom.—Shaft will show grooves or roughness, and will probably revolve stiffly.

Remedy.—Turn shaft in lathe or smooth with fine file, and see that bearing is smooth and fits shaft.

4. **Cause.**—*Shaft and bearing fit too tight.*

Symptom.—Shaft hard to revolve by hand.

Remedy.—Turn or file down shaft in lathe, or scrape or ream out bearings.

5. **Cause.**—*Shaft "sprung" or bent.*

Symptom.—Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

Remedy.—It is almost impossible to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

6. **Cause.**—*Bearings out of line.*

Symptom.—Shaft hard to revolve, but is much relieved by slightly loosening the screws which hold bearings in place. Bearing sometimes moves perceptibly when loosened. This should be tried, however, when the motor is not running and the belt is off.

Remedy.—Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up and down; then file the screw-holes of that bearing or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature must be kept, however, in the centre of the space between the pole-pieces, so that the clearance is uniform all around. (See Cause 9.)

7. **Cause.**—*Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.* (Figs. 66 and 67.)

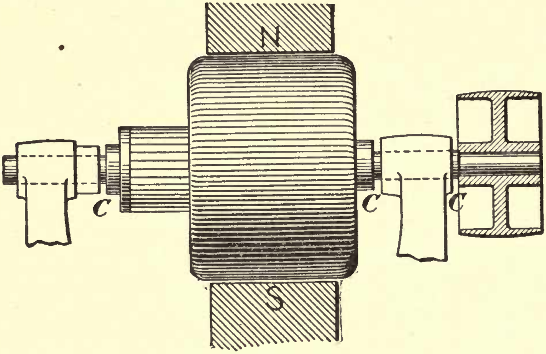


FIG. 66.—ARMATURE WITH GOOD CLEARANCE AT C.C.

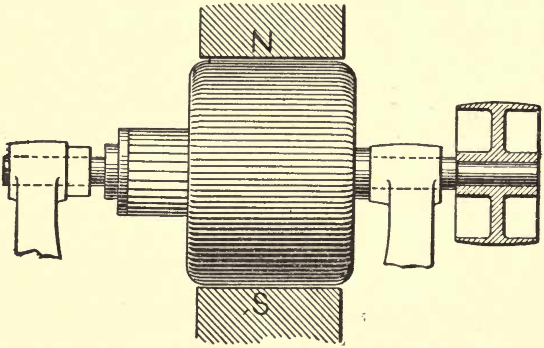


FIG. 67.—ARMATURE FORCED AGAINST BEARING.

Symptom.—Move shaft back and forth with the finger or a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. A dynamo or motor shaft should usually be capable of moving freely back and forth a sixteenth or an eighth of an inch to make commutator and bearings wear smooth, except in machines in which the pole-pieces surround the ends of the armature. (See Remedy "Sparking," Cause 3.) This trouble may be relieved in one of the following ways :

Remedy.—Line up the belt, shift collar or pulley, turn off shoulder on shaft or file off bearing until the shoulder does not touch when running or until pressure is relieved.

8. **Cause.**—*Too great load or strain on the belt.*

Symptom.—Great tension on belt. In this case pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 68, in which case the shaft may be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

Remedy.—Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting," Chapter IV.)

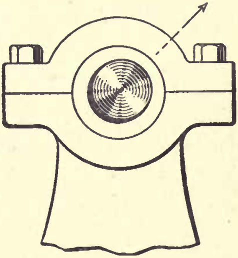


FIG. 68.—BEARING WORN ELLIPTICAL.

9. **Cause.**—*Armature too near one pole-piece, producing much greater magnetic attraction on nearer side.*

Symptom.—Examine the clearance of armature, and see if it is uniform on all sides. Charge and discharge the field-magnet, the armature being disconnected (by putting wood under one set of brushes), and see if armature seems to be drawn to one side and turns very much less easily when field is magnetized.

Remedy.—This fault is either due to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centred exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place, or the pole-piece may be filed away where it is too near the armature. In small machines it is sometimes possible to spring the pole-piece farther away from the armature, but this is difficult and dangerous to attempt. Trouble from this cause is greater in multipolar than in bipolar machines; therefore the clearance between the armature and pole pieces should be larger in the former than in the latter, and the former are sometimes provided with screws for shifting the fields. This difficulty always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the centre of the space formed by the pole-pieces, the magnetic pull is practically balanced in all directions.

It is risky to file bolt holes or make any such change in a machine, and it should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or there is dirt between them. If the bearing is warm or the shaft out of centre, the former may be rebabbitted or renewed.

10. **Cause.**—*Bearing heated by hot pulley, commutator, or armature.*

Symptom.—Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and are the real source of the trouble.

Remedy.—A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

CHAPTER XXV.

NOISE.

1. **Cause.**—*Vibration due to armature or pulley being out of balance.*

Symptom.—Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

Remedy.—Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out and rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 69). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will

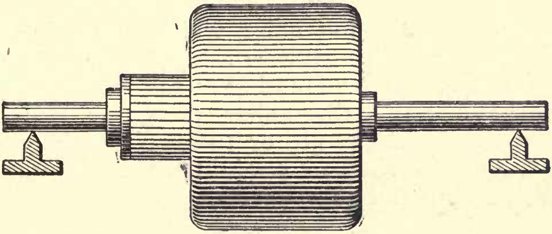


FIG. 69.—METHOD OF BALANCING ARMATURE.

give the shaft a strong tendency to "wobble." A perfect balance is only obtained when the weights are directly opposite, i.e., in the same line perpendicular to the shaft.

2. **Cause.**—*Armature strikes or rubs against pole-pieces.*

Symptom.—Easily detected by placing the ear near the pole-pieces or by examining armature to see if its surface is abraded at any point, or by examining each part of the space between armature and field, as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. Or turn armature by hand when no current is on, and note if it sticks at any point. It is unwise to have a clearance of less than $\frac{1}{8}$ to $\frac{1}{4}$ inch.

Remedy.—Bind down any wire or other part of the armature that may project abnormally, or file out the pole-pieces where the armature strikes, or centre the armature so that there is a uniform clearance between it and the pole-pieces at all points.

3. **Cause.**—*Shaft collar or shoulder, hub or edge of pulley, or belt strikes or scrapes against bearings.*

Symptom.—Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of the Bearings," Cause 7.)

Remedy.—Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft or straighten the belt until there is no more striking and noise ceases.

4. **Cause.**—*Rattling due to looseness of screws or other parts.*

Symptom.—Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

Remedy.—Tighten up the loose parts, and be careful to keep them all in place and properly set up. It is very easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

5. **Cause.**—*Singing or hissing of brushes.*—This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 12), or by tips of brushes not being smooth, or the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon which is gritty or too hard. Vertical carbon brushes or brushes inclined against the direction of rotation are apt to squeak or sing. A new machine will sometimes make noise from rough commutator, no matter how carefully it is turned off, because the difference in hardness between mica and copper causes the cut of the tool to vary, thus forming inequalities which are very minute, but enough to make noise. This can best be smoothed by running.

Symptom.—Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more on each side, so that the circuit is not opened. If there is no current, there is no objection to raising the brushes.

Remedy.—Apply a *very little* oil or vaseline to the commutator with the finger or a rag. Adjust the brushes or smooth the commutator by turning, filing, or fine sand-paper, being careful to clean thoroughly afterwards. Carbon brushes are apt to squeak in starting up or at slow speed. This decreases at full speed, and can usually be reduced by moistening the brush with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Run the machine on open circuit until commutator and brushes are worn smooth.

Cause.—*Flapping or pounding of belt joint or lacing against pulley.* (Fig. 70.)

Symptom.—Sound repeated once for each complete revolution of the belt, which is much less frequent than any other dynamo or motor sound, and can be easily detected or counted.

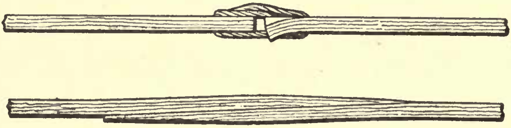


Fig. 70.—Bad Joints in Belt.

Remedy.—Endless belt or smoother joint in belt. A perfect joint and a straight, smooth belt are always very desirable for dynamos and motors. (See "Belting," Chapter IV.

7. **Cause.**—*Slipping of belt on pulley due to overload.*

Symptom.—Intermittent squeaking noise.

Remedy.—Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion; but it is a makeshift, injurious to the belt, only to be adopted if necessary. (See "Belting," Chapter IV.)

8. **Cause.**—*Humming of armature-core teeth* (*if any*) *as they pass pole-pieces.*

Symptom.—Pure humming sound less metallic than Cause 5.

Remedy.—Slope or chamfer the ends of the pole-pieces so that each armature tooth does not pass the edge of the pole-piece all at once. Decrease the magnetization of the fields. Increase the cross-section or magnetic capacity of the teeth, or reduce that of the body of the armature. But these are nearly all matters of first construction, and are made right by good manufacturers.

9. **Cause.**—*Humming due to alternating or pulsating current.*

Symptom.—This gives a sound similar to that in the preceding case, but louder. The two troubles can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth of generator passing per second. Usually the latter is considerably greater than the former. This trouble is confined to alternating-current apparatus, and to motors on circuits operated by some forms of dynamos having commutators with few segments, or having toothed armatures. (See "Heating of Field Magnets," Cause 2.)

Remedy.—It is practically inherent in alternating apparatus, but its effects can be reduced by mounting the machine on rubber, or otherwise deadening the sound.

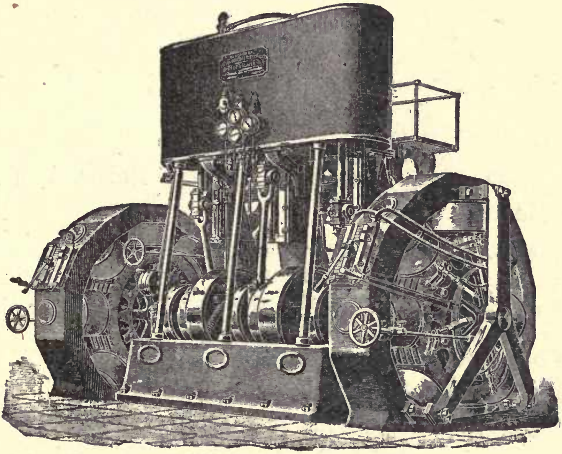


FIG. 71.—DIRECT-CONNECTED GENERATORS.

Note.—It often happens that a dynamo or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is coupled (Fig. 71), or by other connections that may be used. Very careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive way to locate a noise or vibration is to hold a short stick or pencil by one end between the teeth and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

CHAPTER XXVI.

SPEED TOO HIGH OR TOO LOW.

THIS is generally a serious matter in either dynamo or motor, and it is always desirable and often imperative to shut off the power or current immediately, and make a careful investigation of the trouble.

SPEED TOO LOW.

1. **Cause.**—*Overload.* (See "Sparking," Cause 1.)

Symptom.—Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature and bearings heat. Belt very tight on tension side.

Remedy.—Reduce the load on machine by taking off lamps in the case of a dynamo, or mechanical work in the case of a motor; decrease the diameter of driving pulley or increase the diameter of driven pulley. If necessary to relieve strain of overload temporarily decrease the E. M. F. on either a dynamo or motor.

2. **Cause.**—*Short-circuit or ground in armature.*

Symptom and **Remedy** the same as "Heating of Armature." (Cause 2 and Cause 7.)

3. **Cause.**—*Armature strikes pole-pieces.*

Symptom and **Remedy** the same as "Noise," Cause 2.

4. **Cause.**—*Shaft does not revolve freely in the bearings.*

Symptom.—Armature turns hard by hand; bearings and shaft heat when running.

Remedy.—Oil the bearings; clean and smooth, if necessary, the shaft and bearings; line up the bearings. (See "Heating of Bearings," all cases).

SPEED HIGH OR LOW.

5. **Cause.**—*Field-magnetism weak.*

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field-magnet is not excited at all, as, for example, when the field circuit is broken. It makes a dynamo fail to "build up" or excite its field, or give the proper voltage in any case. A motor on a constant-current (arc) circuit would probably run slowly if the field-magnetism is weak, due to a short-circuit in the field-coils, or some other cause.

Symptom and **Remedy** the same as "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate.")

6. **Cause.**—*Too high or too low voltage or current on the circuit.*

Symptom.—This would cause a motor to run too fast or too slow, respectively. It can be proved by measuring voltage or current of the circuit.

