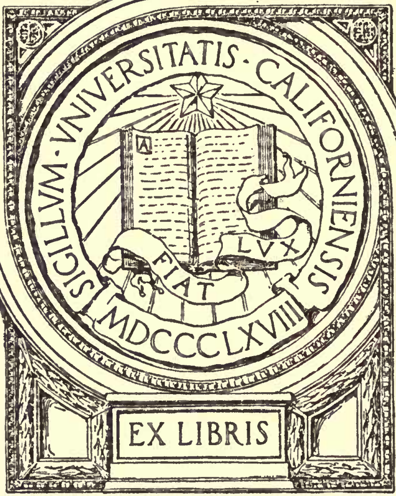
MANAGEMENT of ELECTRICAL MACHINERY

A REVISED AND ENLARGED EDITION of

PRACTICAL MANAGEMENT OF DYNAMOS AND MOTORS

CROCKER AND WHEELER

D. VAN NOSTRAND COMPANY
NEW YORK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BY

FRANCIS B. CROCKER, E.M., PH.D.,
PROFESSOR OF ELECTRICAL ENGINEERING, COLUMBIA UNIVERSITY, N. Y.; PAST PRESIDENT OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

AND

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FOR REVIEW.

PRICE, $ 1.00 *NET.*

NEW YORK:
D. VAN NOSTRAND COMPANY,
23 MURRAY AND 27 WARREN STS.
1906

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SIXTH EDITION
NINETEENTH THOUSAND

NEW YORK:
D. VAN NOSTRAND COMPANY,
23 MURRAY AND 27 WARREN STS.
1906

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to
ENGINEERING LIBRARY

The Plimpton Press Norwood Mass. U.S.A.

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 SIXTH EDITION

SINCE the appearance of the original edition in 1892, one complete revision of this book has been made and corrections introduced from time to time. The rapid progress of electrical engineering has now brought about changes so radical that another thorough revision is necessary. The arrangement and object of the book remain the same, but much matter, more or less obsolete, has been eliminated. For example, constant-current motors are no longer used and various types of constant-current machines have lost some of their prominence compared with many modern examples of electrical apparatus; nevertheless a large number of these machines are still in use, so that considerable matter relating to them is retained in the present edition and may have renewed importance due to the introduction of flaming arcs. To a large extent direct connection has taken the place of belting, and the maximum as well as average size of electrical machines has greatly increased. These changes are only partly true of motors, the use of belting and motors of moderate size being still common practice. For that reason it is now necessary to consider the two classes separately in some respects. A large amount of new and amended material has been introduced, such as the management of alternating-current generators and motors both single and polyphase, also that of railway motors. In the preparation of this new edition a great deal of the work has been done by Morton Arendt, E.E., of the Electrical Engineering Department of Columbia University, who has rendered much valuable assistance in the obtaining and arrangement of new material, illustrations and data, also in the labor of proof-reading.

NEW YORK, *May*, 1906.

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PART I

SELECTION, INSTALLATION, CONNECTION, AND OPERATION

INTRODUCTION

THE purpose of this book is to set forth the more important facts which present themselves in the actual handling of electric generators and motors, as a guide for those who use or study these machines.

Heretofore writers on the generator or motor have usually treated these machines individually, and books or papers relating to the one often contain nothing about the other, or merely consider it briefly in a few special chapters. There is no necessity for this separation; in fact, nine out of ten statements which apply to the generator 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 generators and for motors is often less than for different kinds of generators; for example, a shunt generator and a shunt motor are much more similar in their construction and action than a shunt generator and a series generator. These statements apply particularly to constant-potential, direct-current apparatus, but it is a fact that all electrical machinery, including alternating-current types, may be covered by the same general treatment. Synchronous motors are precisely similar to the corresponding generators, and the action of induction motors is remarkably like that of shunt motors. The same series motor may be operated by either alternating or direct currents. In some cases special instructions are necessary, as for example for railway motors, constant-current dynamos and very large generators; these being given in Part IV. 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 generator and the motor has related almost entirely to theory, design, and construction, and comparatively little has been written about 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 structural features 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 non-electrical reader is also referred to any elementary work on the principles of electricity, including electrical laws, phenomena, units, methods of measurement, etc., as these should be learned before attempting to understand or handle electrical apparatus.

CHAPTER I

PRINCIPLES OF ELECTRIC GENERATORS AND MOTORS

Definitions. — *A dynamo-electric generator is a machine for converting mechanical energy into electrical energy;* in other words, *it generates electric current when driven by mechanical power.* The term dynamo-electric generator is so long that it is usually and unavoidably shortened into "dynamo," which has the same meaning. The name "electric generator," or simply "generator," is commonly used when the machine performs that function, in order to distinguish it from the motor which is also a dynamo-electric machine. This last term is employed generically to include practically all electrical machinery — direct and alternating current, generators, motors, rotary converters, etc. An alternating-current generator is commonly called an "alternator."

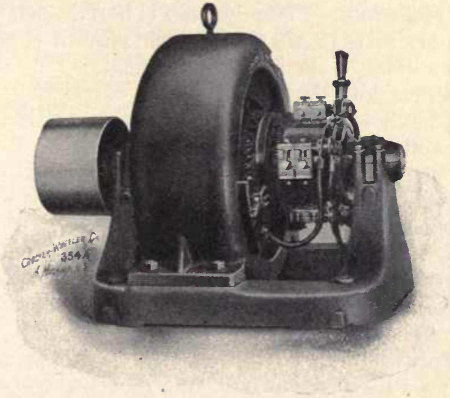

FIG. 1. — 25-K. W. Crocker-Wheeler Generator.

An electric motor is a machine for converting electrical energy *into mechanical energy;* in other words, *it produces mechanical power when supplied with 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, motor-dynamo, or motor-generator, is, as its name implies, a combination of the two machines, and consists of a motor and a generator, either directly coupled together or built as one machine. It is used to transform electrical energy at a certain voltage into electrical energy at either a higher or lower voltage, with a corresponding decrease or increase in the number of amperes. When these machines are employed for direct currents they are called direct-current transformers, but they are also used to convert direct into alternating currents, or the converse. For this purpose, a single armature winding usually performs both motor and generator functions, in which case the machine is called a rotary converter.

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 it 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 they are exactly the reverse of each other in action.

Similarity of Generators and Motors. — The two machines are, however, very similar in construction. In fact, the same machine can be used equally well for either purpose. They are usually made slightly different, but this is only done to adapt them more perfectly to certain purposes. 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 generator 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 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 machines this arrangement is often reversed, the field-magnet being made to rotate and called the *rotor*, the armature being fixed and called the *stator.*

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;* usually in the form of thin disks separated by paper, varnish, or rust. If made of one solid piece of iron it would have useless (*eddy* or *Foucault*) currents generated in it, which would waste a great deal of 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.

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.

Parts of Generators and Motors. — The names of the various parts of generators and motors depend upon whether the machine has two poles, four poles, or a greater number, and whether it be designed for direct or alternating currents. The terms applied to the parts of an induction motor are quite different from those applied to direct-current motors, similarly the names of the various parts of traction motors would differ somewhat from those of a stationary motor. The parts of a four-pole direct-current generator are well shown in Fig. 2, the name of each being given in the table below:

1. Armature (includes 2 and 3).
2. Commutator.
3. Shaft.
4. Base.
5. Bearing Cap.
6. Bearing Cap Screws.
7. Oil Cock.
8. Oil Hole Cover.
9. Journal Box.
10. Oil Ring.
11. Lower Magnet Frame (includes 13 and 14).
12. Upper Magnet Frame (includes 13 and 14).
13. Pole.
14. Pole Shoe.
16. Magnet Frame Bolts.
17. Terminal Board.
18. Terminal Block.
19. Series Field Shunting Device or Compounding Adjustment.
20. Field Coil.
21. Field Cable.
22. Rocker Seat with Screws.
23. Brush Rigging (includes 24, 25, 26, 27, 28, 29, 30, 31, 32, and 33).
24. Rocker (includes 25).
25. Rocker Handle.
26. Brush Stud.
27. Brush Stud Nut.
28. Brush Stud Insulating Washer (Round Hole).
29. Brush Stud Insulating Washer (Oval Hole).
30. Brush Stud Insulating Sleeve.
31. Brush Stud Cable.
32. Armature Cable.
33. Brush-holder.
34. Brush.
35. Pulley.
36. Pulley Key.

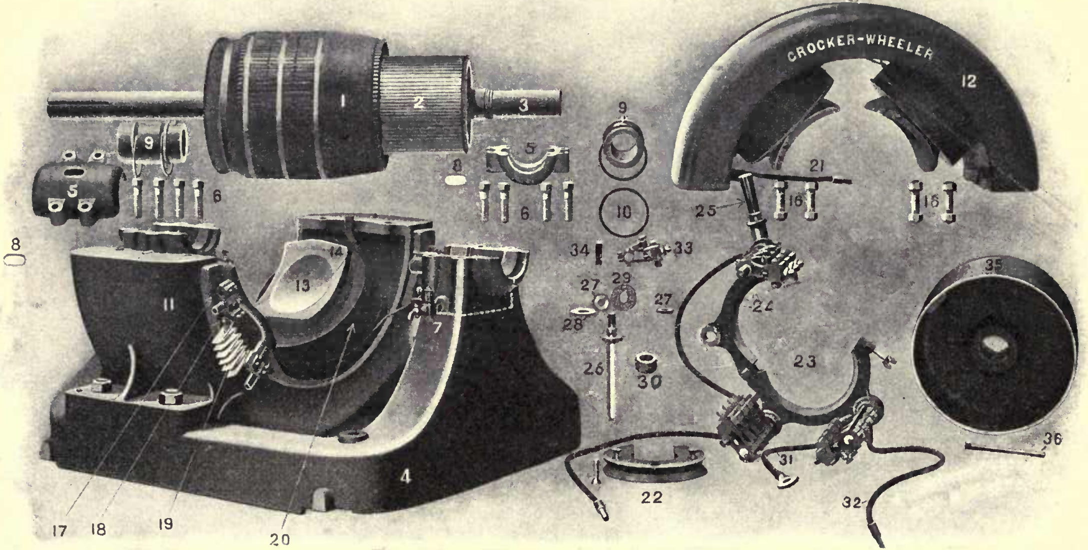

FIG. 2. — Dissected Generator.

CHAPTER II

SELECTION OF DYNAMO-ELECTRIC MACHINERY

THE voltage, current capacity, and type of the machine depend upon the system to which it is to be connected and the purpose for which it is intended. There are, however, certain general features to be considered in almost every case.

Construction. — This should be of the most solid character and guaranteed first-class in every respect, including material and workmanship. All 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, it stimulates the interest and pride of the attendant; and third, it makes evident the least dirt or neglect.

Simplicity. — The machine and all its parts should be as simple as possible, any peculiar or complicated features being avoided, unless necessary to the operation of the system.

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

Handling. — The machine should be provided with an eye-bolt or other means by which as a whole or in parts 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, or by sliding the halves sidewise if the frame is split vertically.

Interchangeability. — Machines should be made with interchangeable parts (Fig. 2), so that a new piece which will fit perfectly can be readily obtained; for this reason standard and established types of machine are preferable to special or unsettled forms.

Regulation. — Some form of regulating device should be provided by which the e.m.f. or current of a generator, or the speed and in some cases the direction of rotation of a motor can be reliably and accurately controlled.

Capacity. — The machine should be provided with the maker's name plate, stating the rated voltage, current, speed, serial number, etc. It is a common mistake to underestimate the work required and even if a 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 generator or motor with a considerable margin of capacity, as these machines only consume power in proportion to the work they are doing. For example, a 25-h.p. machine would probably operate with a 20-h.p. load more economically and satisfactorily in the long run than a 20-h.p. machine with the same load.

Form. — The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions of the machine should be placed as low as possible to give greater stability.

Weight. — It is a mistake to select a very light machine when it is for stationary use, because weight increases strength, stability, and durability.

Cost. — It is usually an error to select a generator or motor simply because it is cheap, both the materials and workmanship required for the construction of a high-grade electrical machine being costly.

These suggestions as to selecting a generator or motor may be followed when it is possible to make merely a general examination of the machine, or even in cases where it is only practicable to obtain a drawing or description of it. But to make a complete investigation it is necessary to carry out a thorough test, and measure exactly its various constants in accordance with the methods given in Part II.

A satisfactory test cannot usually be made, however, until after the machine is set up in place; so that it is ordinarily installed under the manufacturer's guarantee, a certain time being allowed to determine whether it fulfills the requirements.

The Number and Size of Units. — The question of selecting the best size and number of machines for an electrical plant is not nearly so serious as the corresponding problem in connection with steam engines; because the efficiency of the former is higher, and does not reduce at light loads nearly so much. A generator or motor is usually not very much less efficient at one-quarter load than at full load, while a steam engine is only about one half as efficient. There is rarely any necessity, therefore, for running the former at a low efficiency; because it would not require much engineering skill to design a plant in which no machine was obliged to operate at less than one-quarter load. It is also a fact that small generators of say 50 kilowatts capacity are built to give an efficiency of 90 per cent or more, and are nearly as good in this respect as larger machines; so that the electrical generating plant can be subdivided, if desired, without detriment, except the multiplicity of units. It is, therefore, very evident that the size and number of generators should be suited to the requirements of the engines, because the difficulty lies with the latter.

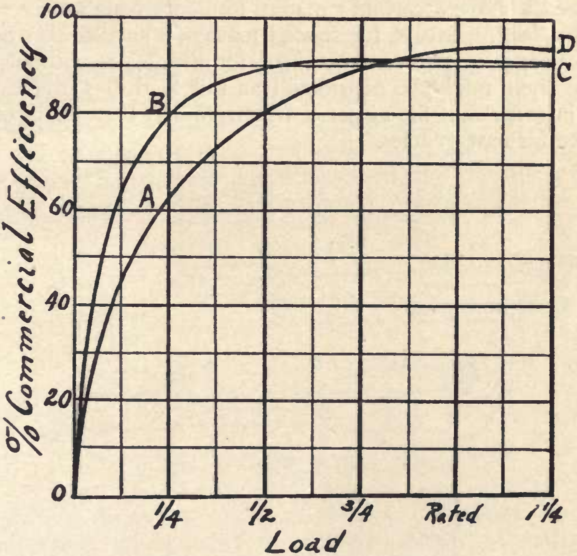

FIG. 3. — Efficiency Curves of 100-K.W. Generators.

A point often misunderstood is the fact that the efficiency of a generator at maximum load is not so important as at *average* load. Assume, for example, a 100-K.W. generator having an efficiency shown by the curve *OBC* in Fig. 3, and another machine whose efficiency is represented by the curve *OAD*. It would be in accordance with common practice to compare them at rated load, at which the efficiency of the first is only 91 per cent, while the other gives 93 per cent. But, as a matter of fact, the first machine (*OBC*) is far better than the second; since its *average* efficiency is much higher, and is nearly 91 per cent, between one-half load and 25 per cent overload. It should always be remembered that full load is a *limit* which should be but occasionally reached, and then only for short periods of time. Cases arise in which machines would be run steadily at full load, but they would be comparatively rare. Electrical apparatus is sold and guaranteed to have a certain capacity for continuous service and this is its *rated load*. Except for special reasons it should also be guaranteed to carry 25 per cent overload for two hours without injury. Either of these might be considered as full load, but preferably the former, in order that the 25 per cent margin may be a factor of safety or reserve for emergencies.

CHAPTER III

INSTALLATION OF MACHINES, FOUNDATIONS, AND MECHANICAL CONNECTIONS

Location. — The place chosen for a machine should be *dry, light, well ventilated, and free from dust or grit.* There should also be room enough for removing the armature without moving the machine.

Foundations. — It is of great importance to have the machine firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation are likely to produce sparking at the brushes.

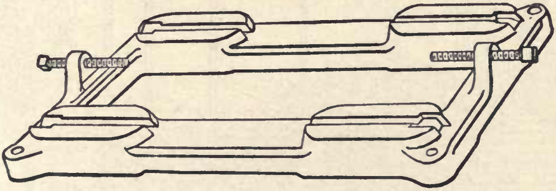

FIG. 4. — Sliding Base Frame.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate or base-frame provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 4.) The foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation during construction, as shown in Fig. 5. The bolts are preferably surrounded by iron pipes that fix them approximately but allow a little side play which may be necessary to enable them to find and enter the bed-plate holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or masonry foundations should be finished with a capping of bluestone or cement or stone that tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with, this base being grouted on top of the foundation.

Fixing a Machine. — In fixing either direct-connected or belt-driven machines, first determine, with a long straight-edge and spirit level, that the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly-wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the generator bed-plate and armature shaft must be carefully aligned and adjusted with

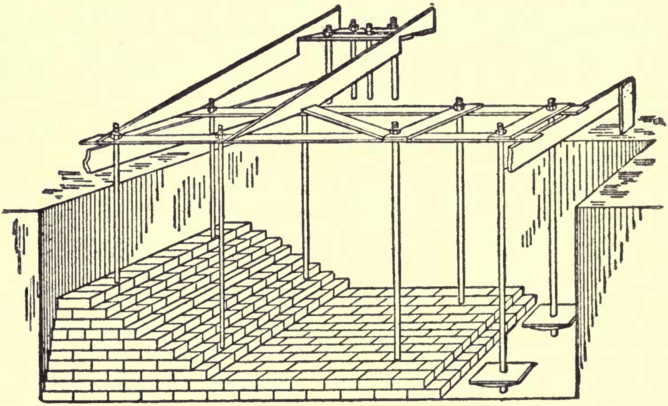

FIG. 5. — Template for Use in Building Machinery Foundations.

respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin sheet-iron "liners" or "shims" and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up, thus firmly fixing the machine upon its foundation.

MECHANICAL CONNECTIONS

Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

1. Direct driving.
2. Belting.
3. Rope driving.
4. Toothed gearing.
5. Peculiar forms of connection, such as friction and magnetic gearing.

Other apparatus, such as shafting, clutches, hangers, pulleys, etc., are used in connection with the above-named methods.

Direct Driving. — This term may be applied generally to all cases where a generator is driven without intermediate belting or gearing. Direct connection may be used specifically to designate the arrangement in which the revolving armature or field is mounted on the engine or turbine shaft; and direct-coupling should mean that each has its shaft, the two being coupled together either rigidly or flexibly. These distinctions are desirable, but ordinarily the terms are all used in the same general sense. This method is the simplest, and for that reason the most desirable connection, provided it can be carried out without involving sacrifices that offset its advantages. It compels the engine and generator to run at the same speed, and gives rise to certain difficulties, for the reason that the most desirable speeds of the two machines may not agree. The most advantageous speed of a generator is considerably higher than that of the corresponding reciprocating steam or gas engine. Hence it is necessary either to raise the speed of the engine above the point at which it works well or reduce the speed of the generator below that at which it gives its full capacity, in order to make the two coincide. The running of an engine above a certain speed is decidedly objectionable, because it reduces its efficiency, requires more attention, increases the vibration, wear and repairs, and consumes more oil.

The speed of a generator, on the other hand, can be brought down without much sacrifice of efficiency or other disadvantage, except that the output is decreased, or, what is the same thing, the size, weight, and cost for a given output are increased. The usual way to construct a low-speed generator is to make the armature of large diameter, thus securing a sufficiently high peripheral velocity; at the same time the armature core is made in the form of a ring, with comparatively small radial thickness, in order to reduce the weight of iron required. Nevertheless, the frame, shaft, bearings, and other parts of such a machine are somewhat heavier and more costly than if the armature were of smaller diameter and higher speed. The compactness, simplicity, and general advantages of direct coupling are so great, however, that they generally warrant the extra cost.

The direct driving of generators by water turbines can usually be carried out without departing much from the normal speed of either machine; that is to say, the ordinary speed of a turbine agrees fairly well with the normal speed of a generator of corresponding power provided the head of water is sufficient. The shaft of the former, however, is usually vertical, while that of the latter is horizontal; hence, in order to drive directly, one or the other must be changed from its ordinary arrangement. This can be done either by constructing a generator to revolve on a vertical shaft, or a turbine having a horizontal shaft (Figs. 6 and 7) can be obtained. If the armature is mounted directly upon the shaft of a vertical turbine, the total weight becomes large and must be supported on some adequate form of thrust- or step-bearing. In some cases provision is made to take a portion or all of the weight off of the bearings, either by magnetic attraction or by causing the upward pressure of the water in the turbine to balance the weight. But with this latter method the serious difficulty arises that this pressure varies with the amount of opening of the gate and is therefore insufficient at light loads. In the case of the 5,000-h.p. two-phase generators of the Niagara-Falls Power Company, the revolving field-magnet is mounted on the top

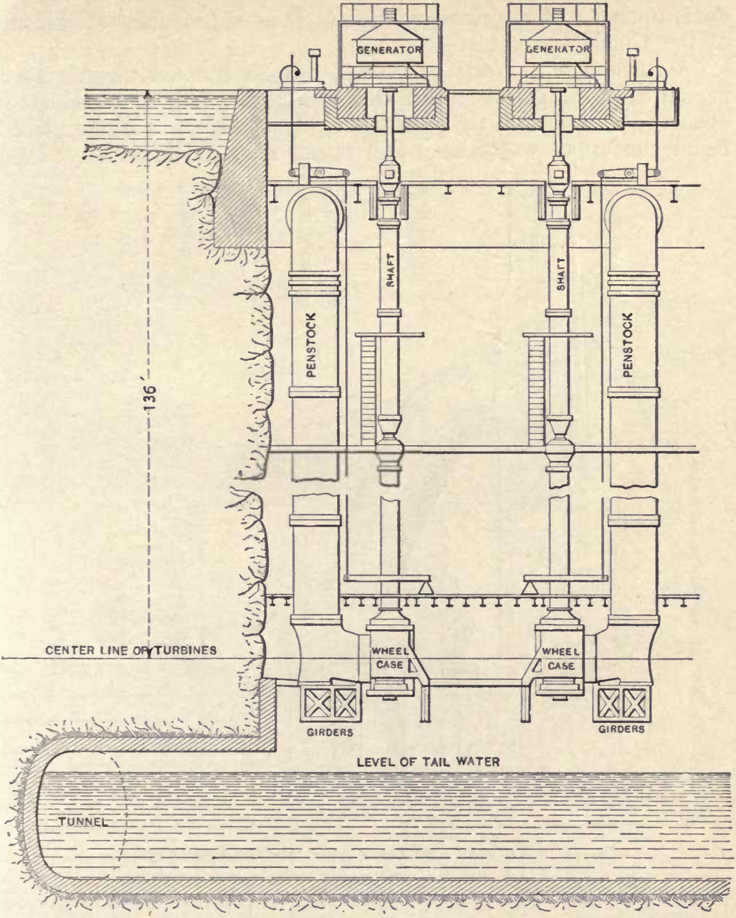

FIG. 6. — Vertical Connections between Turbine and Generator.

of the vertical shaft of the turbine. The weight of the moving parts is about 150,000 lbs. and is carried on a single flange attached to the shaft and revolving upon a fixed ring bearing, oil under high pressure being forced between the two surfaces so that the weight practically floats upon it. The principle is the same as that of the step-bearing of the Curtis steam turbine.

A turbine with horizontal shaft can be coupled directly to a generator in the manner illustrated in Fig. 7. This arrangement is open to the objection that the electrical machinery must be placed below the upper water level and rather near the lower level even when a draught-tube is used. Hence it is exposed to moisture to which it is vulnerable or may actually be flooded in case the tail water backs up, as it often does. Nevertheless this plan is frequently adopted on account of its simplicity and its convenience if moisture is properly guarded against. To make any kind of direct driving advantageous it is generally necessary that a considerable head, 30 to 50 feet or more, be available. Otherwise the speed of the

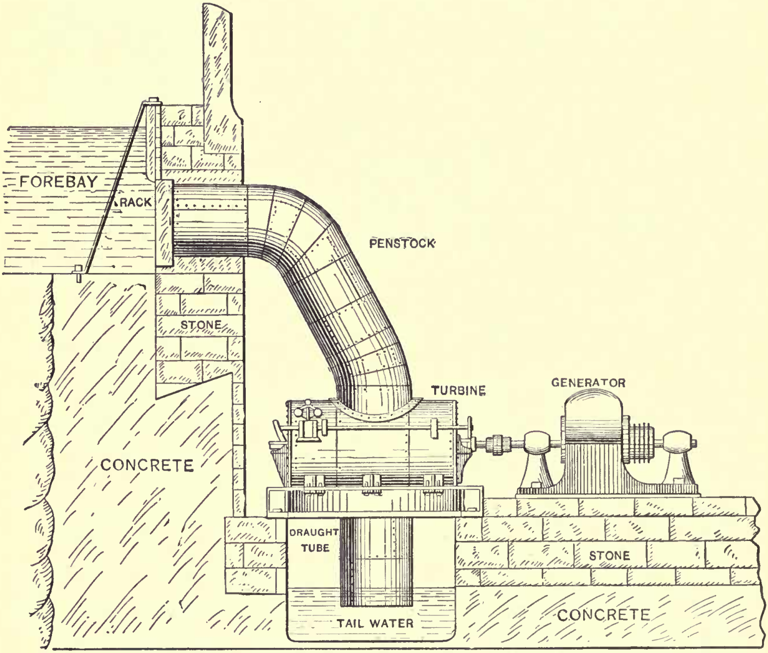

Fig. 7. — Turbine and Generator on Horizontal Shaft.

wheel is so low that a generator to correspond would be unduly expensive. Furthermore the power of a single wheel of reasonable diameter is not sufficient to run a generator of the large size usually desired. For these reasons the arrangement represented in Fig. 8 is commonly adopted for low heads, several wheels being used to give enough power for one generator and bevel gearing introduced to multiply the speed as well as to change the axis of motion. When generators are driven by Pelton or other forms of tangential water-wheels, it is almost universal practice to couple them together as illustrated in Fig. 9. In many cases each machine is complete in itself and the two are placed on a cast-iron bed-plate. Sometimes

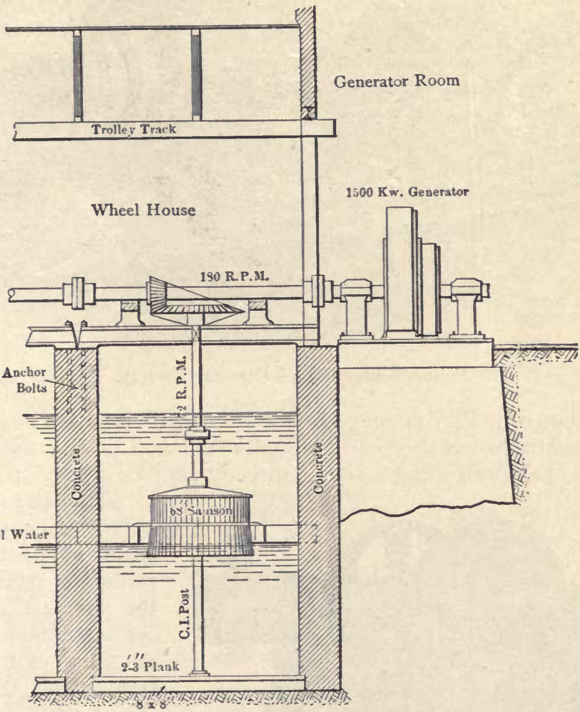

FIG. 8. — Vertical Turbine and Horizontal Generator.

one of the four bearings is omitted, requiring the armature to be rigidly mounted upon or connected to the shaft. Rigid couplings are often used for direct coupling, or flexible couplings similar to that shown in Fig. 11 may be employed with four bearings. With a tangential wheel the head is usually sufficient to give the requisite power and speed using a single, directly coupled wheel.

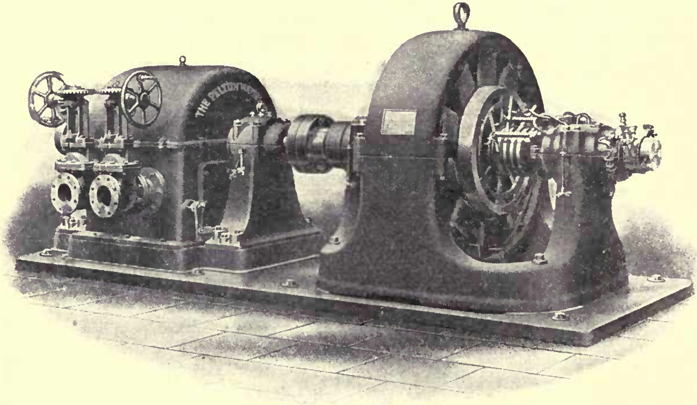

FIG. 9. — Pelton Water-Wheel Directly Coupled to Generator.

The direct driving of a generator by a steam or gas engine is accomplished in several ways, the simplest of which consists in mounting the armature of the generator on one end of the engine-shaft. For example, the pulley on the farther side of a center-crank engine may be replaced by the armature, in which case there are only two bearings. Very often another bearing is applied outside of the armature, as illustrated in Fig. 10, producing what is known as the three-bearing arrangement. In other

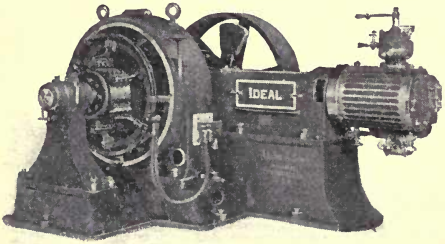

FIG. 10. — Direct Connection of Engine and Generator.

cases the armature is mounted alongside of the governor-wheel, only two bearings being required, with an engine of the side-crank type.

For large engines, which are usually cross-compound, the armature as well as the fly-wheel may be mounted on the shaft between the housings of the high- and low-pressure cylinders. In other instances the armature is mounted on one end of the shaft, even in the largest sizes. For smaller sizes of direct-connected units from 25 to 200 K.W. the standardization recommended by the American Society of Mechanical Engineers has been adopted.

STANDARDIZATION OF DIRECT-CONNECTED ENGINES AND GENERATORS.

Recommended by the American Society of Mechanical Engineers.

As arranged for horizontally parted generators.

Stools to be made and located to suit feet of horizontally parted generators. Builders of latter note that radius of outside of field piece must be ¼″ to ½″ less than "C."

As arranged for vertically parted generators.

Rectangular seatings to be made and located to suit bases of vertically parted generators.

Capacity of Unit K. W.	Revolutions per Minute.	Armature Bore.		Space Occupied on Shaft between the Limit Lines.		B Length of Extension Pieces.	C Height of Axis of Shaft above Top of Base.	D Width of Top of Sub-base.
		Center-crank Engines.	Side-crank Engines.	Long Class A.	Short Class A.			
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
25	310	4	4½	30	25	5	23	48
35	300	4	5½	33	28	5	25	54
50	290	4½	6½	37	31	6	28	60
75	275	5½	7½	43	37	6	31	66
100	260	6	8½	48	42	6	35	72
150	225	7	10	51	45	6	41	84
200	200	8	11	54	48	6	49	96

Five per cent variation of speed permissible above and below speed in table.

Distance from center of shaft to top of base of outboard bearing may be less than "C" (to suit engine builder), though not less than possible outside radius of armature.

Up to 6 inches diameter engine shaft is 1-1000 inch larger than armature bore, and over 6 inches diameter it is 2-1000 inch larger.

Direct coupling comprises an engine and a generator, each complete in itself, and each having two bearings, coupled together by some mechanical connection, which may be either rigid or slightly elastic or adjustable. In the first case, the two shafts are practically equivalent to a single shaft; in fact, they might be made in that form, but it would be very inconvenient in replacing or repairing either the engine or the generator, whereas the mere connecting of entirely distinct machines affords great advantages in this respect. It is somewhat difficult to adjust three or four bearings exactly in line; nevertheless it can be accomplished with care and good workmanship.

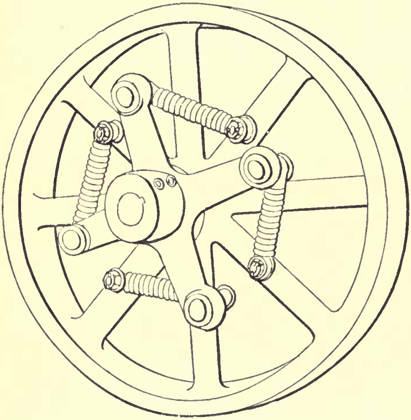
FIG. 11. — Flexible Shaft Coupling.

The interposition of a coupling having more or less flexibility avoids the necessity for perfectly aligning the bearings of both machines, and also the serious difficulties which arise if any of the bearings settle or wear more than the others. There are numerous forms of such flexible or adjustable couplings, one of which, that would allow for very imperfect alignment of the two shafts, is represented in Fig. 11, and consists of a wheel and a spider, one rigidly mounted on each shaft. Both are provided with pins, which are connected by springs. Besides taking care of differences in alignment, a flexible coupling tends to reduce fluctuations in angular velocity due to gas or steam engines, especially if the armature is heavy or has a fly-wheel attached.

An ordinary friction clutch or a magnetic clutch is a convenient means for directly coupling an engine and generator. It is easily applied, being especially designed to connect two shafts together, and has the advantage over almost any other coupling of being readily disconnected, so that one or more generators can be stopped without interfering with the engines.

Direct driving with steam turbines is almost universal, in most cases the turbine and generator being specially designed for each other and built by the same manufacturer, which is not usually the case with reciprocating steam or gas engines or with hydraulic turbines employed for the direct driving of electric generators.

BELTING

A generator not directly driven by the engine or other prime mover is usually connected by some form of belting. In fact, belting was almost universally employed until about 1892. The simplicity, compactness, and positive action of direct driving have caused it to become the approved method, and belting is somewhat unpopular by comparison. Nevertheless, belting is still utilized in a number of instances, more often for smaller machines but in some cases for large ones. One reason for the continued use of belt-driven generators is the fact that they can be applied to second-hand engines or those already on hand that were not designed for direct driving. Greater flexibility in the original design of a plant is possible and new arrangements of old apparatus can be made at any time. Electric motors being of smaller average size and used under more varied conditions than generators, are very often belt-connected. The advantages of belting in general are:

1. It gives almost any desired ratio of speed simply and conveniently.
2. It is cheap itself, and on account of higher speed enables a cheaper generator or motor to be used.
3. It is applicable to almost any case provided the space is sufficient.
4. The machines are almost entirely independent, so that either can be changed, repaired, or operated without interfering with the other.
5. The machine is insulated so far as the belting is concerned.
6. The connection is somewhat elastic.

The general disadvantages of belting are :

1. It requires considerable space, since the machines must be placed a certain distance apart in order to make the belt work properly.
2. The action is not positive, there being a certain slip even in normal working, and with overload or other trouble the belt may run off or break.
3. Belting is somewhat unsteady in action and likely to cause slight fluctuations in speed and voltage on account of slipping or flapping. This is objectionable, particularly in incandescent lighting; but it can usually be avoided by proper planning.
4. Belting produces a certain amount of noise which might be objectionable in some cases, and would be a special reason for the adoption of direct driving.
5. Belts exert a side pull on the bearings which produces loss of power by friction, also wear. However, many belt-connected machines have run for years without showing any considerable wear from this cause.

Plain Leather Belting is generally the most reliable and satisfactory. There are three standard thicknesses — single, light double, and double. For driving generators or other high-speed machinery, "light double" belting is usually best.

The amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that a "single" belt will transmit 1 h.p. for each inch in width at a speed of 1,000 feet per minute. If the speed be greater or less, the power is correspondingly increased or decreased. This rule 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. With an arc of contact less than half a circle, the power transmitted is less in the following proportion: An arc of 135°, or three eighths of the whole circumference, gives .84, while 90° gives only .64 of the power derived from a belt-contact of 180°.

On the other hand, when the upper side of the belt sags downward, and the belt is in contact with more than half of the circumference of the pulley, then the grip is increased, and more power can be transmitted. These facts make it very desirable to arrange the direction of rotation so that the *loose side of the belt is on top.* With the loose side below, the belt sags away from the pulleys, and is also likely to strike the floor.

The expression for determining the width of a single belt required to transmit a given horse-power is

$$W = \frac{\text{h.p.} \times 1000}{C \times S},$$

in which W is the width in inches, h.p. the horse-power to be transmitted, C a factor depending upon the arc of contact, the values of which are given above, S the speed of the belt in feet per minute, which is equal to the circumference in feet of the driving pulley multiplied by the r.p.m. Belts slip or "creep" on the pulley about 2 per cent; hence the proper size of pulley should give a calculated belt speed 2 per cent too high.

"Double" belting is expected to transmit one and one-half, and "light double" one and one-quarter, times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, because the grip of the belt upon the pulley varies considerably under different conditions of tension, length of service, special treatment of surface by "belt dressing," moisture in the atmosphere, etc.

The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. The common idea that the rough side of a belt "has more friction" is entirely erroneous.

Belts for electrical or other high speed machinery should be made "endless" for permanent work; but may be used with laced joints temporarily. It is best to order an endless belt of the right length from the manufacturer; but if necessary it may be spliced, with ordinary skill. Both ends of the belt are pared down on one side (opposite) with a sharp knife into the form of a long, thin wedge, so that when laid together a long uniform joint is obtained of the same thickness as the belt itself. The parts are then firmly joined by cement and often with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys, and for that purpose some form of belt-clamp (Fig. 12) should be employed.

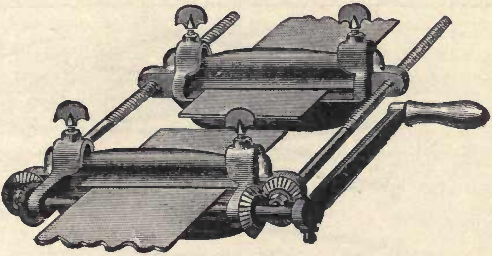

FIG. 12. — Belt Clamp.

When a belt is ordered to be made endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. The best way to avoid a mistake in making this measurement is to use string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt. In measuring for a belt, the generator should be moved on its sliding base so as to make the distance the shortest, in order to allow for the stretch of the belt, which usually amounts to from $\frac{1}{4}$ to $\frac{1}{2}$ inch per foot of total length.

The lacing of a belt is a simple and common method of making a joint. At high speeds, however, a laced joint is apt to pound on the pulleys, producing noise, and in the case of incandescent lamps it causes flickering; nevertheless, its simplicity and reliability make it allowable in an emergency or for temporary use.

In lacing belts the ends should be cut perfectly square, and there should 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 may catch the clothing of persons. There are various methods of lacing, in one of which, shown in Fig. 13, two rows of holes are made in each end with a punch. The nearest hole should be ¾ inch from the side, the first row ⅞ inch from the end, and the second row 1¾ inch 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. Very often, particularly for smaller sizes, only a single row of holes is made in each end of a belt.

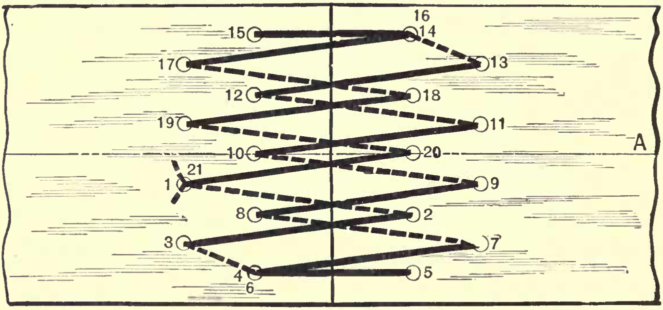

FIG. 13. — Method of Lacing Belts.

Perforated belts are often used for the reason that a film of air is likely to be imprisoned between the belt and the pulley, preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (above 2,500 feet per minute), to allow the air to escape; and being in the form of narrow slits, with their longest dimension in the direction of the length of the belt, they do not materially reduce its strength.

Arrangement and Care of Belting. — It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. If absolutely necessary to connect pulleys at different levels, the belt should be as nearly horizontal as possible, and should make an angle of at least 45° with the vertical, if possible; otherwise it will not be likely to work well for more than a few horse-power. The distance between centers of two belt-connected pulleys should be at least three times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping without straining the shaft or bearings. A new belt will not carry as much power as one that has been properly used for a few months.

The two shafts to be belt-connected must be perfectly parallel, and the centers of the two pulleys exactly opposite each other. The machines should then be turned slowly with the belt on, to see if the latter tends to run to one side of the pulleys, which would show that they are not yet properly "lined up"; in this case one of the machines should be slightly moved until the belt runs properly.

Belts should be as pliable as possible; hence the occasional use of some good belt dressing is recommended, especially as it permits the belt to be run with less tension. Rosin is sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface. In places where they are likely to catch in the clothing of any person, belts should be inclosed by a casing or railing.

ROPE DRIVING

The rope runs in V-shaped grooves in the peripheries of the pulleys, and in some cases this means of driving is preferable to any other.

The advantages of rope driving are:

1. It is cheap.
2. More power can be transmitted with a given diameter and width of pulley, on account of the increased grip in the V grooves.
3. It is almost noiseless.
4. Ropes can be used, by reason of their lightness, to transmit power over greater distances than with any other form of belting.
5. Rope belting can also be employed for very short distances because of the wedging action in the grooves.

The first of the above advantages — cheapness of the rope itself — is offset by the fact that grooved pulleys cost more than those for flat belts, hence the total cost is about the same.

Manila rope is generally preferred for transmitting power, but cotton, rawhide, and wire ropes are also used. The first has an ultimate strength of 7,000 to 12,000 lbs. per square inch of cross-section, but this is not important, since a driving rope transmits only 3 to 5 per cent of its tensile strength. Durability is the chief point, rope belts being rather likely to break owing to internal wear between the fibers and failure of the splice.

The diameter of a single rope necessary to transmit a required h.p. is given by the following formula;

$$D = \frac{825 \text{ h.p.}}{V\left(200 - \frac{V^2}{1{,}072}\right)},$$

in which h.p. is horse-power transmitted, V is velocity of rope in feet per second, and D is its diameter in inches.

The maximum power is obtained in rope driving at a speed of 80 or 90 feet per second. With higher velocities the centrifugal force becomes so great that the power decreases rapidly, and at 140 or 150 feet per second it counteracts the whole allowable tension (usually about 200 V^2 lbs.) and no power is transmitted.

Arrangment of Rope Driving. — There are two methods of arranging rope transmission: one consists in using several separate belts, and the other employs a single endless rope which passes spirally around the pulleys several times and is brought back to the first groove by a slanting idle pulley, the latter being called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks those remaining are sufficient to transmit the power temporarily, whereas an accident with the single-rope arrangement entirely interrupts the service. The carrying-over pulley is often carried in bearings moved by a screw or weight and so used as a belt-tightener; but as belt-driven machines are almost always mounted upon sliding bases, this advantage is not of much value. The difficulty with separate ropes is the necessity for making several splices, and the fact that it is practically impossible to make and maintain the belts of exactly equal length; consequently they are of unequal tension, and hang at different heights on the slack side, producing an awkward appearance. The single rope is often supposed to have a perfectly uniform tension in all parts; but it is evident that with the slightest slip the rope will be tighter in the first groove than it will be in the last; this variation is regular, however, and is less unsightly than the very uneven sag of separate ropes.

Shafting. — An intermediate or counter-shaft or "jack shaft" is undesirable, because it increases the complication and friction losses; but it is used in some electrical generating plants, especially old ones, either to obtain a greater multiplication of speed than is possible by belting directly or to enable a single engine to drive a number of generators; as, for example, in constant direct current arc-lighting stations. In electric power applications, it is common practice for one motor to drive a group of machines by means of a line or counter-shaft.

The two important kinds of shafting are "cold rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but is difficult to make perfectly true and straight; and if any portion of the surface is removed to make a key-way, for example, it is apt to cause the shaft to bend, owing to unequal internal strains. Turned steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can easily be made in it. The following table gives the ordinary data of shafting:

SHAFTING.

Diameter in Inches.	Weight. Lbs. per Ft.	Allowable h. p. at 100 r. p. m.	Average Price per Ft.	Width of Key-seat in Inches.
$1\frac{7}{16}$	5.5	4.3	$0.25	$\frac{3}{8}$
$1\frac{15}{16}$	10.	10.	.35	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	.50	$\frac{3}{4}$
$2\frac{15}{15}$	23.	34.	.70	$\frac{3}{4}$
$3\frac{7}{16}$	31.5	54.	.95	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1.30	1
$4\frac{7}{8}$	62.8	156.	2.00	1
$5\frac{7}{8}$	91.1	270.	4.00	1

The allowable h.p. that the shaft will transmit is given in the table at 100 r.p.m.; for any other speed the power varies in proportion; that is, at 200 r.p.m. it would be twice as great. It is not convenient to make or use shafting in greater lengths than 25 feet for sizes from about 1 7-16 to 3 7-16 inches diameter; for larger or smaller sizes it is desirable to have the lengths still less.

In addition to the means for mechanical connection already given, there are several other important devices used for this purpose, namely, *toothed*, *friction*, and *chain gearing.*

Toothed Gearing. — The method in most general use for the prevention of slipping between rotating parts is to form *teeth* upon them. *Gearing* is the general term which includes all forms of mechanical devices for the transmission of motion by means of teeth. The two principal kinds of gearing are *epicycloidal* and *involute*, depending upon the shape of the teeth. The former is theoretically more perfect in its action, but the latter is not so much affected by wear or by a slight variation in the distance between the two shafts. The object of both forms is to obtain a *rolling* action of the teeth with the minimum amount of sliding; nevertheless a certain amount always occurs.

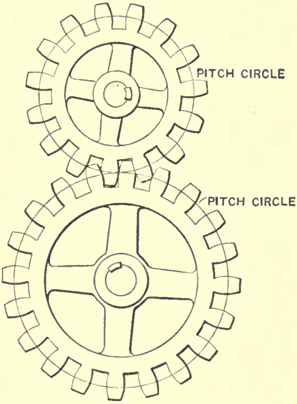

FIG. 14. — Gear Wheels.

The *pitch diameters* of gear-wheels (Fig. 14) are their effective diameters and determine the ratio of speeds. The *pitch circle*, which is described on the pitch diameter, is usually about midway between the tops and the bottoms of the teeth, but the latter might be cut deeper or extended outward, without affecting the pitch circle. The size of the teeth is given in either *circular pitch* or *diametrical pitch*, the former being in inches from the center of one tooth to the center of the next, measured on the pitch circle. The diametrical pitch which is more commonly used is the total number of teeth divided by the pitch diameter. *Obliquity* in gearing is the angle between a tangent to the surfaces of contact of the teeth and a line joining the centers of the two wheels. Theoretically, the acting surfaces of the teeth should be exactly on the line between the centers; but, practically, in involute teeth the obliquity either varies between 0° and about 30° during approach and recess of the teeth, or it is constant at about $14\frac{1}{2}°$. The obliquity tends to force the wheels apart, and exerts a side pressure on the bearings of both wheels. The minimum number of teeth that the pinion (the smaller wheel) should have is twelve, for the reason that the obliquity becomes too great with a lesser number. In fact, noise, wear, side pressure, and inefficiency are all greatly increased by using a small number of teeth on the pinion.

The strength of gearing depends upon the size and shape of the teeth, each of which may be considered as a cantilever or beam firmly fixed at one end and loaded at the other. If P is the total pressure exerted at the outer edge of a tooth, h the height, b the width of the face, t the thickness of the tooth, and f the greatest safe stress, which is from 3,000 to 6,000 lbs. per square inch for cast-iron and 6,000 to 15,000 for steel, depending upon the speed and type of service, we have

$$P = \frac{bt^2f}{6h}$$

It is frequently assumed that two pairs of teeth are always in action, so that each carries one half of the total pressure; but it is not advisable to count on this, because a slight shifting of position or the presence of grit might throw the whole strain upon one tooth. In fact the pressure might all be exerted at one corner of a tooth, in which case the strength of the entire width is not available. This, however, is covered in any ordinary case by the factor of safety of 3 to 5 employed in the formula above. The force P or pressure exerted on the teeth increases with decrease in diameter of the wheel, assuming the speed and power as constant, so the teeth must be made stronger. This condition again brings out the need of having the pinions as large as possible. The limiting speeds of gearing at the pitch circle are about as follows:

Ordinary cast-iron gearing	30 feet per second
Machine cut wheels	50 feet per second

The ordinary material for gear-wheels is cast-iron, but steel should be employed for the pinion when the ratio of speeds is great. Gearing subjected to shock is often made of gun metal or phosphor bronze, and rawhide or wooden teeth are sometimes used to deaden the noise.

The Arrangement of Gearing. — Gearing is seldom employed for the driving of generators, except when the source of power is a turbine with a vertical shaft, and the generator has a horizontal shaft. In this case the transmission is by means of a set of bevel gears as already explained (Fig. 8). Generators are also driven by gearing when the prime mover is a high-speed steam turbine.

The principal uses of gearing in connection with electrical machinery are:

In electric traction the motor is geared to the driving shaft, usually by single reduction spur gears with a ratio of 4: 1 or 5: 1.

In the driving of machine tools through a nest of spur gears, when large and variable speed ratios are required (Fig. 15).

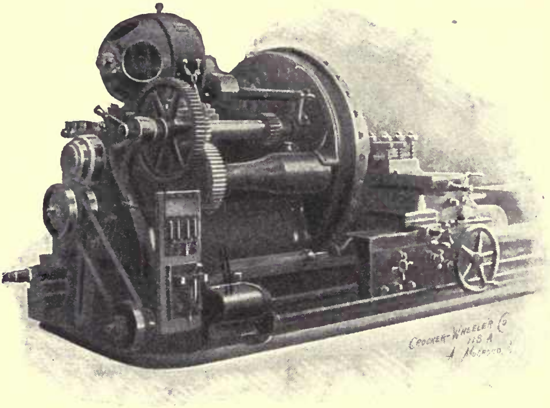

FIG. 15. — Semi-Enclosed Motor Driving a 62″ Lathe.

In printing press work, single reduction gears are employed in preference to direct connection, since a higher speed and therefore cheaper motor can be used, with resulting economy in space and ease of handling in case of repairs.

In the operation of electrically driven elevators, the connection between the motor and the hoisting drum is preferably made by means of a worm or screw gearing (Fig. 16) on account of the large speed ratios obtainable, as well as noiseless operation. The worm should be of hammered steel and the wheel of phosphor bronze.

In the operation of electrically driven pumps, either spur gearings or worm gearings are very frequently employed. Direct connection would require too large a motor, as pump speeds should not exceed fifty strokes per minute, and a belt connection is very likely to suffer from the moisture usually present around pumps.

Friction Drive. — One of the simplest means of driving a machine is to cause its pulley to press against the fly-wheel of the engine or other mover, thus obtaining what is known as a friction drive. This has the advantages of simplicity, compactness; it can be designed for any reasonable ratio of speeds, and is instantly thrown out of gear by merely moving the machine a small fraction of an inch on its sliding base. In all these respects nothing could be more desirable; but friction gearing has not been very extensively or successfully applied to driving dynamos, or any other purpose requiring considerable power. The chief objections to its use have

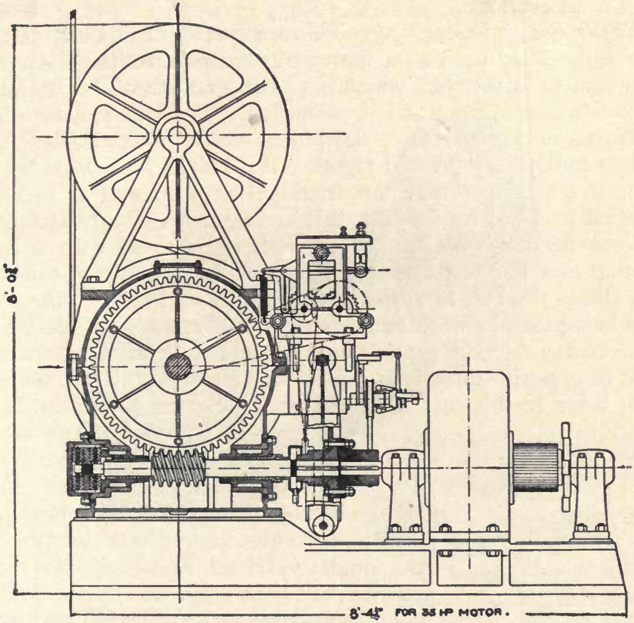

FIG. 16. — Single Worm Gear Connecting Motor and Hoisting Drum.

been the small amount of power transmitted compared with the side pressure on the bearings, and the fact that considerable vibration is likely to occur, owing to the pulleys being rigidly in contact with no elasticity or opportunity for play; hence the slightest irregularity on either pulley would cause both machines to vibrate. This difficulty is aggravated by the wear which occurs at one point of a wheel when the other wheel slips, as is sure to occur occasionally in starting up or from overload.

Evans Friction Gearing. — This is a special form which has been quite extensively used as a power-transmission device. It consists of an endless leather belt which fits loosely on one of the two pulleys between which the power is transmitted. The belt is held in place by flanges on both sides of the pulley which it surrounds. When the two pulleys are pressed together this belt is interposed between them, and acts to secure the frictional grip as well as to deaden vibration and noise. In fact, this arrangement simply amounts to cast-iron friction wheels, one of which is provided with a leather covering that is free to revolve or stop independently of the wheel. This allows the belt to adjust itself, or slip, and reduces the danger of its being torn or worn badly in case of overload. A special form of the Evans friction gearing consists of two conical pulleys which taper in opposite directions, the loose belt being placed on one of them, being in this case a little larger in diameter than the base of the cone (Fig. 17). If one of these cones is fixed to the driving shaft, and the other is connected directly or by belting to the driven shaft, then any desired ratio in speed may be obtained by simply moving the belt back and forth by means of an ordinary belt-shifter. This is one of the best mechanical ways to secure a variation in speed which can be gradually and perfectly adjusted, but it is hardly applicable to the transmission of much power.

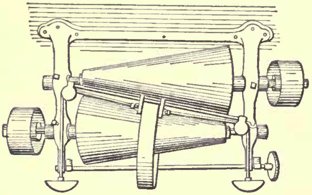
FIG 17.— Evans Friction Gearing.

Chain Gearing. — In cases where a large amount of power has to be transmitted from one shaft to another at *low speeds*, the tension in a flexible transmitter may easily be much greater than ordinary belting can sustain, unless made very wide. In such instances, chains of iron or steel may be used, the pulleys being toothed wheels (sprocket wheels). There can then be no slipping of the belt, and as the chain may have any desired strength, an extremely large driving effort can be exerted through it. Such chains form a class of transmission devices intermediate between belting and gearing and are called *gearing chains.* The chief objections to the use of ordinary chains and sprocket wheels are: No matter how well the chains may fit the sprocket wheels at first, they are liable to become, due to stretching of the links and wearing of the pins, slightly greater in pitch than the toothed wheel and thus work poorly. They are also noisy above moderate speeds, and cannot be used at high speeds as their weight is likely to throw them off the sprocket wheels.

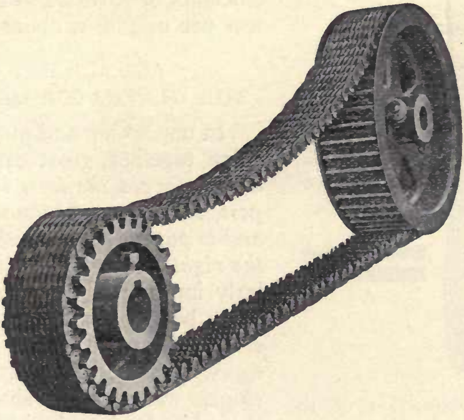

FIG. 18 —50-H. P. Silent Chain Drive.

Silent Chain Gearing. — The introduction of motor-driven tools and shafting, requiring frequently a distance between shaft centers too small for belting and too great for toothed gearing, has resulted in the development of silent chain gearing (Fig. 18). This silent chain gearing differs from the ordinary form, first, in the fact that the sprocket teeth do not pass through it, but are covered by the chain and mesh with teeth on its inner surface; second, in the fact that total stress is not carried by a small part of the pin surface, but distributed uniformly over its entire length by means of bushings (A) so that excessive wear does not occur upon the pins (B) or link holes (Fig. 19).

The driven wheel must always be flanged, and in cases where the distance between centers is great or the drive is reversible both wheels must be flanged. Another precaution advisable with silent chain drives, especially when the load is variable over wide ranges, is to employ a spring-center driving gear. This gear is similar to the flexible coupling shown in Fig. 11, except that the periphery of the outer member is toothed to fit the chain. The silent chain operates successfully at speeds as high as 1,800 feet per minute. In the case of vertical drives, the distance between shaft centers should be adjustable. The efficiency of the drive at 1,200 to 1,800 feet per minute is about 98 per cent.

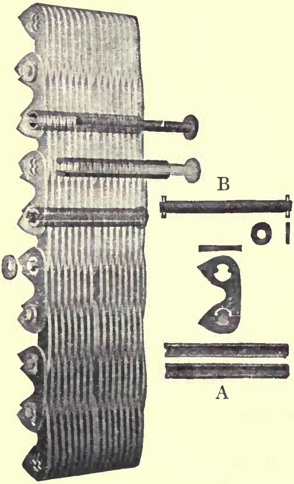

FIG. 19. — Construction of the Silent Chain.

ASSEMBLING OF THE GENERATOR OR MOTOR

In unpacking and putting the machine together, great care should be used *to avoid the least injury to any part, to clean scrupulously each part, and to put 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, metal chips, waste, etc., should be removed. It is advisable to study carefully the blueprints or instruction matter usually sent with each machine, before attempting to assemble it. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The bearing caps should be left slightly loose for a short time, so that the tendency to heat at the first run may be decreased; and after that they should be drawn up tight. The field frame should be set so that the air gap is the same for all pole-pieces, as otherwise the machine will be magnetically unbalanced, producing a side pull on the bearings and may also give rise to a tendency to sparking. The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to undergo its trial run.

CHAPTER IV

INSTALLATION OF GENERATORS, ELECTRICAL CONNECTIONS AND AUXILIARY APPARATUS

Methods of Wiring. — Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the National Electrical Code. Otherwise unnecessary trouble, delay, and expense may be incurred.

The wire may be installed in various ways, as follows:

Exposed on
- Cleats.
- Knobs.
- Bushings.

Concealed in
- Wooden moulding.
- Flexible Conduit
- Iron conduit.
- Terra-cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead-covered cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short-circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially when placed under the floor, have the great advantage over exposed wiring, of being entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires of the circuit, must be run in the same duct, otherwise the inductance drop would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus-bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed $\frac{1}{2}$ per cent at full load, because it interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the National Electrical Code, and their ohmic resistance per 1,000 feet, are given in the following table:

TABLE II

SAFE CARRYING CAPACITIES OF COPPER WIRES

B. & S. Gauge.	Rubber Insulation. Amperes.	Weather Proof Insulation. Amperes.	Circular Mils.	Resistance per 1,000 ft. in International ohms at 75° F.
18	3	5	1,624	6.567
18	3	5	1,624	6.567
16	6	8	2,583	4.04
14	12	16	4,107	2.565
12	17	23	6,530	1.601
10	24	32	10,380	1.010
8	33	46	16,510	0.6413
6	46	65	26,250	0.4004
5	54	77	33,100	0.3172
4	65	92	41,740	0.2525
3	76	110	52,630	0.2004
2	90	131	66,370	0.1579
1	107	156	83,690	0.1258
0	127	185	105,500	0.0995
00	150	220	133,100	0.0789
000	177	262	167,800	0.0625
0000	210	312	211,600	0.0497
Circular Mils.				
200,000	200	300		0.0525
300,000	270	400		0.0350
400,000	330	500		0.0263
500,000	390	590		0.0210
600,000	450	680		0.0175
700,000	500	760		0.0150
800,000	550	840		0.0131
900,000	600	920		0.0118
1,000,000	650	1,000		0.0105
1,100,000	690	1,080		0.0095
1,200,000	730	1,150		0.0087
1,300,000	770	1,220		0.0081
1,400,000	810	1,290		0.0075
1,500,000	850	1,360		0.0070
1,600,000	890	1,430		0.0065
1,700,000	930	1,490		0.0062
1,800,000	970	1,550		0.0058
1,900,000	1,010	1,610		0.0055
2,000,000	1,050	1,670		0.0052

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos. 16 and 18 B. & S. gauge wire is given, but nothing smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 20) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), that carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades, and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of maximum current to be carried. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc formed upon opening a loaded circuit, will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; so that switches should never be opened on heavily loaded circuits except in an emergency. In practice some form of electromagnetic circuit-breaker is employed for the purpose, being operated automatically with overload, or by hand at any time.

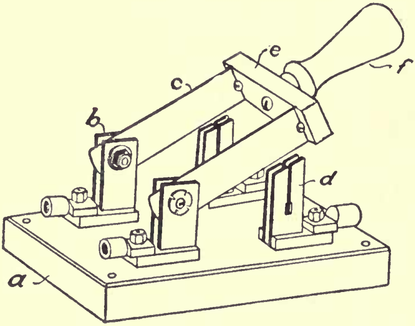

FIG. 20. — Front-Connected Double-Pole Knife Switch.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible. If located in exposed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III

SWITCH DATA

125 VOLTS OR LESS:	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
For Switchboards and Panel Boards —		
10 amperes or less	¾ inch	½ inch.
11–25 "	1 "	¾ "
26–50 "	1¼ inch	1 "
For Individual Switches —		
10 amperes or less	1 inch	¾ inch.
11– 35 "	1¼ "	1 "
36– 100 "	1½ "	1¼ "
101– 300 "	2¼ "	2 "
301– 600 "	2¾ "	2½ "
601–1,000 "	3 "	2¾ "
126 TO 250 VOLTS:		
For all Switches —		
10 amperes or less	1½ inch	1¼ inch.
11– 35 "	1¾ "	1½ "
36– 100 "	2¼ "	2 "
101– 300 "	2½ "	2¼ "
301– 600 "	2¾ "	2½ "
601–1,000 "	3 "	2¾ "

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings, intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters "A.C."

251 TO 600 VOLTS:		
For all Switches —		
10 amperes or less	3½ inch	3 inch.
11– 35 "	4 "	3½ "
36–100 "	4½ "	4 "

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed for more than 100 amperes at a pressure greater than 300 volts.

For three-wire systems, switches must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. — Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

(*a*) Open or link fuses.
(*b*) Enclosed or cartridge fuses.

The open or link fuses (Fig. 21) consist of strips of fusible alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

Fig. 21. — Link Fuse, Old Practice.

Enclosed fuses (Fig. 22) have a casing around the fusible material, which prevents dangerous spattering and smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain, or other incombustible non-absorptive bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and current carrying capacity.

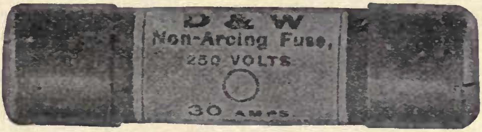

FIG. 22. — Enclosed Fuse, Present Practice.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their general construction and application are indicated in Fig. 23. The current is led through a helix A the electro-magnetic action of which,

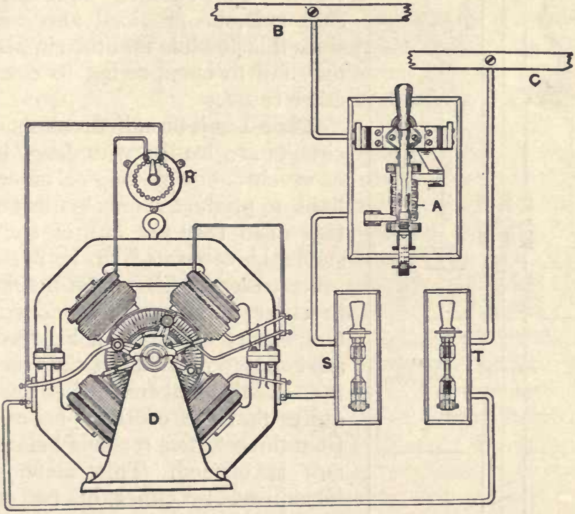

FIG. 23. — Circuit-Breaker Protecting Generator.

when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

1. They can be employed as switches if desired.
2. They can easily be reset and thus put into condition for acting again.
3. Their range can be easily varied within considerable limits.
4. They can also be made to operate "telltales" whenever the circuit they control is opened.
5. They are usually arranged (when used on motor circuits) to open the circuit with "no voltage," so as to protect the machine when the circuit is reestablished.

On account of these general advantages, the use of circuit-breakers is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Time-Limit Circuit-Breakers.—Where circuits are loaded with large induction or synchronous motors, or other devices liable to produce short-circuits on the system when they get out of step or are suddenly connected, it is necessary to protect them with circuit-breakers, and in order to prevent their operation by momentary overloads it has been found advisable to introduce a time element on the circuit-breakers. This feature requires that the overload be maintained from three to five seconds before the circuit is opened. This factor may be introduced by either of two methods, namely, by a clock mechanism or by an adjusted dash-pot. The clockwork time-limit breaker devised by Mr. L. B. Stillwell, Fig. 24, is so arranged that the wheels are prevented from revolving by

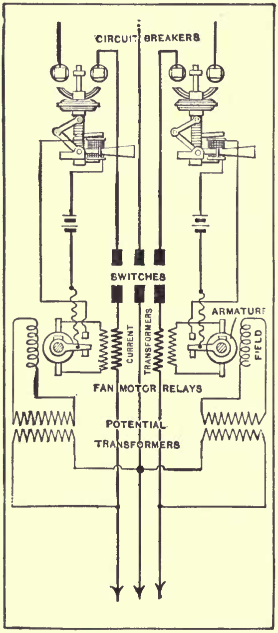

FIG. 24.—Time-Limit Circuit-Breaker.

a pawl which may be lifted out of place by relay magnets, energized from the line by means of current transformers. The lifting of the pawl allows the clockwork to operate and close a low-tension relay circuit, which trips the trigger of the breaker and thus opens the main circuit. The clock movement can be adjusted to close this second relay circuit in any desired time; and in case the mechanism is started by an overload, which is removed before the expiration of the time limit, the pawl drops and the movement returns to its original place.

In the case of the dash-pot circuit-breaker, the core of the solenoid is lifted against oil or air pressure, which can be so adjusted that the overload must be maintained for a definite period before the core can be lifted far enough to strike the release-trigger.

High-Tension Oil Switches. — Alternating-current generators for high voltages usually have oil switches to interrupt the main circuit, that is, switches in which the contact is made and broken under oil. These switches have been found very efficient in preventing the formation of a destructive arc upon opening circuits up to 30,000 volts. Some larger oil switches are operated by electric motors or solenoids energized from secondary or relay circuits. The machine-type oil switch of the General Electric Company, Fig. 25, has the energy for operating it stored up in a spring, which is wound up by a small electric motor. This motor runs every time the switch is opened or closed, and winds up the spring enough to compensate for the amount it was unwound in operating the switch. Each "leg" of the circuit is broken under oil in a long tube, and these tubes are mounted in individual cells, separated by masonry walls, so that there can be no flashing across from one to another.

Switchboards. — In the early electric-lighting plants the switchboards were made entirely of wood; but so much trouble was caused by short-circuits and fire, that some non-combustible insulating material is now considered essential. One of the best of these is marble, which is a good insulator, is not hygroscopic, has a fine appearance, is not affected by any reasonable temperature, and can be obtained free from conducting veins; the last named being, in the case of slate switchboards, a source of great trouble. Slate is often used for switchboards; and when free from the conducting veins just mentioned, it is an excellent material. Alberene stone, earthenware tiles, etc., have also been used with good results.

Since panels of marble, slate, etc., cannot be readily obtained in sizes over two feet wide, it is necessary to make up large switchboards of many panels, which are held together usually by angle iron frames. The presence of a metal frame is, of course, objectionable, since it may cause short-circuits, but its use is standard practice, because this is a simple and reliable way to support the panels of insulating material.

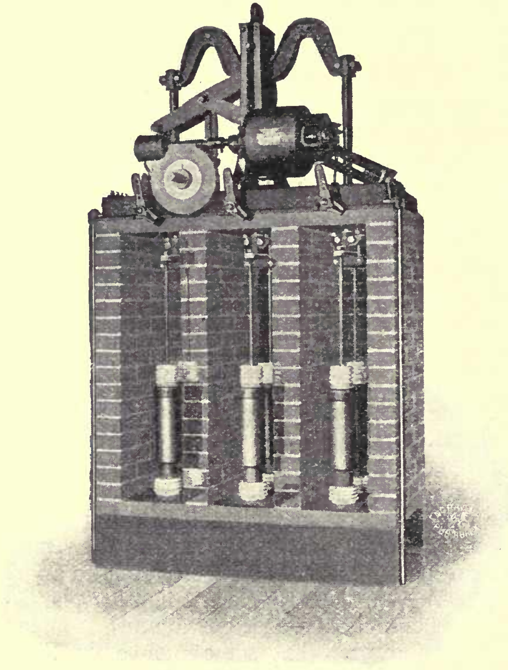

FIG. 25. — Motor-Operated, High-Tension Oil Switch.

The arrangement of instruments, switches, bus-bars, etc., on a switchboard, should be conveniently carried out. The path of the current should be as short as possible, and preferably always in one direction; that is to say, it may pass from right to left, or from top to bottom, or *vice versa*, the wires being brought in at one side, and carried out at the other. The crossing of wires and connections is to be avoided as far as possible.

Wires and all current-carrying parts should be placed far enough apart at all points to prevent accidental contact, or the jumping across of the current where the difference of potential is great. Wires and parts carrying current must be kept at a sufficient distance from conducting bodies, such as screw heads, metal brackets, pipes, etc., to avoid accidental grounds or short-circuits. Instruments, switches, and all other controlling devices should be accessible for observation and operation; but at the same time parts carrying high-voltage currents must, if possible, be placed out of reach of accidental contact by persons, or else be protected by an insulating shield.

Location of Switchboard. — In the design of buildings for central-station or isolated lighting plants, the switchboard should be located in an easily accessible place, and have plenty of space both in front and behind. In many instances the board can be placed to advantage on a gallery overlooking the generating machinery. Care should be taken to locate the switchboard with respect to the machinery and distributing feeders it is to control, so that the cost of machine leads may be kept down.

As extension should always be allowed for, the panels controlling the generators should be placed at one end of the board and the panels controlling the feeders should be placed at the other end.

For ordinary direct-current switchboards a space of not less than 2 feet should be left between the back of the board and the wall; for heavy work or high-tension systems a space of 6 to 8 feet would be advisable. In all instances a space of not less than 10 inches should be left between the bottom of the board and the floor, and as much as 3 feet if possible between the top of the board and the ceiling, in order to lessen the danger of communicating fire to the floor or ceiling, and to prevent the formation of a partially concealed space very likely to be used for the storage of rubbish, oily waste, etc.

