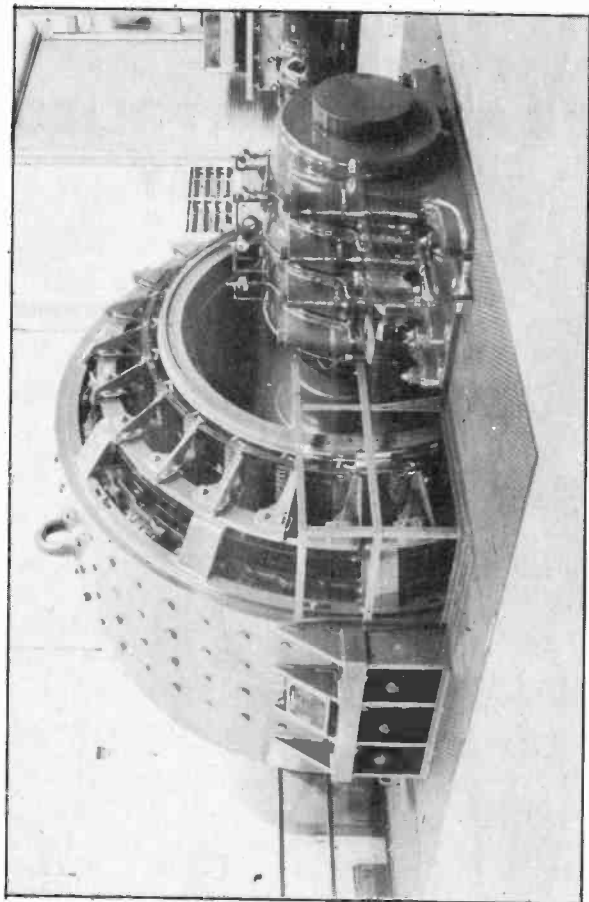


**COYNE**  
**PRACTICAL APPLIED**  
**ELECTRICITY**



This photo shows a mammoth Direct Current mill motor. Large equipment of this type is used extensively in steel mills and other large manufacturing plants.

# COYNE PRACTICAL APPLIED ELECTRICITY

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A Set of Complete Practical Books  
For Home Study  
and  
Field Reference  
On

Electrical principles, telephones, wiring, meters, D.C. and A.C. motors, controls, and equipment, household appliance repair, Rural Electrification, Armature winding, Generators, Diesel Electric Plants, Automotive Electricity, Batteries, Electrical Refrigeration and Air Conditioning, Industrial Electronics, Radio Electric Welding — laws, rules, etc. — Over 3,000 subjects, 5,000 Electrical facts, thousands of photos and diagrams.

By  
THE TECHNICAL STAFF  
of the  
COYNE ELECTRICAL SCHOOL

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Chicago, Illinois

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## FOREWORD

**ELECTRICITY** is the greatest force known to mankind.

**ELECTRICITY** is leaping ahead at an unbelievable rate. It is moving into practically every part of the world and has become **the most important factor in modern civilization**. Practically every month the Kilowatt hour demand sets a new high—it has been doing this for the past 25 years. **ELECTRICITY**, even though it is one of America's youngest industries, already employs directly and indirectly over 3 million people.

All of our marvelous developments in Radio, Television, Electronics, Radar, etc., employ **electrical power** and the principles of **Electricity**. It is truly **one of the world's greatest industries**.

Because of the tremendous opportunity in the field of **Electricity**, there have been many books written on the subject. Most treat with **one** specific phase of **Electricity**. This set of books—Coyne Practical Applied Electricity (of which this volume you now read is an integral part)—covers the entire field.

This set is **NEW**. It includes the very latest methods and explanations of Electrical installation, operation and maintenance.

### **COYNE PRACTICAL APPLIED ELECTRICITY WRITTEN BY A STAFF OF EXPERTS**

Most Electrical publications are written by **one man** and can therefore **only** cover his own specific knowledge of a subject. **COYNE PRACTICAL APPLIED ELECTRICITY**, however, represents

## F O R E W O R D

the combined efforts of the entire Coyne Electrical School Teaching Staff and the assistance of other authorities on the subject. These men have a wide field and teaching experience and practical knowledge in electricity and its allied branches.

### HOW THIS SET WAS DEVELOPED

In submitting any material for these books these experts kept two things in mind—1. MAKE IT SIMPLE ENOUGH FOR THE “BEGINNER”—2. MAKE IT COMPLETE, PRACTICAL and VALUABLE FOR THE “OLD TIMER”. All material that was submitted for these books by any individual was then rewritten by an editorial group so that added explanations for the benefit of clarity and easier understanding could be included.

**Coyne Practical Applied Electricity** can pay you big dividends every day “on the job”. However, if you only use the set occasionally when you **MUST BE SURE** before going ahead on a job—the set will pay for itself many times over.

Coyne Practical Applied Electricity is to an electrician what a set of complete law books is to a lawyer or a set of medical books is to a doctor. Regardless of whether a lawyer or a doctor is “just starting out” or is an “old timer” and has been practicing his profession for many years he has many occasions to refer to his reference books. Many doctors and lawyers spend thousands of dollars on complete sets of reference books—they find it a very wise investment.

In **ELECTRICITY** the need for good reference books is just as great. So, when you make a purchase of this set you are not just buying a set of books—you are making an investment in your future that can pay dividends all your life.



PRESIDENT  
COYNE ELECTRICAL SCHOOL

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# ACKNOWLEDGMENTS

We wish to acknowledge and express our appreciation for the assistance and co-operation given by the following companies, in supplying data and illustrations for the preparation of this Electrical Set.

GENERAL ELECTRIC COMPANY  
WESTINGHOUSE ELECTRIC & MFG. CO.  
ALLIS CHALMERS MFG. CO.  
POWER PLANT ENGINEERING JOURNAL  
AMERICAN BROWN BOVERI CO.  
CUTLER HAMMER, INC.  
PHILADELPHIA ELECTRIC CO.  
EDISON STORAGE BATTERY CO.  
PHILADELPHIA BATTERY CO.  
WALTER BATES STEEL CORP.  
FAIRBANKS MORSE CO.  
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NATIONAL CARBON CO.  
CENTRAL SCIENTIFIC CO.  
OHIO BRASS CO.  
GRAYBAR ELECTRIC CO.  
WELSH SCIENTIFIC CO.  
CENTRAL SCIENTIFIC CO.

You will note that in some places in this Set we have explained and shown illustrations of some of the earlier types of Electrical equipment.

WE HAVE A DEFINITE REASON FOR DOING THIS, namely, many of the earlier units are much easier to understand. An important point to keep in mind is that the BASIC PRINCIPLES of these earlier machines are the same as those of the modern equipment of today.

Modern equipment has not materially changed in principle — IT IS MERELY REFINED AND MODERNIZED. It is from the earlier basic theories and simple beginnings that the complicated mechanisms of today have been developed. IT IS TO THESE EARLY BEGINNINGS WE MUST OFTEN TURN IN ORDER TO GET A FULL UNDERSTANDING OF THE PRESENT ADVANCED TYPES OF EQUIPMENT.

In the early days many of the parts and mechanism of Electrical equipment were visible whereas today much of it is not. However, the PRINCIPLES OF THE EARLY EQUIPMENT ARE SIMILAR TO THOSE OF MODERN ELECTRICAL APPARATUS.