Remedy.—The central station should be notified that the voltage or current is not right.

7. **Cause.**—*Motor too lightly loaded.*

Symptom.—A series-wound motor on a constant-potential circuit, or any motor on a constant-current circuit, is liable to run too fast if the load is very much reduced, or removed entirely (by the breaking of the belt, for example).

Remedy.—Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is positively connected or geared to the motor, so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off. On a constant-current circuit a motor must be provided with an automatic governor or cut-out, which acts to reduce the power if the speed becomes too great. This applies to all constant-current motors, except those to which the load is positively connected, so that it will never be thrown off.

CHAPTER XXVII.

MOTOR STOPS OR FAILS TO START.

THIS is an extreme case of the previous class ("Speed Too High or Too Low"), but it is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to dynamos, since any trouble in setting them in motion is outside of the machine itself.

1. **Cause.**—*Great overload.* (See "Sparking," Cause 1.)—A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it.

Symptom.—On a constant-current circuit no harm results, and motor starts properly when load is reduced or taken off.

On a constant-potential circuit the current is excessive, and safety-fuse melts, or, in the absence or failure of the latter to act, armature is burnt out.

Remedy.—Turn off switch instantly, reduce or take off the load, replace the fuse or cut-out if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

2. **Cause.**—*Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole-pieces.*

Symptom.—Similar to previous case, but is distinguished from it by the fact that armature is hard to turn by hand, even when load is taken off. Examination shows that the shaft is too large, bent, or rough, or that the bearing is too tight, that the armature touches pole-pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

Remedy.—Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

3. **Cause.**—*Circuit open*, due to (*a*) safety-fuse melted, (*b*) wire in motor broken or slipped out of connections, (*c*) brushes not in contact with commutator, (*d*) switch open, (*e*) circuit supplying motor open, (*f*) failure at generating station.

Symptom.—Distinguished from Causes 1 and 2 by the fact that if the load is taken off the motor still refuses to start, and yet armature turns freely by hand.

On a constant-current circuit the switch arcs badly when turned on if motor circuit is open; but there is no current, motion, or other effect in motor. On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole-pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault there is no spark when the brushes are lifted, and if both are without current there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is apt to be burnt out if the current is thrown upon its armature then.

Remedy.—Turn current off instantly. Examine safety-fuse, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field-coils and other parts of circuit for continuity with a magneto or a cell of battery and an electric bell to see if there is any break in the circuit. (See "Instructions for Testing," Part II.)

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test with an incandescent lamp. Two or five lamps in series should be used on 220 and 500 volt circuits, respectively.

4. **Cause.**—*Wrong connection or complete short-circuit of field, armature, switch, etc.*

Symptom.—Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a motor or change its connections.

In the three-wire (220-volt direct-current) system several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system (page 62) may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the middle or "neutral" wire and either of the outside wires will burn perfectly.

(*b*) If one of the outside wires is open by the "blowing" of a fuse, an accidental break, or other cause, then a motor (220 volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is very great.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will be likely to burn it out.

CHAPTER XXVIII.

DYNAMO FAILS TO GENERATE.

THIS trouble is almost always caused by the inability of a dynamo to sufficiently "excite" or "build up" its field-magnetism. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately excited machine, and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

1. **Cause.**—*Residual magnetism too weak or destroyed*, due to (*a*) vibration or jar, (*b*) proximity of another dynamo, (*c*) earth's magnetism, (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up a current of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage-batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

Symptom.—Little or no magnetic attraction when the pole-pieces are tested with a piece of iron.

Remedy.—Send a magnetizing current from another machine or battery through field-coils, then start and try machine; if this fails, apply the current in the opposite direction since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward from the neutral point to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in harmony. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the North (which is magnetically the *south* pole of the earth), but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

2. **Cause.**—*Reversed connections or reversed direction of rotation.*

Symptom.—When running, pole-pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in Cause 1, because whichever way field might be thus magnetized the resulting current then generated by armature opposes and destroys the magnetism.

Remedy.—(*a*) Reverse either armature connections or field connections, *but not both*. (*b*) Move brushes through 180° for two-pole, 90° for four-pole machines, etc. (See page 44.) (*c*) Reverse direction of rotation. After each of the above the field may have to be build up with a battery or other current, since the causes of this case operate to destroy whatever residual magnetism may have been present.

3. **Cause.**—*Short-circuit in the machine or external circuit.*

Symptom.—Magnetism weak, but usually perceptible.

Remedy.—If short-circuit is in the external circuit, it will prevent the building up of a shunt dynamo until switch on external circuit is opened. But with a series dynamo it will hasten the "building up." If the short-circuit is within the machine, it is likely to prevent the building up of either shunt or series machines, and it should be found by careful inspection or testing. In these cases do not connect the external circuit till short-circuit is found and eliminated. A slight short-circuit, such as that caused by a defective lamp socket or copper dust on the brush-holder or commutator, may prevent a shunt machine's magnetism from building up.

(See "Sparking," Causes 5 and 8.) Too many lamps or other load might prevent a shunt dynamo from building up its field-magnetism, in which case the load should be disconnected in starting.

4. **Cause.**—*Field-coils opposed to each other.*

Symptom.—Upon passing a current from another dynamo or a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them both to be of the same, whereas they should always be of opposite, polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both pole-pieces at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

Remedy.—Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass) in practically all dynamos and motors.

5. **Cause.**—*Open circuit.*

(*a*) Broken wire or faulty connection in machine, (*b*) brushes not in contact with commutator, (*c*) safety-fuse melted or absent, (*d*) switch open, (*e*) external circuit open.

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

Remedy.—Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity with magneto or cell of battery and electric bell. (See "Instructions for Testing," Part II, and also "Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes, respectively, care being taken not to make a short-circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

6. **Cause.**—*Brushes not in proper position.*

Symptom.—The magnetism and current are increased by shifting the brushes.

Remedy.—It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But Edison, Sprague, and some other drum armatures are wound so that the brushes have to be set nearly at right angles to this position, and T. H. machines at about 45°. Some multipolar machines have as many sets of brushes as there are pole-pieces, while others have armatures which are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; six-pole machines, either 60° or 180°; eight-pole, either 45° or 135°; ten-pole, either 36°, 108°, or 180°; twelve-pole, either 30°, 90°, or 130°; and sixteen-pole, either $22\frac{1}{2}$°, $67\frac{1}{2}$°, $112\frac{1}{2}$°, or $157\frac{1}{2}$°; and so on.

In machines having two brushes they may be set directly opposite (i.e., 180°) whenever the number of poles is twice an *odd* number.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed, and if these are not available the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a "forward lead," that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which to a certain extent distorts the field-magnetism.

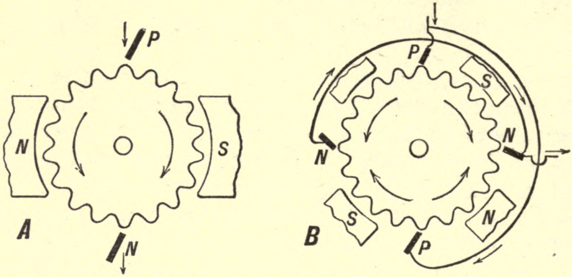
The positions and number of brushes for each kind of armature is shown in Fig. 72, which shows also the *arrangements of circuits* in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum or ring wound. The current enters from the positive brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a two-circuit armature.

B is a plain armature used in a four-pole machine. As there are two more poles, it is necessary to use two more brushes to collect the currents. This gives two brushes through which current enters and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

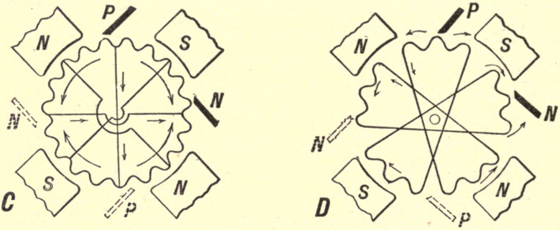
C is a four-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the centre of the armature. Therefore the entire current may be taken off by these brushes, or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case *B*.

With either *B* or *C*, since there are two parts of the



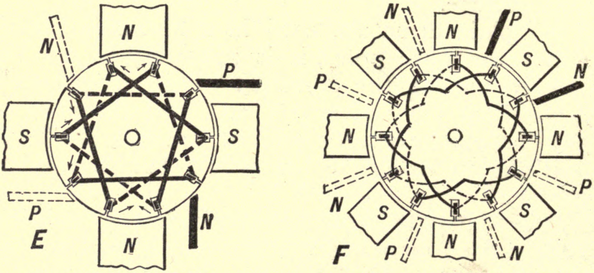
Two Pole, Two Circuit

Four Pole, Four Circuit, Four Brushes, In Multiple.



Four Pole, Four Circuit Cross Connected Two Brushes or Four Brushes, In Multiple.

Four Pole, Two Circuit Ring Two Brushes or Four Brushes, In Multiple.



Four Pole, Two Circuit Drum Two Brushes or Four Brushes, In Multiple.

Eight Pole, Two Circuit Drum Two Brushes, or Four, Six or Eight Brushes, In Multiple.

FIG. 72.—PRINCIPLES OF THE CONNECTIONS IN THE DIFFERENT TYPES OF ARMATURES.

armature winding, under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in *A*, because both parts of the winding are influenced by the two ends of a single magnet.

D is a four-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It is a ring-winding, and each coil is connected to the one diametrically opposite, giving the effect of a single coil of twice the size under a single magnet of double size, instead of two smaller ones of one polarity.

An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in *A*. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

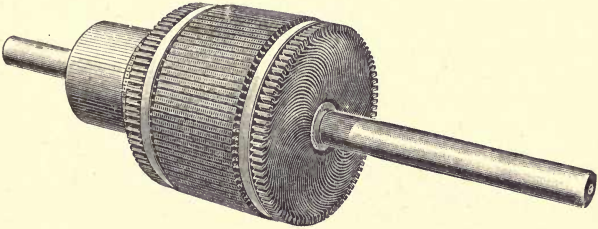


Fig. 72*a*.—40 H.P. Crocker-Wheeler Four-pole Bar Wound Drum Armature, using no wire or solder. Bars sunk in slots in iron core (Type E, Fig. 72).

E is a drum armature all in series, as with *D*. This winding is made with bars instead of wire. Inspection will show that the action of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

The bars pass through slots in the periphery of the armature, and their ends on the nearer side are connected together by the solid lines and the ends on the other side of the armature by the dotted lines. (Fig. *72a.*)

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars. About ten times as many are used in practice.

F is a series bar-wound drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from 0 to full E. M. F. is covered by moving the brush $\frac{1}{8}$ of the circumference.

As the winding is all in series, two brushes only are necessary, but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because the single pair of brushes would become heated from carrying excessive current, but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

CONCLUSION.

In the treatment of diseases of motors and dynamos it is evidently impossible to give complete directions for every case. But it will be found that nearly all causes of trouble have been covered, the exceptions being for the most part in certain special forms of machines. A mere list of these troubles, particularly if it is systematically arranged, is of the greatest help, and promptness and intelligence in dealing with troubles or accidents are the best proofs of an engineer's knowledge and ability.

PART IV.

Arc Dynamos and Motors Requiring Especial Directions.

Giving only those features which are special for each machine, general features being covered in main part of book.

CHAPTER XXIX.

THE THOMSON-HOUSTON ARC DYNAMO.

By Horatio A. Foster.

Preface.—The length of the following chapters need not alarm the dynamo man, but rather win his confidence, as it is the result of a desire for completeness. No one dynamo ever has all the diseases described; in fact they rarely have more than one or two at a time and many of the symptoms merely cause annoyance to the careful dynamo man. The attempt has been made to cover the field thoroughly, but the individual machine should be studied carefully before attempting to apply the remedies. The directions peculiar for left-hand dynamos are given separately on page 179 to avoid confusion. They are similar but reversed, and special fittings are required. It is much easier to turn the regular machine end for end before belting up, if necessary, to make its direction of rotation agree with the driving pulley, than to reverse its rotation.

DIRECTIONS FOR SETTING UP.

See the general directions given in Part I.

The speed should be that recommended by the manufacturer, but a slight departure from this does no harm, unless high enough to endanger bursting or low enough to cause flashing. Increased speed increases ventilation.

ADJUSTMENTS.

The Air-blast or Blower, (Fig. 80) is attached to the back-plate on the front bearing by four bolts, *a* (Fig. 82). The armature shaft passes through the hole in the centre without contact, excepting by a key set in the shaft fitting into a slot in the blower spider. The bearings of the spider are in the air-blast casing.