In systems working at 2,000 volts or more, it is excellent practice to remove all high-tension apparatus from the face of the board, the switches being placed in fire-proof compartments of brick or soapstone, and operated mechanically through bell-cranks and levers by means of handles on the face of the panel, or electrically by means of low-tension relays. The instruments are connected to the secondaries of potential or current transformers, which are conveniently located, and connected to the lines of the high-tension system. This construction naturally requires more space than the simple low-tension switchboard, but the danger of accidental contact is thereby greatly reduced. The main current-carrying apparatus may be placed directly back of the board, in the basement or upon a gallery, and inclosed in fire-proof compartments, or, if electrically controlled, the main apparatus may be located where desired.

Starting-Boxes should always be furnished with D.C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, because the resistance is low and no counter e.m.f. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the voltage at its terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached (Fig. 45, page 69). All motor starting-boxes must also be provided with a *no-voltage release.* This may consist of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt-field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of motors should also always be equipped with *overload releases.* These, practically, are electromagnetic circuit-breakers that open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the National Electrical Code:

> "Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.
>
> "Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.
>
> "Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.
>
> "The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to acci-

dents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit may, however, serve as both switch and cut-out."

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

TABLE IV

Types of Machine for Various Kinds of Circuits

DIRECT-CURRENT, CONSTANT-POTENTIAL

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

Currents Intended for—	Potential.	Generator shoud be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2- or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway. Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway work. Shunt-wound for stationary use.

DIRECT, CONSTANT-CURRENT

Circuits in which the current is kept constant; machines, lamps, etc., being run in series

Circuits Intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, SINGLE-PHASE

Almost always constant-potential

CIRCUITS INTENDED FOR —	POTENTIAL IN VOLTS.		GENERATOR SHOULD BE —	MOTOR SHOULD BE —
Incandescent lighting. Arc lighting. Sometimes constant current, in secondary circuit for series arc lighting. Electric power.	Primary, 1,000 or more.	Secondary, 104–208. Same as above or variable according to number of lamps in use.	Separately excited. Also sometimes composite-wound.	Induction. Synchronous. Series. Repulsion.

ALTERNATING-CURRENT, POLYPHASE

Constant-potential, two- or three-phase currents

CIRCUITS INTENDED FOR—	POTENTIAL IN VOLTS.			GENERATOR SHOULD BE —	MOTOR IS —
Power transmission, also lighting.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000.	Secondary, 100 to 600.	Separately excited.	Induction or Synchronous.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Generator, Supplying Constant-Potential Circuit. — A machine of the above type is represented in Fig. 26, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils *Sh* through a resistance box R, to regulate the current in them and therefore the field magnetization. A voltmeter is also connected to the two main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter

A, which measures the total current in the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension direct-current system for electric light and power distribution from isolated plants or central stations.

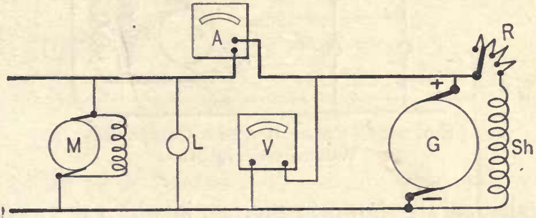

FIG. 26. — Connection of Shunt Generator.

Series Dynamo Supplying Constant-Current Circuits. — The connections in this case are extremely simple, the armature, field-coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 27), the current being kept constant. This system is used for series D.C. arc lighting.

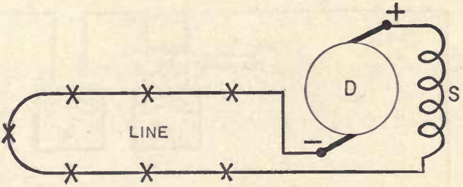

FIG. 27. — Connection of Series Generator.

Compound Direct-Current Generator. — This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 28. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The more the resistance of Z, the greater the current passing through the series field-coils, and the greater the compounding. This type of machine is most extensively employed in electric railway and isolated plants.

The important case of operating these machines in parallel is considered in connection with Fig. 36, page 59.

Alternating-Current Plants. — The connections for a single-phase installation are shown in Fig. 29, in which the names of the different parts are given. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

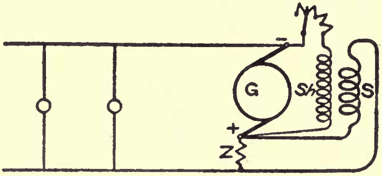

FIG. 28. — Connection of a Compound-Wound Generator.

The wiring of a three-phase system is as shown in Figs. 30 and 31, the former being known as the "Y" or "Star" system, and the latter as the "Delta" (Δ) or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 32, the neutral point being connected to the ground or to a neu-

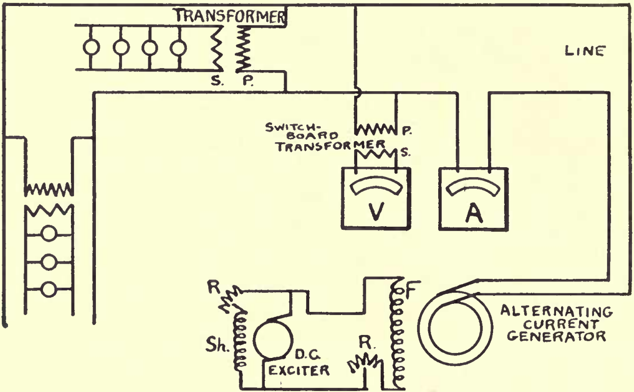

FIG. 29. — Connections of Single-Phase System.

tral conductor, in order to give equal voltages on the three "phases" or branches when they carry different loads.

The *Direction of Rotation* of the various machines is sometimes a matter of doubt or trouble. Almost any generator 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 does or does not revolve like the hands of a clock, when looked at from the pulley or driving end. Generators 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 engine or 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

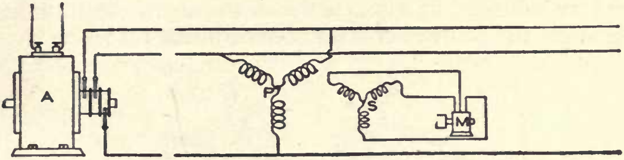

FIG. 30. — Connections of Three-Phase Y System.

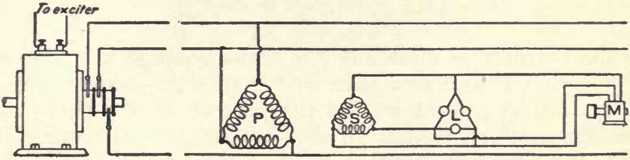

FIG. 31. — Connections of Three-Phase Δ System.

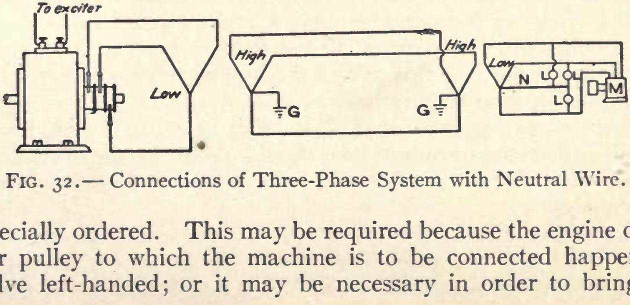

FIG. 32.— Connections of Three-Phase System with Neutral Wire.

loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 33, without changing any connection. This changes the point of contact of each brush tip 180°.

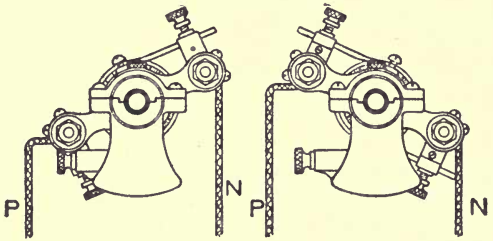

FIG. 33. — Reversal of Brush Position.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc. The direction of current in, 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, the latter having the effect of reversing the armature current. This applies to almost any shunt or compound direct-current machine, whether generator or motor, except a few special generators for arc lighting, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator 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 stated, if the rotation is to 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 allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places at the switchboard terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original 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 the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

CHAPTER V

OPERATION OF GENERATORS

Examination before Starting. — The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near the electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups, if used, have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In case self-oiling bearings are used, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on the centers of the pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator 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. The person who starts either a generator or a motor should watch the machine and everything connected with it closely, being ready to throw the apparatus out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to locate and correct the trouble before starting again. (See Part IV, "Locating and Remedying Troubles.")

Starting a Generator. — A generator is usually brought up to speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion. The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult, but should be done carefully, even if it is necessary only to throw in a friction clutch or shift a belt from an idle pulley. To put a belt on a pulley while in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one 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 used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are 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 stopped, before any injury is done. In fact, if the machine is working *alone* on a system, and is absolutely free from 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 paragraph.) With a large number of lamps, etc., connected to the circuit, the field magnetism and voltage of a shunt generator might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made. Two or more machines are often connected in this way to a common circuit, especially where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit, being set forth in the following ten pages.

Generators are connected together in parallel or in series.

Generators in Parallel. — In this case the + (positive) terminals are connected together or to the same line, and the — (negative) terminals are connected together or to the other line. The currents (amperes) of the machines are thereby added, but the e.m.f. (voltage) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may differ.

For example: A generator producing 100 amperes may be connected to another generating 500 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator, 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 might burn out its armature. Hence it 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 through it and cause it suddenly to accelerate and to 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 compound-wound machines require more careful handling.

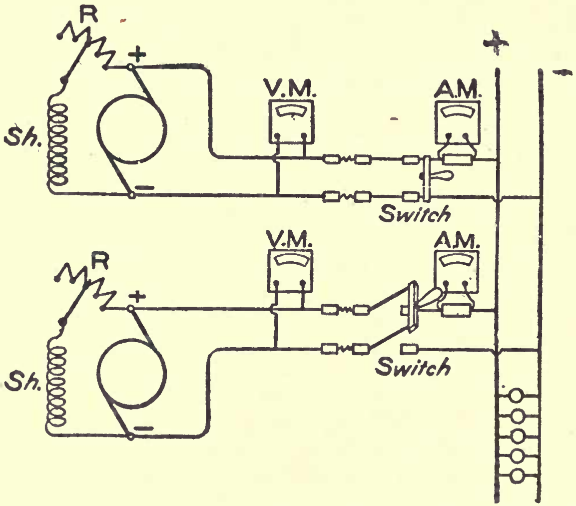

FIG. 34. — Connections of Shunt Generators for Parallel Operation.

Direct-Current Shunt-Wound Generators in Parallel. — The test for equal voltages is made by first measuring the pressure of the circuit and then that of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 34); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and an ammeter. When the latter indicates no current it shows that the voltage of the generator is equal to that of the circuit. A simpler and rougher way to do this is to raise the voltage of the generator until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect it to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. In connecting machines in parallel it is essential to connect the positive terminal to the positive conductor, and the negative terminal to the negative conductor (Fig. 34); otherwise there will be a very bad short circuit.

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

Series-Wound Generators in Parallel Not Used. — If the machine is series-wound, and its voltage is less than that of the circuit, the back current that would flow through it may cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse 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, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes by the line and the two — brushes by the line and by what is called an *equalizer* (Fig. 35). In this way 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 very important.

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

The manner of connecting two or more compound generators to operate in parallel is represented in Fig. 36, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus-bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

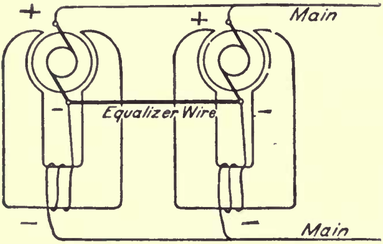

FIG. 35. — Connections of Series Dynamos for Parallel Operation.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows: Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the generator and to the bus-bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids any error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* machine has been properly regulated, the three switches E, F, and D are closed in the order named. If these points are closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this generator, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of load thus produced may be so sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a triple-pole switch, which guards against the possibility of any accident due to closing the wrong circuit first. After the machines have been thrown in parallel, their voltages should be adjusted by the shunt-field rheostats so that the load is properly divided between them as shown by their ammeters.

Any number of compound-wound generators may be operated in parallel in this way, and even those of different size or current capacity may be connected, provided their voltages agree, and provided also that the resistances of the series field-coils are inversely proportional to the current capacities of the several machines. When compound-wound to maintain a constant potential at their terminals they work well after their voltages are once made to agree, even with a variable load. But machines which are "over-compounded" (to generate higher potential at greater loads) must give *exactly the same percentage of increase* at full load, and agree at all intermediate points, otherwise the one that tends to produce a higher voltage will generate more than its share of the current. This may be corrected by increasing the resistance of the series coil of the

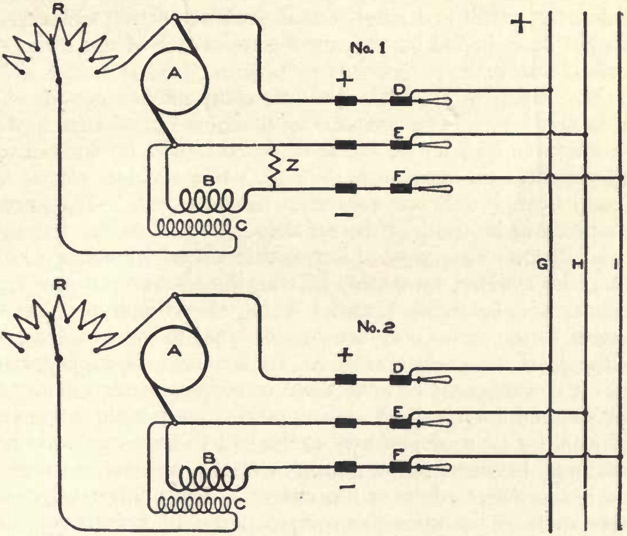

FIG. 36. — Connections of Compound Generators for Parallel Operation.

machine which tends to take too large a share of the load; a few extra feet of conductor, of the same current capacity as the series coil, being interposed between it and the main conductor or bus-bar. The shunt which is often used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 36) operates properly in the case of a machine working *singly*, but it is worthless for machines in parallel, because it affects all alike, and simply reduces their voltage equally. Hence a shunt may be used when this latter result is desired; but the relative action of the generators should be adjusted by varying the resistance of the series coils as described above.

Another difficulty arising with over-compounded generators in parallel is that when, for example, one machine out of four is working alone at one quarter of the total load, it will be fully loaded, and will generate the maximum voltage, while the loss of potential on the conductors is only one quarter of the maximum. The pressure at the lamps will be too high by an amount equal to three quarters of the full drop. This very objectionable excess of voltage at the lamps may be avoided by merely leaving the equalizer connected to all the generators (switches E and F being closed in Fig. 36) so that the currents in the series coils are proportional to the *total* load, and not to the load on each machine. In the case of high-potential machines it is dangerous to have them connected to the circuit while they are stopped for cleaning and repairs, consequently a resistance (strip of iron, for example) exactly equivalent to the series coil should be substituted between the equalizer and the bus-bar, whenever a machine is disconnected from the circuit. More frequently (since the above method becomes too complicated and expensive with a number of machines) the machines that are shut down are entirely disconnected and regulation, if desired, is obtained by variation of the shunt-field resistance of the operating generator. In the case of high-tension systems with sub-stations, the secondary voltage is adjusted to the proper value by means of an induction regulator.

Shunt-wound generators 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 a belt, or even small differences in the governing action of the different engines that may be driving them. *Compound-wound generators exert far less mutual regulation, owing to the effect of the series coil; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines.* They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and adjustment they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be made directly from one machine to the other with the equalizing switch (E, Fig. 36) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

In disconnecting a compound-wound or other generator working in parallel with others, the current shown by its ammeter is reduced to a small value by means of the field regulator, and the main switch is then opened. The reasons for this are: The switch is not injured by arcing and the gradual shifting of the total load to the remaining machine or machines will not cause a jump in the voltage.

Alternators in Parallel. — To run two alternators in parallel, several conditions have to be fulfilled: The incoming machine — as in the case of direct-current generators — must be regulated to give nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency is called *synchronism.*

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining when agreement in frequency and phase is reached. In Fig. 37, let M and N represent two single-phase alternators, which can be connected to the distributing bus-bars by the switches *m* and *n* respectively. The synchronizing lamps being connected, as shown, across points of the same potential. B and D are plug connections which can be made on any incoming machine. The two alternators may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N to approximately the proper speed and voltage; then watch the lamps. If machine N is running a very little slower or faster than machine M, these lamps will glow for one moment and be dark the next. At the instant when the voltages are the same in pressure and phase, these indicators will remain dark; but when the two are displaced by half a period, the lamps will glow at their maximum brilliancy. Since a flickering of the lamps indicates a difference in frequency, the machines, so long as flickering occurs, should not be thrown in parallel. The prime mover of the incoming machine must be brought to the proper speed; and the closer the machine N approaches synchronism, the slower the flickering. When it is very slow, we can use the moment that the lamps are dark to throw the machines in parallel by closing the switch n. The machines are then in phase, and tend to remain so, because either one that lags is driven as a motor by the other. It is better to close the switch when the machines are approaching synchronism

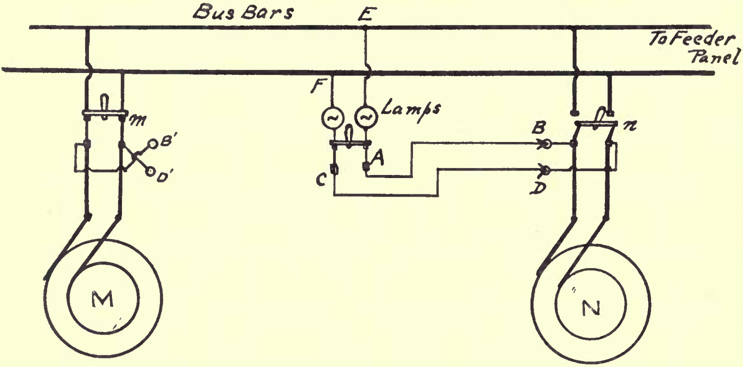

FIG. 37. — Connections for Parallel Operation of Low-Tension Single-Phase Alternators.

than when they are receding from it, that is, at the instant the lamps become dark.

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamps may be dark owing to a broken filament.

Hence it may happen, with this arrangement, that machines are connected in parallel while there is a considerable difference in voltage or phase, and an excessive rush of current will result.

A method not open to the above objections is shown in Fig. 38.

The alternators to be thrown in parallel are each connected to the bus-bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between E and a given point is the same as that between B and the same point; likewise F and D have the same relative potential values. Hence a lamp connected between E and D would burn with the same brilliancy as if connected directly across EF; which is also true of the other lamp. If, however, the machines happen to be directly opposite in phase, but generating the same voltage, E and D are of the same potential, F and B being also of equal value; hence lamps cross-connected as in Fig. 38 would be dark. At other phase differences the lamps will glow, but not as brightly as when there is no difference in phase. Hence, with this arrangement, the machines should be thrown in parallel the instant before the lamps reach maximum brightness, a condition readily determined, so that this method is more definite than the other.

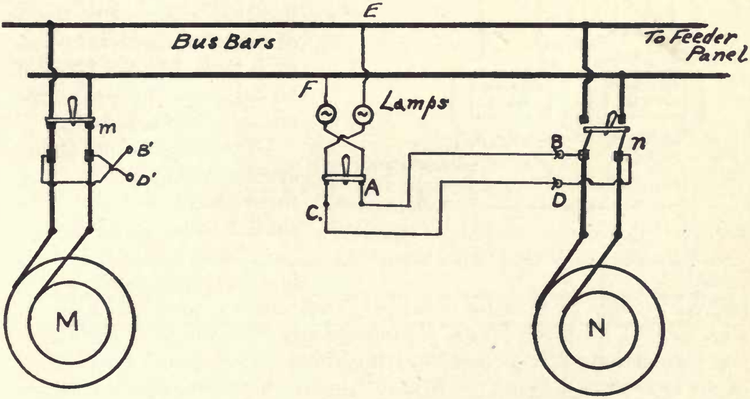

FIG. 38. — Connections for Parallel Operation of Low-Tension Single-Phase Alternators.

The connections as shown in Figs. 37 and 38 are not directly applicable to high-tension working, but require the introduction of transformers as shown in Fig. 39, which is a modification of Fig. 38.

The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dark. If the lamp flickers badly, the frequencies are different; but if the lamp is steady at full brightness, the machines agree in frequency and in phase, and they may be connected without disturbing the circuit, by closing the main switch.

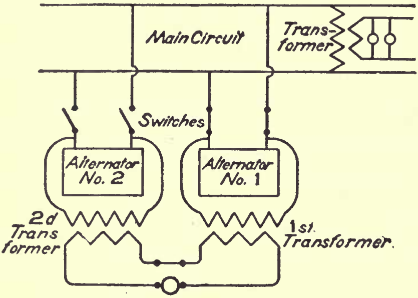

FIG. 39.— Connections for Parallel Operation of High-Tension Single-Phase Alternators.

If alternators are rigidly connected to each other or to the same 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.

The connections of the synchronizing lamps for a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 37 may be extended, and lamps connected in as in Fig. 40. If all three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively. This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension three-phase systems, two single-phase transformers, connected as shown in Fig. 41, are sufficient.

Generators in Series. — This arrangement is much less common than parallel working, being applied only to series-wound dynamos on arc circuits and to "boosters." (See page 72.) The conditions are exactly opposite to those of generators in parallel.

To connect machines in series, the positive terminal of one must be connected to the negative terminal of the next; and each

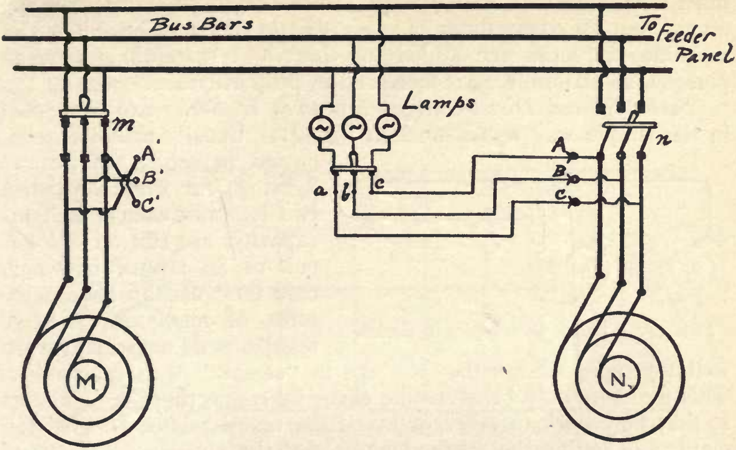

FIG. 40.— Connections for Parallel Operation of Low-Tension Three-Phase Alternators.

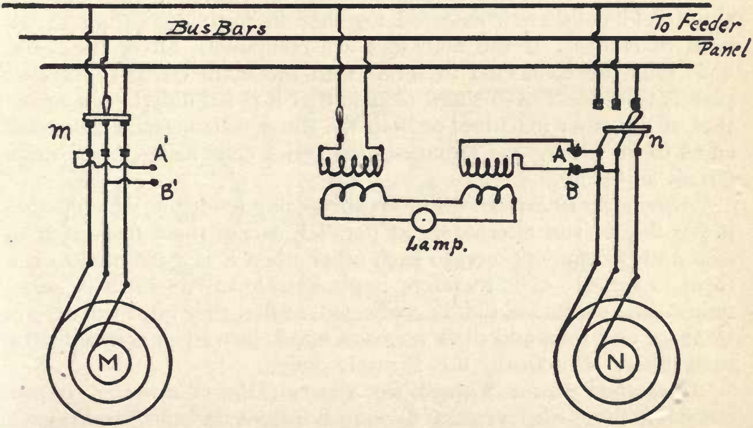

FIG. 41.— Connections for Parallel Operation of High-Tension Three-Phase Alternators.

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 Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 42. 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 they 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 regulator to give full e.m.f. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the capacity of one machine.

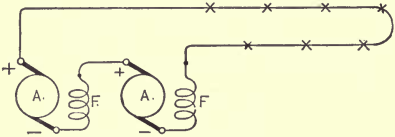

FIG. 42.—Series Generators in Series.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only by the armature of the other machine; 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 to run alternators in parallel, 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, so that they must run exactly in phase and thus add their waves of e.m.f. instead of counteracting each other. Practically this is rarely done.

Generators on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 43 and 44 may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 43) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt three-wire systems (except in the case of machines of $\frac{1}{4}$ h.p. or less capacity), and to connect them across the outside conductors so that the motor load shall not unbalance the system.

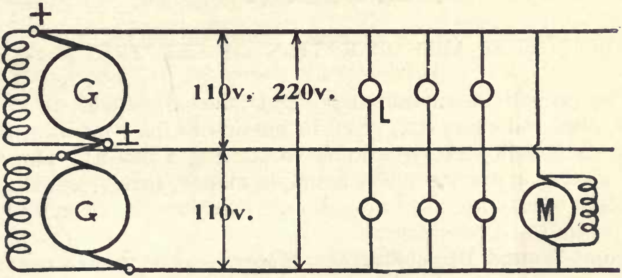

FIG. 43.—Three-Wire System with Two Generators.

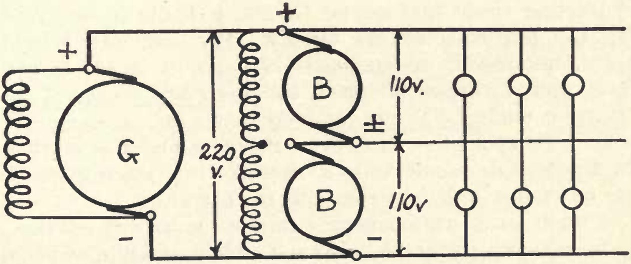

FIG. 44.—Three-Wire System with Balancer Set.

CHAPTER VI

CONNECTION AND OPERATION OF ELECTRIC MOTORS

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual starting of a motor is usually a simple matter, involving merely the operation of a switch; but in each case there are one or more important points to be considered.

Shunt-Wound Direct-Current Motor. — A motor to operate at nearly constant speed, with varying loads, on a D.C. constant-potential system (110- or 220-volt lighting and power circuits) is usually plain shunt-wound. Most stationary D.C. motors are of this type. The field-coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field-coils to the circuit. The difficulty is with the armature, because its resistance 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 avoid this excessive current, a motor is started on a constant-potential circuit with a rheostat or "starting-box" containing resistance coils in series with the armature.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and starting-box, as indicated in Fig. 45. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *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 the speed rises it generates a counter e.m.f., so that the arm S can be turned as shown until all the resistance coils *a*, *a*, *a* are cut out, the armature being then directly connected to the circuit operates 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 must positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 45 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the position shown. If, however, the supply of current to the motor is accidentally or otherwise cut off and the armature comes to rest, the core of the magnet loses its attractive force, the arm S is released, being automatically thrown back to the starting position by a spring. Without this device there would be an excessive rush of current in the armature when the supply is reëstablished, because the field mag-

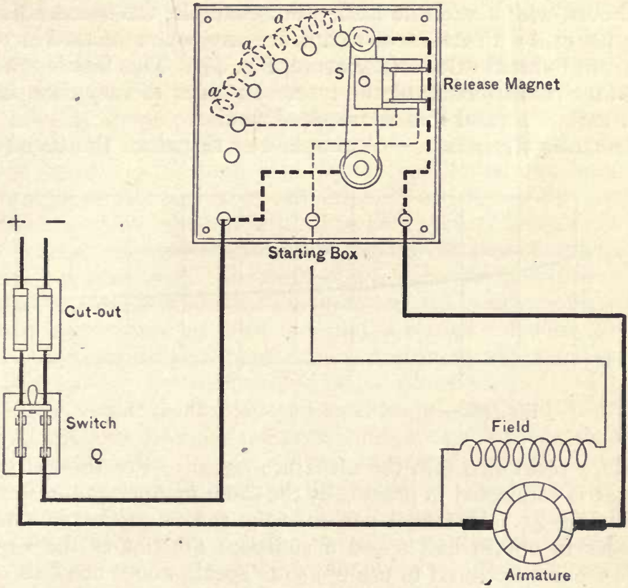

FIG. 45. — Shunt-Wound Motor Connections.

netism and armature speed require several seconds to reach full value.

The coils *a*, *a*, *a* in a starting box are made of comparatively fine wire, which can carry the current only for a few seconds. In a rheostat for varying the speed the wire must be large enough to carry the rated current indefinitely, as explained below.

Speed Regulation of Direct-Current Shunt Motors. — The plain shunt motor on a constant-potential circuit operates at nearly constant speed even with a variable load. For example, the speed falls only 3 or 4 per cent with motors of 10 h.p. or more, when the load increases from zero to rated value. (See curve, Fig. 46.) This fact is the most important characteristic of the type. In order to vary the speed of shunt motors several means are employed:

Armature Resistance. — A simple way to reduce the speed is to introduce resistance into the armature circuit. For this purpose a rheostat is connected in practically the same manner as the starting-box in Fig. 45. In fact it performs the same function in starting. In order to obtain half speed a sufficient amount of the rheostat resistance is introduced to use up, so to speak, about one half of the voltage supplied to the armature circuit. For example, a 10-h.p. shunt motor operating at rated load on a 220-volt system has a current of about 38 amperes flowing through the armature. The introduction of 2.8 ohms would cause a drop of 38 x 2.8 = 106.4 volts, so that the armature, which has resistance of .2 ohms, will be supplied with 220 — 106.4 = 113.6 volts, and therefore revolves at about half speed, but with full torque. If the latter is also reduced, correspondingly greater resistance is required for half speed. To reduce the speed to zero, 2 × 2.8 = 5.6 ohms would be needed for full torque (38 amperes) and twice that resistance for half torque.

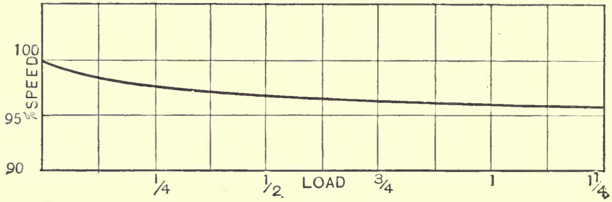

FIG. 46. — Speed-Load Curve of a Shunt Motor.

In this way any desired speed and torque may be obtained, but serious disadvantages are involved. First, power is lost in proportion to the speed reduction; that is, at half speed the rheostat destroys half the watts supplied, three quarters at one-quarter speed, and so on. Second, a bulky rheostat is required to get rid of the heat corresponding to this large waste of watts. Third, the speed varies greatly with changes in load (torque); for example, a motor running at one-quarter speed with full torque will run up to about five-eighths speed if the torque be reduced one half, and will run at nearly full speed at no load. Hence the rheostat must be adjusted for each variation of load in order to maintain a constant speed.

Variation in Field Magnetism. — A reduction in the flux or the total lines of force passing through the armature of a constant-potential shunt motor tends to increase its speed. By means of a suitable rheostat in the shunt-field circuit, this flux may be diminished, for example, to one half of its full value, in which case the armature speed is approximately doubled. The field current being only 1½ to 4 per cent of the armature current, the loss of energy and bulk of rheostat required with this method are correspondingly less than with the preceding method. Furthermore, the speed is reasonably constant even when the load (torque) is varied. Hence all three of the objections to the former method are practically avoided. On the other hand it has one serious limitation of its own; weakening of the field tends to cause sparking at the brushes, and in order to avoid this serious difficulty the permissible torque must be decreased at the higher speeds. These motors are usually designed to give a *constant horse-power* throughout the range of speed control, hence at lower speed the motor would have to develop a greater torque and consequently require a larger amount of copper than is necessary for the same horse-power at the higher speeds. Thus we obtain our speed regulation by paying for more material, and in many cases it is well worth the cost. Ordinarily this method demands a 15-h.p. frame to give a 10-h.p. machine with a range of speed regulation of two to one; or a 20-h.p. frame to give a 10-h.p. motor with a speed range of three to one.

Multiple Voltage System. — If the field of a shunt motor be kept at constant strength, and the voltage applied to the armature be altered, the speed will vary approximately in proportion to this voltage. A simple way to accomplish this result is to connect the field to the two outside wires of an ordinary three-wire direct current circuit, and connect the armature first to the middle wire and either outside wire, and then to both outside wires. One-half speed is obtained in the former case and full speed in the latter. By the use of four wires it is possible to obtain six different voltages, as represented in Fig. 47, these steps being 40, 80, 120, 160, 200, and 240 volts. The field circuit is always connected to the two outside wires whenever the motor is operating, and the armature is successively connected by means of a controller (switch) to receive 40, 80, 120, 160, 200, and 240 volts, and will run at about one-sixth, two-sixths, three-sixths, four-sixths, five-sixths, and six-sixths speed respectively. The total energy and voltage are produced by the main generator G (or generators in parallel), this voltage being subdivided by the balancer B into three parts in the ratio 1: 2: 3.

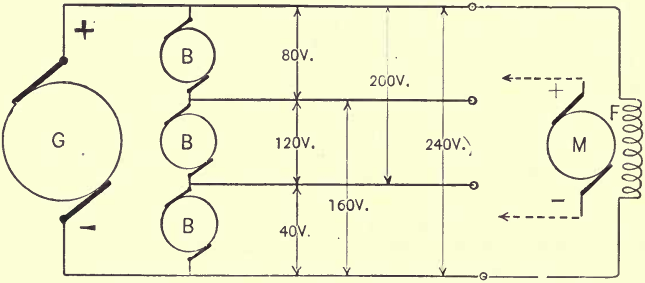

FIG. 47. — Four-Wire Compound-Wound Multiple Voltage System.

Another system also employs four wires, but the voltages are 60: 80: 110: 140: 190: 250; which is approximately a geometrical progression instead of the arithmetical progression in Fig. 47.

Boost and Retard System. — In another variable voltage method indicated in Fig. 48, the field F of the working motor is connected to the main supply wires + and — as before. The working armature A is also connected to these wires, but in series with it is the armature B of an auxiliary machine. The latter is directly coupled mechanically (as indicated by the horizontal line J) to the armature C of a shunt motor connected to the supply wires + and — in the usual way. This motor will run at practically constant speed so that the voltage set up in the armature B will be proportional to the flux produced by its field-coil E. The current in the latter may be varied by means of the rheostat R from full strength down to a very small value. In the former case the armature B will generate its full e.m.f., which is equal to the potential difference between the main wires + and —; hence the working armature A receives twice the voltage of the supply circuit. Being designed for this double voltage it runs at full speed. If now the current in the field-coil E be weakened by the rheostat R, the e.m.f. of the booster armature B is diminished, so that the speed of the working armature A is correspondingly lowered. When the current in the field-coil E is reduced to zero the e.m.f. set up in the armature B is so small that the working armature A runs at practically half speed, receiving only the voltage from the main wires. The field-coil E may now be reversed by means of a switch not shown and its current strengthened so as to generate in the armature B an e.m.f. opposing that of the supply circuit, until finally the latter is nearly neutralized and the working armature A stops. In this way, by "boosting" or "retarding" the supply voltage the speed may be regulated at any point from full value to zero. The machine B E must be capable of generating one half the voltage and the same current as that taken by the working motor, that is, one half of the K.W. capacity. The same is true of the motor D C, with an allowance (about 10 per cent) for losses.