SO IN VARIOUS PLACES IN THIS SET, WE SHOW YOU SOME OF THIS EARLIER EQUIPMENT BECAUSE ITS CONSTRUCTION IS SIMPLER AND EASIER TO UNDERSTAND AS YOU STUDY THE MODERN EQUIPMENT. THEN FROM THESE EARLIER TYPES OF EQUIPMENT WE CARRY YOU ON TO THE VERY LATEST DEVELOPMENTS IN THE FIELD.



# HOW TO USE THIS SET OF BOOKS

Coyne Practical Applied Electricity will be of use and value to you in exact proportion to the time and energy you spend in studying and using it.

A Reference Set of this kind is used in two distinct ways.

FIRST, it is used by the fellow who wishes to make Electricity his future work and uses this Reference Set as a home training course.

SECOND, it is especially valuable to the man who wishes to use it strictly as a Reference Set. This includes electricians, mechanics or anyone working at any trade who wishes to have a set of books so that he can refer to them for information in Electrical problems at any time.

You, of course, know into which group you fall and this article will outline how to properly use this Set to get the most value for your own personal benefit.

## **How To Use This Set As A Home Training Course In Electricity**

The most important advice I can give the fellow who wishes to study our set as a home training course in Electricity is to start from the beginning in Volume 1, and continue in order through the other 6 volumes. Don't make the mistake of jumping from one subject to another or taking a portion of one volume and then reverting back to another. Study the set as it has been written and you'll get the most out of it.

Volume 1 is one of the most important of the entire Set. Every good course of training must have a good foundation. Our first volume is the foundation of our course and is designed to explain in simple language terms and expressions, laws and

## **How To Use This Set of Books**

rules of Electricity, upon which any of the big installations, maintenance and service jobs are based. So, become thoroughly familiar with the subjects covered in the first volume and you will be able to master each additional subject as you proceed.

One of the improvements we made in this set was to add "review" questions throughout the books. You will find these questions in most cases at the end of a chapter. They are provided so "beginners" or "old timers" can check their progress and knowledge of particular subjects. Our main purpose in including the "review" questions is to provide the reader with a "yardstick" by which he can check his knowledge of each subject. This feature is a decided improvement in home study material.

Above all, do not rush through any part of these books in order to cover a large amount at one time. You should read them slowly and understand each subject before proceeding to the next and in this way you will gain a thorough understanding as you read and think it out.

For the special benefit of the fellow desiring to learn Electricity at home, we have prepared a great number of diagrams and illustrations. Refer to these pictures and diagrams in our books regularly.

### **How To Use Coyne Practical Applied Electricity Strictly As A Reference Set**

The man who is interested in using these books mainly for reference purposes will use it in a little different way than the fellow who is trying to learn Electricity as a trade. Some of the types of fellows who use this set strictly for reference purposes are: home owners, electricians or mechanics, garage owners or workers, hardware store owners, farmers or anyone who has an occasional use for electrical knowledge. Those types of fellows should use this set in the following manner.

If some particular type of electrical problem presents itself, refer immediately to the Index—it will give you the section in which the subject is covered.

## How To Use This Set of Books

Then, turn to that section and carefully read the instructions outlined. Also read any other sections of the set mentioned in the article. As an example, in checking over some information on electric motors, some reference might be made to an electrical law of principles contained in Volume 1 of the Set. In order to thoroughly understand the procedure to follow in working out the electrical problem, you should refer to Volume 1 and get a better understanding of the electrical law on principles involved.

### Use The Master Index To Locate Electrical Subjects

Thousands of men use this Set in their daily problems, both on the job and around the home as well. If you follow the instructions outlined you will be able to locate any information you may want at any time on your own electrical problems.

And here's a very important point. Although this set of books starts in Volume 1 and proceeds through the other 6 volumes in order, it makes an ideal home study course—nevertheless, **any individual book in the series is independent of the others and can be studied separately.** As an example, Volume 3 covers D.C. motors and equipment. If a man wanted to get some information on D.C. machines **only he could find it completely covered in this volume** and it would not be essential to refer to any other volume of the set unless he wanted some additional information on some other electrical principle that would have a bearing on his problem.

This feature is especially beneficial to the "old timer" who plans to use the set mainly for field reference purposes.

**We believe, however, that the entire set of 7 volumes should be read completely by both the "beginner" or the expert.** In this way you get the greatest benefit from the set. In doing so the experienced Electrician will be able to get very valuable information on subjects that he may have thought he was familiar with, but in reality he was not thoroughly posted on a particular subject.

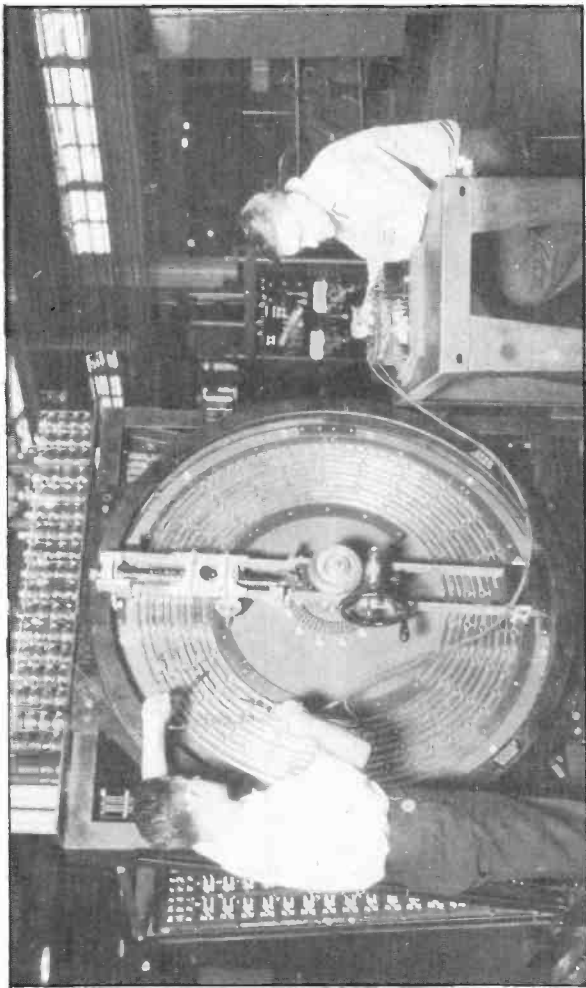


Photo shows workmen testing intricate electrical control system in a mid-western steel mill. Testing with instruments and meters is covered completely in this book.

## DIRECT CURRENT

Direct current energy and machines are very extensively used for traction work and certain classes of industrial power drives.

The principal advantages of D. C. motors are their very excellent starting torque and wide range of speed control.

D. C. motors are ideal for operating certain classes of machines which are difficult to start under load, and must be driven at varying speeds, or perhaps reversed frequently. Their speed can be varied over a very wide range, both above and below normal speed.

Many thousands of factories and industrial plants use electric motors exclusively for driving various machines, and in certain classes of this work D. C. motors are extensively used. They are made in sizes from 1/10 h. p. to several thousand horse power each, and are used both for group drive and individual drive of various machines.