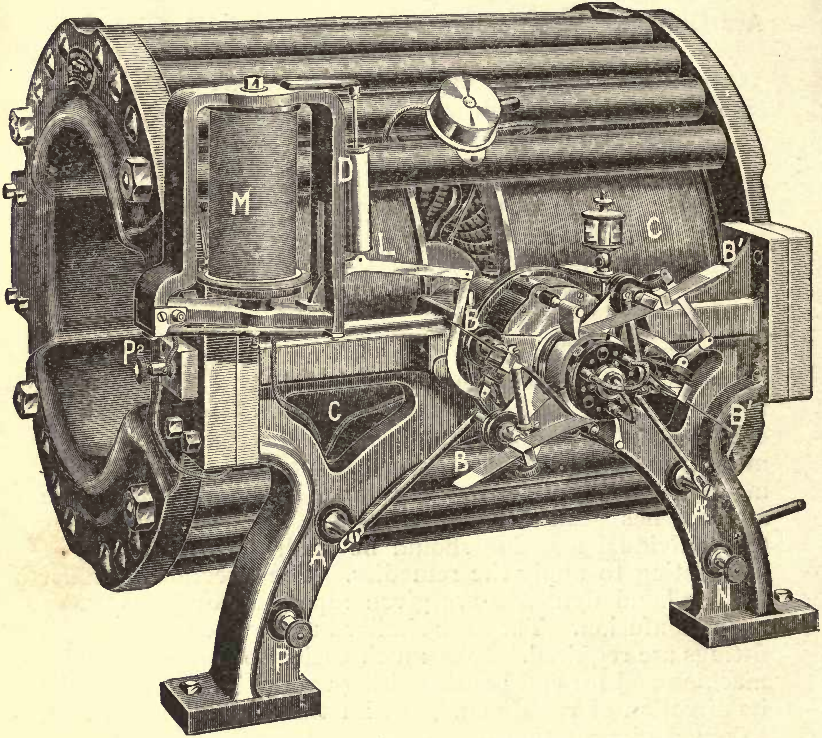


FIG. 73.—T. H. ARC DYNAMO.

The armature shaft is sometimes bent out of line at the small end: this can be detected by a piece of thick paper wound around the shaft and inserted under the blower bearing; the space should be clear and even all the way

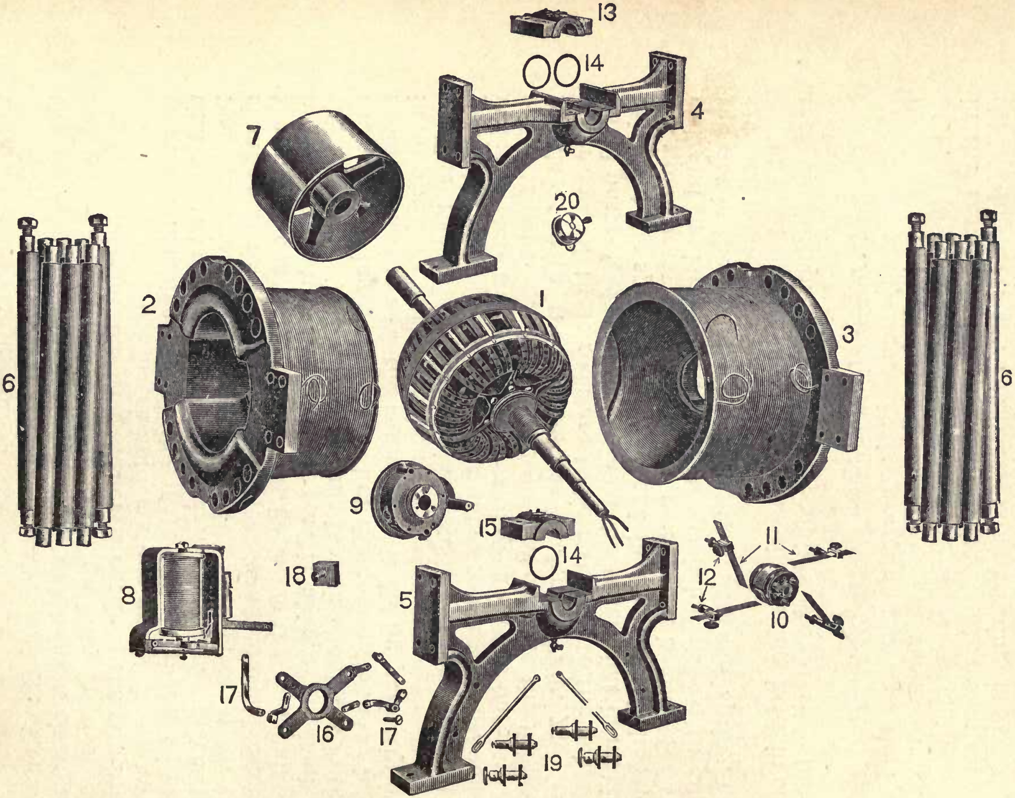


FIG. 74.--PARTS OF T. H. ARC DYNAMO.

1, Arma; 2, 3, fields; 4, 5, frames; 6, yoke bolts; 7, pulley; 8, regulator; 9, blower; 10, commutator; 11,12, brush holders; 13, 15, journal cap; 14, oiler rings; 16, brush yoke; 17, sliding links; 18, vulcanite connection block; 19, binding posts; 20, field switch.

around; if not so, the shaft must be bent back to place, or the back-plate readjusted.

Yokes and Sliding Connections.—To adjust: Remove the small plate from front bearing of air-blast, clean the yokes and attachments, and place in position on the bearing; see that the thin iron washer is between the two brass yokes, and that the brush-holder studs are outward, away from the machine; screw the plate back in place, and see that all parts work freely around the bearing. Place the two longer brush-holder studs in the back yoke; then the clamps will all be in line around the commutator. Secure the sliding connections in place between the two pairs of brush-holder studs; the barrel part is always fastened to the top stud. The screws are made with shoulders so that the small spring with each end of the connection may have room for action and the connection itself be perfectly free in all positions of the brushes.

The two lower brush-holder studs are secured to the yokes by long studs in place of nuts; to these studs, one of which is longer than the other and goes on the outer yoke, are fastened the ends of the rods that connect the field-terminals *A* with the brushes, as shown in Fig. 73. The other ends of these rods are to be fastened to the field-terminal posts A, A^1, and care must be taken that in making this joint the spring is first placed in the end of the stud, the small brass washer coming next for a bearing for the rod, and the large flat-headed screw being passed through the slot in the rod and through the washer and spring, and screwed home.

The rod should have a firm bearing, being held in contact by the springs at either end, but should slide freely endwise.

The *field terminals* and binding-posts A, A^1, P, P^2, and N are easily adjusted. P^2 is secured in place on the fibre bearings provided, and will only fit on one way. For each of the others the hard-wood bushing is placed in the hole in the casting; a hard-rubber washer, with recess on one side fitting over the shoulder of the bushing, is placed on either side, and the stud of the binding-post is passed through and secured in place by a nut.

The *regulator* *M* is bolted to the top of the left leg as shown in Fig. 73; the arm *L* is screwed on to the armature, and the curved link connecting this arm to the yoke mechanism is allowed to swing free. The bolt on the top of the regulator is loosened and regulator turned until the link hangs in line with the slide connection on yoke, keeping pole of magnet well centered in hole in armature so as not to touch; the top bolt is then tightened and the screw fastening link to yoke is inserted.

Place *dash-pot D* temporarily in position and work whole regulator mechanism up and down to test for stickiness or tight fitting before putting glycerine in. When regulating system works freely, remove dash-pot plunger and fill about three-quarters full with concentrated glycerine; don't use cylinder oil unless you have had much experience; replace plunger and cap, and secure the whole permanently in position.

Terminal Wires.—The wire of the left-hand field-magnet starts from the terminal post P^2, reaching the bottom layer through a recess in the casting, the lead wire of the outer layer terminating at the back end of *A*; the right-hand field-wire starts at *N* and terminates at A^1, being fastened, like the outside terminal wire of left field, to inner end of post by a small screw.

The short terminal wire from the regulator magnet is also secured to the post P^2, the long terminal wire of the same being run down inside the frame to inner end of post *P*.

Commutator.—The lead wires emerging from end of shaft are colored red, white, and blue to indicate coils, one, two, and three, respectively; straighten them out, thoroughly clean the commutator, and slip it onto the shaft with the terminal posts on the outside; place it so the segments are in line with the brush-holders, and turn it until the chisel-mark on the front collar exactly coincides with the mark on the shaft; then tighten the six set-screws. Place the red, white, and blue lead wires in the terminal posts numbered one, two, and three, respectively.

To adjust a new commutator, or one with no marks: After placing it on the shaft, adjust the brush-holder studs and the top negative brush, as per directions following this; then proceed as follows: First find the thick insulated wire which lies in the division between the two sides of, and is the lead wire for, the number one or outside armature coil; rotate the armature to the left until this wire is underneath to the right, as shown in Fig. 75, and the right-hand side of

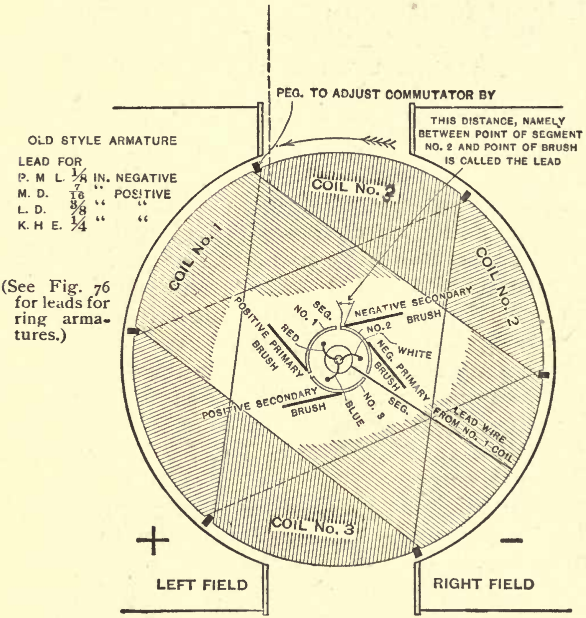
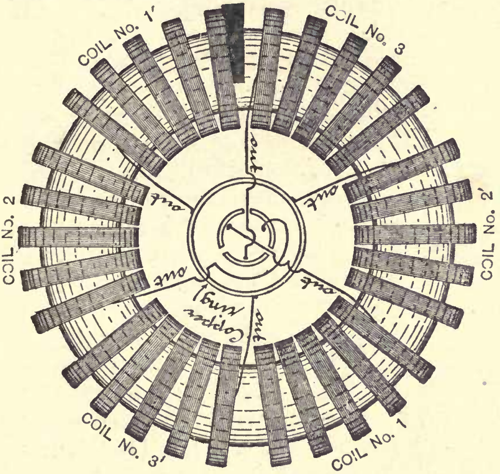


Fig. 75.

peg on the right of coil number one is just in line with edge of left field, as shown in the same figure; then turn commutator until the segment numbered *one* is in a position opposite to coil number one and the slot edge of number two segment projects beyond and to the left of the tip of the top negative brush the distance or lead as given in Fig. 75; tighten the set-screws in each end of commutator, secure lead wires in proper holes, and test for correct spark by running up to speed with full load.

In the new-style ring armatures the peg is replaced by a black mark painted on the armature or by a double-pointed tin arrow secured to the centre band, the points of which are to be brought into line with the edge of field in the same manner as the side of the peg is used (Fig. 76).


Black mark to use in place of peg..

Leads for ring-pattern armature.

M.D. = $\frac{3}{16}$ positive.
L.D.12 = $\frac{1}{4}$ "
L.D.2 = $\frac{1}{8}$ "
M.12 = $\frac{1}{4}$ negative.
M.2 = $\frac{1}{2}$ "

FIG. 76.—CONNECTIONS, COMMUTATOR END, RING-PATTERN ARC ARMATURE.

It must be understood that this adjustment of the commutator is only preliminary and approximate, and that the real and accurate adjustment is done by test under full load in order to regulate the proper length of spark; as the iron varies in different machines, the length of lead to give the best results will also vary. In the new ring armatures the lead in many cases is negative, that is, the edge of segment is to the right of and under the top brush.