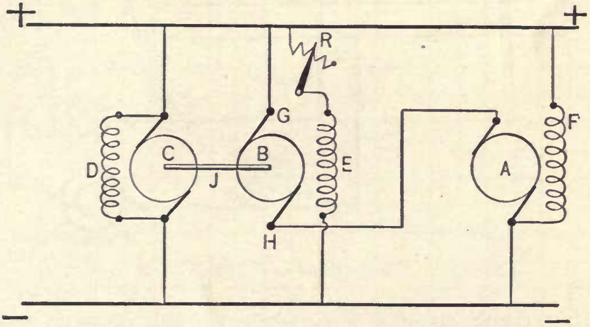

FIG. 48. — Ward–Leonard Boost and Retard System.

Series-Wound Motor. — The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class. Motors for fans, pumps, electric elevators, and hoists are also of this kind or of the compound type. A rush of current tends to occur when the series motor is started, similar to that in the shunt motor already described; but it is less, because the field-coils are in series with the armature, so that their resistance and inductance reduce the excess. Furthermore, the counter e.m.f. is greater even at low speed, because the heavy current produces a strong magnetic field. The connections, as indicated in Fig. 49, are very simple, the armature, field-coils, 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 suited only to railway,[1] pump, fan, crane, or other work where variable speed is desired, or when there is no danger of the load being removed by a belt slipping off or otherwise. It is 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. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with only one half or one third of the normal current. The objects being to secure a nearly constant speed with varying loads, as with a shunt type, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking.

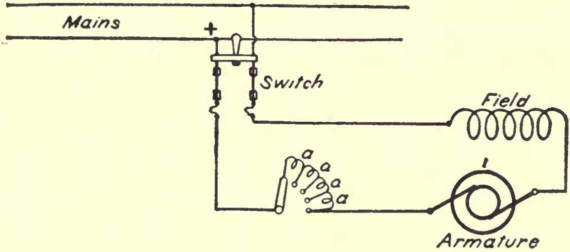

FIG. 49. — Connections of Series-Wound Motor.

In bipolar or multipolar motors having two or more field-coils, the coils are all connected together, and are equivalent to the single coil shown in the diagrams. It has just been stated that the speed

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[1] The management of railway motors is specially considered in Chapt. XXVIII.

of a series-wound motor varies greatly with the load (torque) when supplied with constant potential as is usually the case. Curves showing the speed regulation of a series motor at different loads are given in Fig. 50. Comparing these curves with those given in Fig. 46, we find the radical difference in action between series and shunt motors. In order to control the speed of a series motor, a rheostat is inserted in the main circuit, as indicated in Fig. 49, being operated by hand to obtain a constant or variable speed as in the case of an electric railway or crane. When two or more series motors are working together, as is usual on an electric car, for example, they are connected in series for starting and at low speeds, being put in parallel for higher speeds. The particular arrangements employed are described under "Railway Motors" (Chapt. XXVIII). This gives practically the same effect as multiple voltage (Fig. 47), since with two machines in series each receives one half of the total voltage and with a given torque would run at approximately one-half speed. The speed of series motors can be successfully controlled by either

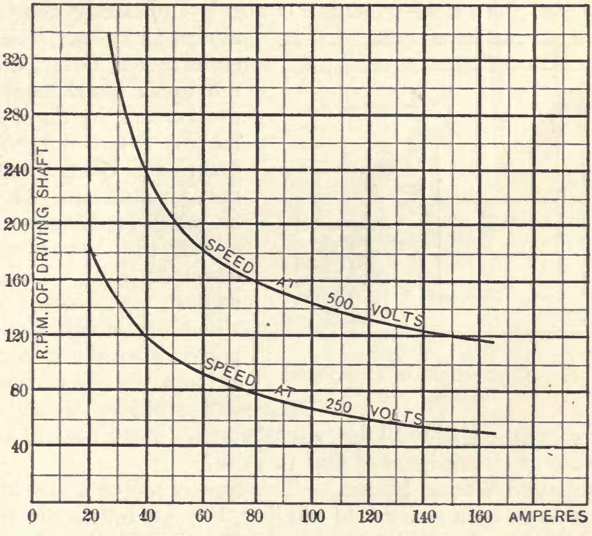


FIG. 50. — Speed-Current Curves 75-H. P. Series Motor.

of the variable-voltage methods described for shunt motors, but it is not common practice.

Differentially-Wound Motor. — This is a shunt-wound motor with the addition of coils of large wire on the field-cores, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and decrease the field flux, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly 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, if overloaded, has the great disadvantage that 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 likely 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, if the fuse or circuit-breaker fails to work.

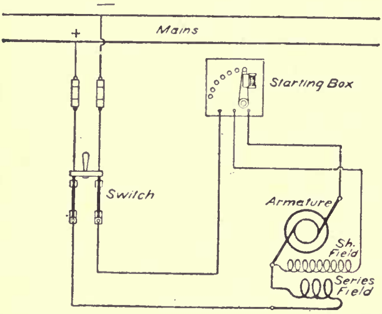


FIG. 51. — Connections of Compound Motor.

Compound-Wound Motor. — This type of motor is also provided with a shunt and a series field winding, Fig. 51, but in this instance they magnetize the field in the same direction, or, in other words, their effect is cumulative. This type possesses to a certain extent the powerful starting torque of the series motor, but has a less variable speed with varying loads. It is generally employed where great starting torque and fairly uniform running speed are required, as, for example, in electric hoists or elevators.

Dynamotors and Motor-Generators 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 type of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner described in relation to Fig. 45.

The current generated by the dynamo portion of the combination 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 generator. In case the generator 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." When the armatures of both motor and generator are acted upon by the same field, the e.m.f. of the latter cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes; but the latter method is likely to cause sparking.

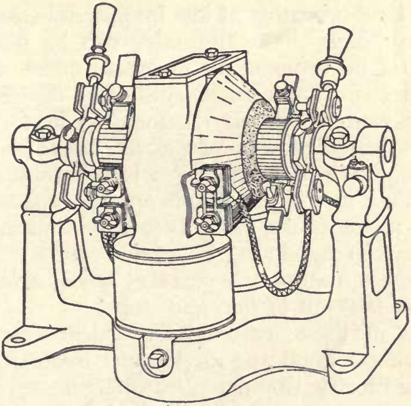


FIG. 52. — Dynamotor.

ALTERNATING-CURRENT MOTORS

Alternating-current motors operate on constant-potential circuits, practically all A.C. systems being of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D.C. motor, except that its field must be laminated. The troubles with this type of A.C. motor are as follows:

(*a*) Large no-load current, low power-factor, due to the nature of the windings, and the considerable air gap necessary to reduce armature reactions.

(*b*) The sparking likely to take place, especially at starting and with overloads, due to the fact that as each armature coil is in turn short-circuited by a brush, it becomes the seat of induced currents, which may cause heating and sparking.

(*c*) Increased iron losses.

Many attempts were formerly made to utilize this type of motor with alternating currents, as it possesses the valuable features of great starting torque, convenient speed control, and simple circuits (single-phase); but on account of the high frequencies then universally employed, they were not successful. Recently, however, the Westinghouse and General Electric Companies have brought out motors of this kind operating at low frequencies (usually 25 cycles).

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor*. The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel," pages 62 and 63. After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not suitable for general application. Various manufacturers, notably the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 53), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field-magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and provides the direct current for field excitation.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

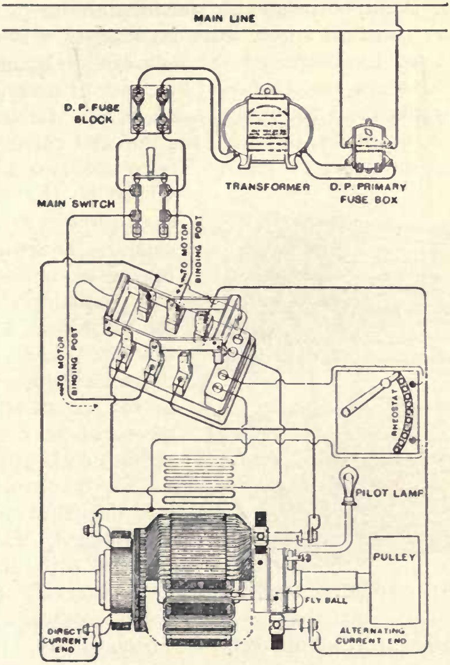


FIG. 53. — Connections, Fort Wayne Self-Starting Single-Phase Synchronous Motor.

A great advantage of the synchronous motor is that when its field is over-excited it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of the lines, induction motors, and other apparatus, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction lighting and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A.C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. It is designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings at both ends of the core.

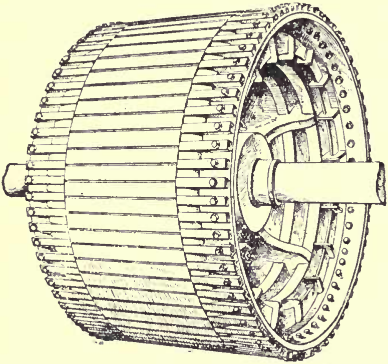


FIG. 54. — Squirrel-Cage Rotor.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings; and on this account this type of rotor is frequently called the "slip-ring" rotor.

Starting Induction Motors. — In small sizes, up to 3 or 5 h.p., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush of current is excessive, reaching three or four times the current at rated load, so that it is likely to disturb the system; accordingly some form of starting device is usually necessary.

Starting by Means of Compensators. — This rush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied e.m.f. The torque of an induction motor decreases as the square of the applied voltage, so that this method results in a greatly reduced starting effort. However, in many instances motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer having but one coil, which serves as both primary and secondary), or *compensator*, as it is called when used for this purpose. A compensator and connections for a three-phase motor are represented in Fig. 55. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportional to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the particular work is used after the equipment is permanently installed. When the switch is in the lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is

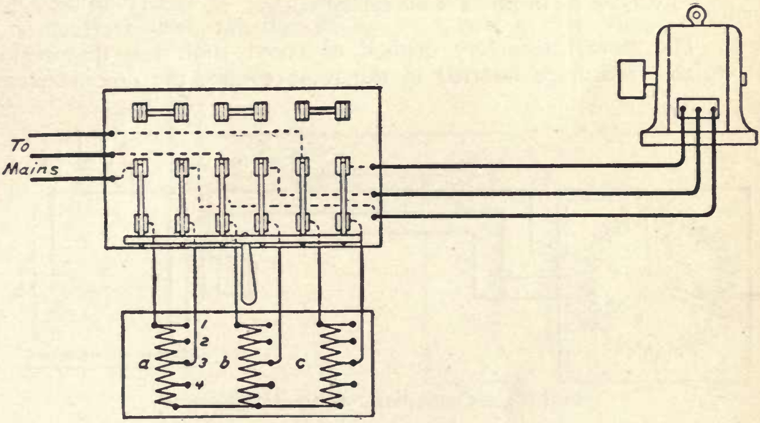


FIG. 55. — Compensator Connections.

correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. — This may be accomplished by one of the following methods :

(*a*) The insertion of a variable resistance in the rotor circuit.
(*b*) Cutting down the voltage applied to the stator, as just described.
(c) Varying the number of primary poles.
(*d*) Varying the frequency of the applied voltage.

The more satisfactory method of speed control is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. This involves, however, collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine, and would heat it too much. The controller itself looks like an ordinary trolley-car controller, but for simplicity it is represented as a three-armed controller (Fig. 56) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle closes

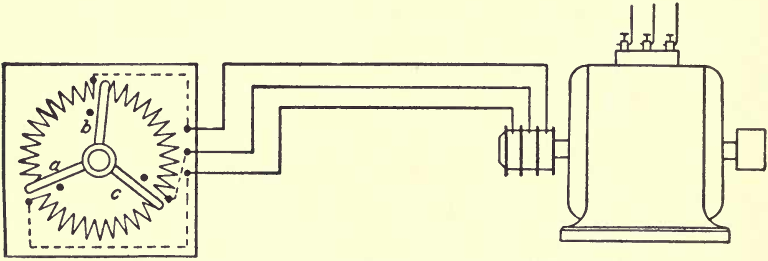


Fig. 56. — Connections of Slip-Ring Control.

the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

In another method of speed control, the winding on the primary is arranged so that by means of a suitable controlling switch the number of poles can be changed. This is a very economical method from the electrical standpoint, with a wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor is not so well adapted to variable-speed service as the direct-current motor, and the methods employed for the purpose are not so satisfactory, the disturbing effect upon the system being greater.

Single-Phase Induction Motor. — A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not, however, start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This may be accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 57). The currents flowing through these two windings will differ in phase, one lagging more than the other because of the lower resistance, and will thus produce a rotating field, and the motor will then start up. When the motor has reached full speed, one phase may be cut out

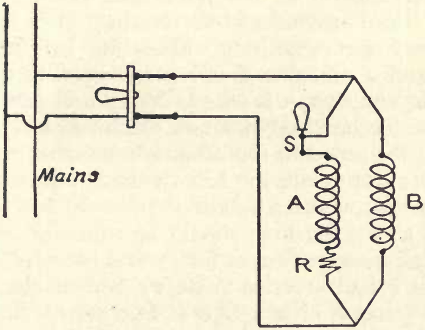


FIG. 57. — Connections of Split-Phase Motor.

by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

The Wagner, as well as several European self-starting single-phase motors, are constructed and connected like direct-current motors but with laminated fields. They are started as repulsion or series motors, and when a certain speed is reached the commutator sections are short-circuited (automatically or by hand), after which they run as single-phase induction or repulsion motors.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS

After any of these machines have been properly started, they usually require little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is 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 spread to the armature, or other part that would be injured by it; and to run the belt (if used) rather slack until the bearings are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or 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 that would cause trouble. Machinery requires 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. In the case of a generator its voltage or current should be observed and regulated. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it in accordance with the directions given in Part III. These directions should be thoroughly learned in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

All tools or pieces of iron or steel should be kept away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole-pieces and ruining the machine. For this reason a zinc, brass, or copper oil-can is to be used instead of one 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," Chapter XIII.)

A brush should never be raised from the commutator while the machine is operating, unless there are one or more other brushes on the same portion of the circuit to carry the current, as the resulting arc might make a bad burnt spot on the commutator or collector rings and is also likely to burn the hand.

The bearings and field-coils should be touched occasionally to see whether or not they are hot. To determine whether the armature is running hot, the hand is placed in the current of air thrown out from it by centrifugal force. Systematic methods for determining heating are given under that heading in Chapter XIV.

Special care should be observed by any one who runs a generator 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 the 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 or rubber shoes, or both, should be used in handling circuits of over 500 volts. The former should be tested each day before using them, to detect whether they are punctured. 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, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

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 current 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 through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed by artificial electricity have been experienced linemen or station men.*

Stopping Generators or Motors.— This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating *alone* on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without flashing or any other difficulty.

When a generator is operating in parallel with others, or with a storage battery, *it must not be stopped or reduced in speed* until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A Constant-Current Generator may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field-coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit,* and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, or other device on a constant-current system.

Except in an emergency, a circuit should not be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock, which result, are decidedly objectionable. When necessary, heavy currents are interrupted by circuit-breakers (Fig. 23) either automatically or by hand.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 45); or, *if there is a switch* (Q) *connecting the motor to the circuit*, as there always should be, it is opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped, it is advisable to clean it thoroughly and put it in condition for the next run. When not in use, machines should, where it is feasible, be protected from dirt and moisture by covers of waterproof material.

PART II

INSPECTING AND TESTING

CHAPTER VII

ADJUSTMENT, FRICTION, BALANCE, NOISE, HEATING, AND SPARKING

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, or other part 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 exactly as before. In taking a machine apart or putting it together, only moderate force should be used. The apparent need of much force usually indicates that something wrong is being done. A wooden or rawhide mallet is preferable to an iron hammer, because it does not bruise or mar the surfaces and edges. Usually screws, nuts, and other parts should be set up fairly tight, but not 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 show whether any of them are too loose or otherwise out of adjustment.

Friction. — The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, 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 revolve the armature 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 several minutes after the current and turning force are shut off.

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 thereto. The force required to overcome the friction and to turn the armature without current is then determined by known weights or by an ordinary spring balance. The friction of the bearings alone — that is, the pull which is required to turn the armature when the brushes are lifted off the commutator and the field circuit is open — 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 not then exceed 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force. The measurement and calculation of torque are explained in Chapter X.

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 field circuit being open in each case. 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 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 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 center 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. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by magnetizing 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 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction. (See "Separation of Losses," Chapter XI.)

Balance. — The balance of the armature, revolving field, pulley, or other moving part should be carefully tested and perfected by the maker, and any lack of balance should be corrected 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 way to find in which direction the armature or other part 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. 58). If the armature be then rolled slowly back and forth, the heavy side will tend to turn downward. The armature, pulley, etc., 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 may when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the axis of the shaft.

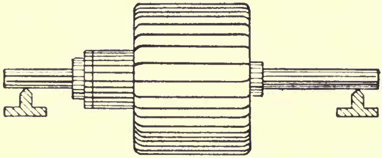


FIG. 58. — Testing Mechanical Balance of Armature.

The balance of the revolving parts can be roughly tested by simply running them at normal speed and noting if there is any objectional vibration. Practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. Balance of a machine can also be tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to operate the machine as a motor, even though it be actually a generator, in order to avoid the necessity of driving it by a belt or other mechanical connection, 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. 59 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale. Vibration is usually much increased at certain speeds because the rates happen to agree. This condition may be selected for test but avoided in regular operation.

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

Heating. — The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (3 to 6 hours, depending upon the size of machine) under rated load. Calling the rise in temperature θ, we have:

$$\theta = (238.1 + t)\left(\frac{R_{t+\theta}}{R_t} - 1\right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_{t+\theta})$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C.; and if it differs from this, the determined rise should be corrected by $+\frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C.

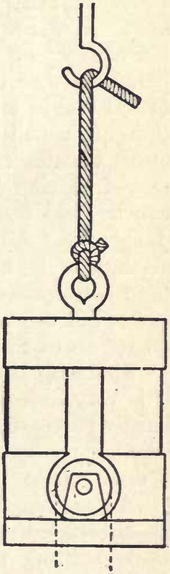


FIG. 59. — Determining Dynamic Balance of Completed Machine

rise in temperature. The allowable rise in temperature for field or armature windings is 50° C., hence their resistance for continuous operation at rated load should not increase more than 20 per cent above what it was cold. The heating of commutators, collector rings, and brushes that cannot be measured electrically is tested by thermometers when the machine is stopped, the permissible rise being 55° C.; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about 1½ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test rise in temperature; but it should be noted that their indications are usually about 5° C. lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made 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 to 20 seconds.

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

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the current, 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 regular operation it should not be necessary to shift the brushes at all after they are adjusted. It is usually required that a machine should be able to run with 25 per cent overload without objectionable sparking. If a machine begins to spark at 50 per cent of its rated load, it is evidently only half as useful as it should be, and this may be taken as a measure of its sparking.

CHAPTER VIII

ELECTRICAL RESISTANCE

THERE are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and second, the resistance of the insulation of the wires, known as the *insulation* resistance. 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 by the "drop" (fall-of-potential) method.

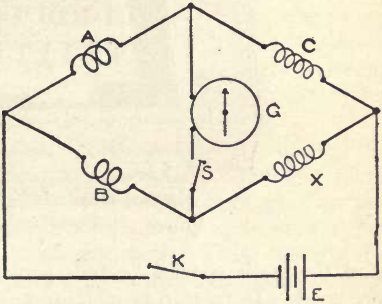


FIG. 60. — Connections of Wheatstone Bridge.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 60. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the inductive effect would produce a deflection of the galvanometer needle, and cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 61). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected in the proper way. In some cases further convenience is secured by including the battery E in the box; 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 1-10 ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below 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 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

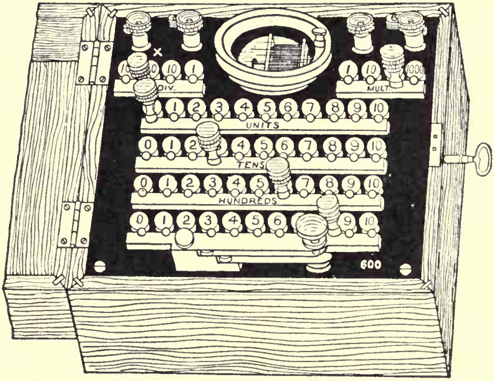


FIG. 61. — Portable Wheatstone Bridge.

It should be observed, however, that a ratio of 1,000: 1, or even 100 : 1, is not desirable, since it is 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 must be measured. The Wheatstone bridge may be used for testing the resistances of almost any shunt-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. The resistance of the series coils of compound-wound machines is usually very low, being measured by the methods applied to armature resistance, given under the next heading. Series fields for constant current (arc) dynamos 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-inductive effect of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 5 K. W. usually have resistances less than 0.1 ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Constant-current dynamos have armatures of about 1 to 20 ohms resistance, which are therefore easily tested by the bridge.

The Drop (or **Fall-of-Potential**) **Method** is well adapted to locating faults quickly, and testing the armature resistance of most generators and motors, 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, 1-100 ohm), all connected in series, as represented in Fig. 62. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter 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 voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The proper current depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current, which must be kept constant during the test, but need not have a known value. Instead of employing a known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law; *viz.*, if E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

A "station" or a portable voltmeter 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 low-reading voltmeter are needed for low resistances.

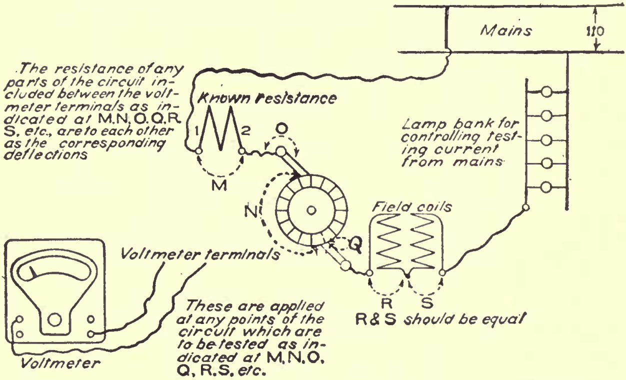


FIG. 62. — Measurement of Resistance by "Drop" Method.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a considerable current from a generator or supply circuit cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram (Fig. 62) indicates the testing of a machine with series fields. Shunt fields, on account of their high resistance, are tested by the bridge method, as explained; by the drop method, using a correspondingly high known resistance; or with simultaneous ammeter and voltmeter readings, while the armature can be connected as shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines — for instance, to two adjacent commutator segments, or to a brush tip and the commutator; in which case any break or poor contact will be indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one millionth of its rated current will pass through the insulation at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable — the "direct-deflection" and the voltmeter methods — explained in the next two paragraphs.

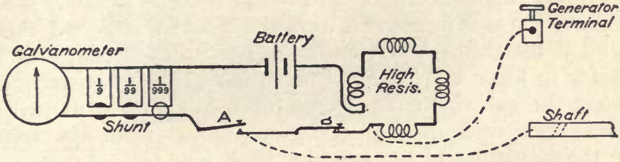


FIG. 63. — Connections for Direct-Deflection Insulation Test.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, or more conveniently a D'Arsonval galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 63. The galvanometer should be shunted with the 1-999 coil of the shunt, so that only 1-1000 of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then 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 1-99, 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:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d}$$

in which D is the first deflection without the machine being connected, and *d* the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of shunts. That is, if the shunt is 1-999 in the first test, and 1-9 in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. 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 of the machine itself.

By the above method it is possible to measure 1,000 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. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving 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 type. Take, for example, the 150-volt portable instrument, Fig. 64, 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 110 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 65. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{D \times R}{d} - R$$

in which D is the first and *d* the second deflection, and R the resistance of the voltmeter. If the circuit is 110 volts, D is 110; and if *d*, the deflection through the insulation resistance of the machine, is 2 divisions, R, the voltmeter resistance, is 15,500 ohms; then the insulation resistance is (110 × 15,500 ÷ 2) — 15,500 = 837,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say 110 volts). This method does not test very high resistances; but if little or

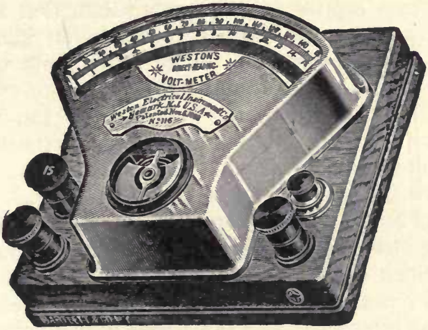


FIG. 64. — Weston Portable Voltmeter.

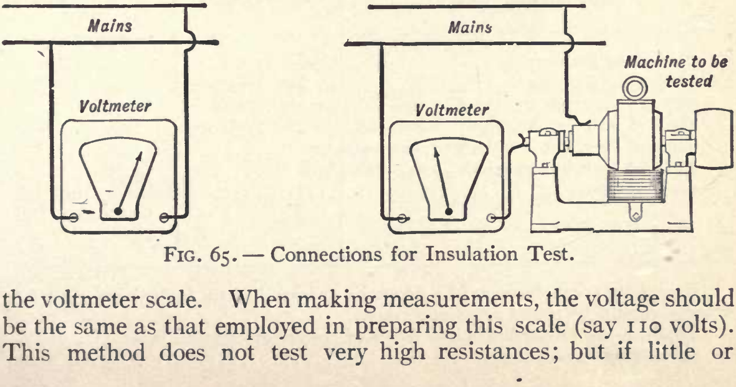


FIG. 65. — Connections for Insulation Test.

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 a circuit 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 shows only 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.

Besides the mere insulation resistance, it is necessary to consider the point at which the insulation will break down entirely. A test might show, for example, an insulation resistance of 10 megohms, but it might be punctured and destroyed if 500 volts were applied to it. It is therefore necessary to make a "break-down test" also, at a voltage usually about twice that for which the machine is intended. The A.I.E.E. Standardization Rules recommend the following voltages for this test:

Rated Terminal Volts.	Rated Output.	Test Voltage A. C.
Not exceeding 400 volts	Under 10 kw. ..	1,000 volts
Not exceeding 400 volts	10 kw. and over	1,500 "
400 and over, but less than 800 volts	Under 10 kw. ..	1,500 "
400 and over, but less than 800 volts	10 kw. and over	2,000 "
800 and over, but less than 1,200 volts	Any	3,500 "
1,200 and over, but less than 2,500 volts	Any	5,000 "
2,500 and over	....	Double the normal rated voltages

Except that transformers of 5,000 volts or less, directly feeding consumption circuits, should be tested at 10,000 volts.

Synchronous motor fields and fields of converters started from the alternating current side..................................5,000 volts.

Alternator field circuits should be tested under a break-down test voltage corresponding to the rated voltage of the exciter, and referred to an output equal to the output of the alternator; *i. e.*, the exciter should be rated for this test as having an output equal to that of the machine it excites.

Condensers should be tested at twice their rated voltage and at their rated frequency.

The values of voltage in the table above are effective values, or square roots of mean squares, being those measured by a voltmeter.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at rated load. This increases the resistance of conductors and decreases the insulation resistance, but gives actual working values.

CHAPTER IX

VOLTAGE AND CURRENT

Voltage. — Instruments for measuring voltage, known as voltmeters, are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible — at least 5,000, and preferably 10,000 ohms or more per 100 volts — in order not to take too much current, which might lower its reading on a high-resistance circuit or consume too much power. It should not be affected by the stray magnetism of a generator or motor at any distance over a few feet.

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. To measure the *external* voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage, also called the pole difference of potential or terminal voltage, is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator 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 caused by the drop (=IR) in the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. The potential of a compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more to make up for loss on the wiring.

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 possible to estimate if the voltage is even one or two per cent above or below the normal. 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 by using lamps in series. Thus 1,000 volts can be measured by means of nine 110-volt lamps in series, and so on.

The internal or total voltage induced in the armature winding of a generator is its e.m.f., and this is greater than the terminal voltage, by the amount of the drop due to armature resistance. Hence $E_g = V + I_a R_a$ in which E_g is the e.m.f. generated, V the terminal voltage, I_a the armature current and R_a the armature resistance. Similarly e, the counter e.m.f. in the case of a motor, is less than the terminal voltage, that is, $e = V - I_a R_a$

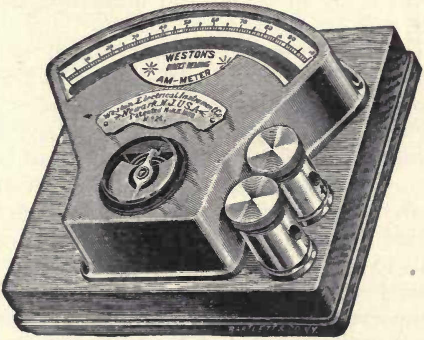


FIG. 66. — Weston Portable Ammeter.

Current. — This is measured by an ammeter (Fig. 66), which is usually somewhat cheaper than a voltmeter because it contains a comparatively small length of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field-coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field winding, when only one ammeter is used. It is better to insert a separate instrument in each branch circuit, because the field current is usually only 1 or 2 per cent of the armature current, so the same ammeter is not adapted to both. In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The voltage thus indicated, divided by the resistance in ohms, gives 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 obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires (page 37); or the resistance can be measured by a Wheatstone bridge (Fig. 60), or by putting an ammeter, when one can be spared, into the circuit while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. 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, and 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, 0.1 or 0.01 ohm. In fact it is well to purchase or make known resistances of various values for general use in testing and calibrating, also in combination with a voltmeter as a substitute for an ammeter. These should be made of German silver or other alloy, the resistivity of which does not vary materially with temperature.

In testing the output of a generator, 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 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. 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 weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor rapidly corrodes 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 amount of soda in 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 X

SPEED AND TORQUE

Speed. — This is usually measured by the well-known *speed counter* (Fig. 67), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator 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.

Another instrument for testing the number of revolutions per minute is the *tachometer*. The stationary form of this instrument is shown in Fig. 68. It must 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. 69) 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, 1,000, or 2,000 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.

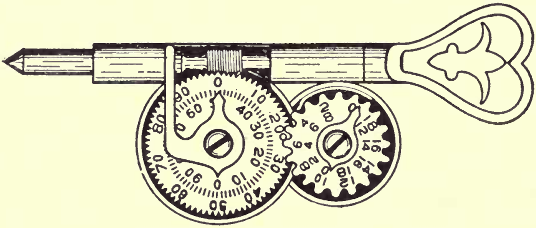


FIG. 67. — Speed Counter.

A simple way to test the speed in 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

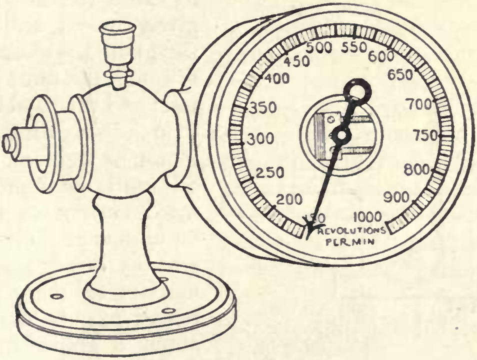


FIG. 68. — Belted Tachometer

determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the 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

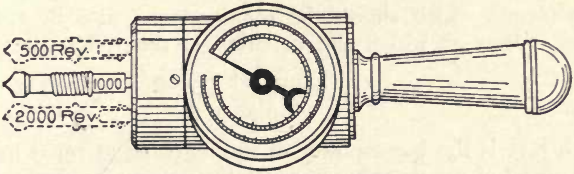


FIG. 69. — Portable Tachometer.

taken not to allow any slip when speed is tested by means of a belt. For example, the tape belt just referred to should pass around the pulley of the machine and around some light wheel of wood or metal which turns so easily that it does not cause any appreciable slip of the belt on the pulley of the machine.

Torque or *turning force* 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 the pulley of the machine to be tested, as indicated in Fig. 70. The pressure of the screws SS 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 the speed is then noted. Usually, the rated torque is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its rated current as indicated by an ammeter. The proper current at rated load 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 1.6 amperes per h.p. for 550-volt motors. If the machine is rated in kilowatts, the current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque 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 other fraction of the rated current, also at 25 or 50 per cent overload.

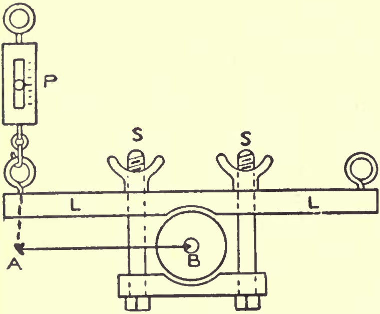


FIG. 70. — Prony Brake.

The torque which should be obtained can 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 rated load, and S is the speed of the machine in revolutions per minute at that 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. One h.p. produced at a speed of 1,000 revolutions requires a torque of 5.25 pounds at the end of a one-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions, half as much; and so on. If the lever is 4 feet, the pull is one quarter as much, etc.

The Torque of a Generator, that is, the power required to drive it, is conveniently determined by operating it as a motor, and testing it by the Prony brake as described above. The torque of a generator corresponds to that of a motor under similar conditions, but the effect of friction, air resistance, and core losses are added to the theoretical torque, while they are subtracted in a motor. Hence the torque of a generator is the same as that obtained by running it as a motor, plus twice the torque required to overcome friction and core losses. *The friction and core losses* are readily determined by running the machine free as a motor, with normal field excitation, and such applied voltage as will make it revolve at its rated speed. Note the current input, multiply this by the applied voltage, and from this product subtract the $I^2 R$ losses of the armature, at the noted current; the remainder is equal to the sum of the friction and core losses or *stray power* losses in watts. To determine the torque required to overcome these stray power losses the following equation is used:

$$\text{Torque} = \frac{\text{Stray power in Watts} \times 33{,}000}{746 \times 6.28 \times S}$$

where S is the revolutions per minute at rated speed.

CHAPTER XI

POWER AND EFFICIENCY

Power. — The electrical power of a direct-current generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, 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 1,000. In testing alternating-current machinery, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later, to avoid error due to lag or lead of current.

The mechanical power of a generator or motor, that is, the power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. "Pull" is used here because torque is measured at one foot radius, which is inconvenient. 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.

Efficiency. — This is determined by dividing the power output by the power input, *both* expressed in watts or both in h.p.

$$\text{Efficiency of generator or motor} = \frac{\text{Output}}{\text{Input}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 h.p. and over. The so-called "electrical efficiency" is misleading and of little practical importance, and need not be considered in commercial work. The mechanical or electrical power in the above equation is determined as explained under the preceding heading.

It is usually more convenient to determine the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined easily by driving it with a calibrated electric motor, that is, one in which the output for any given number of volts and amperes consumed has already been determined by brake test. Then it is only necessary to measure the watts produced by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts developed by it* divided *by the watts output of the motor;* which latter is the same as the generator input, neglecting belt losses.

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction is likely to cause a small loss. The watts produced by the generator, 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 machine 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 from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine to be used as a motor, so that it tends to speed up and drive the other as a dynamo, or cause it to drive the other by putting a little larger pulley on it. In this way the motor will consume power in watts from the circuit while the generator yields power in watts to the circuit. The efficiency is calculated as in the preceding paragraph.

The efficiency of a motor-generator or transformer is easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured; and their product gives the power in watts. When alternating-current machinery is being tested, wattmeters should be used. Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. — The total losses in a generator 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 the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing efficiency. The motor should previously be calibrated, 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. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field-magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by friction of bearings and belt and air friction or "windage." The brushes are then adjusted in contact with the commutator, with usual pressure. The increase in power required of the motor 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 eddy currents and hysteresis in the iron core of the armature, provided there is not excessive magnetic side pull on the armature. The power wasted in eddy currents varies as the square of the speed, while the hysteretic loss is 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 eddy currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is, the eddy loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$.