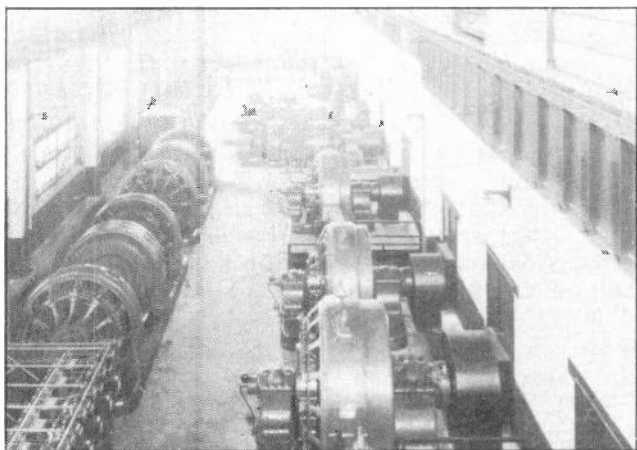
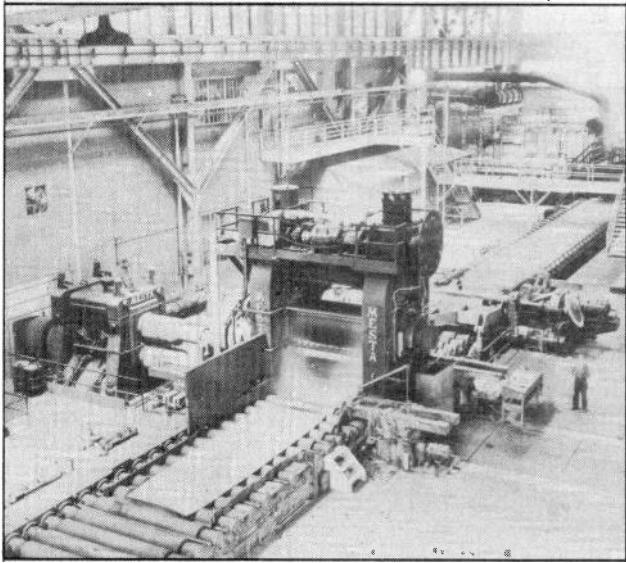


Fig. 1. This photo shows a group of large D. C. motors in use in a steel mill. Machines of this type, ranging from several hundred to several thousand horsepower each, are used in this work.

Fig. 1 shows an installation of large D. C. motors in use in a steel mill. These motors are located in the power room as shown, and are connected to

## D. C. Power

shafts extending through the wall at the right, to drive the great rolls which roll out the hot steel in the adjoining room.



LARGE MACHINES LIKE THIS USED TO ROLL OUT STEEL INTO STRIPS ARE POWERED BY HEAVY DUTY ELECTRICAL-EQUIPMENT.

For operation of street cars and elevated trains in cities, and electric railways across the country, series D. C. motors are extensively used, because their great starting torque enables them to easily start a loaded car or train from a standing position, and quickly bring it up to very high speeds.

Fig. 3 shows a powerful electric locomotive which is driven by several electric motors of several hundred horse power each.

D. C. motors are commonly made to operate on voltages of 110, 220, and 440, for industrial service; and from 250 to 750 volts for railway service.

Elevators in large skyscraper office and store buildings also use thousands of powerful D. C. motors, to smoothly start the loaded cars and swiftly shoot them up or down; ten, forty, or 70 stories as desired.

## Direct Current

Here again their good starting torque, smoothness of operation, and accurate control for stopping exactly at floor levels, make them very desirable.

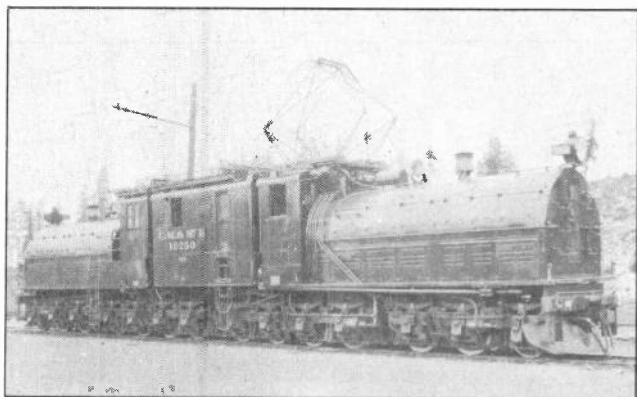


Fig. 3. Electrical locomotives of the above type often use six or eight powerful D. C. motors to turn their driving wheels.

One modern type of elevator equipment uses direct current motors and what is known as variable voltage control. The variable voltage for each elevator motor is supplied by a separate D. C. generator, which is designed to vary its voltage as the load on the car varies, thus providing even speed regulation and extremely smooth starting and stopping.

Fig. 4 shows a large D. C. elevator motor with its cable drum and magnetic brake attached on the right hand side.

Because of the extensive use of direct current for elevators in large buildings, and for traction purposes, some large cities have their central business districts supplied with D. C., and the outlying districts where the power must be transmitted farther are supplied with A. C.

Direct current generators are used to supply the direct current wherever it is extensively used; and many privately owned power plants use D. C. generators because of the simplicity of their operation in parallel, where several are used.

In the operation of D. C. generators the speed at which they are driven is not as critical as it is with

## D. C. Power

A. C. generators. Small D. C. generators can be belt driven; but this is not practical with A. C. generators, because a slight slip of the belt would cause their speed to vary, and make trouble in their parallel operation

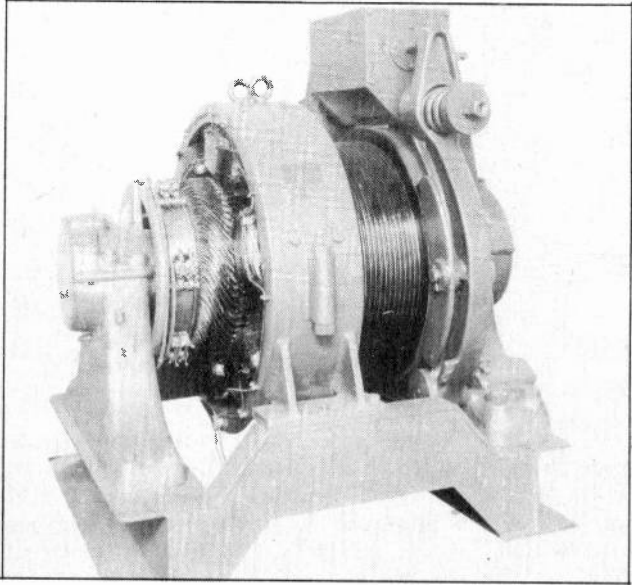


Fig. 4. This photo shows a D. C. elevator motor with the magnetic brake on the right end of the cable drum.

D. C. generators are made in sizes from 60 watts for automotive use, up to those of several thousand kilowatts for industrial and railway power plants. Their voltages range from 6 volts on automotive generators to 440 volts for industrial purposes; and on up to 600 and 750 volts for railway work.

The smaller sizes for belt drive operate at speeds from 300 to 1800 R. P. M., while the larger sizes which are direct connected to steam, oil, or gas engines, run at speeds from 60 to 250 R. P. M.