Full load is indicated when the bottom of regulator armature remains at $\frac{1}{8}$ inch above the stop, which is a small projection on the brass cross-bar underneath it.

The normal spark at full load is about $\frac{3}{16}$ inch long from the tips of top and bottom brushes, no spark showing on the side brushes: if less than this length, the machine is apt to flash, and the commutator must be turned a trifle in the direction of rotation; if longer than $\frac{3}{16}$ inch, the capacity in voltage is lessened, as also is flashing, and commutator should be shifted backward.

Brush-holder.—Adjustment: A brush-holder gauge (Fig. 77) is provided with each dynamo.

The curved surfaces are turned to same radius as the commutator. The gauge being placed on the surface of commutator, the flat bearing-surface of each brush-holder must be brought to coincide exactly with the straight edge of the gauge, and securely fastened by tightening the nuts and studs back of the yokes; the lips of all the holders must be carefully tested for distance from the commutator, by marking with the sharp point of a knife-blade a point *z* on the straight edge. This distance must be the same for all yokes. If it does not show so on gauge, either yokes are bent or wood bushings are not central with holes in yokes. This should be investigated and remedied.

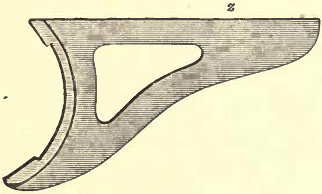


FIG. 77.—BRUSH-HOLDER GAUGE.

Brush Gauge consists of a strip of sheet brass about an inch wide and of the proper length for the brush to project beyond the lip of the holder, as shown at *l*, Fig. 78. All

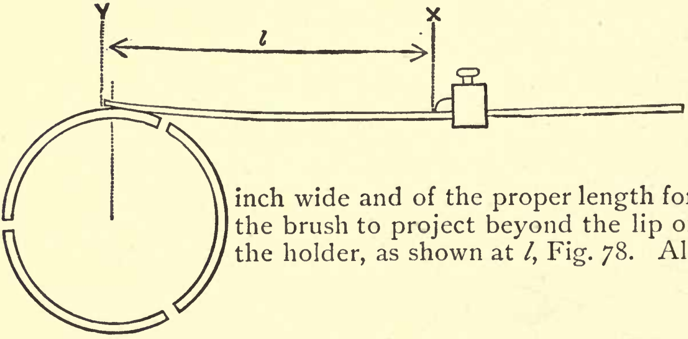


FIG 78.

brushes must be perfectly straight before setting, and must be set by this gauge.

The lengths of gauges for the different sizes of machines are as follows:

C. = $3\frac{3}{16}$ inches; E.2 = $3\frac{11}{16}$ inches.
E.12, H., L., M., L.D., M. D., each = $4\frac{1}{4}$ inches.
P. = $4\frac{11}{32}$ inches.

Cut-out.—Adjustment: The relation of brushes and commutator segments is such that with the proper adjustment two armature coils are in multiple, and this pair is in series with the third coil.

The relation is also such that, excepting when the regulator is down on the stop, the armature is short-circuited six times in each revolution, by each segment reaching from brush B^1 to brush B^4, and from B^3 to B^2 (Fig. 79), the duration of this short-circuit being determined by the position of the regulator.

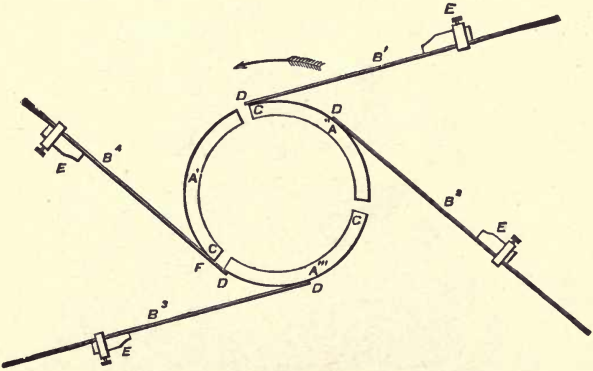


FIG. 79.—ADJUSTMENT OF CUT-OUT.

Adjust as follows: Lower regulator to the stop; in this position, with straight brushes carefully set by gauge and with brush-holders set at the proper angle and distance, the commutator must be turned in the direction of rotation until point C just comes in contact with the brush B^4; the tip of brush B^1 should then project over the edge of the following segment $\frac{1}{64}$ inch.

Take care that the contact at C is *just a contact*, and *no more.* This is best determined by placing a light or a piece of white paper back of the commutator while adjusting.

All segments must be tried in this manner on brush B^4, ; then the test must be repeated, using brush B^2 in place of B^4, the cut-out now being shown at the tip of brush B^3. Should the tip D of brush B^1 or B^3 project further across the slot than $\frac{1}{64}$ inch, the cut-out is called *weak*, and the adjusting slide on the yoke connecting with the regulator-arm must be loosened and *raised* slightly. If the tips of the above-mentioned brushes are back further, and do not project into the slot at all, the cut-out is *strong*, and the slide is lowered to correct it.

Weak cut-out decreases the voltage capacity; strong cut-out endangers flashing. Each machine needs its own special adjustment for best working.

Air-blast, Wings, and Jets.—Adjustment: The air-blast

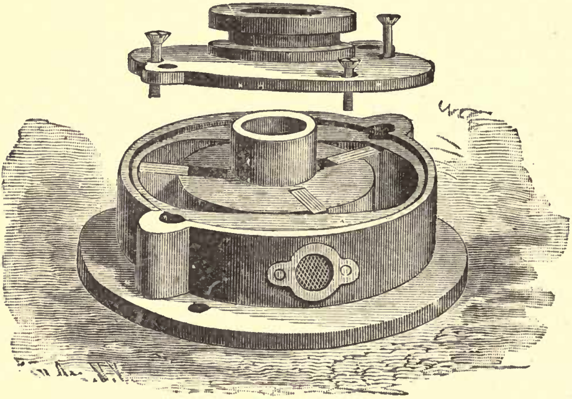


FIG. 80.—THE AIR-BLAST.

or blower as seen in Fig. 80 is a rotary blower, having hard-rubber wings fitted loosely into the slots in the hub, filling them flush with the periphery of the hub: as the hub is turned the wings are thrown outwardly by centrifugal force against the inner surface of the chamber, forcing the air which has entered through the screen-protected holes, *B*, Fig. 81, into the outlets leading to the jets. Jets must be set at the right point, and blower must be so adjusted as to deliver the strongest blast at the moment of sparking, and the

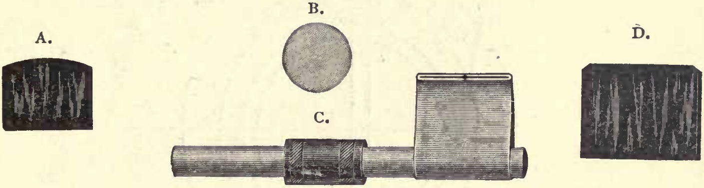


Fig. 81.—(A) Air-blast Wing for Small Blowers. (See Fig. 82.) (B) Inlet Screen. (C) Air-blast Jet. (D) Air-blast Wing for Large Blowers. (See Fig. 84.)

bolt-holes are located to do this; the slots in the back-plate for the bolts *a*, Fig. 82, allow any slight adjustment needed. The outer or rubbing edge of the wings *A* or *D*, Fig. 81, is rounded off in a peculiar form, the forward side being highest; this high side must *always* be placed forward in direction of rotation.

Carefully clean the jets *C*, see that the delivery slots are clear, place them in the holes provided; loosen the four bolts *A* on the back-plate. The brushes being set by gauge, lift the regulator-arm to highest point, then turn blower and jets so the tip *D* of the jet is on a perpendicular line with the tip *P* of top brush (see Figs. 82 and 84, which show exact position of jets), and the tip of the jet clears the segments $\frac{1}{32}$ inch. Tighten bolts *a*, fasten jets in position with the thumb-screws, and set the lower jet in same relative position with lower brush.

As segments wear down, air-blast must be turned to the right, as shown in Figs. 83 and 85, to follow up the change in position of brushes.

Wall Controller.—This must be fastened to a firm perpendicular support and stand plumb, so that the cores of the solenoids hang central and work freely.

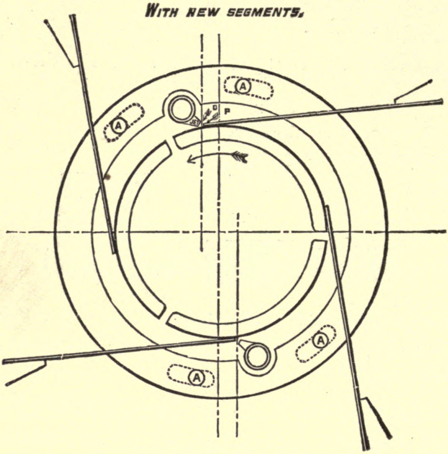

WITH NEW SEGMENTS.
A
A
JET
D
P
A
A

FIG. 82.

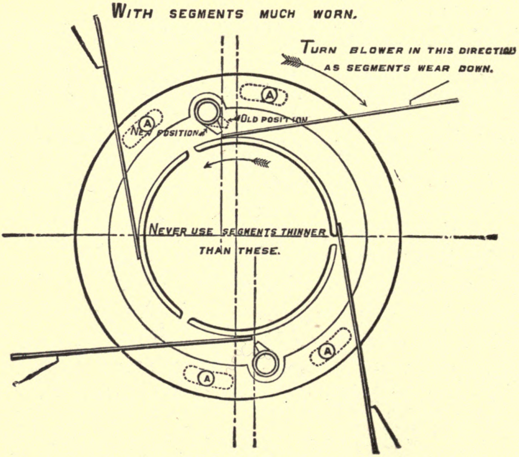

WITH SEGMENTS MUCH WORN.
TURN BLOWER IN THIS DIRECTION AS SEGMENTS WEAR DOWN.
A
A
OLD POSITION
NEW POSITION
NEVER USE SEGMENTS THINNER THAN THESE.
A
A

FIG. 83.

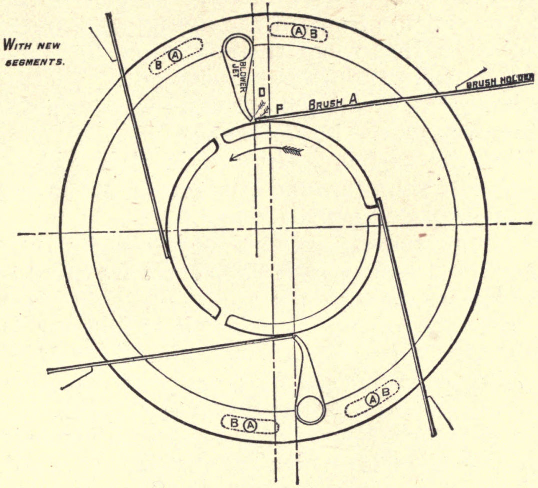

WITH NEW SEGMENTS.
B A
A B
BLOWER JET
D
F
BRUSH A
BRUSH HOLDER
A B
B A

FIG. 84.

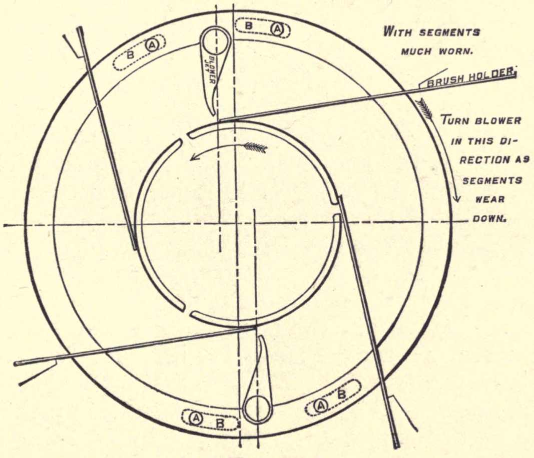

B A
B A
BLOWER JET
WITH SEGMENTS MUCH WORN.
BRUSH HOLDER
TURN BLOWER IN THIS DIRECTION AS SEGMENTS WEAR DOWN.
A B
A B

FIG. 85.

Connect binding-posts P and P^2 (Fig. 86) to binding-posts on the dynamo lettered the same. A convenient way to remember is, that when the box *faces* the commutator side of the dynamo the wires run straight.

Do not remove packing-blocks and wedges until the box is permanently secured in position.

See that the carbon resistance in right side of box is intact; this is a shunt around contacts O, and if broken bad sparking takes place between them.