Air friction increases the apparent loss due to eddy currents, but it is small and almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The remaining losses are quite easily measured and separated as follows:

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula: Watts $= \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any two of these three quantities are known. The loss in the armature conductors, due to ohmic 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 "I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether for 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 generator or motor of 1,100 and 1,000 k.w. capacity are *approximately* as follows:

	Size of Machine		
	1 k.w.	100 k.w.	1,000 k.w.
Useful power developed	81%	92 %	95 %
Used in magnetizing field	3-4%	1 -1.5%	.75-1 %
Loss due to armature resistance (I^2R)	4-5%	1.5 -2 %	1.0 -1.25%
Loss due to friction of bearings	3 %	1.0 -1.5%	.5 - .75%
Loss due to friction of brushes	1 %	.25 - .5%	.25- .5 %
Loss due to friction of air	1 %	.25 - .5%	.25- .5 %
Loss due to hysteresis in armature core	2 %	1.0 -1.5%	.5 - .75%
Loss due to Foucault currents in armature core	2 %	1.0 -1.5%	.5 - .75%

Measurement of Power in A.C. Circuits. — In circuits carrying alternating currents and having some inductive load in the form of motors, arc lamps, partly loaded transformers, etc., the ordinary method of determining the power, by voltmeter and ammeter, is not applicable, as the current is seldom in phase with the e.m.f., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A.C. circuit, the simplest being a *wattmeter*. This instrument is essentially an electro-dynamometer provided with two coils; a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the impedance is practically equal to the resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence the force tending to deflect the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of this force, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

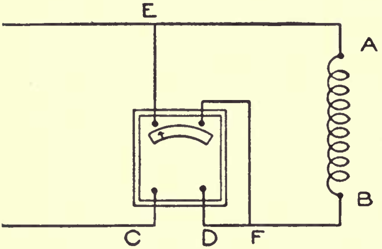


FIG. 71. — Wattmeter Connections for Two-Wire System.

In Fig. 71, A B represents an inductive load — say a single-phase motor — of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above shown, the wattmeter indicates directly the power in watts supplied.

In the case of a *two-phase system*, where the two circuits are independent, the power may be measured by placing a wattmeter in each phase, and adding the two readings. If two-phase circuits be supplied with three wires as shown in Fig. 72, the conductors A B forming a common return, the wattmeters are placed as indicated, *care being taken to insert the current-coils in the outside mains ;* and the power supplied is equal to the sum of the two wattmeter readings.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as shown in Fig. 73. The current-carrying coils are placed in series with two of the wires, and the pressure-coils respectively connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively. It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed,

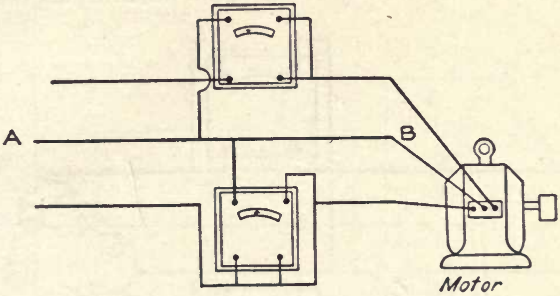


FIG. 72. — Measuring Power, Two-Phase Three-Wire System.

its readings are negative. The connections for a three-phase Δ system are precisely similar, as in Fig. 74.

To measure the power of a balanced four-wire, three-phase system, one wattmeter may be connected as represented in Fig. 75, and the wattmeter reading multiplied by 3. Usually, however, a four-wire three-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be

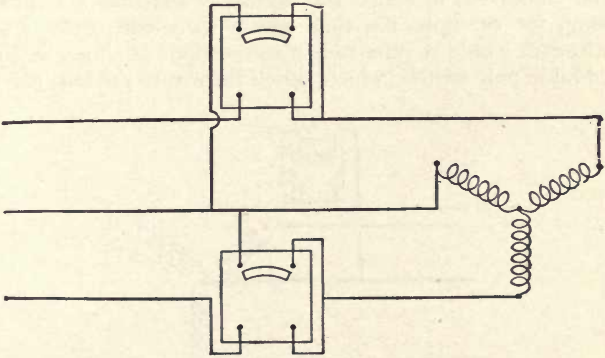


FIG. 73. — Wattmeter Connections, Three-Phase Y System.

employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the three-phase three-wire case (Fig. 74), one wattmeter would require switch connections as shown in Fig. 76. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between

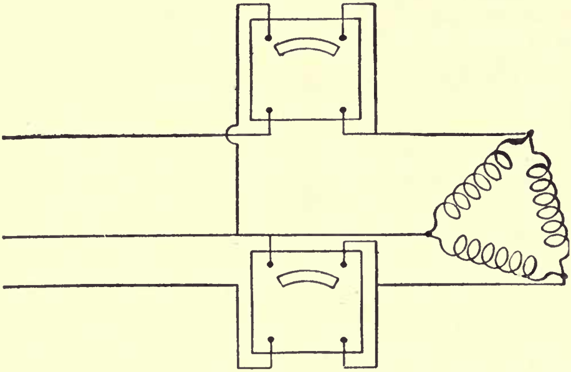


FIG. 74. — Wattmeter Connections, Three-Phase Δ System.

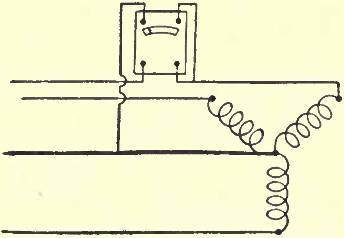


FIG. 75. — Measuring Power, Three-Phase Four-Wire System.

I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is connected as indicated.

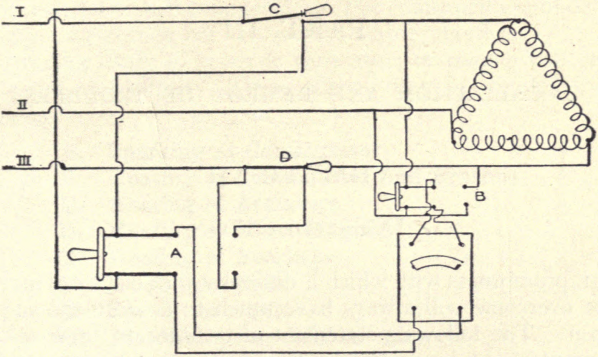


Fig. 76. — Measuring Power, Three-Phase System with One Wattmeter.

PART III

LOCALIZATION AND REMEDY OF TROUBLES

CHAPTER XII

INTRODUCTION

THE promptness with which a difficulty with electrical machinery may be overcome will always have much to do with the success of the plant. The following statement of troubles or "diseases," with their symptoms and remedies for the various types of generators and motors, has been prepared to facilitate the detection and elimination of these troubles. It is evident that the subject is somewhat complicated and difficult to handle in a general way, since much depends upon the particular conditions in any given case, each of which must be stated in such a way as to distinguish it from all others. Nevertheless, a great deal can be covered by systematic treatment. It may frequently happen 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 so easily detected, may also occur. In such cases even a 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. The principal object should always be to separate clearly the various causes and effects from each other. A careful and thorough examination should be first made, and as far as possible one should be 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 and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are generally and deservedly followed by accidents of some sort. It is usually advisable to stop the machine when any trouble manifests itself even though it does not seem serious. In a properly equipped plant spare apparatus is provided for such emergencies. The continued use of defective machinery is a common but very objectionable practice.

All troubles likely to occur in generators or motors will produce one or more bad effects. These effects may be divided into ten classes, *viz.:*

A. Sparking at Commutator.
B. Heating of Commutator and Brushes.
C. Heating of Armature.
D. Heating of Field Magnets.
E. Heating of Bearings.
F. Noisy Operation.
G. Speed not right.
H. Motor stops or fails to start.
I. Dynamo fails to generate.
J. Voltage not right.

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence about nine tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in the remaining class is responsible for the trouble. This requires more careful examination. One cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the list covers this point as far as possible. In a complicated or difficult case it is well to read through the entire list and note what causes can possibly apply. Generally there will be few; and the particular one can be picked out by following the directions, which show how each case may be distinguished.

CHAPTER XIII

SPARKING AT THE COMMUTATOR

THIS is a common trouble that is not very objectionable if moderate in amount and duration. Beyond these limits, however, it is likely to become serious because it burns and roughens the commutator, thus aggravating the difficulty. At the same time it produces heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to spark, including practically all direct-current and some alternating-current machines. Most alternating-current machines have collecting rings which are not likely to spark; but rotary converters, self-exciting or composite-wound alternators, as well as series and other types of self-starting, single-phase motors, require a commutator which may spark. This trouble can be prevented in most cases by proper design and construction. The inductance per section must be limited by correct form of slot, sufficient number of sections, and strength of magnetic field. Carbon brushes also tend to reduce sparking. 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.

Cause 1. — *Armature carrying too much current*, due to (*a*) overload (for example, too many lamps fed by a generator, or too much mechanical work done by a motor); a short circuit, leak, or ground on the line may also have the effect of overloading a generator; (*b*) excessive voltage on a constant-potential circuit or excessive amperage on a constant-current circuit. In the case of a motor any abnormal friction due to the armature striking or rubbing against the pole-pieces, or the shaft not turning freely, will have the same effect as an overload. It often happens, especially with a new machine, that an overload, short-circuit, etc., creates a very excessive current. This may produce, even if only momentary, a burned and rough spot on the commutator.

Symptom. — If the excessive current flows for any considerable time the whole armature becomes overheated. The belt (if used) is very tight on tension side, sometimes squeaking, because it slips on the pulley. Overload, due to friction, may be detected by stopping the machine and, if not too large, turning it slowly by hand or with a lever, the load being disconnected. A convenient and sensitive test for any size of machine is to determine the current required to run the armature free (operating as a motor), which should not be more than about 4 or 5 per cent of the current at rated load, except in machines of 10 h.p. or less, which may take 6 to 10 per cent. The field current should be measured first, with the armature circuit open, and deducted from the ammeter reading. (See "Heating of Bearings" and "Noisy Operation," Chapters XVIII and XIX.)

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 "Noisy Operation."

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start very suddenly and spark badly at first. The only remedy is to increase this resistance.

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

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

Remedy. — Carefully shift the brushes backwards or forwards until sparking is reduced to a minimum. If only slightly out of position, heating alone may result, the conditions not being bad enough to show sparking. If the brushes are not exactly opposite, or in a four-pole machine 90° apart, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars, by measuring with a strip of paper, or by separately adjusting each set of brushes to its minimum sparking point.

The usual position for the brushes is opposite the spaces between the pole-pieces, but in some machines the brushes must be set in some other position, which can be determined by finding the non-sparking or minimum sparking points. If the brushes are placed exactly wrong, namely, half-way toward the proper position for the next set of brushes, they will cause a dynamo to fail to generate and a motor to fail to start, and in the latter case the fuse will blow or the circuit-breaker open. (See Chapters XXI and XXIII.)

Cause 3. — *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 will interfere with good contact of the brushes or cause them to be thrown out of contact with the commutator (Figs. 77 and 78). Flat or high bars in machines usually result from looseness of the nut or screws which hold the commutator parts together. The effect of eccentricity may be produced by the shaft being loose in the bearings while the commutator is perfectly true on shaft. This will allow the whole armature to chatter when running at full speed. Hard mica between the bars which does not wear as rapidly as the copper will tend to throw the brushes off.

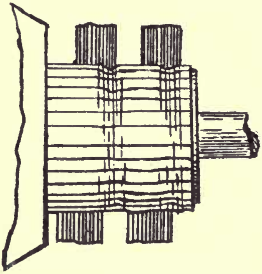


FIG. 77. — Rough Commutator.

Symptom. — Note whether there is a glaze or polish on the commutator, which shows smooth working; touch the revolving commutator with tip of finger-nail and the least roughness is perceptible, or feel of the 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 the commutator turns slowly, or a chattering of the brush when running fast. Sometimes by sighting in line with brush contact one can see daylight between the commutator and brush, because the latter jumps up and down.

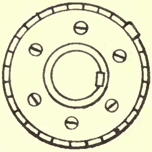


FIG. 78. — Commutator with a High Bar.

Remedy. — Smooth the commutator with a fine file or fine sandpaper, the latter being applied by a block of wood which exactly fits the commutator. Carborundum paper or a carborundum hone is also applicable, but *emery should never be used*. In all cases particles of grit or copper should be very carefully removed before the brushes are allowed to touch the commutator. To set up a loose nut on a commutator requires considerable force, a long wrench being used. The effective length of a wrench may be increased by slipping over the handle a piece of iron pipe. Screws may be tightened by means of a heavy screw-driver. If the bearing is loose, put in a new one. If the commutator is very rough or eccentric, the armature should be taken out, put in a lathe, and the commutator turned off. Large machines may be provided with a slide-rest attachment or grinding device, so that the commutator can be turned off or ground true without removing the armature. This is clamped on the pillow-block or rocker ring.

For turning off a commutator, a diamond-pointed tool should be used, with a very sharp and smooth edge, only an exceedingly fine cut being 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 an eighth of an inch in the bearings, but in some machines this is not practicable. A commutator should have a dull glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes it is desirable to apply a little vaseline or a drop of oil to a commutator which tends to become rough. Much oil is bad, and causes the following trouble.

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

Symptom. — In general, all of the cases under Cause 3 will have this effect, but the two classes are usually distinguishable. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on the surface of contact. Sometimes, owing to the presence of too much oil or from other causes, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with a slightly oily rag or one moistened with benzine, or by other means. In some cases a commutator becomes sticky, which causes the brushes to "chatter," and, therefore, to make poor contact.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch only at one or two points. Some carbon brushes are of abnormally high specific resistance, so that they do not make good electrical contact. In both cases new brushes should be substituted. Vibration (Sparking, Cause 10), also interferes with good brush contact.

Remedy. — Carefully clean the commutator, also fit, adjust and clean the brushes until they rest evenly on the commutator, with the maximum surface of contact and with sure but not too heavy pressure. In order to fit copper brushes properly on the commutator, a brush jig is required (Fig. 79). Carbon brushes may be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature slowly revolved by hand or by power and the brushes pressed upon the commutator. The brushes may make poor contact, because the brush-holders do not work freely.

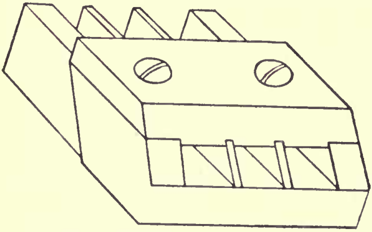


Fig. 79. — Jig for Copper Brushes.

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

A short circuit is often called a "short" and sometimes a "cross." The former term, however, applies properly to an accidental connection between conductors belonging to the same circuit, while the latter is applied to an accidental contact between two separate lines or circuits. A "flying" short circuit is one that exists only when the machine is running, being caused by centrifugal force.

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

The short-circuited coil is heated much more than the others, and is very apt to be burned out entirely; therefore, the machine should be stopped immediately. If necessary to run the machine to locate the short circuit, one or two minutes is usually long enough, but may be repeated until the short-circuited coil is sufficiently warmed to be found by feeling the entire surface of the armature.

A screw-driver or other iron or steel tool held between the pole-pieces 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. Care should be taken not to allow the piece of iron to be drawn in and jam the armature.

The current pulsates and the torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature turns rather slowly. If a large portion of the armature is short-circuited the heating is distributed and more difficult 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 generators, see "Dynamo Fails to Generate," Cause 3, Chapter XXIII.)

A "flying" short circuit may not have any effect when the armature is standing still. It can often be forced to show itself momentarily, by pounding the armature core or the end of the shaft with a mallet or stick of wood. It may then be detected by the drop-of-potential method which would indicate intermittent variations in resistance.

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 effective remedy 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.)

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

Symptom. — Commutator flashes violently while running, and the commutator bar nearest the break is badly cut and burned; but in this case no particular armature coil will be heated as in the last case (Cause 5), though 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" in, or eccentricity of, the commutator ("Sparking," Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if the circuit is broken, but not with an eccentric commutator or even with a "high bar," unless the latter is very bad, in which case it is easily felt or seen. A very bad contact at some point would have almost the same effect as a break in the circuit. In the case of a so-called "flying break" the circuit is only open when the machine is running, the effect of centrifugal force.

Remedy. — A break or bad contact may be located by the "drop" method or by a continuity test, while the armature is not running. Under these conditions a "flying break" does not manifest itself, but may be made to do so momentarily by pounding the armature core or the end of the shaft with a mallet or stick of wood, as in Cause 5. The trouble is most 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 properly connected and fastened. When the trouble is due to a broken commutator connection, which cannot be repaired immediately, the disconnected bar may be temporarily connected to the next by solder; or the brushes may be "staggered" by putting one forward or the other backward so as to bridge over the break. It may be impracticable to "stagger" radial brushes, but usually a brush is thick enough to make contact with more than one commutator bar. 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 insert a copper peg or wedge, or to force the metal of the bars 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 the bruised material can afterward be picked out and the cavity filled in with wood. In carrying out any of these methods care should be taken not to short-circuit any other armature coil, which would produce sparking (Cause 5).

Cause 7. — *Ground in the armature.*

Symptom. — Two or more "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 should 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 (overhead trolley) or other circuit which employs the earth as the return conductor, or a three-wire system with the neutral conductor grounded, one or more grounds in the armature would allow the current to pass directly through them, and would cause the machine to spark and have a very variable torque at different parts of a revolution.

Remedy. — A ground may be detected by testing with a magneto and bell. It may be located by the drop-of-potential method. 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 shaft (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection 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 slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. The armature core may be more or less insulated from the shaft and ground by the insulation between the laminæ, in which case one contact with the conductors would not have the effect of a ground. Sometimes the ground may be in a place where it can be removed 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 earth the static charge will flow away harmlessly, but such grounding by means of a good conductor is sometimes undesirable. In those cases the frame may be connected to the earth 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 the static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble. Large direct-connected machines are almost necessarily grounded.

Cause 8. — *Weak magnetic field.*

Symptom. — Pole-pieces are 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 reaction. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case it may run slowly, stop, or even run backwards. A generator fails to produce the full voltage 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 first to disconnect the 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. 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 midway between the pole-pieces will be attracted to one more than to the other. It may be determined by the drop-of-potential or other method whether one coil has considerably less resistance than any of the others. It is highly improbable that simultaneous short circuits would affect two or more coils equally. It is to be noted that a short circuit in one of the field-coils, which are usually in series, causes that coil to be heated *less* than the others. "*Grounding*" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete circuit, is equivalent to a short circuit. With overhead trolley electric railways a ground return is used, and the neutral conductor of three-wire systems is often grounded, in which cases one ground may be sufficient to cut out one or more field-coils.

A field-coil reversed and opposed to the others 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 to find whether the poles are alternately N. and S. (See "Dynamo Fails to Generate," Cause 4.) The series coil of a compound-wound machine is often connected wrongly, and has the effect of forcing down the voltage the more the load is increased, instead of raising it.

Remedy. — A broken circuit or a short circuit or a ground is easily repaired if 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 armature is connected before the field. This may be avoided by proper arrangement and manipulation of the switches. If the voltage is too low on the circuit, it is likely to cause sparking in a shunt generator or motor; and if it cannot be raised the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils.

To suit the speed of an engine or on account of a mistake in the size of pulleys or gearing, the speed of a generator may be higher than that at which it was designed to run. In such a case the field is necessarily weakened by means of its rheostat in order to obtain the rated voltage, thus producing a tendency to spark. The only remedy is to reduce the speed to the prescribed value. The same difficulty may occur in a shunt motor which is run above the rated speed by weakening its field. To avoid sparking it may be necessary to strengthen the field and change the pulley or gearing ratio or the speed of the driven machine to suit the diminished speed of the motor, unless the latter was specially designed to operate with weakened field in order to vary its speed. This method is now commonly employed, but is not applicable to ordinary types of shunt motor working at or near full torque. By reducing the load or current in such a machine below the rated amount, a corresponding field weakening is permissible without excessive sparking. For example, a motor intended for 40 amperes with full field may carry 30 amperes with its field weakened to give about 30 per cent increase in speed, so that the *power* is nearly constant, because speed rises as torque diminishes.

These conditions apply to other commutator machines in which there is any considerable variation in field strength, such as a booster for charging storage batteries, its voltage being regulated between wide limits. The general fact is that the allowable current in the armature must be reduced as the field is weakened.

Further information on this subject may be found under "Sparking," Cause 9; "Speed Too High or Low," "Motor Stops or Fails to Start," and "Dynamo Fails to Generate."

Cause 9. — *Unequal strength of magnetic poles.* This might be regarded as a special case of the preceding cause of sparking — "weak magnetic field" — but is sufficiently important and different in principle to warrant separate consideration.

Symptom. — With bipolar generators or motors, one pole carries the same flux as the other, there being only one magnetic circuit. The distribution may differ, owing to different pole shape or magnetic leakage, but is not likely to produce sparking or other trouble. In a machine having more than two poles the flux in one may be much greater or less than that in each of the others. Multipolar armature windings for generators or motors (except railway motors, as stated later) are usually of the parallel or multiple-circuit type which offer as many paths for the current as there are poles. With this arrangement, the fluxes through the several poles must be exactly equal in order that equal e.m.fs. shall be generated in the corresponding portions of the armature. If one pole were weaker than the others a back current would flow through that part of the armature winding even with the external circuit open, all of the positive brushes and all the negative brushes being respectively connected together so that the paths of the armature winding act in parallel.

A difference in e.m.f. of only 1 or 2 per cent might cause the full armature current to flow, although there may be no external current. With greater differences in flux and e.m.f. this internal current may rise above the normal value and cause sparking. Fortunately this trouble tends to counteract itself, because the back current strengthens a weak pole and current in the proper direction weakens a strong one. Nevertheless, differences of this kind often exist and should be looked for when sparking occurs with little or no external current, especially in a new machine. To detect them, the brushes are disconnected from each other, or when this is difficult they are all raised from the commutator and two small temporary brushes of copper leaf or wire are applied successively in the usual brush positions. These brushes being connected to a voltmeter, any difference in e.m.f. between the different portions of the armature may be determined.

Remedy. — This difference is usually due to the fact that the armature is closer to one or more poles than to the others, tending to give greater flux and e.m.f. at the former. In such a case it is usually perceptible to the eye, or found by measuring with a wedge that the armature is not properly centered. This condition may be corrected by slightly shifting the bearings, but with most machines, especially when direct-connected, it is preferable to shift the field-magnet. Ordinarily, this adjustment can be made by putting in or taking out sheets of iron between the lugs or feet on the field-ring and the bed-plate. Some machines are built with several thin sheets of iron interposed between each field-core and the ring, so that adjustment of the individual poles can readily be made at any time.

When the armature gets out of center, owing to considerable wear in the bearings, the proper remedy is to renew the latter. To anticipate slight wear the armature is sometimes adjusted a little nearer the upper poles. Another way to remedy this trouble is to vary the number of turns of wire in the several field-coils until the same flux is produced by each. Of course, this trouble cannot occur in a bipolar machine, not only because the fluxes are equal for the two poles, as already noted, but also because it is not possible for one path through the armature to have less e.m.f. and act as a short circuit for the other. For the same reason, a multipolar armature with series or two-circuit winding is free from this trouble. This type of winding, however, is not generally used, except for railway motors.

Cause 10. — *Vibration of the machine.*

Symptom. — Considerable vibration is felt when the hand or a stick held in the hand is placed upon the machine, and the sparking decreases when the vibration is reduced. Vibration of the brushes, due to a rough or sticky commutator, is hardly sufficient to cause the whole machine to vibrate; nevertheless, reference may be made to "Sparking," Causes 3 and 4.

Remedy. — The vibration is usually due to an imperfectly balanced armature or pulley (see "Noisy Operation," Cause 1, Chapter XIX), "knocking," due to looseness of the engine parts, a bad belt (see "Noisy Operation," Cause 6), or to unsteady foundations, and the remedies for these troubles should be applied.

Any considerable vibration is likely 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 should be stopped by the remedies referred to above.

CHAPTER XIV

HEATING IN GENERATORS OR MOTORS

Methods of Locating and Measuring. — The methods for determining temperature rise have already been given in Chapter VII.

It is very important to locate the heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. All parts of the machine should be tested to find which is the hottest, since heat generated in one part is rapidly diffused. It is more definite to start with the whole machine cool, after it has stood without current for several hours or over night. Any serious trouble from heating is usually perceptible after a run of a few minutes at full speed with the field-magnets excited.

CHAPTER XV

HEATING OF COMMUTATOR AND BRUSHES

THIS trouble, like sparking, may occur in direct-current machines, and in the types of alternating-current apparatus that have commutators already enumerated under the head of "Sparking."

Cause 1. — *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 the trouble is in the part that heats first.

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

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

Symptom and Remedy. — (See "Sparking," Chapter XIII.)

Cause 3. — *Tendency to spark or incipient sparking hardly visible.* Sometimes, before sparking appears, serious heating may be produced by one or more of the causes of sparking.

Symptom. — The heating is reduced by applying the principal remedies for sparking, such as slightly shifting or more carefully fitting the brushes. Fine sparks may be seen by sighting in exact line with the surface of contact between the commutator and brushes. Incipient sparking due to excessive inductance in each armature section can be corrected only by reconstruction. When caused by a weak magnetic field see "Sparking," Cause 8.

Remedy. — (See "Sparking.")

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

Symptom. — Commutator covered with black coating; commutator brushes and holders show signs of abnormal heat.

Remedy. — Commutator and brushes should be thoroughly cleaned, and the latter carefully fitted to make good contact at the proper points. (See "Sparking," Causes 2, 3, and 4.) It may be necessary to substitute a different kind of carbon brush.

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

Symptom. — Holder, cable, etc., are abnormally high in resistance, which may be found in these parts by "drop method."

Remedy. — Improve the connections.

Cause 6. — *Arcing or short circuit in commutator* across the insulation between bars or between bars and end rings.

Symptom. — Burned spot between parts; arc or spark appears in the insulation when the machine is operating.

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

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

Carbon brushes require less attention than copper, because they do not cut the commutator, and their higher specific resistance usually reduces sparking, but it may also cause them to heat more than copper brushes.

Symptom. — Brushes hotter than other parts.

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 so that the current density does not exceed 30 or 40 amperes per square inch of contact area.

Cause 8. — *Friction of brushes on commutator.* — This may be due to excessive pressure or speed. In turbo-generators or unipolar machines the speed is usually very high.

Symptom. — Excessive heat even when brushes carry little or no current.

Remedy. — Reduce spring tension. Decrease speed, keeping up voltage by increasing field strength. Lubricate with very little oil or vaseline.

CHAPTER XVI

HEATING OF ARMATURE

THIS trouble, excepting Causes 6 and 8, may occur in any direct or alternating-current machine, whether generator or motor. The two causes excepted may give trouble in direct but not in alternating-current machines.

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

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

Cause 3. — *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. — The armature should be baked for several hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of injuring the insulation. A convenient and safe method to dry an armature (or field winding) is to pass through it a current which should be regulated to be about three quarters of the rated current, the armature being held still or turned over occasionally.

Cause 4. — *Eddy 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.

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

Cause 5. — *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 a difference in the e.m.f. generated on the two sides of each armature conductor. 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 the effects. Rounding or beveling off the edges of the pole-pieces will also reduce the trouble. The usual and most effective cure is to put the armature inductors in slots or perforations in the armature core.

Cause 6. — *One or more reversed coils in one part of armature,* which will cause a local current to circulate around a direct-current armature.

The armature coils of an alternating-current generator or synchronous motor being usually arranged in series, the only effect of a reversed coil is to reduce the e.m.f. corresponding to a loss of two coils. It does not cause short-circuiting or heating.

Symptom. — Excessive current in a direct-current motor running free, or excessive power required to drive a generator without load. In a direct-current motor running with considerable load, the half of the armature containing the reversed coil is heated more than the other (the opposite being true of a generator), but no individual coil is abnormally heated. If a moderate current is applied to each coil in succession by touching wires to each two adjacent commutator bars, and a compass needle is held over the corresponding coils, the latter will behave differently when the reversed coil is reached.

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

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

Symptom. — Other parts hotter than armature. Start with the machine cool and determine by thermometer or hand which parts heat first and to the greatest extent.

Remedy. — (See Heating of Bearings, Field, and Commutator.)

Cause 8. — *Unequal strength of magnetic poles* may cause excessive current to flow in an armature, thereby heating it abnormally in the case of a multipolar direct-current machine with multiple-circuit armature winding.

The armature coils of an alternating-current generator or synchronous motor being usually arranged in series, the effect of weakening or even omitting one of the field-poles is merely to produce a corresponding reduction in e.m.f. which may be overcome or avoided by slightly strengthening the other poles. No short-circuiting or heating is likely to result.

Symptom and Remedy are the same as for "Sparking," Cause 9.

Note. — Any excess of energy taken by an armature when running *free*, as a motor, whatever the cause, must be converted into heat by some defect, hence the "free current" or "stray power" is the simplest and most searching test of efficiency and perfect condition.

CHAPTER XVII

HEATING OF FIELD-MAGNETS

All direct-current generators and motors as well as alternating-current generators, synchronous motors, and rotary converters, have field-magnets excited by direct current. Induction motors and generators, also single-phase self-starting motors, carry alternating current in their field-coils, but the following troubles might occur in any of these types:

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

Symptom. — Field coils too hot to be bearable to the hand. Their temperature more than 50° C. above that of the room by resistance test. (See Chapter VII.)

Remedy. — In the case of a shunt-wound or separately excited machine, decrease the voltage at terminals of field-coils, or increase the resistance in field circuit by winding on more wire or by putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease the current passing through the field, or take a layer or more of wire off the field-coils, or rewind with a coarser wire. This trouble might be due to a short circuit in field-coils in the case of shunt-wound or separately excited generator or motor and would be indicated by the pole-piece with the short-circuited coil being weaker than the others; a wholly or partially short-circuited field-coil being also *cooler* than the others. The short-circuiting of a portion of the field winding may not cause serious harm, except in the case of those excited by alternating currents, in which case the defective coil or coils will act as the short-circuited secondary of a transformer and be burnt out by the large induced currents. Measure resistance of field-coils to see if they are nearly equal. If the difference is considerable (*i.e.*, more than 5 per cent), it is an almost sure sign that one coil is short-circuited or double-grounded. (See "Sparking," Causes 8 and 9.)

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

Symptom. — The pole-pieces hotter than the coils after a short run.

Remedy. — This trouble is due either to faulty design and construction, which can only be corrected by rebuilding, or to fluctuations in the current. The latter can be detected, if 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 currents generated by the open-coil armatures used in arc lighting (Thomson-Houston and Brush) are decidedly pulsating in character and may cause this trouble. With this exception, however, direct currents rarely pulsate sufficiently to cause heating due to eddy currents.

Cause 3. — *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. The insulation resistance also tests low.

Remedy. — The same as for moisture in armature. ("Heating of Armature," Cause 3, Chapter XVI.)

CHAPTER XVIII

HEATING OF BEARINGS

THIS may arise in almost any machine, including all direct-current as well as alternating-current generators and motors. 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.

Cause 1. — *Lack of oil.*

Symptom. — Oil-cup or reservoir empty. Oil passages clogged. Self-oiling rings, or other devices not revolving or acting properly. 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.

Cause 2. — *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 a 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, and should be removed as completely as possible afterward, lubricating oil being again introduced.

Cause 3. — *Shaft rough or cut.* (Fig. 80.)

Symptom. — Shaft will show grooves or roughness, and will probably not revolve freely.

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

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

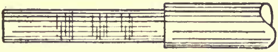


FIG. 80. — Rough Shaft.

Symptom. — Shaft does not turn easily, but excessive friction is immediately and completely relieved by slight loosening in the case of a split journal. In case the latter is not split, the bearing cap may be removed, and the journal examined to see whether it grips the shaft tightly.

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

Cause 5. — *Shaft "sprung" or bent.*

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

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

Cause 6. — *Bearings out of line.*

Symptom. — Shaft does not revolve freely, but is much relieved by slightly loosening the screws which hold bearings in place.

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 revolving part must be kept, however, in the center of the space in which it turns, so that the clearance is uniform all around. (See Cause 9.)

Cause 7. — *Thrust or pressure of pulley*, collar, or shoulder on shaft against one or both of the bearings.

Symptom. — In the case of a belt-connected machine, move the shaft back and forth with a stick applied to the end while revolving, and note whether the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth an eighth of an inch to make the commutator and bearings wear smooth. (See "Sparking," Cause 3.)

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

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

Symptom. — Great tension on belt. The pulley bearing is probably much hotter than the other, and in time will be worn elliptical as indicated in Fig. 81, in which case the shaft may be shaken in the bearing in the direction of the belt pull, when the belt is off.

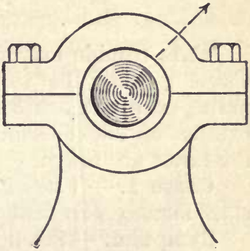


FIG. 81. — Elliptical Bearing.

Remedy. — Reduce the load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft.

Cause 9. — *Armature nearer the pole-pieces on one side*, producing greater magnetic attraction on nearer side.

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

Remedy. — See "Sparking," Cause 9, and remedy therefor. This condition does not produce sparking or armature heating except in multipolar direct-current machines with multiple-circuit armature windings. It can produce heating of bearings in any machine, but is worse with multipolar than with bipolar machines; therefore, the clearance between the armature and pole-pieces should be larger in the former than in the latter. 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 center of the space formed by the pole-pieces, the magnetic pull is practically balanced in all directions.

Cause 10. — *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 examination shows that these parts are hotter than the bearing and are the real source of trouble.

Remedy. — A sparking commutator, hot armature, or a slipping belt, can be cured as described in Chapters XIII, XVI, and XIX.

CHAPTER XIX

NOISY OPERATION

This trouble may occur in any electrical machine, except that Cause 5 (noise due to brushes) is not likely to be serious in alternating-current machines having no commutator. Nevertheless, the brushes on the collector rings may make a noise, for example, when the latter are rough.

Cause 1. — *Vibration due to revolving armature, field, pulley, or other moving part being out of balance.*

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

Remedy. — Armature, pulley, or other revolving part may be properly balanced as explained in Chapter VII.

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

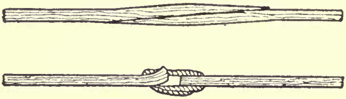


Fig. 81 a. — Poor Belt Splices.

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. In small machines the armature may be turned slowly by hand or with a lever, to ascertain whether it tends to touch or "stick" at any point.

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

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

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

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.

Cause 4. — *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 part is loose.

Remedy. — Tighten up the loose parts, and be careful to keep all properly set up. It is an easy matter 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.

Cause 5. — *Humming, squeaking, or hissing of brushes.* — This is often occasioned by rough or sticky commutator. (See "Sparking," Causes 3 and 4.) The commutator and brushes of a new machine may make considerable noise that is reduced after it has been running for a day or two.

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 that the circuit is not opened thereby.

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 with fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are apt to squeak in starting up or at low speed. This decreases at full speed, and can usually be reduced by slightly moistening the brush with oil, care being taken not to leave any drops or excess of oil. Shortening or lengthening the brushes or varying the brush pressure sometimes stops the noise. Run the machine with little or no load until the commutator and brushes are worn smooth.