When these generators are driven by direct shaft connections to reciprocating steam engines, a large flywheel is usually provided on the same shaft to produce a more even speed. It will also deliver power to the generator during suddenly increased loads, until the engine governor can respond.



## Direct Current

D. C. generators are not so well adapted for direct connection to steam turbines, because of the very high speeds of the turbines, and the great stress these speeds would set up in the commutators and windings of the generators.

When driven by turbines, they are usually coupled together by gears. For example a 360 R. P. M. generator can be driven by a 3600 R. P. M. turbine, through speed reducing gears with a ratio of 10 to 1.

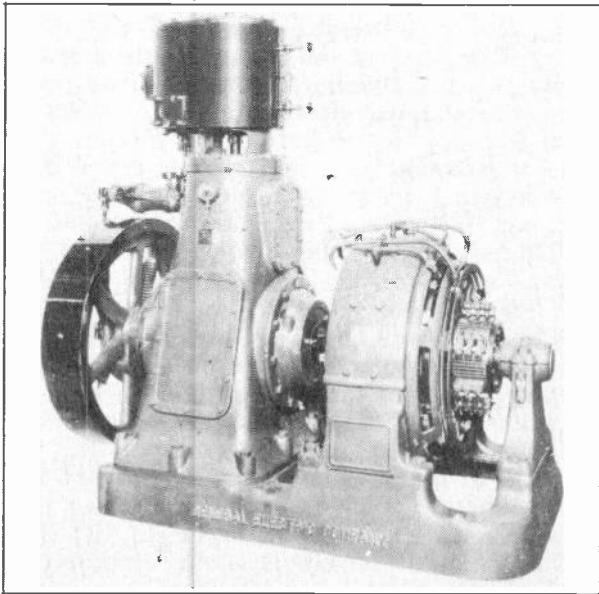


Fig. 5. Small engine-driven D. C. generators of the above type are used in a great number of privately owned power plants.

Fig. 5 shows a small D. C. generator driven by a vertical steam engine. Note the flywheel used to maintain even speed and voltage, and also note the commutator and brushes which are in plain view on this generator.

Direct current is not much used where the energy must be transmitted over distances more than one-half mile to a mile, as it requires high voltage to transmit large amounts of power over longer dis-

## D. C. Power

tances; and it is usually not practical to operate large D. C. generators at voltages above 750.

Where large amounts of power are used in a compact area, such as in a large factory, in mines, steel mills, or densely built up business section of cities, D. C. finds its greatest use.

Where direct current is desired for use at a considerable distance from the location of the power plant, alternating current may be used to transmit the energy at high voltage, to a substation in which a motor generator set is used to produce D. C.

Fig. 7 shows a motor generator of this type, consisting of an A. C. motor on the left, driving a D. C. generator on the right. In this case the two machines are coupled directly together on the same shaft.

Other common uses for Direct Current are for electro-plating, electrolytic metal refining, battery charging, operation of electro-magnets, farm lighting plants, and automotive equipment.

D. C. generators for electro-plating and electrolytic refining, are made to produce low voltages, from 6 to 25 volts, and very heavy current of several thousand amperes on the larger machines.

Garages use thousands of small motor generators, to produce D. C. for battery charging; and stores and plants using large fleets of electric trucks, charge their batteries with D. C. from larger charging generators.

Train lighting with the thousands of batteries and generators for this work is another extensive field for D. C. equipment.

Many thousands of D. C. farm lighting plants are in use throughout this country, supplying direct current at either 32 volts or 110 volts for light and power on the farms.

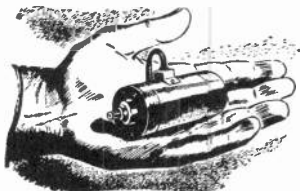
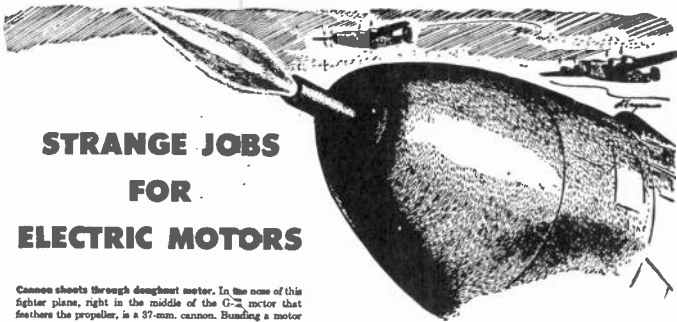
Powerful electro-magnets requiring direct current for their operation, are used by the thousands to speed up the handling of iron and steel materials in industrial plants, railway shops, etc. Fig. 8 shows a large magnet of this type which is used for lifting kegs of nails and bolts. This illustration also shows how the magnetism acts through the wooden kegs,

## Direct Current

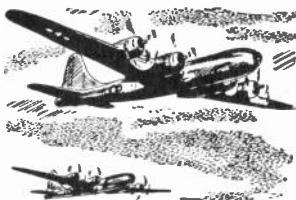
proving what we have learned in an earlier lesson—that magnetism cannot be insulated.

### STRANGE JOBS FOR ELECTRIC MOTORS

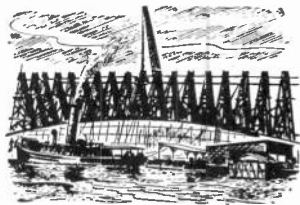
Cannon shoots through doughnut motor. In the nose of this fighter plane, right in the middle of the G-2 motor that feathers the propeller, is a 37-mm. cannon. Bounding a motor with a hole where the shaft ought to be was a brain twister, but G-E engineers solved this problem with an electric motor shaped like a doughnut.



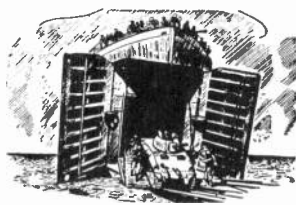
This Tom Thumb motor loads the guns on our bombers and fighters. Other electric motors raise and lower wheels, open bomb bay doors. War requires more than 40,000 different motor models, keeping G-E research and engineering men busy.



B-29 Superfortress. 150 electric motors act as muscles beneath the sleek exterior of the B-29. They power, among other things, the gun turrets in the G-E designed fire-control system that arms the Superfort against enemy attacks.



Turning a battleship over. 21 G-E motors teamed up for a 21-thousand-ton pull to turn the capsized Oklahoma right side up at Pearl Harbor. Electric motors see action on every front, in weapons, and in tools to repair them in the field.



Push-button doormen for LST's. Push a button, and out pops a tank. It's not quite that simple, but the doors and ramp on an LST are opened, at the push of a button, by electric motors. On an LST, there are 140 electric motors.

The automotive field is an enormous user of direct current equipment. Each modern automobile has a complete little power plant of its own, consisting of its D. C. generator, series D. C. starting motor, battery, lights, ignition coil, horn, etc. Many millions of D. C. generators and motors are in use on cars and trucks in this country alone.