See that no screws are strained or loosened; that the contacts O are separated $\frac{1}{32}$ inch when cores are lifted to top; if not, bend lower contact down.

The operation of the controller is as follows: When the contacts O are closed the regulator magnet M, Fig. 73, is short-circuited, its armature falls, and more pressure is generated in the dynamo; as the full current from the machine goes through magnets C of the controller, when it exceeds the normal amount for which the instrument is adjusted by spring S, these magnets lift the cores, break the contact at O, and current again flows around the regulator magnet, lifting its armature, shifting the brushes into position to generate less pressure, until *less* than the normal current flows, when the cores C fall, closing contact O, again short-circuiting the regulator, and the entire operation is repeated. The regulating system is in best condition when contact O is constantly moving very slightly.

Adjustment.—To increase amount of current, loosen the check-nuts N at the top of spring in regulator (Fig. 86), and weaken tension of spring S; to decrease current, draw up spring. Drawing up spring draws up regulator.

Binding-post P^1 on top of box is positive terminal of dynamo system, to which must be connected the positive or upper carbon side of the lamp circuit. A series incandescent lamp placed directly in the circuit above the box, to light it up and serve as a pilot-lamp to indicate trouble on the circuit, is convenient.

Field Switch.—This is screwed in place on the two bars next above the commutator, tapped holes being provided. The handle goes up and the terminal wires will be found directly underneath, ready for attaching.

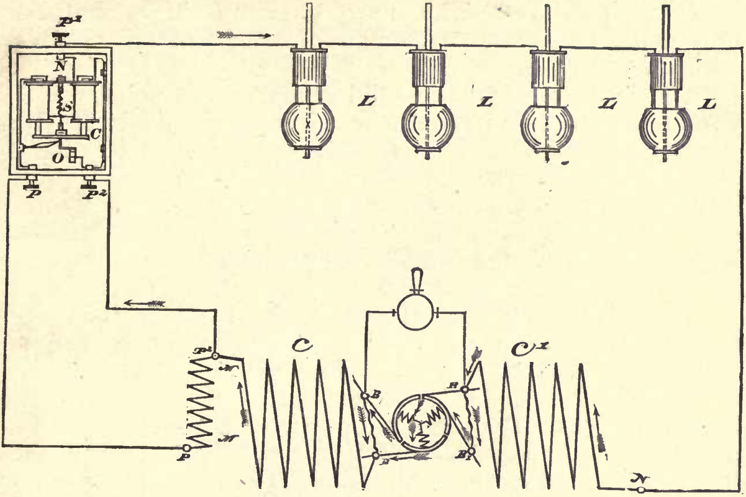


FIG. 86.—DIAGRAM COMPLETE ARC CIRCUIT.

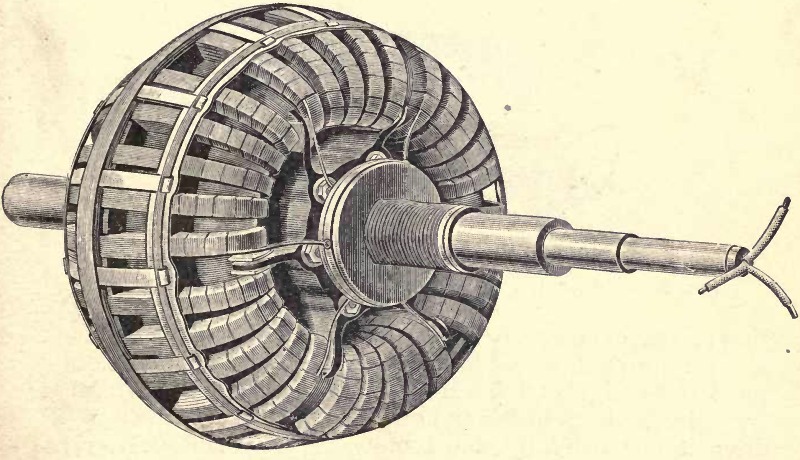


FIG. 87.—ARC-DYNAMO ARMATURE, RING TYPE.

Ring Armatures.—The new Gramme ring armatures now made for the most common sizes are interchangeable with the old style.

The iron core is made solid except at one point, where there is a removable wedge to permit replacing the coils. Its position is indicated by a *W* stamped on the hub of the loose spider. These coils are wound on a form and slipped into place, and the wedge inserted and insulated; and after properly spacing the coils, the gun-metal spider is clamped in position, the shaft inserted, and the bands wound on after wooden spacing-blocks have been placed between the coils.

To replace a coil, cut the brass wire bands with a hack saw; disconnect the damaged coil; remove the lead wires and wooden disks at either end of the armature. These disks are held in position by set-screws in the pieces of brass let into their sides. Remove the bolts from the spider; with a drift remove the key from the spider and shaft; take off the loose spider at the commutator end. The fixed spider at the pulley end is held in place on the shaft by a pin; by driving on the commutator end of the shaft this spider and the shaft may be removed, and the loose spider in the interior of the ring can them be removed by striking it with a block of wood. Next remove the wooden wedges, move the coils around until the wedge is uncovered, cut away the core insulation for 3½ inches both inside and outside the ring over the wedge; drive it out carefully, and remove the bad coil. After replacing with a good coil, the operation is reversed; reinsulate the wedge and its surroundings carefully.

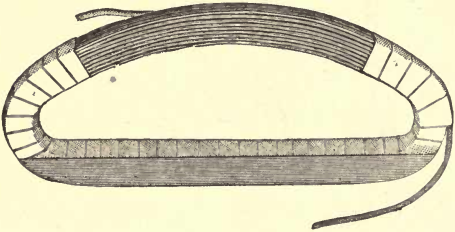


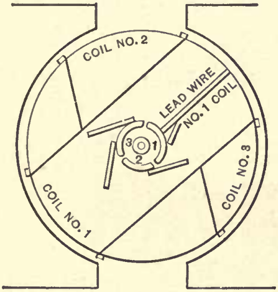
FIG. 88.—COIL WITH LONG TERMINAL FOR CROSS CONNECTION.

The insulation used is as follows, and should break joints: Commencing at the core, two layers paper and a layer each of the following in the order named: canvas, mica, tape, canvas, tape, and paper.

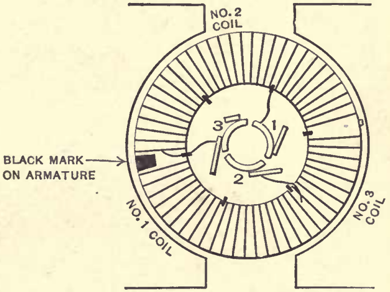
Before starting dynamo, try all screws and connections; see that brushes are carefully and correctly set; carefully clean all insulation that can be gotten at, especially the hard-rubber parts of commutator, and the hard-rubber washers on both front and back of binding and terminal posts.

A good test of the carefulness of the cleaner is to try the cleanliness of washers on back end of posts *P* and *N*. In starting the dynamo, see that the field switch is closed, arrange the switchboard so that a circuit is attached to the machine; then lift the regulator to a point about right to catch the load and open the field switch; watch the machine until the regulator settles well to its work.

Caution.—Always lift regulator by taking hold just under dash-pot; *never* lift by the end of the lever, as in a short time it will be bent enough to destroy all cut-out adjustments.



DRUM ARMATURE



RING ARMATURE

To change a right-hand T. H. arc dynamo to run left-handed, the following special left-handed parts must be ordered: Back plate, air blast, air-blast jets, yokes, brush holders. The regulator, *M*, Fig. 73, and the vulcanite block which carries binding post, P^2, must be taken off and fastened to the opposite field, for which new holes must be drilled and tapped, the regulator being itself reassembled with supporting arm on opposite side. In *M*, *L*, *K*, *H*, and *E* 12 dynamos, a new air-blast key must be fitted in shaft 60° from former position. In *MD* and *LD* machines this is not necessary. The controller will now be on negative side of machine, and if it is desired to make this the positive side, fields must be remagnetized so that right field will attract north end of compass needle, but then the line terminals must be reversed. The cut-out is set precisely as with right-hand machines. To set commutator, set brushes accurately to gauge, turn armature so that lead wire of No. 1 coil is on top, then turn armature in direction in which it is to rotate until coil No. 1 just disappears under right field; then set commutator with segment No. 1 corresponding in position with coil No. 1, and set the lead on segment 3 and fasten commutator.

CHAPTER XXX.

THOMSON-HOUSTON ARC DYNAMO.

LOCALIZATION AND REMEDY OF TROUBLES.

Sparking at Commutator is a small flame appearing at the ends of the brushes, which is long or short, purplish or yellow, according as it is normal or abnormal.

Normal spark is on forward brushes; its character denotes condition of dynamos; it varies a trifle with different machines, but in general, with full load and rated speed, should be about $\frac{3}{16}$ inch long, and purplish in color. As load decreases, length of spark increases. It does no harm, and its adjustment is given on page 169.

Flashing at Commutator is a sudden violent flash of flame about the commutator, immediately followed by a momentary lowering of the regulator to catch the current again. A flash acts as a momentary short-circuit of the armature, which stops generating current until caught up by the regulator.

FLASHING OR SPARKING.

1. **Cause.**—*Air-blast loose on back-plate.*

Symptom.—Feels loose to hand; bubbles of air and oil appear at joint with back-plate; air-jet disarranged.

Remedy.—Loosen bolts *A*, Fig. 82; adjust as per directions on page 172, and tighten bolts.

2. **Cause.**—*Screens in air-blast stopped with dirt.*

Symptom.—Decreased power of air-jet.

Remedy.—Clean screens and free the openings.
Note.—Never leave screens out altogether.

3. **Cause.**—*Wings in air-blast stick.*

Symptom.—Same as Cause 2. Examination may show wings to be gummed and sticky from bad oil. Wings in older machines sometimes stick from the vacuum on lower edge of wing; new dynamos have grooves filed in this edge to prevent formation of a vacuum.

Remedy.—Thoroughly clean wings and slots; file grooves in bottom edge of wings if there are none.

4. **Cause.**—*Wings in air-blast reversed.*

Symptom.—Same as Cause 2. Examination shows wings are reversed.

Remedy.—Reverse the wings.

5. **Cause.**—*Jets stopped with dirt or orifice jammed.*

Symptom.—Same as Cause 2.

Remedy.—Clean thoroughly; open and clear slot with knife-blade.

6. **Cause.**—*Air-blast set too far to the left, or jets not adjusted correctly.*

Symptom.—Continued flashing at short irregular intervals, with no apparent cause; spark somewhat irregular; weak jet of air; jets out of position.

Remedy.—Loosen bolts *A*, Figs. 82–85; readjust as per directions on page 172, and tighten bolts.

7. **Cause.**—*Key or slot in air-blast worn or changed.*

Symptom.—Same as Cause 6.

Remedy.—If slot in blower spider is worn, have new slot cut 120° from old, or have original slot repaired by fitting a piece of steel into the worn edge. If key is badly worn, replace it with new one.

8. **Cause.**—*Commutator not set correctly.*

Symptom.—Bad flashing; machine may practically refuse to generate if but slightly out of adjustment; flashing at irregular intervals.

Remedy.—When running, readjust cut-out by the slide on yoke, using insulated wrench and tools; reset commutator as per directions, page 167.

9. **Cause.**—*Regulator yokes and connections not working freely.*

Symptom.—Variation in size of spark; movement of yokes stopped at intervals; several flashes in quick succession.

Remedy.—Remove connection of yokes to regulator-arm; locate and remove the obstruction to their movement.

10. **Cause.**—*Contacts in wall-controller bad.*

Symptom.—A tendency of the regulator armature to stay up, causing violent flashing as soon as the spark disappears at the top brush; will flash two or three times in quick succession.

Remedy.—Clean the contacts with sand-paper or file.

11. **Cause.**—*Dynamo overloaded.*

Symptom.—Regulator down on stop; spark will gradually shorten and disappear; then a violent flash.

Remedy.—Remove part of load.
Note.—A bad joint or contact in the line will produce same effect as overload.

12. **Cause.**—*Dynamo not up to speed to carry the load.*

Symptom.—Same as Cause 11.

Remedy.—Speed up, or remove part of load.

13. **Cause.**—*Too much oil used in blower and on commutator.*

Symptom.—Bad sparking at commutator on all brushes, followed at irregular intervals by weak flashing.

Remedy.—Decrease supply of oil, and remove surplus from commutator with small piece of canvas folded.