Cause 6. — *Flapping or pounding of belt joint or lacing against pulley.*

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

Remedy. — Endless belt or smoother joint.

Cause 7. — *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 in an emergency. Special belt dressings are sold, which increase the adhesion and at the same time are intended to preserve the belt.

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

Symptom. — Pure humming sound less metallic than that due to 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.

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

Symptom. — This gives a sound similar to that in the preceding case. It can be distinguished by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second. Usually the latter is considerably greater than the former. This trouble is naturally confined to alternating-current apparatus. The slight pulsations occurring on direct-current circuits due to the commutator are hardly sufficient to produce an audible sound except in a telephone. (See "Heating of Field-Magnets," Cause 2, Chapter XVII.)

Remedy. — It is practically inherent in alternating apparatus, but its effects can be reduced by mounting the machine so as to deaden the sound as much as possible.

Note. — It often happens that a generator or motor seems to make a noise that in reality is caused by the engine or other machine with which it is connected. 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 XX

SPEED TOO HIGH OR TOO LO

THIS is generally a serious matter in either generator or motor, and it is always desirable and often imperative to stop the machine immediately, and make a careful investigation. This trouble may occur with any type of generator, due to Causes 1, 2, 3, or 4; with direct-current motors for Causes 5, 6, and 7; with series-wound single-phase A.C. motors for Cause 7. It does not apply to synchronous or induction motors except when Cause 1 (overload) becomes excessive, in which case they stop. (See Chapter XXI.)

Speed too Low.

Cause 1. — *Overload.*

Symptom and Remedy. — See "Sparking," Cause 1, and "Heating of Armature."

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

Symptom and Remedy the same as for "Heating of Armature," Causes 2 and 7.

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

Symptom and Remedy the same as for "Noisy Operation," Cause 2.

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

Symptom and Remedy. — See "Heating of Bearings," all causes.

Speed High or Low.

Cause 5. — *Field-magnetism weak.*

This has the effect, on a constant-potential circuit, of making a series or shunt motor run too fast if lightly loaded, or too slowly if heavily loaded, or even run backwards if the field-magnet is not excited at all, as, for example, when the shunt-field circuit is broken. It makes a generator fail to "build up" or excite its field, or fail to give the proper voltage.

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

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

Symptom. — This causes a direct-current motor to run too fast or too slowly, respectively. It would have a similar effect upon a series or shunt-wound alternating-current motor. It would not affect the speed of a synchronous motor until the voltage became so high as to injure it or so low that it stopped. When the voltage of a generator is too high it is likely to give the effects of overload (Cause 1). It can be proved by measuring the voltage of the circuit.

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

Cause 7. — *Motor too lightly loaded.*

Symptom. — A series-wound motor on a direct or alternating constant-potential circuit runs too fast and may speed up to the bursting point 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 it being suddenly removed. A shunt motor should be used if the load is likely to be thrown off.

CHAPTER XXI

MOTOR STOPS OR FAILS TO START

THIS is an extreme case of the preceding class ("Speed too High or too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This trouble may occur in direct or alternating-current motors, but does not apply to generators, because any trouble in setting them in motion is generally outside of the machine itself, but might be due to Causes 1 and 2.

Cause 1. — *Great overload.* (See "Sparking," Cause 1.) — A moderate overload usually reduces somewhat the speed of a direct or alternating current motor (except the synchronous type), but an extreme overload will stop or "stall" any motor.

Symptom. — The current is very excessive, and the safety-fuses blow or the circuit-breaker opens. In their absence or failure the armature is likely to be burned out.

Remedy. — Open the switch instantly, reduce or take off the load, replace the fuses or circuit-breaker, and close the circuit again just long enough to see if trouble still exists; if so, take off more load.

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

Symptom and Remedy. — (See "Sparking," Cause 1; "Heating of Bearings," and "Noisy Operation.")

Cause 3. — *Circuit open,* due to (*a*) safety-fuse blown or circuit-breaker open, (*b*) wire broken or slipped out of connections, (*c*) brushes not in contact with commutator or collector rings, (*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.

The field circuit alone of a shunt motor may be open, in which case the pole-pieces are not magnetic when tested with a piece of iron, and there is an extremely large 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 the main switch is opened. When there is no field-magnetism, or even if it is weak, a motor is apt to be burned out if its armature is connected to the circuit, unless protected by fuses or a circuit-breaker.

Remedy. — Open the main switch or circuit-breaker immediately, and examine fuses, circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, close switch, starter, or controller 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 locate any break that may exist.

One of the simplest ways to find whether current is flowing in the circuit, and to locate any break, is to test with an incandescent lamp, or several in series for higher voltages.

The remedy for a break in a direct-current armature winding was given under "Sparking," Cause 6. Similar expedients are applicable to alternating-current machines, the coil in which the break has been located being cut out by connecting together the adjacent coils. This may be done whether the break is in the armature or field-coils. Furthermore, alternating-current machines are free from the danger of internal short-circuiting which may occur in multiple-circuit direct-current armatures when a field-coil is cut out (see "Sparking," Cause 9), because the armature winding is usually single circuit.

A single-phase motor is stopped by a break in its circuit, but a two or three-phase motor will continue to run as a single-phase motor if the circuit of one phase is broken. It is, however, incapable of starting itself, except by special means.

Cause 4. — *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 the motor.

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. 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 or 440-volt direct-current) system several peculiar conditions may exist, as follows:

(*a*) The generator or generators on one side of the system may become reversed, so that both of the outside wires are positive or both negative. In that case a motor fed in the ordinary way from the two outside conductors will get no current, but lamps connected between the middle or "netural" wire and either of the outside wires will burn apparently the same as usual.

(*b*) If one of the outside conductors is opened 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 the motor 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 power unless the number of lamps is large.

(*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 generator, 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 XXII

VOLTAGE OF GENERATOR TOO HIGH OR TOO LOW

THIS is a common difficulty that may arise with any machine. The particular case of the self-exciting direct-current generator is treated by itself under the following heading, "Dynamo Fails to Generate," because it is a perfectly definite condition like "Motor Stops or Fails to Start." The various circumstances that interfere with the generation of the proper voltage are here stated.

Cause 1. — *Speed too high or too low.*

Symptom and Remedy. — See "Speed too High or too Low."

Cause 2. — *Field-magnetism strong or weak.*

Symptom and Remedy. — See "Sparking," Cause 8, also "Dynamo Fails to Generate," various causes.

Cause 3. — *Brushes not in proper position.*

Symptom and Remedy. — See "Sparking," Cause 2, also "Dynamo Fails to Generate," Cause 6.

Cause 4. — *Generator overloaded.*

Symptom and Remedy. — See "Sparking," Cause 1, also "Speed too High or too Low."

Cause 5. — *Short-circuited or reversed armature coils.*

Symptom and Remedy. — See "Sparking," Cause 5.

Cause 6. — *Open-circuited, short-circuited, or reversed field-coils.*

Symptom and Remedy. — A break in the field circuit of a generator prevents it from producing any voltage except the small amount due to residual magnetism. A short-circuited field-coil produces a corresponding reduction in ampere-turns, provided the field current remains constant. This would be true in the series coil of a series or compound-wound machine. In shunt-wound or separately excited field-coils, however, the current would tend to increase in proportion to the decrease in the effective coils, in which case the field strength and voltage would remain the same. This condition is nevertheless bad, because the active field-coils carry excessive current. (See "Heating of Field-Magnets," Cause 1.) In machines with many field-coils (for example, eight or more, including practically all alternating-current and large direct-current types) the cutting out of one, on account of an open or short circuit in it, would not involve a rise in current likely to do harm.

One reversed coil would have the same effect as the loss of two coils, the field resistance and current being unchanged. Hence the current would have to be considerably increased by means of the field regulator to obtain the proper voltage, this increase being twice as great as for one short-circuited coil. A short-circuited or reversed field-coil is very objectionable in a multipolar, multiple-circuit direct-current machine, as already explained. (See "Sparking," Cause 8, and "Dynamo Fails to Generate," Causes 2, 3, 4, and 5.)

Cause 7. — *Lagging current in alternator.* A direct-current or alternating-current generator, unless compound or composite wound, tends to fall in voltage with increase in load on account of armature resistance, inductance, and reaction. This is usually overcome by raising the field current by cutting out resistance in the field rheostat. In an alternating-current generator a given armature current produces much greater reaction and weakening of the field when it lags, so that the voltage fall and regulation required are correspondingly large.

CHAPTER XXIII

DYNAMO FAILS TO GENERATE

This trouble is a particular case of the preceding class, "Voltage of Generator Too High or Too Low." It is usually due to the inability of a self-exciting generator to "build up" its field-magnetism. The proper starting of such a 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 D.C. or A.C. machine, and if it does it is usually due to the fact that the exciter fails to generate, and therefore amounts to the same thing.

Cause 1. — *Residual magnetism too weak or destroyed*, due to (*a*) vibration or jar, (*b*) proximity of another machine, (*c*) earth's magnetism, (*d*) a strong current through the armature when there is little or no field current tends to neutralize or reverse the field-magnetism, owing to the back ampere-turns, (*e*) accidental reversed current through shunt or series field-coils, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo does not prevent its generating, but will make it set 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. Cases (*d*) and (*e*) are likely to occur with self-exciting D.C. generators working in parallel, or in conjunction with a storage battery, but not in the case of a single machine.

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

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

Shift the brushes backward to make the armature magnetism assist that of the field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the same direction as the residual magnetism. 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 or even materially affect the residual magnetism.

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

Symptom. — When the machine is running, pole-pieces do not attract a piece of iron. The application of external current does not in this case make a dynamo generate, as in Cause 1, because whichever way the field is thus magnetized the resulting current generated by the armature opposes and destroys the magnetism.

Remedy. — (*a*) Reverse either the armature connections or the field connections, *but not both.* (*b*) Move brushes through 180° for two-pole, 90° for four-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above changes the field may have to be built up with a battery or other current, because the conditions in these cases tend to destroy whatever residual magnetism may have been present.

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

Symptom. — Magnetism weak, but usually perceptible.

Remedy. — If the short circuit is in the external circuit, *it will prevent a shunt dynamo from building up its field-magnetism until the 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 until the short circuit is found and eliminated. A comparatively 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 generator from building up. (See "Sparking," Causes 5 and 8.) Too many lamps or other load might also prevent a shunt generator from building up its field-magnetism, in which case the load should be disconnected in starting.

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

Symptom. — Upon passing a current from another generator or battery the following symptom will exist: if the pole-pieces of a bipolar machine are approached with a compass needle 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 much stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

Remedy. — Reverse the connections of half 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 with a magnet).

Cause 5. — *Open circuit.*

This may be due to: (*a*) Broken wire or faulty connection in machine, (*b*) brushes not in contact with commutator, (*c*) safety-fuse blown or removed or circuit-breaker open, (*d*) switch open, (*e*) external circuit open.

Symptom. — If the trouble is due merely to the switch or external circuit being open, the magnetism of a shunt-wound D.C. generator 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.

A break in the field circuit of a separately excited D.C. or A.C. generator will prevent it from generating, and is indicated by the fact that the exciter has its field-magnetism, while the main generator has not. One break in the armature of a D.C. machine does not prevent it from generating but produces sparking (Cause 6). A break in a single-phase series-wound armature prevents it from generating; a two-phase or a three-phase Y armature generates single-phase, but a Δ armature continues to give three-phase currents with diminished capacity in amperes.

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 "Motor Stops," Cause 3.)

A break, poor contact, or excessive resistance in the shunt-field circuit or field regulator of a generator 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, the surest way being to connect the two terminals of the field-coils to the positive and negative brushes, respectively, also trying reversal of these connections.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, because 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 carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

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

Symptom. — The magnetism and voltage 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 usually 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 some drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. On the other hand, some armatures are wound so that the brushes have to be set in line with the centers of the pole-pieces, or in an intermediate position. Most multipolar machines have as many sets of brushes as there are pole-pieces, while some have cross-connected armatures or have a series or two-circuit armature winding (for example, railway motors) so that only two sets of brushes are required. Four-pole machines with only two sets of brushes require them to be set at 90°; six-pole machines, either 60° or 180°, and so on.

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 familiar with the particular type of machine. A blueprint 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 generators and motors, except that in the former the brushes are given a *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 armature reaction, which distorts the field-magnetism.

The positions and number of brushes for each kind of armature are shown in Fig. 82, 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 (in a generator) through the negative brush, passes around both sides of the armature, and out through the positive brush. Hence this is called a two-circuit armature.

B represents a ring armature, but being similar in principle may also represent a four-circuit drum winding 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.

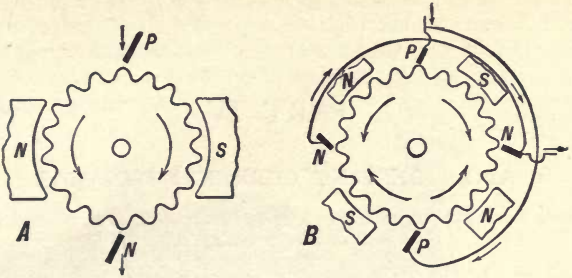
C is a four-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections in the armature or commutator. Therefore the entire current may be taken off by these brushes, or two more may be added to reduce the heating effect, in which case they must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

With either B or C, since there are four circuits or parts of the armature winding, under the influence of different poles, but connected in parallel to the mains, it is evident that if the voltage in one part of the winding is weaker than in the others, through inequality of the poles or otherwise, it will tend to short-circuit the other parts of the winding and give trouble. (See "Sparking," Cause 9.) This does not occur in A, because it is a two-circuit winding, both parts of which are influenced by the two poles of a single magnet which are naturally of equal strength.

D is a four-pole armature in which the winding is also of the two-circuit type, thus overcoming the above objection.

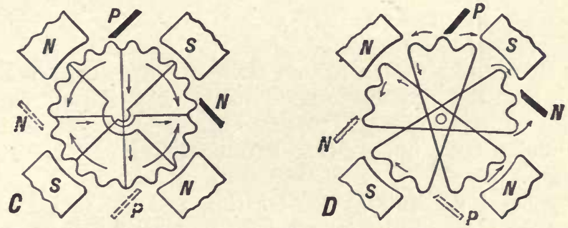
E is a series or two-circuit drum winding corresponding to the ring winding D. To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars. Many more are used in practice.

F is a series or two-circuit drum armature for eight poles. 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.



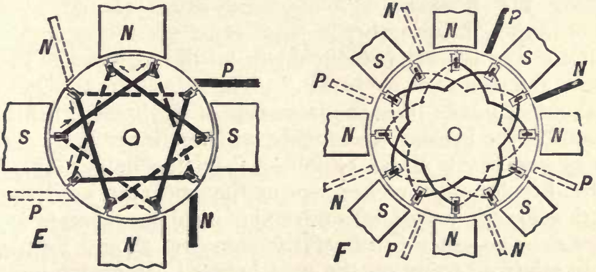
Two Pole, Two Circuit

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. 82.

PART IV

ARC (CONSTANT CURRENT) DYNAMOS

Giving only those features which are special for each machine, general facts being covered in the preceding pages

CHAPTER XXIV

THE BRUSH ARC DYNAMO

THE Brush arc dynamo has an open-coil armature, and, like the Thomson-Houston arc machine, develops a pulsating current of practically constant average value. Originally the machines were of the bipolar type, but as now manufactured they are all multipolar (Fig. 83).

The general precautions for locating and erecting a dynamo, given in Part I, should be followed in the installation of these machines; and there are special features, in the adjustment of the brushes and regulating devices, which should be noted.

Setting the Brushes. — A pressure brush should always be placed over the collecting brush, as it improves the running of the commutator and secures better contact on the segment. The combination is referred to as a "brush." The tips of the brushes should be set about $5\frac{1}{8}$ inches from the front side of the brass brush-holders.

In setting the brushes, commence with the inner pair, and place the tip of one brush about $5\frac{1}{8}$ inches from the holder, then rotate either the brush-holder rocker arm or the armature until the tip of the brush is exactly in line with the end of a copper segment as shown in Fig. 84. The other brush of the same set should be placed in the same relative setting on the next forward commutator segment; but if the length of the brush from the holder is less than $5\frac{1}{8}$ inches, move both brushes forward until the length of the shorter brush is that amount. Now adjust the extreme outer set of brushes in the same manner, clamp them firmly in position, then place a straight-edge across the tips of the inner and outer sets, move all the intermediate brushes to that line, and secure them firmly. The spark at one of the six brushes may be a trifle longer than that at the others; if so, move that brush forward so as to make all sparks of approximately the same length.

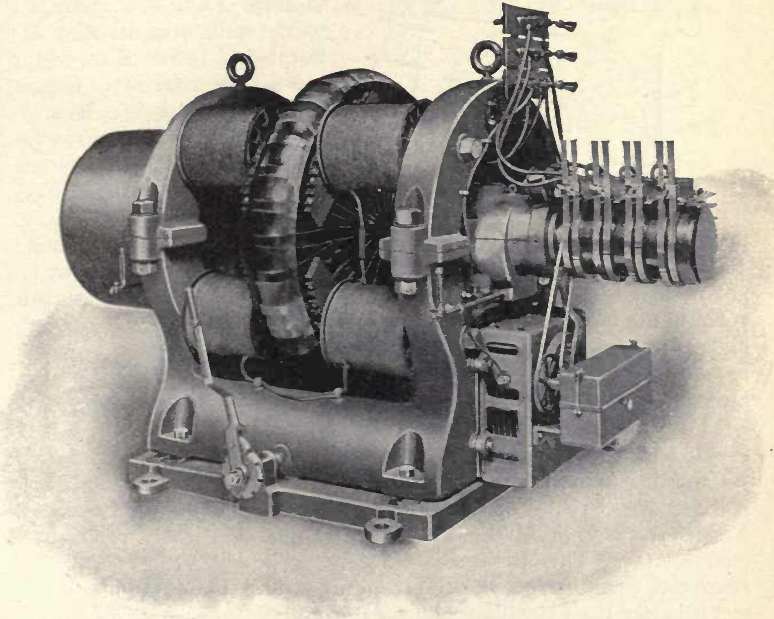


Fig. 83. — Multipolar Brush Arc Dynamo.

Brushes should not bear on the commutator less than $\frac{1}{8}$ inch from their tips, or, as illustrated in Fig. 85 a, they will tend to drop into the commutator slots and, by pounding, ultimately break off their fingers. If the contact is too far from the end, as in Fig. 85 b, the tip of the brush cannot touch the segment, and will therefore prolong the break, allowing the spark to follow to the tip of the brush, with consequent burning of the brush and commutator segments. The correct setting is shown in Fig. 85 c. The tip of the brush is nearly tangential to the segment as it leaves.

Care of Commutator. — Provide the dynamo cleaner or wiper with 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 is shut 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. Much trouble will be saved if care is taken in cleaning the places where the commutator wires and shaft wires are connected.

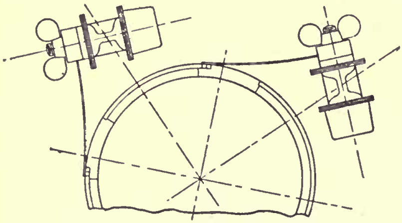


Fig. 84. — Setting of Brushes.

To prevent the commutator from becoming rough and uneven, polish it with fine sandpaper 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 sandpaper 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.

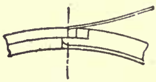


Fig. 85 a.

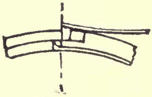


Fig. 85 b.

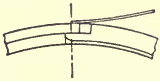


Fig. 85 c.

If the commutator needs lubrication, oil it sparingly; two or three times during a run is sufficient. If the oil has a tendency to blacken the commutator wipe it off with a dry cloth. Too much oil causes flashing. Since the machine generates a high voltage, take great care not to touch any live part with the hand, having the cloth mounted upon a stick.

To Change Direction of Rotation. — The normal direction of rotation of these machines is counter-clockwise, facing the commutator end, but under certain conditions it may be necessary to reverse the rotation, in which case proceed as follows:

1. Remove the brush-holder cables and studs from the rocker. Take off the rocker, and reverse it, so as to bring the handle on the opposite side of the machine; shift the clamp stud to the same side. Replace the brush-holder studs; reverse the brush-holders so that the binding screws may be on the same side of the stud as the cable clips. Square the brush-holders with the stud and clamp firmly.

2. Remove the external rack at the lower end of the rocker arm and replace it by an internal one, using the same insulation, and align it so that it will move freely through its entire arc.

3. Remove the brush-holder caps, place an angle gauge A on the commutator as shown in Fig. 86, and turn the stud until the gauge rests squarely upon the face of the brush-holder. Tighten the stud, and repeat the above operation at the extreme inner and outer sections of the commutator, noting the position of the brush-holder faces relative to the line at A on the gauge in each instant. If the position of the line A is not the same in both cases, the stud is not parallel to the commutator; it should therefore be packed with mica between its shoulder and the rocker until aligned; then secure the stud firmly in position.

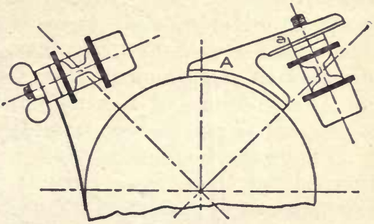


FIG. 86. — Setting of Brush-Holder Stud.

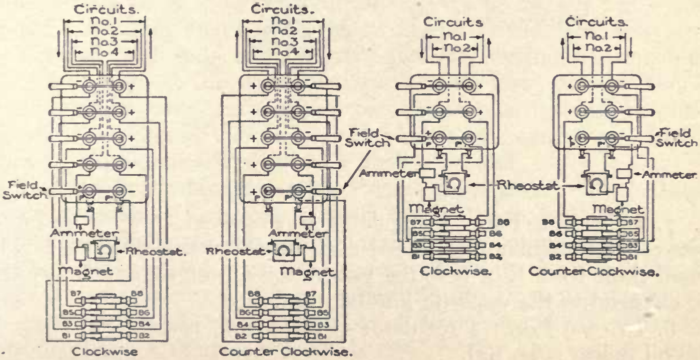


FIG. 87. — Connections, Clockwise and Counter-Clockwise Rotation.

4. Remove the commutator segments and turn the wood blocks end for end, or in such position that the brush in leaving a copper segment will come in contact with the copper tip of the block.

5. Change the terminal-board switches so as to bring their handles on the opposite side, as shown in Fig. 87.

6. Connect the brush-holders to the terminal board as shown in Fig. 87.

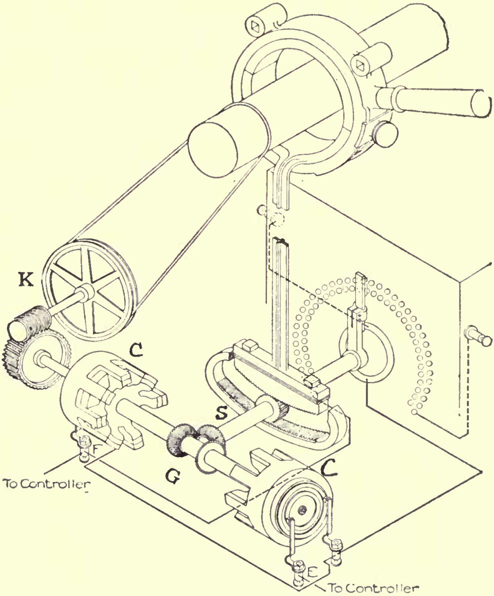


FIG. 88. — Form 1 Brush Regulator.

7. In case a Form 1 regulator is employed, reverse the lines between the regulator (Fig. 88) and the controller (Fig. 89). The small cable from E or F to the last button on the rheostat must also be changed to the opposite binding-post.

8. In case Form 2 regulator is employed, reverse the plugs in the oil pump (Fig. 92).

Regulators. — Brush arc machines are equipped with either of two forms of regulators. Both accomplish the same general result, varying the field strength and shifting the brushes to maintain a constant current with variations in load.

Form 1 Regulator. — The Form 1 regulator is placed on the frame of the machine, beneath the overhanging commutator, and a constant motion is imparted to its main shaft, K, through a small belt running around it and the armature shaft (Fig. 88). By means of magnetic clutches, C, and bevel gears, G, a pinion shaft, S, is rotated, which moves the rack and thus the rocker arm. The brushes are by this method shifted on the commutator to maintain a spark of about $\frac{3}{8}$ inch on short circuit and $\frac{1}{8}$ inch at rated load. The pinion shaft also controls the rheostat contact arm and increases or decreases a shunt resistance across the series field winding.

The current for the magnetic clutches is governed by the controller (Fig. 89). This controller consists essentially of two magnets energized by the main current which act when the current is too high or too low, sending a small current to one of the clutches. It is generally advantageous to fit the yoke which carries the brushes on the machine and the rheostat arm rather tight, as "hunting" of the regulator is then less likely to result.

For shunt lamps, the controller may be adjusted to permit a variation of .4 ampere above and below normal; for differential lamps, the variation should not exceed .2 ampere. If the controller is out of adjustment and fails to keep the current normal, do not adjust both armatures at once, but determine which is not correctly adjusted by noting if the current either exceeds or falls below the desired value, and then correct the setting of the defective relay.

The two small coils, R and S, are connected around the controller contacts simply to decrease the spark. If they become short-circuited in any way, sufficient current might pass through them to operate the regulator clutches, which should be guarded against by frequent examination.

Starting Brush Machine with Form 1 Regulator. — In starting, the lower switch, which short-circuits the field, is opened last.

The switch in the left-hand corner of the controller (Fig. 89) cuts out the two resistance wires used to force the current through wires O and Q to the clutches. Open this switch, which leaves the automatic device of the controller in circuit so that it will move the brush rocker. Unclamp the brush rocker from the rheostat arm rocker. Move the brushes by hand to give the proper spark, allowing the rheostat arm, however, to be moved by the controller. After the switches are opened, the rheostat arm will go clear around to a full load position, and then, as the current rises, the controller takes hold and brings the arm back. In the meantime, rock the brushes forward or backward and keep the spark about the proper length, say $\frac{1}{8}$ inch at full load to $\frac{3}{8}$ inch on short circuit. Gradually the rheostat arm will settle, the spark will become constant, and the machine will give its proper current. Then clamp the rocker and rheostat arm together and let the machine regulate itself.

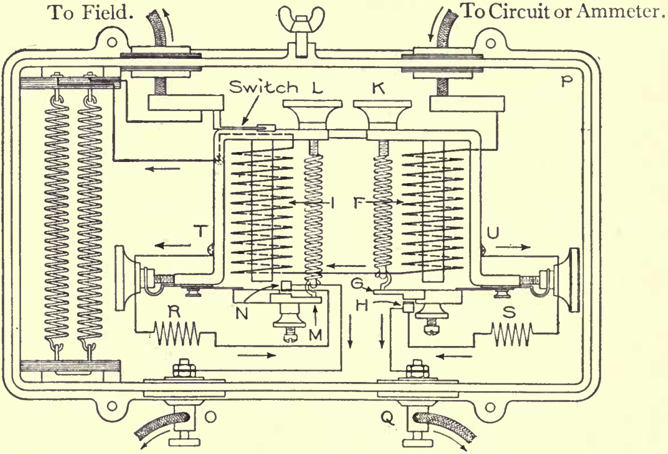


FIG. 89. — Connections of Brush Controller.

This method is much better than opening the switches on the machine and allowing the wall controller to regulate from the start. By allowing the controller to start the machine, a trifle longer spark is obtained than by the other method, unless the machine is run from the beginning on a very full load.

Form 2 Regulator. — The assembled regulator is mounted on the machine frame under the commutator, and the connections are as shown in Fig. 90.

Operation of the Regulator. — A small belt runs over the armature shaft M and drives the rotary oil pump P. This pump draws oil from the containing case and forces it through passages to the valve T, a section of which is shown in Fig. 91. The ports overlap this valve, so that oil may flow when in the central position. The valve is controlled by the electro-magnet F, which actuates the armature U and the lever H, the pull on U varying with the current. The other end of the lever is attached to a tension spring G, adjusted by the nut R, to hold the valve in the central position when the magnet is excited by normal current. If the current is too strong, the armature U is pulled down, the valve raised, and more oil thrown on the upper surface of the piston head S, allowing oil to run out from the lower side, and thus forcing the piston X around clockwise, lowering the current by decreasing the field strength. The brushes are also shifted forward by the same means, until the current is again normal, when the valve reaches its central position and further movement ceases. If the current value is below normal the reverse action occurs.

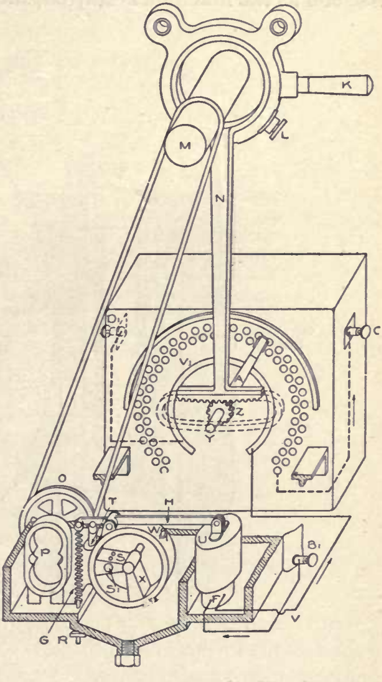


FIG. 90. — Connections, Form 2 Regulator Brush Arc Generator.

Adjustment of Form 2 Regulator. — To increase the normal current value, turn the nut R to the right; or to lower it, turn the nut to the left. The regulator may be made to operate quickly in one direction and slowly in the other by changing the position of the stops on the lever H. By raising the stop on the right-hand side of H, the movement, on increase of current, will be retarded.

A safety valve is set to operate at a pressure of about 15 lbs.

per square inch, so as to relieve the pump. Fig. 92 shows the ports and method of changing the plugs, to run the pump with an open belt for either clockwise or counter-clockwise rotation.

Starting Machine with Form 2 Regulator. — Before starting the machine, the oil box of the regulator should be filled with a light dynamo oil nearly up to the shaft which carries the contact arm. As soon as the machine is started, the level of the oil will be somewhat lowered. If the pump fails to start promptly, it may be started by shifting the brushes backward and forward, and moving the contact arm, to force out the air and draw in the oil.

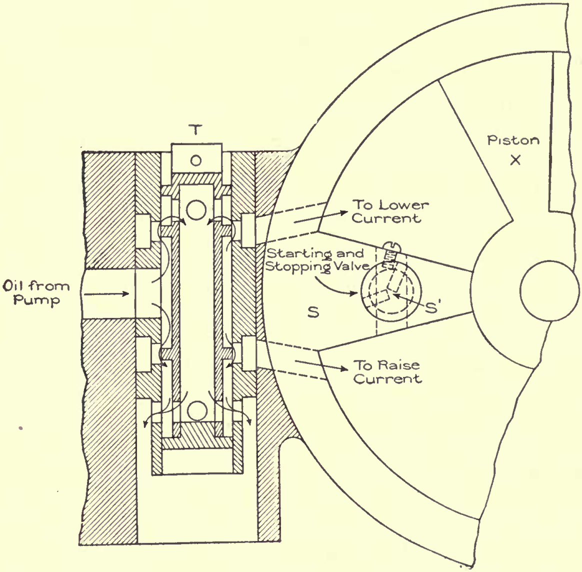
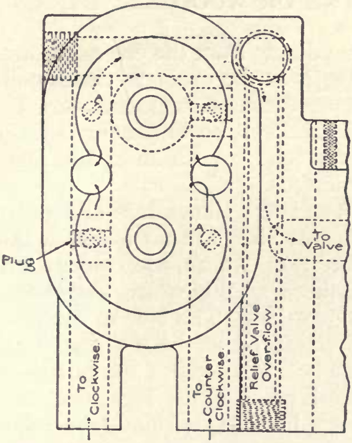


FIG. 91. — Valves Controlling Arm of Regulator.

In a newly installed machine, the oil should be changed at least once a week for the first month, until all dirt and grit are removed. The oil may be drawn off through the pet cock at the bottom of the oil box. The cover of the latter must be kept on to prevent dirt from getting in.

In general, Brush machines with Form 2 regulators are started as described in connection with Form 1 regulators, but the following additional instructions should be noted:

Having correctly adjusted the regulator for the desired current, as previously described, the starting valve handle S¹ (Figs. 90 and 91) should be turned counter-clockwise when the machine is running without load. This connects both sides of the circular cylinder, giving a free flow of oil between them, preventing the operation of the piston, and relieving the pump from undue load.



The arrows show the path of the oil through the pump for counter clockwise rotation, and the stopping plugs are located for a machine running in this direction.

FIG. 92. — Ports and Piston of Rotary Pump, Form 2 Brush Regulator.

To put the machine in operation, the valve is gradually turned clockwise, cutting off the flow of oil from the two sides of the cylinder after the switches have been opened. This valve may also be used to throw the regulator out of operation if desired.

CHAPTER XXV

THE FORT WAYNE OR WOOD ARC DYNAMO

THE Wood Arc Dynamo differs from the preceding arc machine in that its armature winding is of the ordinary closed-coil Gramme ring type, connected to many commutator segments. The voltage and current regulation is obtained by automatic shifting of the brushes, from the maximum voltage position at full load to lower voltage points as the load decreases.

The complete line of Wood Arc Generators originally consisted of twelve sizes. The first four sizes are no longer manufactured; and all types except the latest, or No 10, are constructed with the field-coils horizontal. All these machines are shipped completely assembled and ready for operation. The No. 10 dynamo has vertical field-coils and on account of its height and weight is not shipped complete, but must be assembled at the purchaser's premises (Fig. 93). The general precautions, regarding location and care while assembling, given in Part I, should be followed with these machines.

Starting, Sizes No. 5 to 9 B. — The direction of rotation of these machines, unless otherwise specified, is counter-clockwise facing the commutator end. Clockwise rotation can be obtained by altering the setting of regulator and brush mechanism, as explained on page 172. Before throwing the load on the machine, rock the brushes to no-load or minimum voltage position, lock the regulator arm in mid-position by the stop, and close field short-circuiting switch. Then connect the machine to the line, open the field switch, and release the regulator lever. The regulator immediately shifts the brushes around against rotation until the rated current is generated. If the regulator oscillates excessively, it should be held for an instant at least sparking position until it is steady, after which it will automatically maintain a constant current.

Shutting-down. — Close the field switch, raise the regulator-magnet lever and allow the brushes to move to the no-load position, then raise the regulator stop and open the line circuit at the switchboard. In shutting down type 10 machines proceed as above, with the exception that the lever should be pressed down and the stop thrown in, until the brushes move to the no-load point.

Trimming Brushes. — The ends of the copper-leaf brushes should be filed square and slightly beveled to give about 3-32-inch contact on the commutator when under tension. The leaves composing a brush should be divided equally and the two layers bowed out from each other, so that when placed in the brush-holder the ends of the strips will be pressed tightly together. This prevents spreading as the brush wears. In case it is necessary to trim brushes, while the machine is in operation, either brush on one side of the armature may be removed and replaced without affecting the service, taking care, however, to keep the other set on that side intact, otherwise disastrous arcing occurs.