Many powerful busses also use gas electric drive, having a gasoline engine to drive a D. C. generator,

## D. C. Power

which in turn supplies current to D. C. motors geared to the axles. This form of drive provides smoother starting and stopping, greater hill climb-

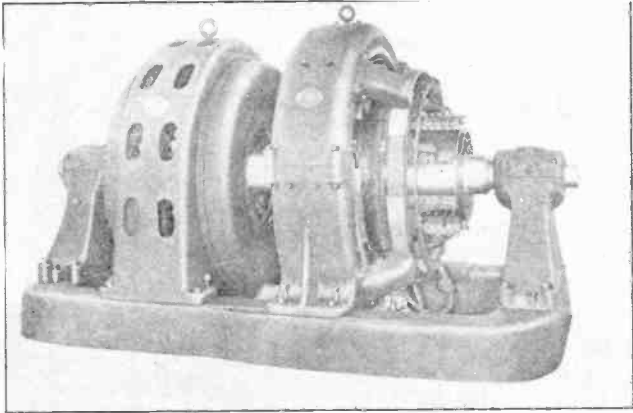


Fig. 7. Motor generator sets of the above type are very extensively used for changing A. C. to D. C. The D. C. generator is shown on the right and is driven by the A. C. motor on the left.



Fig. 8. Direct current is used to operate powerful electro-magnets of the above type for handling metal materials in industrial plants, warehouses, foundries, and iron yards. Note the manner in which these kegs of bolts are lifted by the magnet, even though the wooden heads of the kegs are between the magnet and the metal to be lifted. In plants where the principal supply of electricity is alternating current small motor generators are often used to supply the direct current for magnets of this type.

## Direct Current

ing ability, higher speeds on level roads, and eliminates gear shifting. Diesel-Electric trains also use D. C. generators.

With this great variety of uses for direct current and D. C. machines, you can readily see the value of making a thorough study of the equipment and principles covered in this lesson. The opportunities open to a trained man are certain to be much greater if he has a good knowledge of the operation, care and testing of direct current machines of all common types.

### D. C. GENERATORS

It has already been stated in earlier lessons that D. C. generators and motors are almost exactly alike in their mechanical construction, and that in many cases the same machine can be used either as a motor or a generator, with only slight changes in the field connections, brush adjustment, etc. This is a very good point to keep in mind while studying the following material, as many of the points covered on construction, operation, load ratings, temperatures, etc., will apply to either a motor or a generator.

#### 2. GENERATOR RATINGS

D. C. generators are always rated in kilowatts, a unit of electric power with which you are already familiar. It will be well to recall at this point, however, that one kilowatt is equal to 1000 watts, and approximately 1.34 h. p. You will also recall that the watts or kilowatts consumed in any circuit are equal to the product of the volts and amperes. Therefore, with a machine of any given voltage, the greater the load in K. W., the greater will be the load in amperes of current carried by the windings of that machine.

The K. W. rating of a D. C. generator is the power load that it will carry continuously without excessive heating, sparking, or internal voltage drop.

If a load greater than a machine is designed or rated for is placed upon it for an extended period,

## D. C. Generators

it will probably give trouble due to one of the three causes mentioned; and if the overload is very great and left on too long it will cause the armature winding to burn out.

Nearly all generators are designed to be able to carry some overload for short periods without injury to the machine. This is usually from 15 to 25 per cent, for periods not longer than an hour or so.

### 3. OPERATING TEMPERATURES

The safe temperature rises in electrical machinery are determined by the temperatures the insulating materials will withstand without damage. All other materials in the machine are metals which may be subjected to quite high temperatures without much damage.

Of course the higher the temperature of the copper windings the greater their resistance will be, and the higher will be the losses due to voltage drop in the machine.

Ordinary combustible insulations such as silk, cotton, and paper, should never be subjected to temperatures higher than 212° F. (or 100° C). Mica, asbestos, and other non-combustible insulations may be subjected to temperatures as high as 257° F., or 125° C.

In establishing temperature rise ratings for electrical machinery, it is assumed that the temperature in the rooms where the machines are installed will never be over 104° F. or 40° C. This gives, for the ordinary insulations, a permissible rise of 212 — 104, or 108° F. or 60° C. For non-combustible insulations the permissible rise is 257 — 104, or 153° F. or 85° C.

Ordinary generators and motors are usually guaranteed by the manufacturers to operate continuously at full load, without exceeding a temperature rise of 35° C., 40° C., or 50° C., as the case may be.

The temperatures of machines can be checked by placing small thermometers in between, or close to, the ends of their windings. A good general rule to remember, is that if the hand can be held on the frame of the machine near the windings without great discomfort from the heat, the windings are not dangerously hot.

### 4. GENERATOR SPEEDS

The speeds at which generators are operated depends upon their size, type of design, and method of drive. The speed is of course rated in R. P. M. (revolution per min.) but another expression commonly used in referring to the rotating armatures of electrical machines is the **Peripheral Speed**. This refers to the travelling speed of the outside or circumference of the rotating element, and this surface is commonly known as the **Periphery**. This speed is expressed in feet per second or feet per minute.

The centrifugal force exerted on the armature conductors or commutator bars depends on the peripheral speed of the armature or commutator. This speed, of course, depends on the R. P. M., and the diameter of the rotating part.

The larger the armature, the farther one of its conductors will travel in each revolution. When a coil of a bi-polar, (two pole) machine makes one revolution, it will have passed through 360 actual or mechanical degrees and 360 electrical degrees. But a coil of a six pole machine will only have to rotate 120 mechanical degrees to pass two poles, and through 360 electrical degrees.

So we find that with the same flux per pole in the larger machine as in the two pole one, the same E. M. F. can be generated at a much lower speed with the multipolar machine.

Small generators of two or four poles and for belt drive, have long armatures of small diameter and may be operated at speeds from 120 to 1800 R. P. M. Larger machines for slower speed drive by direct connection to the shafts of low speed reciprocating engines, may have as many as 24 or more field poles, and operate at speeds of 60 to 600 R. P. M. Armatures for these lower speed machines are made shorter in length and much larger in diameter, so their conductors cut through the field flux at high speeds, even though the R. P. M. of the armature is low.

The peripheral speeds of armatures not only determine the voltage induced and the stresses on the

## D. C. Generators

and commutator bars, but also determine the wear on brushes and the type of brushes needed, as will be explained later.

### 5. TYPES OF DRIVES

Belt driven generators are not much used in large plants any more because of possible belt slippage, and the danger of high speed belts. A number of older plants and many small ones use belt driven machines, and with fairly satisfactory results if the proper belts and pulleys are used.

One advantage of small belt driven generators is that they can be designed for high speeds; high speed generators are much smaller in size than low speed generators of the same kilowatt capacity; therefore, high speed generators are used wherever possible, because the purchase cost per kilowatt is considerably lower than with the low speed type.

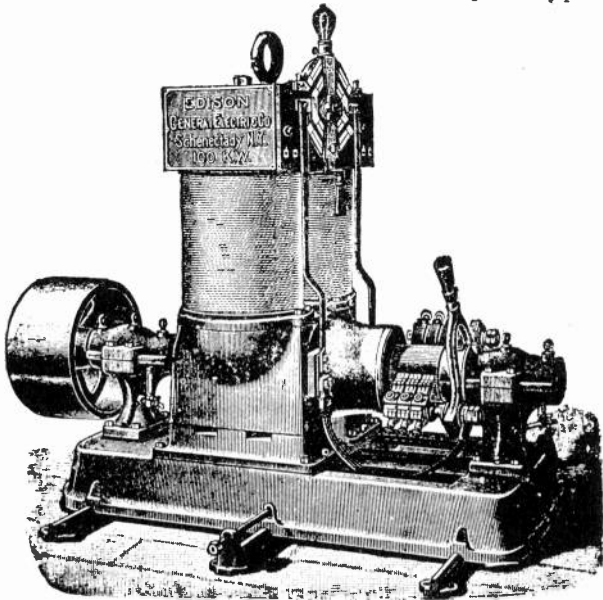


Fig. 10. An early type of D. C. generator developed by Thomas Edison. Note the construction of the field magnets of this machine.