14. **Cause.**—*Animal or other bad oil.*

Symptom.—Same as No. 13, and a gummy appearance of commutator; brushes burn and spark, followed by flashing as in No. 13.

Remedy.—Change oil at once; clean all parts of blower and commutator when shut down.

15. **Cause.**—*Lint from wiping rag.*

Symptom.—Flashing with no apparent reason.

Remedy.—Stop machine; clean commutator thoroughly.

16. **Cause.**—*Dash-pot too weak or too stiff.*

Symptom.—Same as No. 10; regulator works very slowly if too stiff, and if too weak will move too far, thus causing a surging of spark and current.

Remedy.—If too stiff, thin down glycerine with a little water; if too weak, swedge out the plunger a trifle by squeezing it in a vise.

17. **Cause.**—*Current surging.*

Symptom.—Current varies more than usual, as shown by ammeter; contacts of wall-controller stay apart for long period or together for the same time; regulator has much more than usual movement, and gradually rises beyond limits of standard current; spark disappears, and is followed by violent flashing two or three times in quick succession; after which regulator settles back and same effect is repeated after a short time. This rarely happens in any but dynamos newly set up, and is generally due to carelessly adjusted commutator or to too wide separation of controller contacts. The same symptoms in an old dynamo generally indicate that the commutator has moved back.

Remedy.—See that the dash-pot, regulator, yokes, and all moving parts are free.

18. **Cause.**—*Dirt on insulation of machine, forming contact.*

Symptom.—Flashing; arcing across insulating washers or insulating plates on commutator, inspection shows copper dust.

Remedy.—Thoroughly clean the parts and coat with shellac.

19. **Cause.**—*False contact in armature.*

Symptom.—Violent flash, then a spark much longer than usual appears, arching over the regular spark and lengthening and shortening at intervals; it is from ½ to ¾ inch long from the tip of the forward brush. It is much different in appearance from the regular spark, and is a sure indication of a short circuit in a coil, which will burn out if left running long enough; regulator sometimes works normally, but generally settles down upon stop.

Remedy.—Stop the machine; locate the damaged coil by its extra heat; rewind.

20. **Cause.**—*Break in armature circuit.*

Symptom.—Flashing and violent sparking at commutator.

Remedy.—Stop dynamo, remove brushes, and test with magneto, from each segment to back connection; locate break, and rewind as much as is necessary.

21. **Cause.**—*Swinging contact on line; cutting load, i.e., part of circuit on and off.*

Symptom.—Violent flashing, at comparatively regular intervals; regulator rapidly falling to catch load, followed by violent spark and rise of regulator.

Remedy.—Locate the swinging contact and remove it.

22. **Cause.**—*Brushes not accurately adjusted by gauge.*

Symptom.—Bad sparking, with an occasional flash.

Remedy.—Test each brush with gauge; correct any found out of adjustment.

ADDITIONAL CAUSES OF ABNORMAL SPARKING ONLY.

23. **Cause.**—*Brush not set accurately; clamp loose; finger of brush bent out of place.*

Symptom.—Violent sparking on the brush affected; examination shows finger bent under so as to disarrange all commutator adjustments; sometimes caused by turning armature backward.

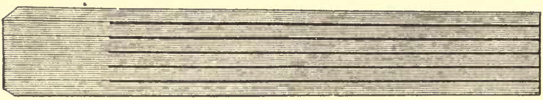


FIG. 89.—ARC DYNAMO BRUSH.

Remedy.—Straighten out the brush (Fig. 89) and replace by gauge; tighten brush clamp, after testing length of brush with gauge. In case this does not stop sparking, stop machine and examine all commutator adjustments.

24. **Cause.**—*Blower-jets worn so that they do not fit hole in body of blower.*

Symptom.—Leakage of air can be felt in front of jet-tube; oil and air bubbles appear around jet-tube; air-jet weakened.

Remedy.—Get new jets at earliest opportunity. Remedy temporarily by wrapping tube of air-jet with tape or paper.

25. **Cause.**—*Rubber thimble between tube and jet bent out of line by heat.*

Symptom.—Jet sets crooked; commutator sparks and flashes because jet of air is not delivered squarely.

Remedy.—Soften the hard-rubber thimble over flame, and bend back into place.

26. **Cause.**—*Copper finger contacts, inside of sliding connection, between side brushes, worn with use.*

Symptom.—Bad sparking on the primary brush, which disappears when the two brushes are short-circuited with a piece of wire; flat groove across face of each segment, causing brushes to chatter.

Remedy.—Examine the parts; bend copper fingers out to make good contact, or replace with new ones; see that interior of barrel is clean.

Note.—Any point of bad contact in or about this connection will give same symptoms.

27. **Cause.**—*Loose commutator segments, causing disarrangement of adjustments, or slightly loose lead-wires; if very loose, will stop current entirely.*

Symptom.—Inspection and feeling show loose parts.

Remedy.—See that all screws and other parts about commutator are tight before starting.

28. **Cause.**—*Lead-wires connected to wrong segments of commutator. This sometimes happens when from long use the distinguishing colors of the wires cannot be seen, and they are misplaced when commutator is removed for any reason.*

Symptom.—Dynamo generates little if any current, while a violent spark appears at brushes and surges back and forth; occasionally breaks altogether and starts over again; regulator remains on stop, as standard current is not generated. This symptom resembles No. 19, although with contact in armature the regulator may be working almost normally.

Remedy.—Stop the dynamo, examine, and reconnect leads.

29. **Cause.**—*Too much oil, or oil of bad quality on blower and commutator.*

Symptom.—Large sparks at primary or side brushes; top spark of yellow color; all brushes wear away at tips, requiring retrimming during a run.

Remedy.—Shut off oil at blower-oiler and wipe commutator with canvas; if quality is bad, change at once.

30. **Cause.**—*Brushes ragged through lack of trimming or rapid wear.*

Symptom.—Brushes grow thin at the ends and look ragged.

Remedy.—Trim brushes off square, and far enough back from ends to have a good bearing-surface.

31. **Cause.**—*Commutator grooved or rough.*

Symptom. (See No. 26.) Sparking and movement at all brushes; feels rough to touch; brushes chatter.

Remedy.—Remove segments (Fig. 90), and turn up the surface by placing them on a "jig," made for the purpose; or, if but thin cut is needed, remove whole commutator and turn them while in position. Brushes should have unlike number of fingers to give smooth commutator.

Note.—Segments should not be used if thinner than one-eighth inch, as slot is widened too much then; slot should be about $\frac{5}{32}$ inch wide.

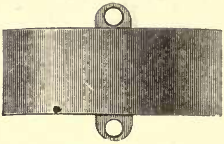


Fig. 90.—Segment of Arc Commutator.

32. **Cause.**—*Too much current being generated.*

Symptom.—Bad sparking; ammeter shows too much current.

Remedy.—Examine connections to wall-controller, which may be broken or reversed; examine controller for trouble; see that spring *S* is properly adjusted; if broken, much heavier current will be needed to lift magnet cores and break contact.

HEATING OF ARMATURE. (See page 136.)

SPECIAL CAUSES.

1. **Cause.**—*Slow speed.*

Symptom.—Less than usual amount of air thrown off, as decrease of speed decreases ventilation; air thrown off very hot; air-jet weak, and sparking worse than usual in consequence.

Remedy.—Speed up to maker's standard.

2. **Cause.**—*Underload, which to a trifling extent increases ampèreage.*

Symptom.—Violent spark at commutator top brush, looping down through slot between segments; regulator high up.

Remedy.—Shift load to another machine, or put on more load if obliged to run for any length of time.

Note.—Although this dynamo is capable of being run on short-circuit for hours, it is not desirable to run on less than one-third full load.

3. **Cause.**—*Increase of current above normal standard.*

Symptom.—Air from armature much hotter than usual; bad sparking at commutator; ammeter shows too much current.

Remedy.—To cool machine down, cut off current and run it with no current for a time; find cause for increase of current (see Abnormal Sparking, Cause 32), and remove.

Heating of Field-magnets. See page 138.

Heating of Bearings. See page 140.

Noise. See page 145.

Special noise features of this machine are the spark and the air-blast jets, which increase somewhat as the load decreases.

Note.—In case of sudden increase of noise, examine dynamo immediately.

Dynamo Fails to Generate. See page 155.

REVERSAL OF POLARITY.

Cause.—*By lightning striking line, or contact with other circuits.*

Symptom.—Arc lamps burning "upside down;" i.e., with bottom carbon positive and light directed upward instead of down; if not soon changed, bottom carbon-holders will be destroyed.

Remedy.—If no other dynamo is at hand, reverse either circuit or machine's terminal wires at switchboard. When another dynamo can be had, short-circuit the armature of the reversed machine either with the field switch or by a wire from terminal post A to post A'; attach the circuit from the live machine to the binding-posts P and N of the reversed machine, noting that the positive terminal of one is attached to negative terminal of the other; turn on current an instant, and the polarity will be corrected.

Caution.—Never attempt to do this while armature is revolving.

CHAPTER XXXI.

BRUSH ARC DYNAMO.

Setting Up.—Set the dynamo so that its base is about one foot above the floor, upon a wooden frame or foundation timbers which are oiled or varnished and firmly fastened to the floor or to a brick foundation. Unpack the "dial" or regulator carefully, and lay it down flat. Remove all the blocks which hold the parts in place during transportation. Take off the slate over the carbon piles, and blow out the carbon dust with a bellows. Replace the slate cover and screw it down, but leave a slight play under the screw-heads. Then mount the dial on the wall or upon a stand near the dynamo, and hang it on hinges or arrange it so that its lower end can be swung outwards a little, in order that the slate cover can be taken off and the carbon piles examined and adjusted without danger of their falling out.

To start a new machine for the first time, connect the two binding-posts on top of the dial to the small posts of the dynamo between the large binding-posts of the machine. Connect the left-hand post at the bottom of the dial to the positive post of the dynamo, and the right-hand post of the dial to the negative post on the machine. In other words, short-circuit the dynamo, with the dial alone in circuit, no lamps being connected. If there be sufficient time, it is well to run a new dynamo in this way several hours. The dynamo will run short-circuited as long as desired without trouble or danger. Take care to have the cleaner on hand when dynamo is shut down; take off the brushes and all the copper segments immediately, and wipe the surfaces of the brass and copper segments thoroughly with a dry rag. Remove the thin film of shellac which will be found on the brass and copper surfaces, as it might get upon the commutator and cause the machine to flash. Pay particular attention to the ends of the commutator. After

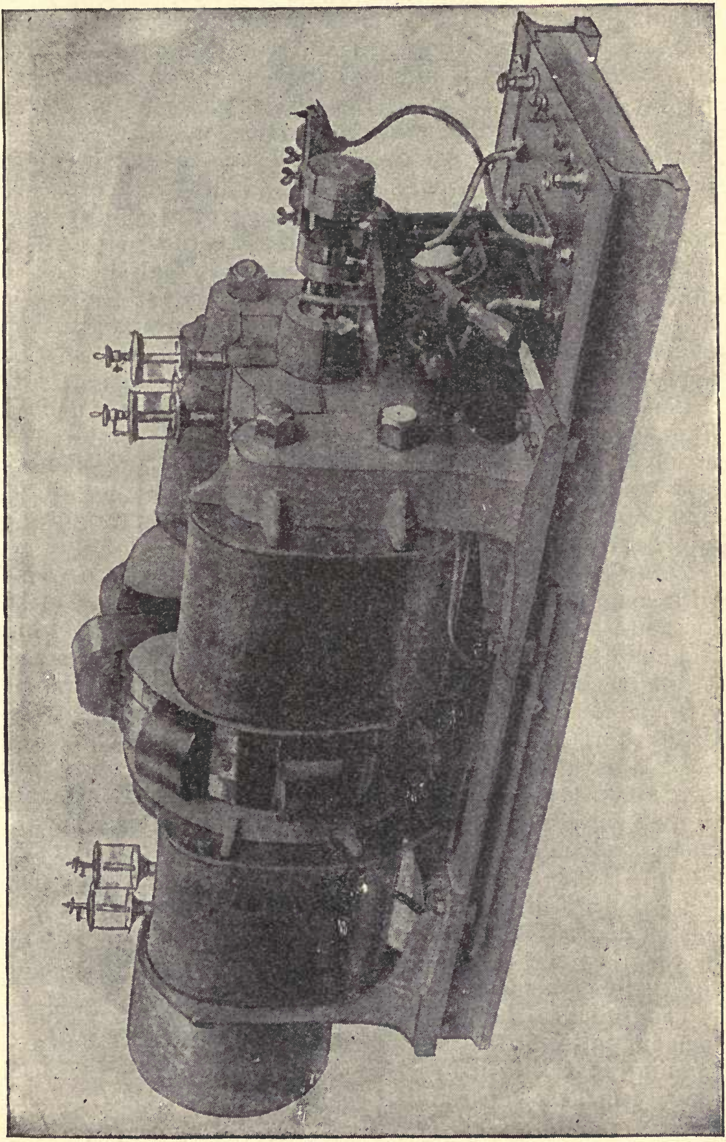


FIG. 91.—BRUSH ARC DYNAMO.

cleaning the commutator, incline the dial backward, take off the slate over the carbon piles and wipe the moisture from the slate frame, etc., and in replacing the slate leave the screws somewhat loose. After the machine is cooled off, tighten up all contacts and connections.