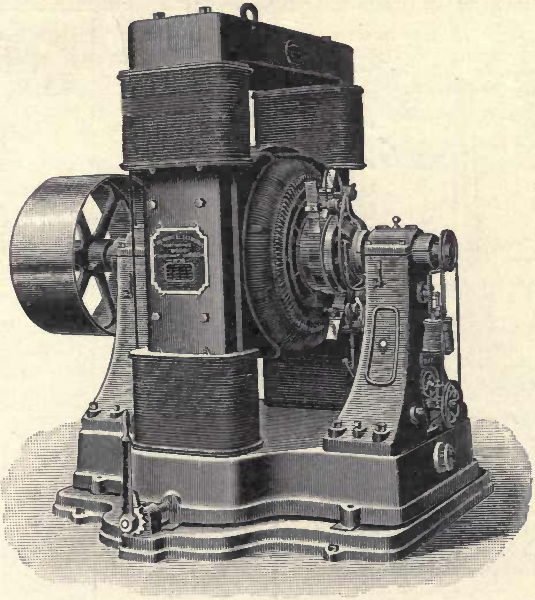


FIG. 93. — No. 10 Wood Arc Generator.

Setting Brushes. — The brushes should be set by means of the gauge supplied with each machine, stamped with its size number and dimensions given in the following table, except with the newer types of No. 9 machines having a 9.75 inch diameter commutator, in which case use the data given for type 9 B sizes.

DIMENSIONS OF BRUSH GAUGES AND GIBS.

FOR WIRE CORE ARMATURES.

Generator Number.	Length Gauge in Inches.	Length Long Gib in Inches.	Length Short Gib in Inches.
4	$1\frac{11}{16}$	$3\frac{1}{2}$	$1\frac{3}{4}$
5	$1\frac{11}{16}$	$3\frac{1}{2}$	$1\frac{3}{4}$
6	$1\frac{11}{16}$	$3\frac{5}{8}$	$2\frac{1}{16}$
7	$1\frac{25}{32}$	$3\frac{5}{8}$	$2\frac{1}{16}$
8	$2\frac{5}{32}$	$3\frac{5}{8}$	$2\frac{1}{16}$
9	$2\frac{3}{8}$	$3\frac{5}{8}$	$2\frac{1}{16}$
10	$2\frac{3}{8}$	$3\frac{27}{32}$	$2\frac{1}{16}$

FOR LAMINATED CORE ARMATURES.

Generator Number.	Length Gauge in Inches.	Length Long Gib in Inches.	Length Short Gib in Inches.
6	$1\frac{11}{16}$	$3\frac{5}{8}$	$2\frac{1}{16}$
7	$1\frac{25}{32}$	$3\frac{5}{8}$	$2\frac{1}{16}$
8	$2\frac{5}{32}$	$3\frac{5}{8}$	$2\frac{1}{16}$
9	$2\frac{3}{8}$	$3\frac{5}{8}$	$2\frac{1}{16}$
9A	$2\frac{3}{8}$	$3\frac{5}{8}$	$2\frac{1}{16}$
9B	$3\frac{1}{8}$	$3\frac{5}{8}$	$2\frac{1}{16}$
10	$2\frac{3}{8}$	$3\frac{27}{32}$	$2\frac{1}{16}$

Setting Yokes of Nos. 4 to 9 B. — Place the friction clutch at no-load point for the proper direction of rotation, and loosen the pinion nut (Fig. 94), then bring the ends of the yoke arms together and rotate them until the short arm is at the proper distance, B, from the pinion, according to the following table, which is only for old machines having wire core armatures. Then separate yokes about 1-16 inch and tighten pinion nut.

Generator Number.	4	5	6	7	8	9
Distance from yoke to pinion, center to center, in inches....	1 7/8	2 1/8	2 1/4	2 3/4	3 1/8	3 1/4

For laminated core armatures bring the ends of yoke arms together and rotate them until the short arm is within about an eighth of an inch from the pinion. Then separate the yokes about 1-16 inch and tighten pinion nut.

Adjusting Yokes and Brushes of Nos. 4 to 9 B. — If the machine does not operate properly when adjusted in accordance with the above directions, but sparks excessively or arcs over, it is probably due to incorrect distances between the spark and the main brushes on one or both sides of the commutator.

By pulling back one or both main brushes in brush-holder, or moving them ahead and noting the effect, the proper distance between brushes may be determined. Then, instead of running with brushes in this position, which is not the correct gauge setting, or cutting off the gibs so that a correct gauge setting may be obtained, run the brushes around to no-load point, and while holding clutch and forward yoke in this position loosen pinion stud nut and move the long arm forward or back until the proper distance is obtained between brushes, when set by gauge as above determined. Then tighten nut without changing relative position of clutch or yokes. This should give the proper setting of the machine, and further trouble must be corrected by adjusting defective lamps or loose connections, by

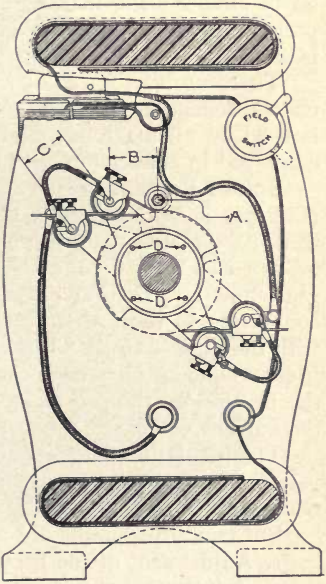


Fig. 94. — Brush Mechanism of Nos. 4 to 9 B (Counter-Clockwise Rotation).

cleaning regulator reversing mechanism, or removing possible short circuits or grounds from machine or line.

Automatic Regulator. — The automatic regulator on the commutator end of the generator is intended to maintain the current at approximately constant value, independent of the number of lights in circuit, by increasing the voltage of the machine in direct proportion to the number of lamps in series with it. It should be kept perfectly clean and well oiled so as to move freely.

The current can be regulated by tightening the regulator spring to increase it, or loosening spring to decrease it. An ammeter should be in circuit while making such adjustments, lamps should be in proper operation and the generator running at rated speed and load.

There are two forms of regulators employed on Wood Arc Machines, depending upon the size of the machine. One type (Form 2) is used on all machines up to the 9 B size, and the other form is employed in connection with the type 10 generator.

Form 2 Regulator. — The operating mechanism of this regulator (Fig. 95) is belted directly to the armature shaft and consists of a three-part clutch comprising a middle double-faced friction cone, mounted on a shaft connected by a train of gears to the rocker-arm gear, and two friction gears driven in opposite directions by belt connection to the armature shaft. The regulator magnet, in series with the line, controls a lever linked to a shifting finger pressing the friction cone against one or the other of the friction gears and shifting the brushes on the commutator in either direction, depending upon the current value.

The regulating magnet is opposed by a coil spring adjustable for variations in current strength. A stop is provided for throwing the regulator out of operation by holding the lever arm in mid-position.

But two adjustments are necessary with this regulator, namely:

1. Adjustment of the friction cones and shifting finger.
2. Adjustment of spring tension to balance the pull of the solenoid at normal current.

The general instructions given for adjusting the friction cones of the No. 10 regulator apply to all Form 2 regulators.

Reversing Form 2 Regulators. — The normal direction of rotation of Wood Arc Machines is, as already stated, counter-clockwise. It may, however, be necessary to run the machine in the opposite direction. This requires a reversing of the regulator, brush mechanism, etc., from the position in Fig. 94 to that in Fig. 96. The various steps for accomplishing this are as follows:

1. With the regulator adjusted for satisfactory operation with counter-clockwise rotation, or as received from the factory if a new machine, run the brushes up to no load position and measure carefully the distance, B, from the center of the pinion, A, and the center of brush-holder stud carrying the front or spark brush. Also measure the exact distance, C, between centers of studs connected by short cable.

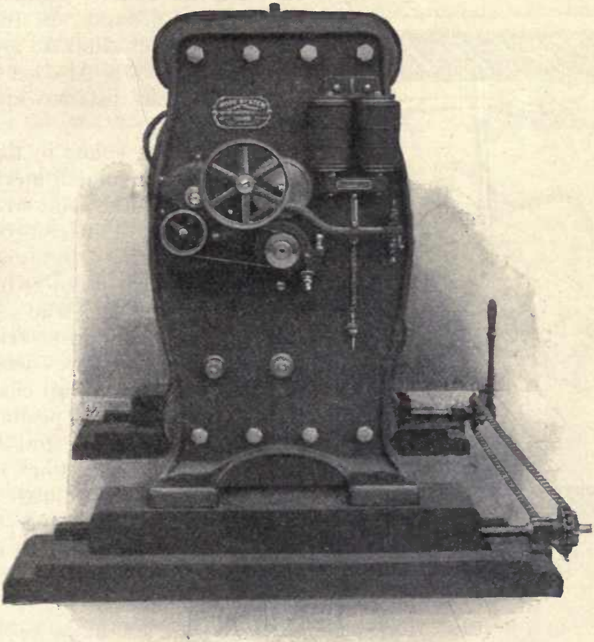


FIG. 95. — Form 2 Regulator, No. 9 B Wood Arc Generator.

2. Remove the small screws, D, and take off the yoke-retaining ring.

3. Loosen nut on the end of the pinion shaft A.

4. Disconnect all cables from the long-arm brush studs.

5. Remove or loosen the double segment yoke carrying the spark brush, and turn it around until the other gear segment meshes with the pinion on stud A, and slide the yoke back into place.

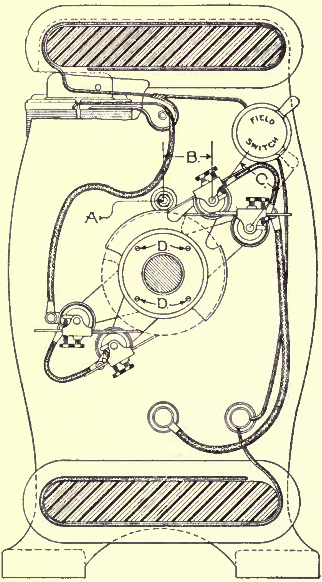


FIG. 96. — Brush Mechanism of Nos. 4 to 9 B (Clockwise Rotation).

6. Put on the yoke-retaining ring, bring the ends of the yokes together and turn them around until the center of the brush-holder stud on the double segment yoke is the same distance, B, from the center of pinion stud, A, as before on the other side. Also set the two yokes the same distance apart, C, as originally.

7. Hold the yokes in this position and turn the clutch mechanism on the outside of the pedestal around to full load position (for counter-clockwise rotation), or until the clutch fingers are just touching on the top side of the stud A, and consequently are just releasing. This position is now correct for no-load when running clockwise. Hold securely in this position and tighten the nut on the stud A without changing the settings of the yokes or regulator clutch. This clamps together all the driving gears in the proper relation to each other for the new direction of rotation.

8. Reverse the main cables, the one from the upper binding-post connecting with the brush stud nearest the regulator magnet, and the one from the lower binding-post connecting with the opposite brush stud. It may be necessary to loosen the lower binding-post to avoid a kink in the cable. Also connect the short cables to the long arm brush studs, thus connecting together the spark and main brushes of similar polarity.

9. Remove and reverse the brush-holders on the studs. It is necessary to remove the spring and tension thumb nut to reverse

them on the brush-holder. Set brushes, tighten all nuts and screws, and start machine.

10. The machine should now operate, running in the new direction as well as before. If it does not, adjust brushes and yokes according to the directions on page 171.

Setting Yokes of Type 10 Generator. — The yokes of No. 10 machine are properly set when shipped, so that it is only necessary to see that they are free to turn on the collar mounted on the bearing, when the regulator wheel is turned by hand. When the machine is started in the proper direction of rotation and excited, the brushes will be brought to the minimum voltage position by the regulator. In this position the insulating washers on the long and short arms are about ¼ inch apart, and the clutch fingers on the inside of the large gear wheel are at the bottom of their path and against the stop on the right-hand side. The main brush will also be opposite the middle of the pole-piece with the spark brush about 1½ inches ahead of it.

Adjusting Yokes and Brushes on Type No. 10. — If the forward or spark brush sparks at no-load or minimum voltage position, the indication is, that it and the main brush are too close together. To increase the distance between them, without varying the position of the main brush, the rod at the left (S, Fig. 97, with counter-clockwise rotation) should be shortened by drawing up on the nut N.

If, at no load, there is flashing over from brush to brush around the commutator, it indicates that the forward and following brushes are too far apart. To decrease the distance between them without changing the position of the main brush, the rod at the right (R, Fig. 100, with counter-clockwise rotation) should be lengthened.

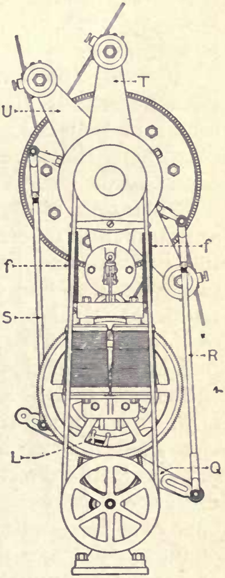


FIG. 97. — Regulator of No. 10 Wood Arc Generator, End View.

If sparking occurs at full load it may be due to the same cause as at no load, namely, too little distance between brushes. This may be remedied by shortening the rod at the left as before. If this corrects the sparking at full load, but causes arcing over at no load, it indicates that the brushes are too far apart at no load, although correctly spaced at full load. The no-load adjustment of length of rod at the left should again be made. Then, in order to secure the same distance between brushes at full load as before, the lower end of the same rod S should be loosened in the slot in the rocking lever Q and moved in toward the center and tightened. If this affects the operation at no load the trouble should be corrected by varying the length of the rod as before. *When the proper adjustment at no load is secured, in most cases the full load adjustment will be correct if the lower end of the left rod is locked at about the middle of the slot in the rocking lever.*

If *arcing over* occurs at full load with correct no-load adjustment, the lower end of the rod should be moved out in the slot *from* the center of pedestal. If *excessive sparking* occurs under the same conditions, the lower end of the rod should be moved *toward* the center of the pedestal.

Operation of Type No. 10 Regulator. — Since the field-coils, armature, and regulator coils are all in series with the lamp circuit, the line current passes through the regulator magnet coils. A predetermined line current should be maintained constant by the regulator. If the resistance of the circuit is increased by the addition of more lamps, the current tends to decrease. This weakens the pull of the solenoids on the cores and allows the tension of the two suspension springs and adjusting spring to raise the bell crank lever arm, draw out the regulator lever and shift the collar on the friction cone shaft, to bring into action one of the friction cones and shift the brushes in the direction of rotation to raise the voltage, overcoming the added resistance and maintaining a constant current. As the current is restored to normal value, the solenoid overcomes the pull of the springs and the friction cone is released, leaving the brushes at proper commutation point for normal current. This action is entirely automatic and is the same from no load to full load, and the reverse from full load to no load.

Description of Type No. 10 Regulator. — The driving mechanism of the regulator consists of two gears (A B, Fig. 98) carrying friction cones C C driven by belt connection to the armature shaft and running in opposite directions; one being driven by a pinion D on the belt shaft, the other by a change gear meshing with a pinion on the belt shaft. These gears A B are mounted on a sleeve within which is the shaft F carrying the counterparts of the friction cones on the gear wheels. These cones G H are so arranged that a slight end play of the shaft F is sufficient to bring into operation one or the other of the friction gears A B and thus drive the shaft in either direction.

On the inner end of the shaft F is a pinion I that meshes with a large gear J inside the pedestal. This gear runs loosely on the shaft M of a clutchwheel K, which it drives in either direction through two clutch dogs or fingers (L L, Figs. 98 and 99), the limit of revolution being set by a stop N at the bottom of the circle.

On the other end of the clutch wheel shaft M is a pinion O that meshes with the gear P on the lower rocking lever (Q, Fig. 98). As the clutch wheel K revolves, this lever Q is rocked and the motion transmitted through two connecting rods, R S, to the brush rocker arms T U, thus shifting the brushes on the commutator.

The mechanism by which the direction of rotation of the friction cone shaft F is determined, consists of a shifting collar V on the friction cone shaft actuated by the main regulator lever W. This lever is linked to a bell-crank magnet lever X, from which is suspended the solenoid cores Y.

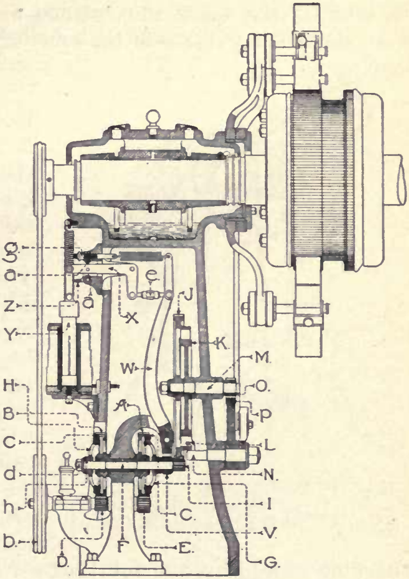


FIG. 98. — Regulator of No. 10 Wood Arc Generator, Side View.

Adjusting Type No. 10 Regulator. — The only adjustments necessary with this regulator are:

1. Adjustment of the friction cones and shifting collar.

2. Adjustment of tension in the springs to balance the pull of the solenoid at normal current.

To adjust friction cones (G H, Fig. 98), set the release catch Z on the solenoid lever X, thus holding it midway between the upper and lower stops *a a*. Turn the regulator wheel by hand in both directions. If the clutch acts in either direction, the friction cones are too near together. Loosen set-screw *h* on the outer cone and loosen nut *d* on the end of the shaft. Tap the end of shaft lightly to take up the space thus gained and tighten set-screw. Repeat until there is no action of the clutch in either direction with release catch set.

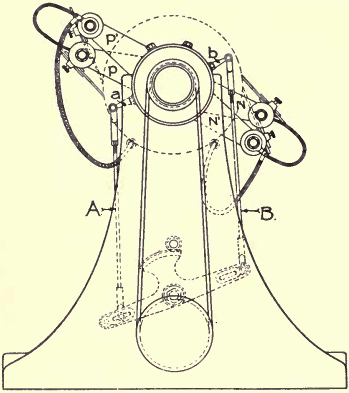


FIG. 99. — Brushes at Minimum Position (Counter-Clockwise Rotation).

There should be about 1-32-inch end play of the friction cones for ordinary regulation, but it should be centered so that there is equal play of the lever X either side of the middle point between stops *a a* before the clutch X. This is secured by means of the adjusting link *e* between the main regulator lever and the bell-crank lever, which has a fine right- and left-hand thread. This adjustment is seldom necessary except when an old worn friction cone is replaced by a new one.

With the friction cones properly adjusted and brushes and rocker arm set for minimum sparking at no-load and full load positions, the solenoids should be adjusted to maintain constant the proper current as indicated by an ammeter in the main circuit.

The pull of the two suspension springs opposes the pull of the solenoids *y*. By varying the strength of these springs, the bell-crank lever should be made to rest approximately midway between its stops with normal current. Final adjustment may be made by means of the adjusting spring thumb screw *g* above the release catch.

Care should be taken in adjusting suspension springs to keep the two solenoid cores properly balanced and free to move in their spools.

Clutch Fingers. — Should the clutch fingers L fail to grip the large gear wheel inside the pedestal, they should be taken out and examined. It may be necessary to tighten the steel spring by bending, or to sharpen the edges of the finger with an oil stone, especially after long service. In removing and replacing the clutch wheel be sure that no change is made in the relative positions of the rocker-arm rack and clutch fingers. The pinion and rack should be marked and the clutch fingers should be at their limiting position against the stop before removing, and these positions retained in assembling.

Reversing Type No. 10 Regulator. — Proceed as follows:

1. With regulator at no-load position for normal direction of rotation (Fig. 99) disconnect the short cables from long arm P′ and from short arm N, and the line leads from both arms; also uncouple the side rods A B from pins *a b* and remove them from the rocker collars.

2. Turn the long arm P′ N′ over until P′ and N are together, then hold them together and revolve them through 180 degrees.

3. Remove the screw plugs from the second set of holes in rocker-arm collars and screw them into the holes from which side rod pins *a b* were removed. Then screw the pins into the screw holes.

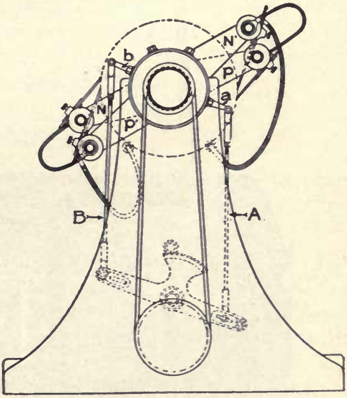


FIG. 100. — Brushes at Minimum Position (Clockwise Rotation).

4. Turn the regulator by means of the belt pulley to the opposite limit and exchange the two connecting rods. If the rod B was in the hole in the right end of the main rocking lever, it should now be placed in the hole in the left end of the lever. If the rod A was in the center of the slot in the left end of the lever, it should now be placed in exactly the same part of the slot at the right end of the lever.

5. Connect the rods to the pins in the yokes and also connect the two brush studs of similar polarity with the short cable and the main line cables to the same side of the armature as before.

6. Remove and reverse brush-holders on studs, placing the brush

with the long gib on the long arm as before. (See Fig. 100 for final arrangement, with regulator completely reversed in no-load position.)

7. Adjust brushes and start machine. If directions have been accurately followed, no further adjustments should be necessary if machine was properly adjusted for previous direction of rotation. If adjustments are necessary, see page 168 for directions.

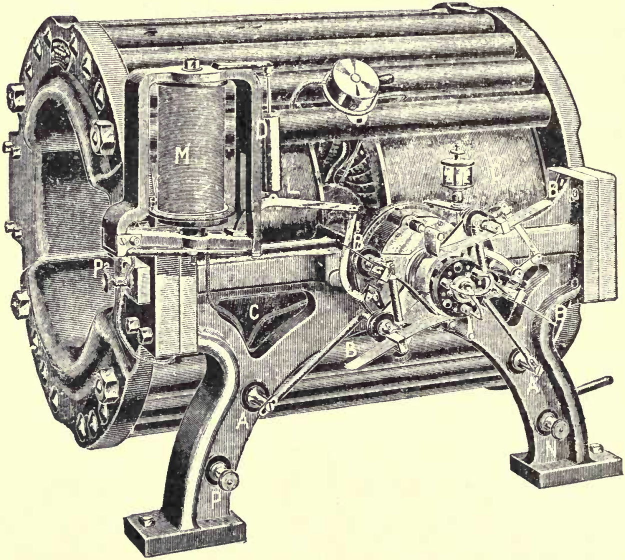


Fig. 101. — Thomson-Houston Arc Dynamo.

CHAPTER XXVI

THE THOMSON-HOUSTON ARC DYNAMO

Directions for Setting up. — See general directions 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 and flickering of the lamps. Increased speed increases ventilation.

ADJUSTMENTS

The Air-blast or Blower (Fig. 108), is attached to the back-plate on the front bearing by four bolts, *a* (Fig. 111). The armature shaft passes through the hole in the center 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.

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 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 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. 101. 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 as a bearing for the rod, the large flat-headed screw being passed through the slot in the rod, 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.

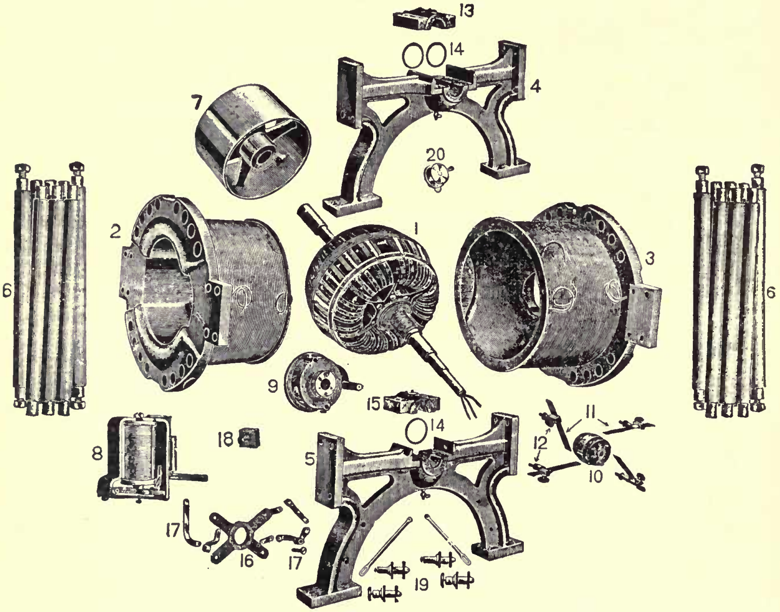


FIG. 102. — Parts of Thomson-Houston Arc Dynamo.

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 fiber bearings provided, and will fit only one way. For each of the others the hardwood bushing is placed in a 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. 101; 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 parts work freely, remove dash-pot plunger and fill about three quarters full with concentrated glycerine (cylinder oil should be used only after considerable 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 of the coil 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 on the shaft with the terminal posts on the outside, the segments being 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, set the brush-holder studs and the top negative brush according to directions on page 186; 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 No. 1 or outside armature coil; rotate the armature to the left until this wire is underneath to the right, as shown in Fig. 103, and the right-hand side of 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 coil No. 1 and the slot edge of No. 2 segment projects beyond and to the left of the tip of the top negative brush the distance or lead as given in the table of brush leads, the letters of which indicate the various types of machines, tighten the set-screws in each end of commutator, secure lead wires in proper holes, and test for correct spark length by running up to speed with full load.

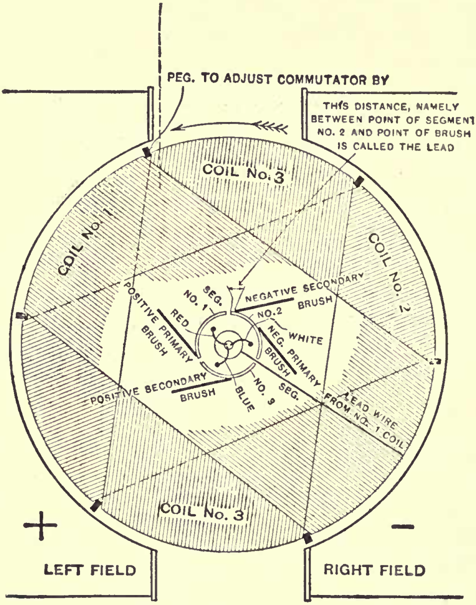


FIG. 103. — Old-Style Drum Winding.

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

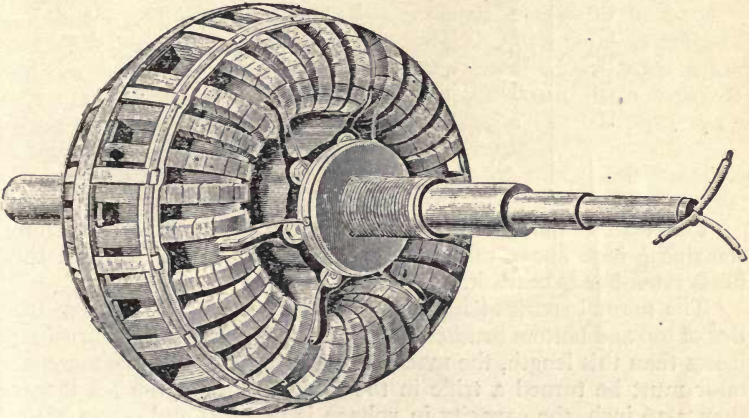


FIG. 104. — New Style Ring-Pattern Arc Dynamo Armature.

It must be understood that this adjustment of the commutator is only preliminary and that the accurate adjustment is made 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.

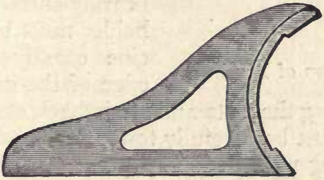


FIG. 105. — Brush-Holder Gauge.

TABLE OF LEADS.

DRUM	ARMATURES.	RING.	ARMATURES.
C^{12}	$\frac{1}{4}$″ positive.	K^{12}	$\frac{3}{16}$″ positive.
C^{2}	$\frac{3}{8}$″ “	K^{2}	$\frac{1}{8}$″ “
E^{12}	$\frac{7}{16}$″ “	M^{12}	$\frac{1}{4}$″ negative.
E^{2}	$\frac{1}{4}$″ “	M^{2}	$\frac{1}{2}$″ “
H^{12}	$\frac{1}{4}$″ “	LD^{12}	$\frac{1}{4}$″ positive.
H^{2}	$\frac{1}{4}$″ “	LD^{2}	$\frac{1}{8}$″ “
		MD^{12}	$\frac{13}{32}$″ “
		MD^{2}	$\frac{13}{32}$″ “

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

The normal spark at full load is about 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 3-16 inch, the capacity in voltage is lessened and commutator should be shifted backward, but there is less tendency to flash.

Brush-holder. — Adjustment: A brush-holder gauge (Fig. 105) is provided with each dynamo, with curved surfaces 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.

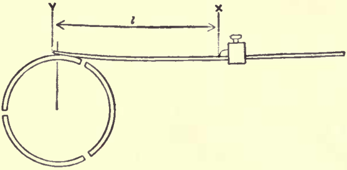


FIG. 106. — Position of Brush.

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

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. 107), the duration of this short circuit being determined by the position of the regulator.

Adjust as follows: Lower regulator to the stop; in this position, with straight brushes carefully set by gauge and with brush-holders

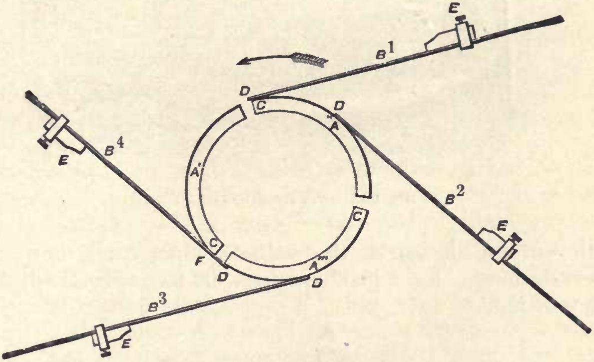


FIG. 107. — Setting of Brushes for Adjustment of Cut-out.

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 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 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 these brushes are farther back, and do not project into the slot at all, the cut-out is *strong*, and the slide is lowered to correct it.

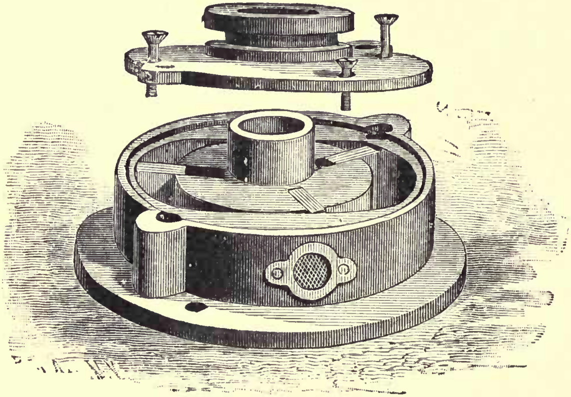


FIG. 108. — The Air-Blast.

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

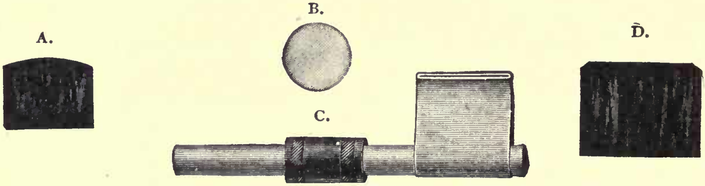


FIG. 109. — (A) Air-Blast Wing for Small Blowers (see Fig. 110). (B) Inlet Screen. (C) Air-Blast Jet. (D) Air-Blast Wing for Large Blowers. (See Fig. 112.)

Air-blast, Wings, and Jets. — Adjustment: The air-blast or blower in Fig. 108 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 enters through the screen-protected holes, B, Fig, 110, 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 bolt-holes are located to do this; the slots in the back-plate for the bolts *a*, Fig. 111, allow any slight adjustment needed. The outer or rubbing edge of the wings A or D, Fig. 110, 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. 110 and 112, which show exact position of jets), and the tip of the jet clears the segments 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 in Figs. 111 and 113, to follow 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 centrally and work freely.

Connect binding-posts P and P^2 (Fig. 114) to the corresponding posts on the dynamo. 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 the right side of box is intact; this is a shunt around contacts O, and if broken bad sparking takes place between them. Make sure that no screws are strained or loosened; that the contacts O are separated 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. 101, is short-circuited, its armature falls, and more voltage 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

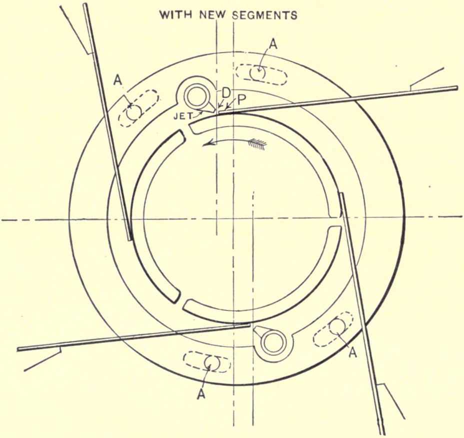


FIG. 110.

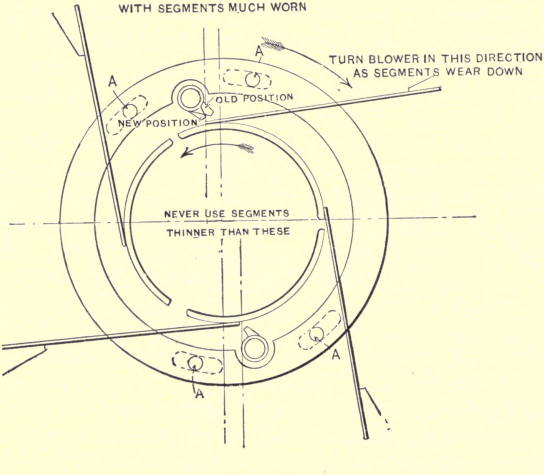


FIG. 111.

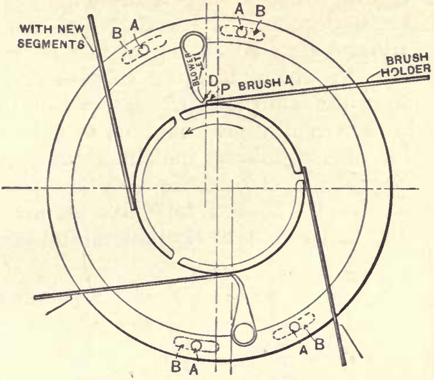


FIG. 112.

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-

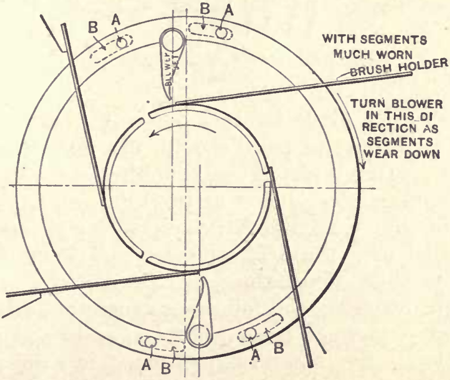


FIG. 113.

nuts N at the top of spring in regulator (Fig. 114) and weaken tension of spring S; to decrease current, draw up spring which draws up regulator. Binding-post P¹ 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 and serve as a pilot-lamp to indicate trouble on the circuit, is convenient.