The engine type generator with the large diameter, slow-speed armature, direct connected to the



## Direct Current

engine shaft, is more commonly used. Steam engines are a very desirable form of prime mover for generators, because of their high efficiency and simple operation, and because they can be operated on the ordinary steam pressure.

Steam turbines are used to drive D. C. generators in plants where space is limited, because they are so small and compact.

Water wheels are used for prime movers where convenient water power is available. Generators for water wheel drive may be either low or high speed type, according to the water pressure and type of water wheel used.

### 6. MECHANICAL CONSTRUCTION OF D. C. GENERATORS

We have already learned that a generator is a device used to convert mechanical energy into electrical energy. We also know that the principal parts of a D. C. generator are its field frame, field poles, armature, commutator, brushes, bearings, etc.

The purpose of the field poles is to supply a strong magnetic field or flux, through which the armature conductors are rotated to generate the voltage in them.

D. C. generators were the first type commercially used, and the early types were very simply constructed with two large field poles in the shape of a huge bipolar electro-magnet. The armature was located between the lower ends of these magnets, as shown in Fig. 10. This figure shows one of the early types of Edison generators of 100 K. W. size.

### 7. FIELD FRAMES

Modern generators and motors have their field poles mounted in a circular frame, as shown in Fig. 11. This figure shows a two-pole field frame with the two large poles mounted on the inside of the frame. The field coils can be plainly seen on the poles.

The circular frame, in addition to providing a support for the field poles, also provides a complete closed path of magnetic material for the flux circuit

## D. C. Generators

between the pole. For this reason the frames are usually made of soft iron.

For the smaller and medium sized machines, they are generally cast in one piece with feet or extensions for bolting to a base. The inner surface is usually machined smooth where the poles are bolted to it, or in some cases the poles are cast as a part of the frame. The ends of the frame are machined to allow the bearing brackets to fit properly.

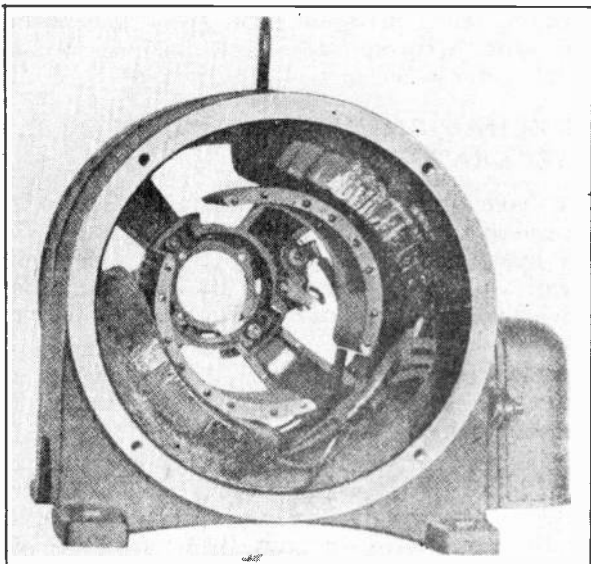


Fig. 11. Field frame of a modern generator or motor. Field coils located on the poles set up powerful magnetic flux in which the armature rotates.

The frames for larger generators are usually cast in two pieces for more convenient handling during installation and repairs. They can be split either horizontally or vertically. Fig. 12 shows a frame of this type for an eight-pole machine. Note where the halves of the frame are joined together and bolted at each side.

### 8. FIELD POLES

There may be any equal number of field poles in a generator or motor frame, according to its size

## Direct Current

and speed. These poles are made of soft iron to keep the magnetic reluctance as low as possible.

The poles can be cast as a part of the frame on smaller machines, but are usually bolted into the larger frames. It is very important that they should

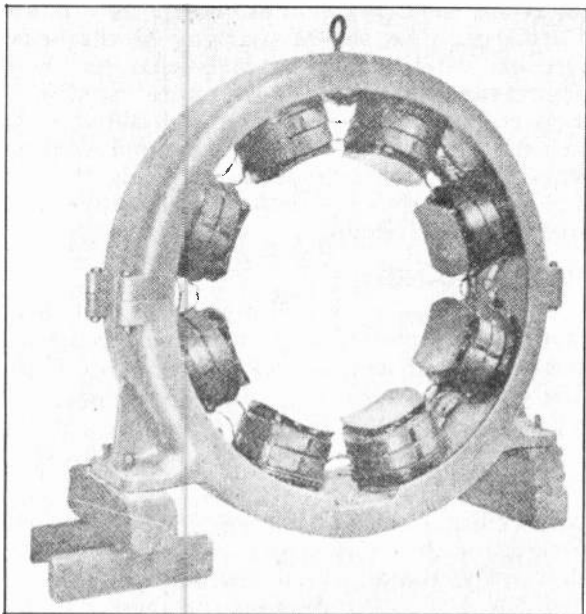


Fig. 12. Field frame for an eight-pole D. C. generator. Note the manner in which the frame is built in two sections for convenience when installing and making repairs.

fit tight to the frame to prevent unnecessary air gaps and reluctance in the magnetic circuit.

The ends of the poles which are next to the armature are usually curved and flared out into what are called **Pole Shoes** or **Faces**. This provides a more even distribution of the field flux over the armature core and conductors. These pole shoes are generally machined to produce an even air gap between them and the armature core.

Pole shoes are often made of laminated strips to keep down the induced eddy currents from the flux of the moving armature conductors. These laminated pole shoes are then bolted to the field poles. The machine in Fig. 11 has laminated pole shoes of this type.

## D. C. Generators

In some machines the field poles or sometimes the entire magnetic circuit is laminated to reduce eddy currents and also to permit the rapid changes in field flux that must take place when the machine is operating under conditions of highly fluctuating load. If the field flux cannot change as rapidly as the armature flux, severe sparking at the brushes may occur when the load rapidly changes. As flux changes can take place much more rapidly in a laminated structure—because the eddy currents which tend to sustain the flux are suppressed, generators and motors designed for loads that vary suddenly through wide limits usually have a laminated magnetic circuit.

### 9. ARMATURES

We have already learned a great deal about this very important part of D. C. machines, as armature construction and winding were thoroughly covered in the preceding lessons. A few of the points that are particularly good to keep in mind throughout the study of D. C. motors and generators will be briefly reviewed here.

The function of the armature, we know, is to carry the rotating conductors in its slots and move these swiftly through the magnetic flux of the field, in order to generate the voltage in them.

The very soft iron and steel in armature cores and its excellent magnetic properties also greatly reduce hysteresis loss. Also remember that the number of turns per coil and the method of connecting these coils will determine the voltage that is induced in a generator armature, or the counter-voltage in a motor armature.