In running the dynamo upon the regular circuit, it is good practice to start with a long spark, about $\frac{1}{2}$ inch, especially in the case of a cold circuit. When the carbon points become hot and the lamps are up to full arcs, the spark will be shorter—about $\frac{1}{4}$ inch. Make it a point to look at the position of brushes after starting the circuit—say at the end of five minutes. To oil the commutator, put a very few drops of oil upon one side or end of a piece of duck or felt, and apply it "*right in the spark*." If the oil is put on at some distance from the end of the brush, the machine is liable to flash. A new wooden block commutator does not require as much oil as an old one. Always have a dry rag at hand, and wipe the commutator with it two or three times during the evening. Use very little oil on the commutator, but apply it often.

Care and Management.—Provide your cleaner or wiper with some cotton cloth and a small hardwood stick, 6 inches long and 1 inch square, tapering down at one end to 1 inch wide and $\frac{1}{4}$ inch thick. The cleaning should begin as soon as the machine shuts down, ten minutes' work while the machine is hot being better than forty minutes the next day. Clean the spaces between the commutator segments thoroughly, using the cotton cloth and the stick. Take care to have all the copper dust wiped off, giving special attention to the ends of the commutator. The front end may become connected to the bushing if the dust is not removed, and the back end will short-circuit two commutator wires if the wooden surface is not kept free from oil and copper dust. A great deal of trouble will be saved if care is taken in cleaning the places where the commutator wires and shaft wires are connected.

To prevent the commutator from becoming rough and uneven, polish it with fine sand-paper when the dynamo is running at full speed. Use a piece of wood 12 inches long, 3 inches wide, and $\frac{7}{8}$ inch thick to hold the sand-paper against the commutator. This treatment twice a week will keep the commutator in good condition, and is much better than cleaning with files or emery.

When using blowers or bellows to remove dust from armatures, there should be an exhaust-fan arranged to draw the dust out of the room while the armatures are being cleaned. If the dust is not drawn out of the room, blowing out the armature does not do much good, as the dust will settle on the other machines.

To get sufficient pressure of the brush upon the commutator, it is better to use a light " pressure-brush " over the regular copper brush than to attempt to bend the regular brush to increase its pressure. Adjust the brushes so that they are just long enough to bear on the commutator at a point about $\frac{1}{8}$ to $\frac{1}{4}$ inch from their extreme ends.

Dynamos are ordinarily made to run right-handed, but they may be ordered for left-handed running, if desired. If it becomes necessary to change the direction of rotation of a machine, it may be accomplished by simply reversing the connections of the field, and changing the lead of the commutator, which should always be set about $\frac{1}{4}$ inch forward, that is, in the direction of rotation. Hence in reversing a machine the position of the commutator should be changed about $\frac{1}{2}$ inch.

TROUBLES AND REMEDIES.

The Brush arc dynamo is simple, and not very subject to troubles; but the following are among the principal faults which might require attention.

The *dial* or regulator may get out of adjustment in one of the following ways:

1. *The dial may not "take hold" at the proper point;* that is, either too much or too little current in the main circuit may be required before the solenoid and movable lever act to press together the piles of carbon plates which shunt more or less current from the field to regulate the machine.

2. *The action of the dial may not be steady;* that is, the resistance of the carbon piles may not decrease uniformly, as the pressure upon them is increased by the pull of the

solenoid. This is ordinarily caused by the *relative* length of the various piles not being right with respect to each other. For example, the pressure may be exerted only upon the middle pile or upon the two end piles, instead of being gradually and successively applied.

This trouble and the previous one are overcome by carefully adjusting the dial which, when properly set, will regulate so effectively that any number of lamps from one to full load may be cut in or out without any considerable change in the current strength.

3. *Falling off in voltage.* Sometimes the ability of a machine to operate lamps decreases gradually after being used a long time, owing to the insulation of the armature bobbins being charred inside, which has the effect of cutting out some of the turns of wire, and of course decreases the voltage of the machine. This charring may extend until only one or two of the outside layers are left intact, and although the appearance of the coils may be all right, most of the coils are actually cut out or connected together by the burnt insulation. In such a case the bobbins should of course be rewound.

4. *If one bobbin of an armature is burnt out*, the machine may be run temporarily in an emergency by cutting out or "connecting by" the opposite one, care being taken to open the circuit of these coils, so that they are not short-circuited.

In a similar manner, the capacity of a machine may be reduced to $\frac{3}{4}$ or $\frac{1}{2}$, respectively, by cutting out two opposite bobbins, or four alternate ones.

5. *Flashing.* If this occurs at regular intervals of about 8 minutes, it is usually caused by the fine-wire circuit in some lamp or lamps being open, so the carbons cannot be fed down. As the burning away of the carbons continues, the resistance of the arc increases and the current as shown by the ammeter (Fig. 92) decreases; the magnetization of the field diminishes, changing the line of commutation in the armature; the spark at the commutator gets smaller and smaller until the machine flashes, the carbons drop together, and the same performance is repeated. As the spark gets smaller, rocking back the brushes will postpone the flash for a few minutes; but it can be readily understood that the only

way to cure the trouble is to locate the lamps that burn with a flashing arc and repair their fine-wire shunt circuits.

Sometimes lightning breaks the fine-wire circuit of several lamps on one circuit. As long as one such lamp is in the circuit the dynamo will flash. Anything that causes the spark to get too short on the commutators, like throwing on more load or slowing of speed, will cause a flash. On large dynamos running old-style Brush arc lamps, sometimes after a flash the machine will not start the lamps for some minutes, unless the switch on the machine board is closed and again opened. This is caused by the glycerine in some or all of the lamps being too thick, and the fine-wire

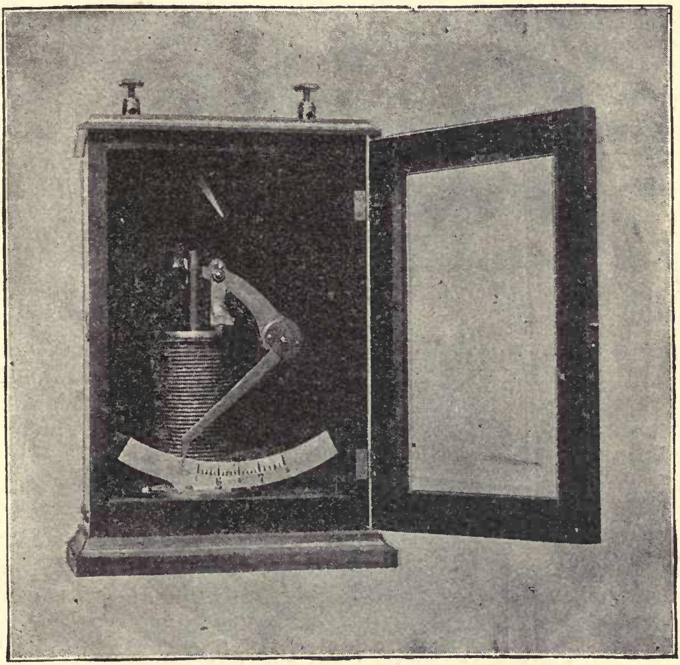


FIG. 92.—BRUSH AMMETER.

circuit of some of the lamps reversing the polarity of the lamp armature and holding the carbons apart, thus preventing the circuit closing.

6. *Sparking* at the commutator of Brush arc machines is legitimate, but should not be allowed to get long enough to permit flashing. A spark about ¼ inch long is right. If the commutator is allowed to get rough or out of round or dirty, or the brushes do not all press fairly upon it, a damaging spark and trouble are likely to follow.

7. *Failure to generate* is sometimes caused by the line being open, in which case test by momentarily short-circuiting across the terminals of the dynamo; if there is yet no current, then test the circuits of the dynamo either with a magneto or the current of another dynamo, as it is likely there is an open circuit in the dynamo itself, or at least a bad connection. After using a current from another source in testing a dynamo, always be sure to see that the polarity of dynamos has not been changed; if it has been, change it back, or transpose the line wires at the dynamo terminals.

8. *Heating of tips of field-magnet poles.* The two upper and the two lower pole-piece tips, that is, those which the armature moves *away* from, may become heated. This is not serious, and is due merely to local or Foucault currents in the iron itself.

9. *The field coils on one side may be warmer than those on the other* in an old-style dynamo for 1200-candle-power lamps, because the regulator only shunts one half of the field. With partial load the shunted side is considerably cooler than the other. This does no harm, but sometimes causes surprise.

CHAPTER XXXII.

FORT WAYNE (WOOD), SPERRY, AND EXCELSIOR ARC DYNAMOS.

THESE are all regular, closed-coil ring-armature machines, such as are treated throughout this book, and therefore require no special directions, except for the regulators. The regulators are mechanical devices for moving the brushes back and forth to keep the current constant in spite of variations in the number of lamps or other changes in the circuit.

Directions for the Wood Machine.—Observe strictly all previous general directions. As it has a closed-coil armature, the brushes should not spark at all, and consequently, with good care and brushes well trimmed according to directions, brushes should last a year or more. When facing the pulley it must turn clockwise or right-handed. The regulator acts

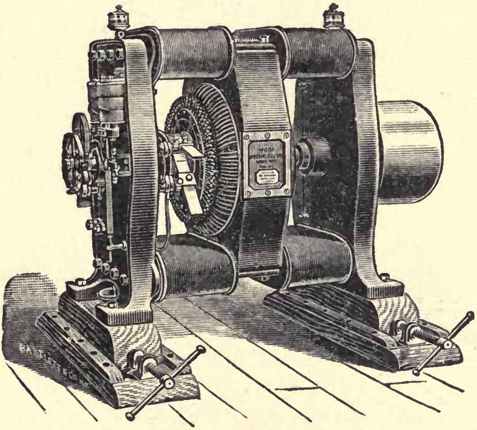


FIG. 93.—WOOD DYNAMO, WITH STEP-BY-STEP BRUSH-MOVING GOVERNOR.

properly if the speed of the machine is at or above the normal, but not if it is below when there are many lights in circuit. It must be kept perfectly clean and well oiled so as to move freely, and the friction-wheel bearings must never be allowed to run dry. The armature should be cleaned once a year after removing the commutator, and the inside of the coils brushed, particularly at commutator end. Before taking out the armature, be sure to remove the regulator pinion to prevent damage, and do not replace it until the armature is again in position. Before removing commutator, mark it so as to replace in exactly the same position and be careful to keep commutator-nut tight always, as the sections are liable to become loose by the swelling and shrinking of the insulation. The strength of current can be increased by tightening the regulator spring, and *vice versa*.

To see if tension of this spring is right, remove the friction-wheel while the dynamo is running and the ammeter is indicating the proper current. Then by turning the large gear a little to the right, so as to increase the current about half an ampere, the magnet lever should move up against the stop ; and by turning the gear to the left, so as to decrease the current about half an ampere, the magnet-lever should be drawn down against the under-stop. When the current is standard, the lever should remain in the middle position.

In adjusting the regulator care should be taken that both of the friction-rollers, which revolve on the roller lever, should be at exactly the same distance from the friction-wheel, and set in such a manner that one quarter of an inch movement of the magnet lever would cause one or other of the rollers to engage with the wheel.

One must also be particularly careful to *oil the rollers* from the centre of the studs every fifteen or twenty minutes, for the first week or two after the dynamo is started, or until such time as they wear to a perfectly smooth bearing. The friction-wheel is placed on a movable stud, allowing it to be moved to and from the rollers in order to compensate for wear. The rollers can also be adjusted tangentially to the wheel by turning the nut on the connecting link which connects the roller lever with the magnet lever. Never stop the dynamo without first raising the magnet lever—in order to bring the brushes to position of minimum voltage —and throwing up the cam.