Rheostat. — An arc (T. H.) machine, to be operated frequently at a small fraction of its normal capacity, requires some special device to secure the best results in regulation, and prevent excessive heating. A rheostat made for this purpose, which allows of three variations, is connected in parallel with the right-hand field of the dynamo (Fig. 114). When facing the rheostat, with the binding-posts at the bottom, the contact at the right, or No. 1, throws the rheostat out of circuit. Point No. 2 places a resistance of 44 to 46 ohms in parallel with the field winding, and Point No. 3 reduces this to 20 or 22 ohms, depending upon the capacity of the machine. With a 75-light machine, the following ranges are allowable with a rheostat: Point 1, 75 to 48 lamps; Point 2, 48 to 25 lamps; Point 3, 25 lamps or less. For other sizes of machines, the adjustment of the rheostat must be made to suit conditions. When the dynamo

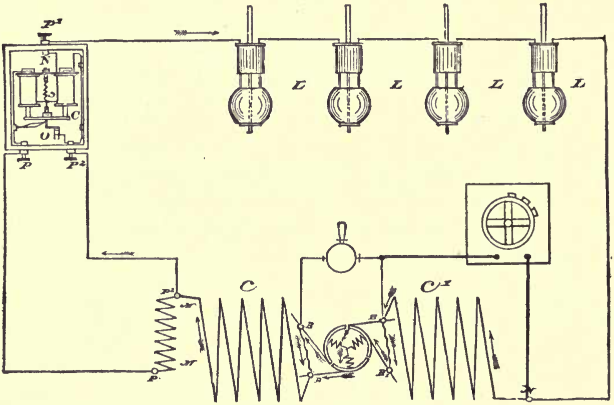


FIG. 114. — Diagram of Complete Arc-Lighting Circuit.

is thus equipped, the sparking at the commutator is somewhat greater than normal, but not detrimental.

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.

Ring Armatures. — The new Gramme ring armatures (Fig. 185), now made for the most common sizes, are interchangeable with the old style.

The iron core is made of three parts connected 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, the wedge inserted and insulated; 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.

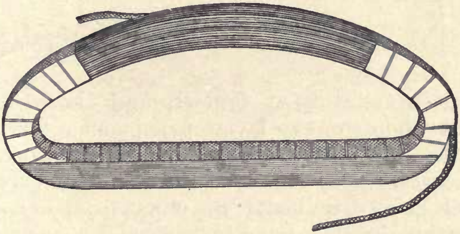


FIG. 115. — Coil with Long Terminal for Cross Connection.

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 then be removed by striking it with a block of wood. Next remove the wooden spacing blocks, move the coils around until the wedge is uncovered, cut away the core insulation for $3\frac{1}{2}$ 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.

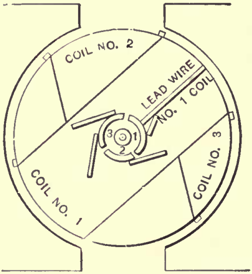


Fig. 116. — Drom Armature.

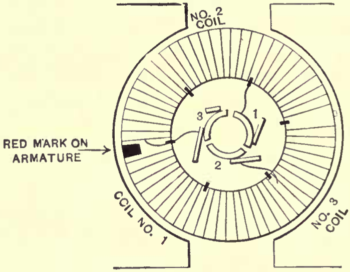


Fig. 117. — Ring Armature.

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. The newer types are not provided with core insulations, that on the coils being extra heavy, the object being to reduce heating.

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,

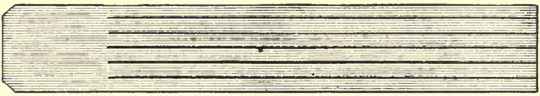


Fig. 118. — Arc Dynamo Brush.

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 connected 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.

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. 101 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 adjust 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.

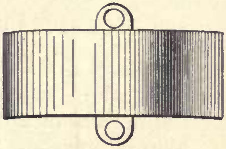


FIG. 119. — Commutator Segments, Thomson-Houston Arc Dynamo.

CHAPTER XXVII

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 the condition of dynamos; it varies a trifle with different machines, but in general, with full load and rated speed, should be about 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 186.

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

Cause 1. — *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. 110; adjust as per directions on page 189, and tighten bolts.

Cause 2. — *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.

Cause 3. — *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.

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

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

Remedy. — Reverse the wings.

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

Symptom. — Same as Cause 2.

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

Cause 6. — *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. 110–113; readjust as per directions on page 189 and tighten bolts.

Cause 7. — *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.

Cause 8. — *Commutator not set correctly.*

Symptom. — Bad flashing; machine may practically refuse to generate; if but slightly out of adjustment it flashes only 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 187.

Cause 9. — *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.

Cause 10. — *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.

Cause 11. — *Dynamo overloaded.*

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

Remedy. — Remove part of load.

A bad joint or contact or other excessive resistance in the circuit will produce same effect as overload.

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

Symptom. — Same as Cause 11.

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

Cause 13. — *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.

Cause 14. — *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.

Cause 15. — *Lint from wiping rag.*

Symptom. — Flashing with no apparent reason.

Remedy. — Stop machine; clean commutator thoroughly.

Cause 16. — *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.

Cause 17. — *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.

Cause 18. — *Dirt on insulation machine, forming partial short circuit.*

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

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

Cause 19. — *False contact or ground 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 very 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; regulator sometimes works normally, but generally settles down upon stop.

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

Cause 20. — *Break in armature circuit.*

Symptom. — Flashing and violent sparking at commutator.

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

Cause 21. — *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.

Cause 22. — *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

Cause 23. — *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.

Remedy. — Straighten out the brush (Fig. 119) and replace by gauge; tighten brush clamp, after testing length of brush with gauge. In case this does not reduce sparking, stop machine and examine all commutator adjustments.

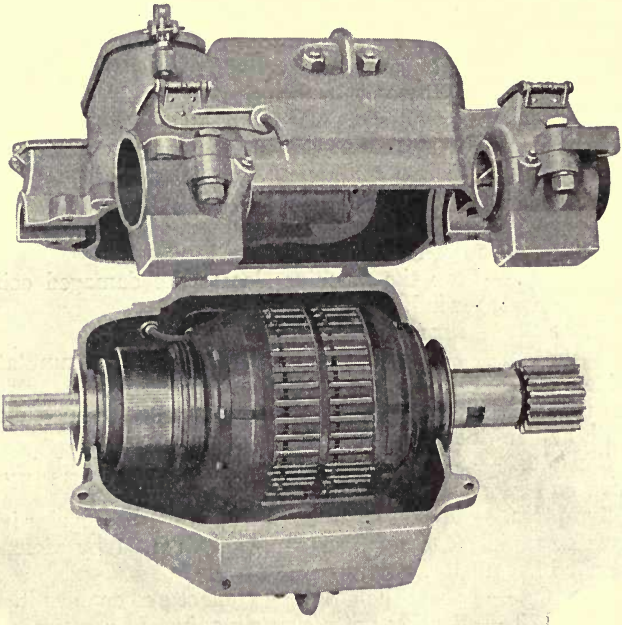


Fig. 120. — General Electric Motor — Lower Frame Dropped.

Cause 24. — *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.

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

Symptom. — Jet 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.

Cause 26. — *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.

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

Symptom. — Inspection and feeling show loose parts.

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

Cause 28. — *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 normal 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.

Cause 29. — *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.

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

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

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

Cause 31. — *Commutator grooved or rough.*

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

Remedy. — Remove segments (Fig. 121), 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 $\frac{1}{8}$ inch, as slot is widened too much then; slot should be about 5-32 inch wide.

Cause 32. — *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 134.)

SPECIAL CAUSES

Cause 1. — *Low 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.

Cause 2. — *Underload, which slightly increases current.*

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.

Although the T. H. arc dynamo is capable of being run on short circuit for hours, it is not desirable to run on less than one third full load, unless provided with field rheostat as explained on page 192.

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

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.

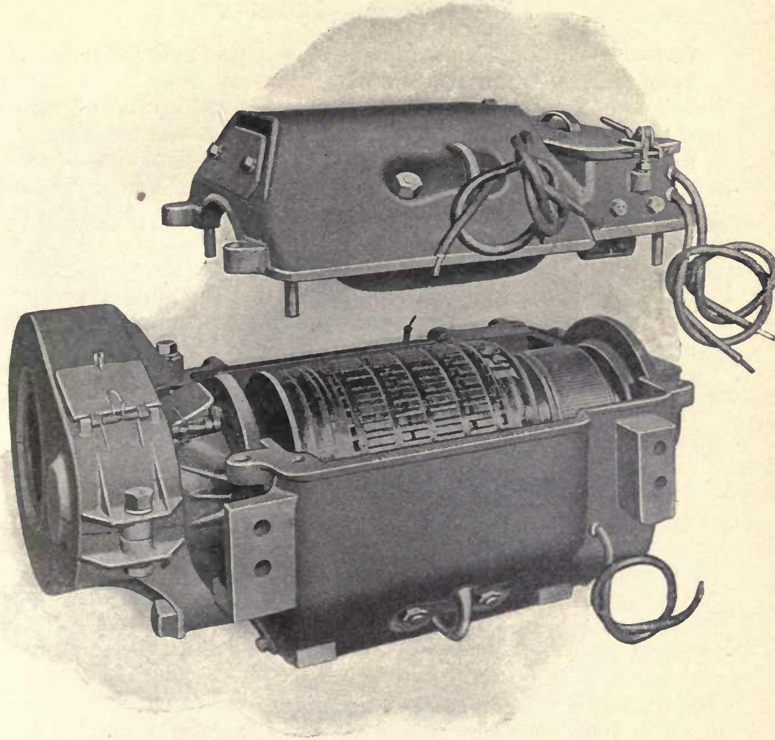


FIG. 121. — General Electric Motor — Top Frame Lifted off.

Heating of Field-magnets. (See page 137.)

Heating of Bearings. (See page 139.)

Noise. (See page 142.)

Special noise features of this machine are the spark and the air-blast jets, which increase somewhat as the load decreases. In case of sudden increase of noise, examine dynamo immediately.

Dynamo Fails to Generate. (See page 152.)

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 downward; 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.

PART V

CHAPTER XXVIII

MANAGEMENT OF RAILWAY MOTORS

Type of Motor. — The direct-current series motor possessing the advantages of powerful starting torque, adaptation of speed to load, and convenient means of speed control, is at present the usual type for traction work. The motor must in general fulfil the following conditions of mechanical design:

(*a*) It must be extremely compact, so that it may be conveniently placed in the space within the truck frame, yet easily accessible, and all parts subject to wear should be interchangeable.

(*b*) It must be entirely enclosed to prevent dust and moisture from getting into its interior.[1]

(*c*) In order to allow inspection of the commutator, brushes, etc., or removal of the armature or bearings, the enclosing case should be divided into two parts, sometimes hinged to each other, the upper part being fixed to the supports, and the lower part swinging downwards. This type, Fig. 120, is employed when the car-barn is provided with pits below the tracks; if not thus equipped, the motor casing must be so arranged that the armature, field-coils, bearings, etc., can be examined or removed through a trap door in the floor of the car, in which case the upper half of the casing lifts off (Fig. 121). The recent types of larger motors for heavy or high-speed work have box frames, being a better mechanical construction.

The modern D. C. railway motor, designed for 550-volt systems, has four poles with a two-circuit, drum-wound toothed armature and an over-wound series field. It is provided with two brush-holder studs, each of which carries two holders and carbon brushes. The

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[1] On elevated railway equipments, the motor need not be entirely enclosed, on account of freedom of roadbed from dirt and water.

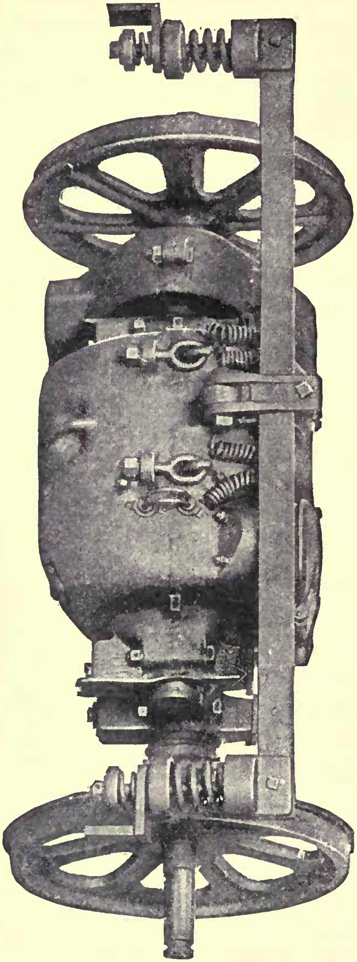


FIG. 122. — Nose Suspension.

motors are electrically reversible, and according to the position of the controller lever will drive the car forwards or backwards.

The commercial rating of a railway motor should be the h.p. output giving 75° C. rise of temperature, above a room temperature of 25° C., after a one-hour continuous run at 500 volts terminal pressure, with the motor covers removed. The required motor equipment varies according to the following considerations:

(*a*) The load (in tons) propelled per motor.

(*b*) The schedule speed in miles per hour.

(*c*) The number of stops per mile.

(*d*) The duration in seconds of each stop.

(*e*) The acceleration to be developed in miles per hour per second.

(*f*) The brake retardation to be developed per second in miles per hour.

(*g*) Closed or open construction according to conditions.

(*h*) The grades and curves existing on the line.

(*i*) Test runs made in both directions over the same track.

One 20 or 30 h.p. motor will handle heavily loaded 20 or 22 foot cars on a 4 per cent grade, but such equipments are not advisable, on account of liability of a single pair of drivers to slip when the

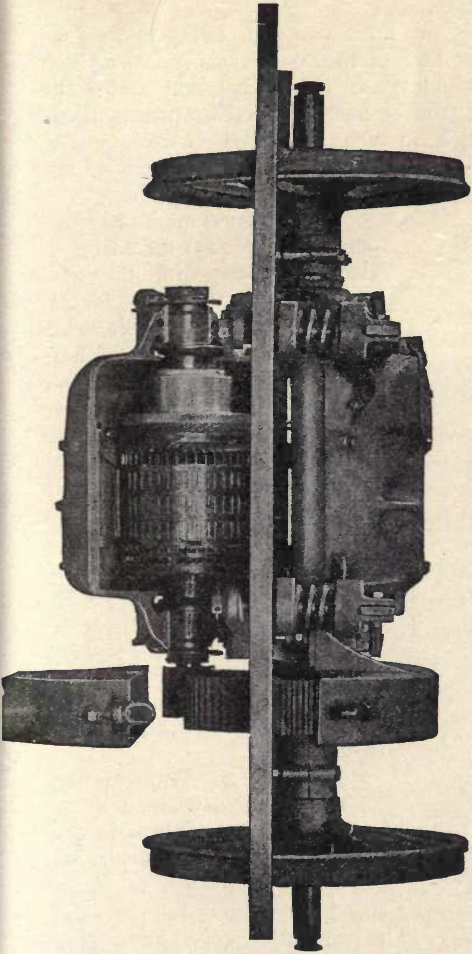


FIG. 123. — Parallel Bar Suspension.

rails are wet or covered with ice. The pounding is also concentrated and the series-parallel method of control is not applicable. In the case of long double-truck cars, not less than two 30 h.p. motors should be employed. For interurban service, two 50 to 75 h.p. equipments are employed, depending upon the size of the car, speed, etc., and four 125-h.p. motors have been used upon a system designed for a maximum speed of 75 miles per hour on a level track.

Motor Suspension. — To minimize the pounding action of the car wheels, the weights resting upon them must be so arranged that when the wheels are lifted by any unevenness of the track surface, the center of gravity of the total mass shall be raised the least possible amount; in addition, the suspension must be such that the connection between motor and driving axle is rigid, so as to keep the gears in mesh. Two general methods of suspension are employed:

(*a*) Nose Suspension.

(*b*) Parallel Bar Suspension.

The former (Fig. 122) is the more common, being effected as follows: The upper or lower half of the motor casing is provided with two bearings through which passes the driving axle, and at the other end of the casing is a stud or nose, secured by means of the spring to a cross-bar, which in turn is secured at each end to the truck frame. In some cases the nose is secured directly to the cross-bar, which then rests upon springs on the truck frame.

In the second method of suspension (Fig. 123) the casing is also equipped with the axle bearings, but the nose is dispensed with, the support being obtained by means of two bars rigidly attached to either side of the motor, the ends of these bars being suspended from or secured to the trunk frame by suitable springs. The object in either case, besides that of supporting the motor, is to keep it from climbing up or down on the gearing, according to the direction of rotation, and consequently the spring suspension must be designed to overcome the upward or downward motion at the other end of the casing.

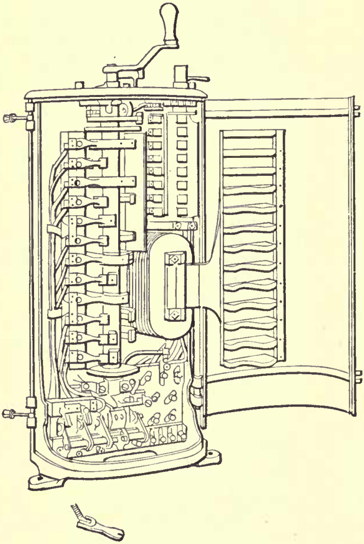


Fig. 124. — Type K 7 Controller.

Methods of Transmission. — The power developed by the motor is usually transmitted to the driving shaft by single reduction spur gearings. The employment of double reduction gearing was necessary with earlier forms of railway motors designed to run at 1,000 to 1,200 r.p.m. and requiring a speed reduction of 10: 1 to 15: 1, which was both costly and noisy. The present low-speed motor operating at 400 to 500 r.p.m., requires but a single reduction in speed of 4: 1 to 5: 1. The best results have been obtained with steel gears, the pinions having 14 to 18 teeth, which will when well lubricated, run about 2,600 miles of car travel under heavy load conditions.

For very heavy work, the gearless motor is sometimes employed, on account of increased efficiency due to the absence of gear losses, though pounding is increased.

The gears should be enclosed in a casing which serves two functions; one being to hold the gear lubrication, and the other to prevent foreign matter, such as dust, grit, or stone, from being drawn between the gears.

Lubrication. — Both grease and oil are used as lubricants, the former having given better results in ordinary street service, on account of its dust-tight properties. Grease has to-day universally superseded oil as a lubricant for street railway motor bearings and trucks, except on some elevated railways, where both are used. It is advisable to employ two slightly varying qualities of grease, one for winter and one for summer use.

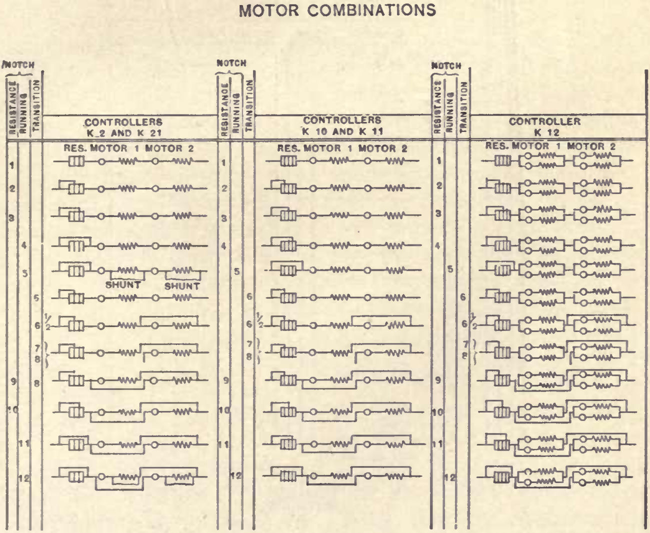


FIG. 125. — Steps in Operation of K 2, 21, 11, and 12, General Electric Controllers.

All active cars should be regularly greased every day, when two pounds of grease for each gear is sufficient, whereas the axle grease cups should be entirely filled. Sometimes, however, such cars need not be greased for three days in cold weather.

A good axle grease for summer use consists of:

	Per cent
Tallow	22.00
Palm Oil	12.50
Sperm Oil	1.30
Crystallized Soda	5.20
Water	59.00

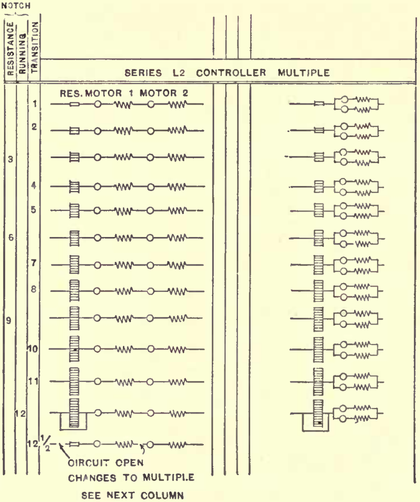


FIG. 126. — Steps in Operation of Type L 2, General Electric Controller.

The first three should be heated and melted in one vessel to about 80° C., and the soda and water separately heated until just below the boiling point. They should then be mixed and continuously stirred until the mass is cool. The hardness of the product varies directly with the cooling.

For winter use the following is suitable:

	Per cent
Tallow	18.75
Palm oil	12.50
Sperm oil	1.75
Crystallized soda	5.70
Water	61.30

Another good grease for gears consists of graphite 1 part, lard 4 parts, to which a very small quantity of camphor is added.

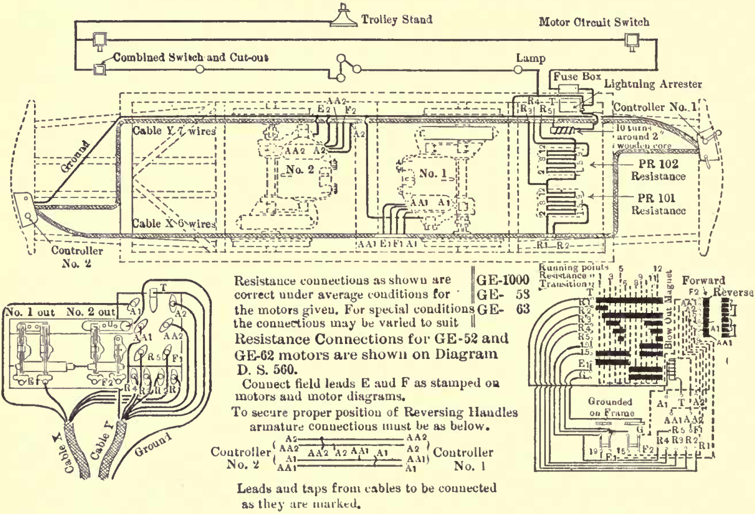
When grease is the lubricant particular care should be taken to prevent its entering the motor. Grease and oil are insulators in themselves, but have a serious rotting and disintegrating effect upon the insulation.

Interchangeability. — It is well to have all motors and trucks of one make, to enable rapid interchangeability and transference of armatures, field-coils, etc., of summer and winter cars. This also reduces cost of maintenance, which is often excessive in electric railway systems.

The changing of field-coils is sometimes necessary on account of failure of the insulation or failure of conductors. The former involves short circuits and grounds, whereas the latter results in an open circuit. The principal faults which occur in the field-coils belong to the former class. Grounds are most frequent and should be tested for first. A convenient method of testing employs five lamps in series for a 500-volt circuit, as explained on page 97. The ground screw in this test should of course be disconnected. A ground in the field-coils of a railway motor makes an enormous demand for current, all of which flows through the windings of the armature, producing excessive heating and flaring at the commutator, also showing burnt spots upon it. These bad burns on the commutator generally indicate a grounded field. The resistance of each field-coil should be measured separately, to detect a short circuit in one of them producing a weak field, but would not be shown by the test for a ground. After locating the trouble in a field-coil it should be replaced by a new one. These short circuits and grounds are frequently due to water getting on the lower field-coils, or to overloads on steep grades, etc. With modern equipment and experienced men, lower coils can usually be changed in half an hour, the upper ones taking about twice as long.

Controllers. — The speed regulator for railway purposes is generally called a *controller*, and being exposed to dirt and wet is entirely enclosed. The controller used with a single-motor equipment is practically the same as any other single-motor starting-box, excepting that the resistance has sufficient carrying capacity to be left in circuit some time. When the motor is to operate at full speed all the resistance is cut out. To change the direction of rotation of the armature and of car travel, a reversing notch is placed in the armature or field circuit, but not in both. Since a railway motor is started and stopped so frequently, the arc which forms when the circuit is opened would injure or ruin the contact tips if maintained for even short intervals; to prevent this a magnetic field is used, with such polarity that it blows out the arc instantly.

With the two-motor equipment the controller becomes more complicated, because the wiring allows the motors to be placed in series or in parallel, giving the series-parallel control, with economical operation at one half and at full speeds. The continued use of resistance wastes power by C^2 R losses, and should be employed only for intermediate steps, not for continuous running. The connections to the motors are made inside the controller case, one at each end. Inside of the case (Fig. 124), is a long spindle, carrying a number of heavy brass or gun-metal segments, making contact for a longer or shorter time with a corresponding number of spring contacts. The spindle is provided at its upper end with



Resistance connections as shown are correct under average conditions for the motors given. For special conditions the connections may be varied to suit

Resistance Connections for GE-52 and GE-62 motors are shown on Diagram D. S. 560.

Connect field leads E and F as stamped on motors and motor diagrams.

To secure proper position of Reversing Handles armature connections must be as below.

Leads and taps from cables to be connected as they are marked.

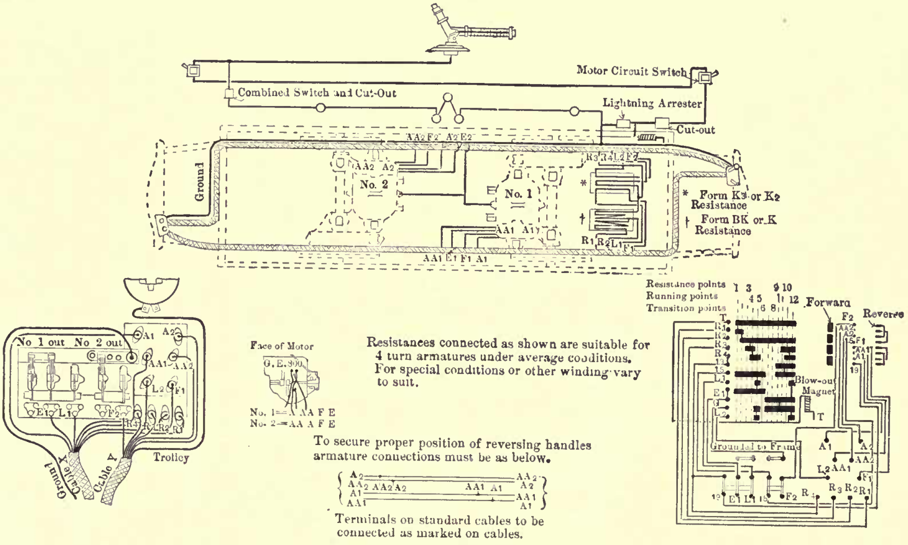
FIG. 127. — Car Wiring for K 10 General Electric Controllers with two Motors.

a handle, and the various contacts are made by turning it through an arc of about 150°. For this method a moderate amount of resistance is employed. The first contact joins both motors and the full amount of resistance in series across the line, and as the motors are standing still maximum current flows so that they exert their full torque. The moment they start to revolve, the current tends to fall, due to the generation of a c.e.m.f.; to prevent this and maintain a heavy current for some time, thus obtaining rapid acceleration, the resistance is arranged so that it can be gradually reduced, until at about the fourth notch (as in G. E. K 2 and K 21 controllers) the two motors are in series without resistance across the line. To increase still further the speed in the above type of controller, the series fields may be shunted, and then the next steps place the motors in parallel with the resistance in series, which is gradually cut out again, giving maximum speed at the last notch. The points which involve resistance in circuit are called resistance points and are not for continuous use. Figs. 125 and 126 represent the various steps in the more important forms of controllers.

Wiring. — The wire or lead, from the trolley base, or contact shoe, passes through both main motor switches to a suitable location for connecting the lightning arrester and fuse box; also the lamp and heating circuits, leaving ends to be connected from the lamp circuits, heater circuits and lightning arrester to the ground. The main lead is continued to the controller, from which the connections are made to the motor by means of cables and then from the motors to ground points usually made at both controller cases. Figs. 127, 128, 129 and 130 indicate the standard wiring for two- and four-motor car equipments, and are for G. E. controllers as they are the types generally employed.

Cleaning and Inspection. — All motors should be cleaned after each day's run, and the car overhauled in every detail and scrupulously cleaned about every eight weeks. On account of the hard usage which a railway motor receives it should never be run 24 hours in succession.

Electric railway motor repairs may be very much reduced by a careful system of inspection. After a thorough mechanical inspection the more difficult electrical inspection should be made. Any trouble and time which this involves is always amply repaid in the end. For example, faulty insulation can be detected before it breaks down and causes a weak field, burning out of an armature



Resistances connected as shown are suitable for 4 turn armatures under average conditions. For special conditions or other winding vary to suit.

To secure proper position of reversing handles armature connections must be as below.

Terminals on standard cables to be connected as marked on cables.

FIG. 128. — Car Wiring for General Electric K 2 Controllers with Two Motors.

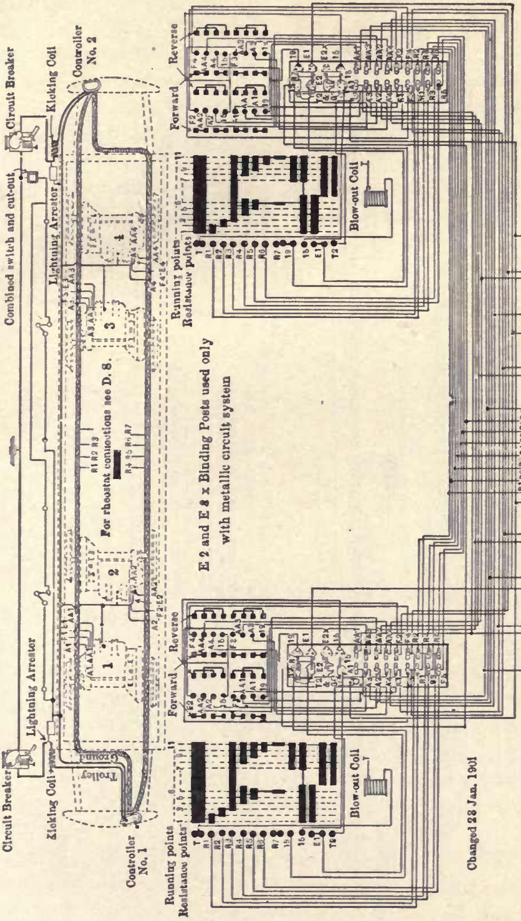
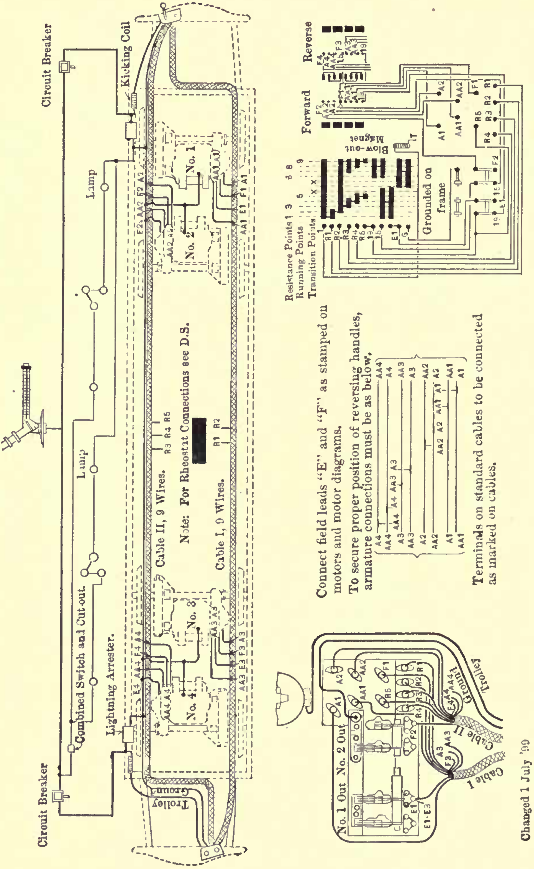


FIG. 129. — Car Wiring for K 6 Controllers with Four Motors.



Note: For Rheostat Connections see D.S.

Connect field leads "E" and "F" as stamped on motors and motor diagrams.

To secure proper position of reversing handles, armature connections must be as below.

Terminals on standard cables to be connected as marked on cables.

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FIG. 130. — Car Wiring for K 12 Controllers with Four Motors.

or destruction of a commutator. A convenient method of making such inspection is here given.

The car house is provided with an insulated section of track and its corresponding insulated trolley wires. The feeders of this track section and trolley wire pass to a suitable located room near the insulated section. In this testing room are located switches whereby the trolley wire can be connected to the power feeders and the rails to the ground. A double-pole double-throw switch is found to be most convenient for this purpose, as it readily permits the car being transferred from the power feeders to the testing circuit, the connections being shown in Fig. 131.

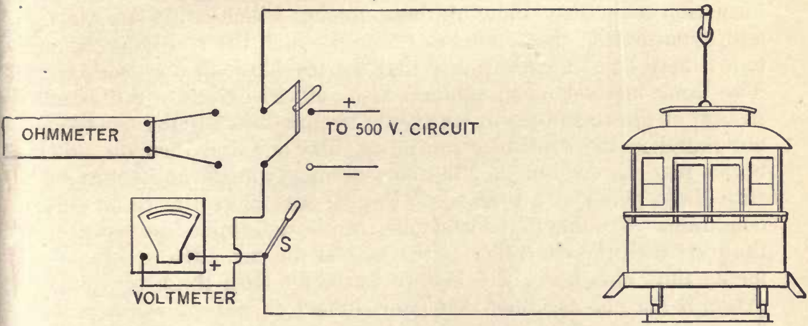

FIG. 131. — Connections Car Test Room.

Connection is first made to the ohmmeter and the resistance of the electrical equipment on every notch of the controller is quickly observed and recorded. The ohmmeter is then cut out, the ground connection broken by a convenient switch S, and a 500-volt pressure is applied with the voltmeter in series, the deflection of the latter being noted. This deflection is then compared with that obtained preferably on the first notch of the controller when all the resistance and other parts of the circuit, including ground, are connected. From these deflections the actual insulation resistance in ohms of the equipment may be calculated (see page 99), but a quantitative determination is not necessary as a limiting deflection can be set, and any car with which this deflection is exceeded can be noted for repairs. The results should be tabulated in a suitable log book. These measurements take but a few moments per car and much may be learned from the records. For instance, if it is noted that the resistance of a car on a certain notch becomes less and less from day to day, it is likely that some of the resistance coils are gradually short-circuiting on each other. If, on the other hand, the resistance measurements become larger from time to time, an inspection will probably show poor contacts in the controllers, on the commutator, or elsewhere in the motor circuits. The insulation resistance of the car from trip to trip may be watched, and long before a ground occurs and creates serious damage, it can be anticipated and removed.

If the car is found to be defective and departing considerably from its usual measurements, the fault can be run down at once while the car is standing on the test station. If, for instance, the insulation resistance is low on these notches which cut in resistance, and is normal on those notches through which the resistance is cut out, it may be assumed at once that the trouble is in the resistance. The same method of elimination also suffices to locate the actual section of the resistance in which the trouble lies. If the trouble is not found in the controller resistance, first one and then the other motor may be cut out and the measurements made and compared with those taken at a time when the car was known to be in good condition. Trouble in the controller can be determined by repeating the tests with the controller at the rear of the car. If the measurements thus obtained are found to be better than those previously made, it may be assumed that poor contact or leakage exists in the first controller. The heater circuit may also be tested in this way.

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