Armature cores are made of thin laminations of soft iron which are partially insulated from each other either by a thin coating of oxide which is formed on their surface when they are being heat treated or by a thin layer of insulating varnish. This laminated construction prevents to a great extent the eddy currents which would otherwise be induced in the core as it revolves through the field flux.

## Direct Current

### 10. COMMUTATORS

A commutator, we already know, is a device used to rectify or change the alternating E. M. F. which is induced in the armature, to a direct E. M. F. or current in the external circuit. A commutator might

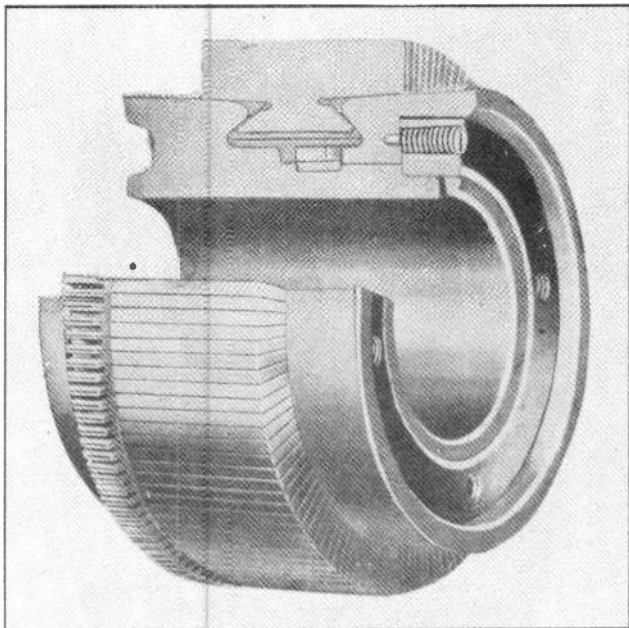


Fig. 14. The above photo shows an excellent sectional view of a commutator for a D. C. machine.

also be called a sort of rotating switch which quickly reverses the connections of the armature coils to the external circuit as these coils pass from one pole to the next.

The manner in which the commutators are constructed of forged copper bars and insulated from each other by mica segments, was covered in a preceding lesson under D. C. armatures.

Figs. 14 and 15 show two excellent views of commutators of slightly different types. The smaller one in Fig. 14 is held together by the ring nut shown on the right, while the larger one is known as a "bolted type" commutator, and has bolts which draw the V-rings tightly into the grooves in the bars.

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### 11. BRUSHES

The brushes slide on the commutator bars and deliver the current from a generator winding to the line; or, in the case of a motor, supply the current from the line to the winding. Most of these brushes

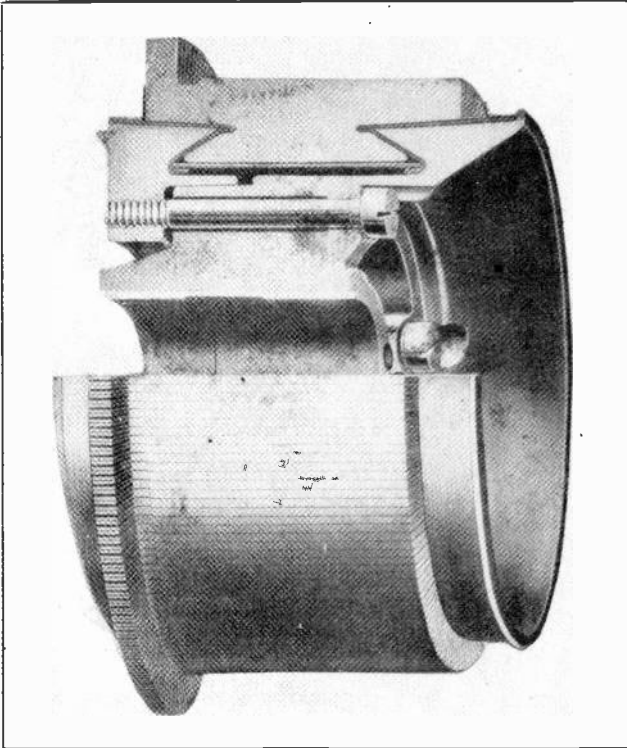


Fig. 15. This view shows another type of commutator in which the bars are held in place by bolts that are used to draw the clamping rings tight.

are made of a mixture of carbon and graphite molded into blocks of the proper size. While this material is of fairly high resistance, the very short length of the brushes doesn't introduce enough resistance in the circuit to create much loss. The properties of the carbon and graphite tend to keep the commutator clean and brightly polished as the brushes slide on its surface. Some resistance in the brush material is an advantage, as it tends to pre-

## Direct Current

vent severe sparking during the period the commutator bars are short circuited. This will be explained in a later section on brushes.

Brushes must be of the proper size and material to carry without undue heat the full load currents of either a generator or motor. The carrying capacity of the brushes is a figure generally set by the manufacturers to indicate the number of amperes the brush will carry per square inch of cross-sectional area. This figure takes into account the heat due to overloads, friction, short circuit currents in the coils, voltage drop at the contact, and the heat produced by sparking.

Fig. 16 shows two common types of generator brushes to which are attached **Pig Tails** of soft stranded copper. These copper pig-tails are used for making a secure connection to carry the current from the brush to the holder and line.

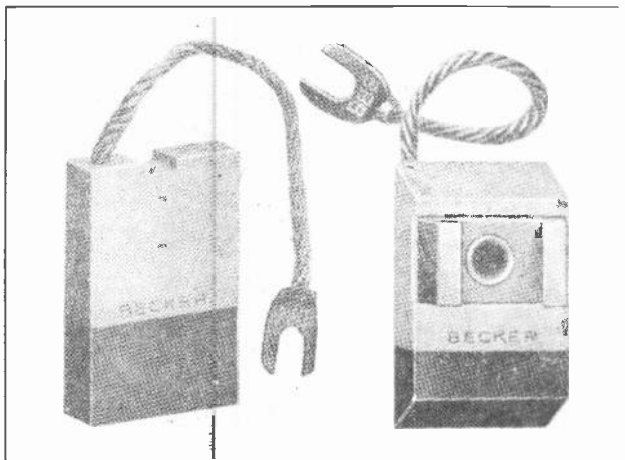


Fig. 16. Two common types of carbon brushes used for D. C. machines. Note the flexible copper leads used for connecting them to the brush holders.

## 12. BRUSH HOLDERS

Brushes are held firmly in the correct position with relation to the commutator by placing them in brush holders. The brush holders in common commercial use today may be classed under three general types, called **Box Type**, **Clamp Type**, and **Reaction Type**.

## D. C. Generators

The box-type holder was one of the first to be developed and used, while the clamp type has been developed in two forms known as the "swivel" and "parallel" motion types. Fig. 17 shows sketches of these several types of brush holders. The upper views in each case show the holders assembled on round studs, while the lower views show them bolted to rectangular studs.