In starting, run the dynamo to speed, then remove the cam and allow the regulator to find proper position for the brushes. In case it becomes necessary to remove the automatic regulator for any cause, be particularly careful to put every part back in its position, and see that the yokes meet properly in gear; that is, when the clutch unlocks at the minimum point, the yokes should be close together: they will then be separated the proper distance the instant the clutch unlocks at maximum point. A failure to comply with these directions will prevent the regulator from working properly.

The Sperry machine is similar in action, and the directions are about the same, with a few changes to suit the exact construction. The differences in detail can readily be understood upon inspection.

The Excelsior (*Hochhausen*) *arc dynamo* (Fig. 94) employs a regulator, comprising an electro-magnetic controller, usually placed on a wall or post near the machine, and a small electric motor, located on the dynamo.

This motor has a pinion upon its shaft, which meshes with a semicircular rack attached to the rocker-arm that carries the main brushes (Fig. 95). When the motor revolves one way or the other the brushes are shifted correspondingly. The rocker-arm is also connected by a rod to a switch (not shown), which cuts into and out of circuit sections of the field-winding.

The path of the current and action of the regulator is as follows (Fig. 95):

Starting from the positive terminal of the machine D^4, the current is led to the binding-post R^4 on the wall-controller and passes through the magnet M into the armature-lever A, through the resistances x, y, and z to the line, and returns by the external circuit to the negative terminal D^1.

The end of the controller armature A bears against two contact points, C, C^1, which are connected through the binding-posts R^2 and R^3 on the regulator and D^2 and D^3 on the dynamo to the brushes of the small regulating motor on the machine.

The regulating magnet M is so adjusted that when the normal current passes over the line the armature *A* stands horizontal and makes contact with both points C, C^1, which are fixed at the end of their lever. The current entering the armature *A* from the magnets *M*, therefore, besides passing to line through the resistance x, has two other paths open to it—through contacts C, C^1 to the brushes of the small regulating motor *via* binding-posts R^2D^2 and R^3D^3. But the currents in these two circuits are in the same direction, and when they meet at the regulating motor they oppose each other, and its armature remains stationary. Thus the main current divides into three parts where *A* is in normal position.

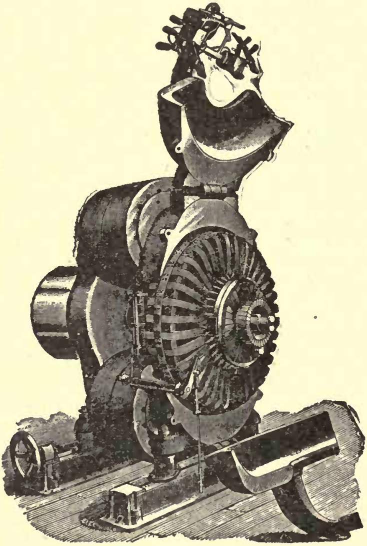
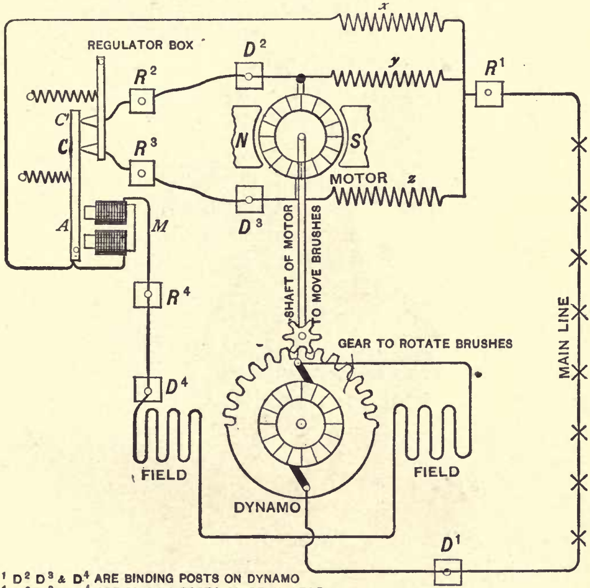


FIG. 94.—EXCELSIOR ARC DYNAMO CONTAINING MOTOR TO REGULATE BRUSHES. THE FRONTS OF THE POLE PIECES SWING OUT ON HINGES TO GIVE ACCESS TO ARMATURE.

If from any cause the current increases above the normal, the armature *A* of the wall-controller is drawn away from its balancing position, breaking the contact at *C*, while that at C^1 is still maintained. The regulating current now has only one path open to it from C^1 to R^2, etc., to the left-hand or upper brush of the motor regulator, thence partly through the armature to the other brush and out to line through the resistance z^2. The motor armature at once starts to revolve and to turn the brushes of the machine in the direction for cutting down the current; at the same time a rod connected to the brush-holders, but not here shown, acts upon a field-switch, which assists the brushes in reducing the current by cutting out sections of the wire upon the field-magnets.



D^1 D^2 D^3 & D^4 ARE BINDING POSTS ON DYNAMO
R^1 R^2 R^3 & R^4 ARE BINDING POSTS ON REGULATOR

FIG. 95.—CONNECTIONS OF EXCELSIOR DYNAMO.

When the normal current has again been established, the controller armature closes contact *C*, and the regulating motor stops. A diminution of the current from the normal causes the breaking of the contact C^1, which sends the regulating current through the motor in the direction opposite to that just described, with a corresponding effect. It is evident that at all times the resistances x and either y or z are in circuit; they therefore always act as shunts to the two points c and c', and no sparking whatever takes place when contact is broken at either of those points.

Thus, with any variation in the current, not only are the brushes revolved in a corresponding direction by the regulating motor, but the field-switch is operated, to cut sections in or out, by means of the connecting arm; both these methods of regulation acting in conjunction serve to bring the current to its normal value.

A switch is provided for the purpose of cutting out the regulating motor when adjusting the position of the magnets M, while the field-switch mentioned above is employed for short-circuiting the field-magnets when shutting down the machine.

CHAPTER XXXIII.

ARC-CIRCUIT MOTORS.

CONSTANT-CURRENT or arc-circuit motors all have mechanical regulating devices for controlling their speed and power, since the power is not reduced by the increase of counter E. M. F. when the motor speeds up, as it is on circuits of constant potential.

Various means of reducing the power have been tried, the most common being a switch arranged to reduce the strength of the magnets. Such are the Excelsior, Brush, Baxter, and "C. & C." machines (Fig. 96). The switch is

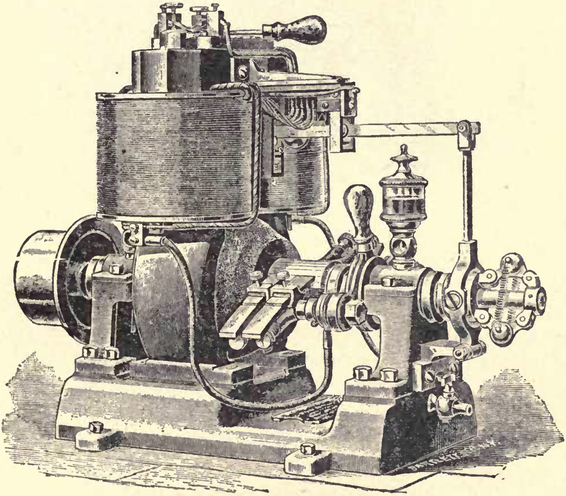


FIG. 96.—"C. & C." ARC MOTOR, ILLUSTRATING ALL THOSE HAVING A CENTRIFUGAL GOVERNOR OPERATING A SWITCH TO VARY THE FIELD STRENGTH.

connected to a centrifugal speed-governor, so as to cut out the magnet-winding as the speed increases. The objections to this arrangement are that the weakening of the fields tends to cause sparking, and the sluggishness of the magnets prevents the changes of strength being effected in time to prevent the motor racing for a moment when the load is thrown off, and *vice versa.*

The regulator is arranged to be operated by hand (Fig. 97) when it is desired to vary the speed from time to time, as in running sewing-machines; but this is usual only in small motors.

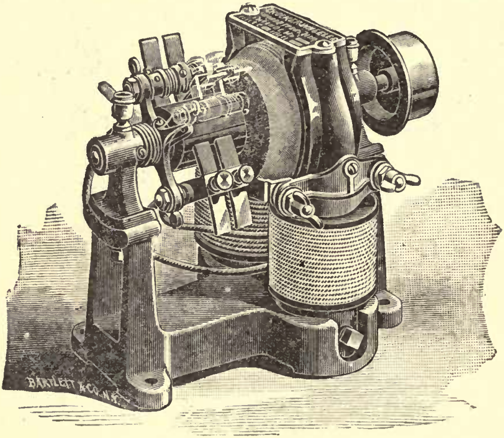


FIG. 97.—CROCKER-WHEELER ARC MOTOR WITH HAND REGULATOR.

To overcome the objections to the methods of control just described, the plan of rotating the brushes from the position of full power to that of no power is also used (Figs. 97 and 98). The brushes are moved in the direction which will bring the magnetism of the armature into opposition to that of the field by degrees so that both are reduced equally, which prevents the weakened field causing sparking; and since the power is reduced by the change of position of the brushes, there is no loss of time on account of sluggishness of the magnets. This can only cause momentary sparking in the interval before the fields are weakened by the armature reaction. The difficulty in this machine is the me chanical one of moving the brushes, maintaining the cable connections, etc. The governor has to be rather large, to secure close speed regulation.

In all these forms the only special points are in the care of the governor. The motors are simple series-wound machines, such as treated in Part I. Those which regulate by a switch are liable to troubles, because the switch or the connections from the switch to the coils get out of order.

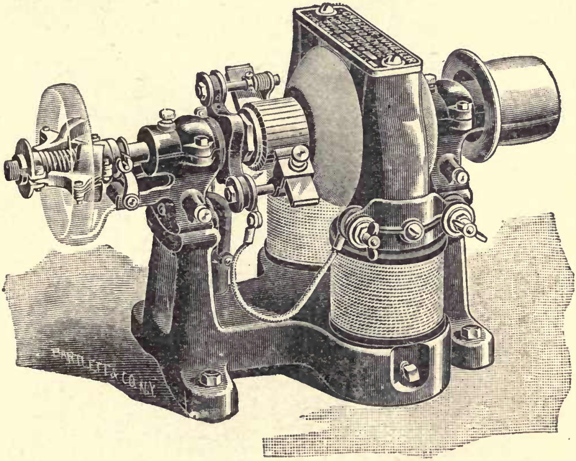


FIG. 98.—CROCKER-WHEELER ARC MOTOR WITH CENTRIFUGAL GOVERNOR TO ROTATE BRUSHES.

In the brush-revolving form the brushes may jump off the commutator an instant when moved suddenly by the governor, if they are not properly adjusted. Or they may not make perfect contact in all positions of the rocker-arm if it does not turn around the commutator truly; that is, the brushes may be held straight when on top of the commutator, and crooked when at the side.

In any form the speed-governor requires attention. A governor which is "quick" or isochronous, that is, goes through its whole motion with a very small variation of speed, will turn on too much power when the load and speed are only slightly varied, thus overdoing the regulation and causing the motor's speed to fluctuate up and down constantly. On the other hand, one that is "slow," or only goes through its whole motion when the speed varies one or two hundred revolutions, will allow the motor to run slow under heavy load and fast under light load.

Most governors are capable of adjustment, and should be adjusted to be as "quick" as is consistent with the nature of the load. Sometimes, when close regulation is required, the governor is set to be sensitive or quick, and a fly-wheel is also used on the motor (Fig. 99) or driven machine to steady the variations of load.

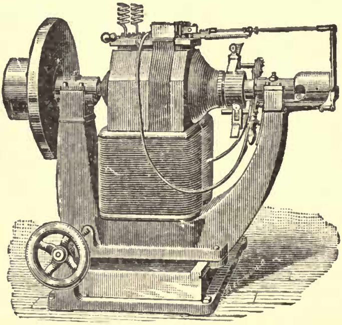


FIG. 99.—EXCELSIOR ARC MOTOR WITH FLY-WHEEL, AND CENTRIFUGAL GOVERNOR, OPERATING FIELD-SWITCH.

When the full power is exceeded, an arc motor will slow down, and then increasing the load or even leaving it overloaded will only reduce the power obtained.

THE END.

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