A brush holder, in addition to providing a box or clamp to hold the brush in place, also has springs

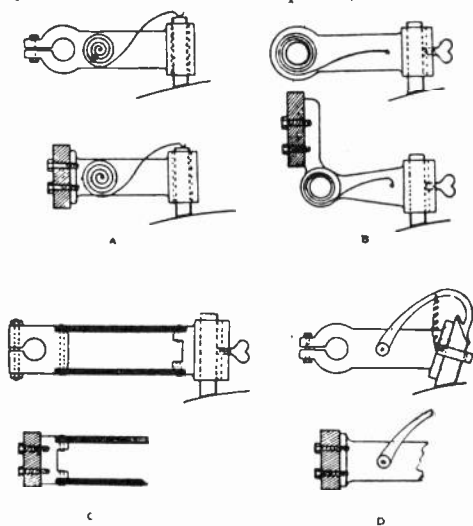


Fig. 17. The above sketches show several common types of brush holders. At "A" are two views of box-type holders. "B" and "C" are known as clamp-type holders; while "D" is a brush holder of the reaction-type.

to hold the brush against the commutator surface and under the proper tension. Fig. 18 shows a box-type brush holder and the springs which apply the tension on the brush, and the view on the right shows this brush holder from the opposite side, mounted in the rocker ring. The requirements of good brush holders are as follows:

1. To provide means for carrying the current from the brush to the holder stud, either with a flexible copper connection or by direct contact between the brush and the holder. This must be accomplished without undue heating or sparking



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between the brush and holder, as this would result in a rapid burning and damage to the holders.

2. To provide means for accurately adjusting the brush on the commutator or ring.

3. To hold the brush firmly at the proper angle.

4. To permit free and quick movement of the brush in order that it may follow any uneven surface of the commutator or ring.

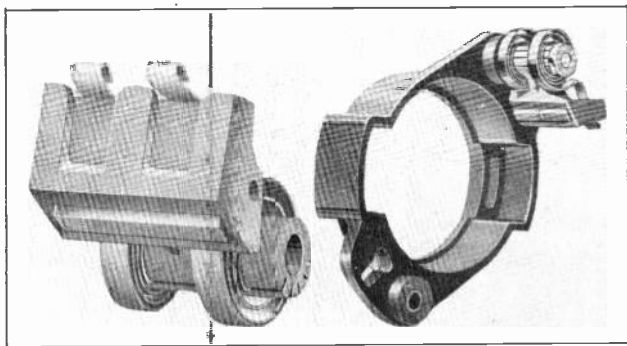


Fig. 18. Above are shown two box-type brush holders. The one at the left is simply attached to its holder stud sleeve and springs, while the one at the right is mounted on the holder stud which is fastened in a brush rocker arm.

5. To provide a tension spring of such length or shape that the tension on the worn brush will be very little less than that on a new brush.

6. To have a brush hammer so constructed that it will bear directly on the top of the brush and not give a side push either when the brush is full length or nearly worn out.

Fig. 19 shows a brush holder of the **Reaction Type**, in which the brush is held securely between the commutator surface and the **Brush Hammer** shown on the top in this view. The spring used with this brush holder is a coiled steel wire and can be seen on the back of the holder near the hammer hinge.

Brush holders are generally mounted or attached to a **Rocker Ring** by means of holder studs, as shown in Fig. 20. The holders can usually be adjusted on these studs both sidewise and up and down, to provide the proper spacing and tension. The purpose of the rocker frame or ring is to allow

## D. C. Generators

the entire group of brushes to be rotated through a small arc, so their position can be adjusted for varying current loads on the machine. This is often necessary on machines that do not have interpoles—as will be explained later.

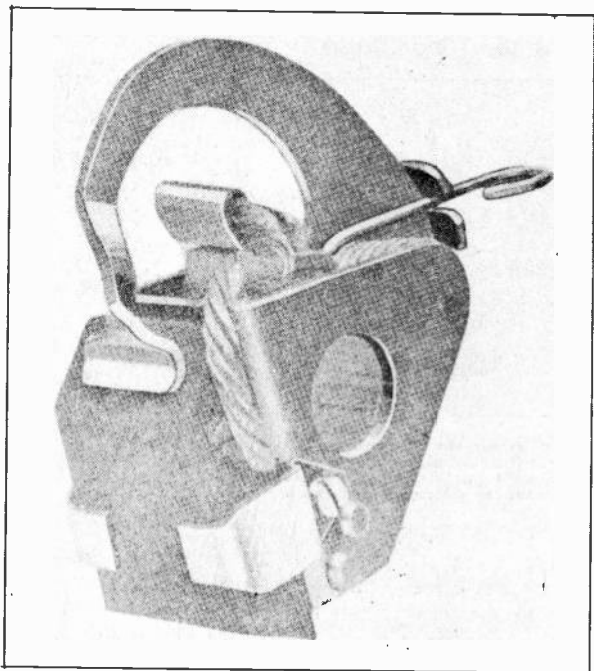


Fig. 19. Reaction-type brush holders keep the brush in place by the pressure of a "brush hammer", as shown on top of the brush in this view.

Frequently there are two or more brushes mounted on each stud, as several small brushes are more flexible and will fit themselves to uneven commutator surfaces much better than one large brush. The brush holder studs are, of course, insulated from the rocker frames by means of fibre washers and bushings.

Fig. 21 shows six sets of brushes mounted on the brush holder studs and rocker frame, which in turn is mounted in the end bracket of the machine.

### 13. BEARINGS

As previously mentioned, the bearings of motors and generators are to support the armature prop-

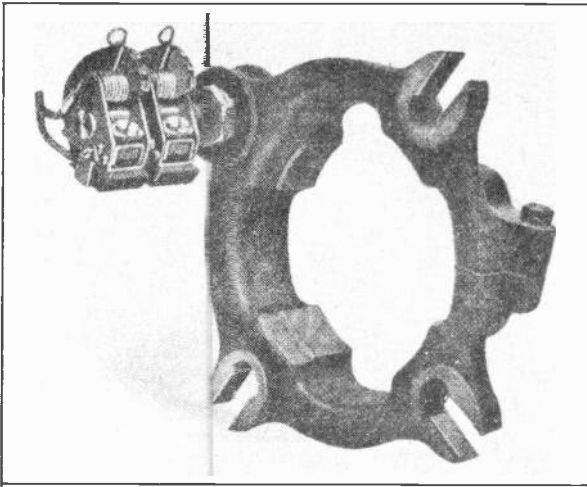


Fig. 20. Above are shown two brushes in their holders which are mounted on a brush rocker arm for a four-pole machine. Note the coil springs by which the brush tension on the commutator can be adjusted.

erly centered between the field poles and to allow it to rotate freely when the machine is in operation. These bearings are mounted in bearing brackets and held firmly at the ends of the machine; or, in some cases, they may be mounted in pedestals which are separate from the field frame.

These bearings are of two common types, called sleeve bearings and ball bearings. Roller bearings are also used in some cases. Sleeve bearings are made of babbit metal on the medium and larger sized machines, while bronze is used for very small, high-speed machines. Bearing metal must always be of a different grade than that in the shaft, because two similar metals will rapidly wear away or eat into each other when they are rubbed together.

Sleeve-type bearings are commonly oiled by oil rings or chains which rotate in the oil well and carry a small amount of oil up on top of the shaft

## D. C. Generators

continuously while it is rotating. In other cases, on smaller machines, the oil is fed to the shaft by a cotton wick. Ball and roller bearings are lubricated with a light grade of grease.

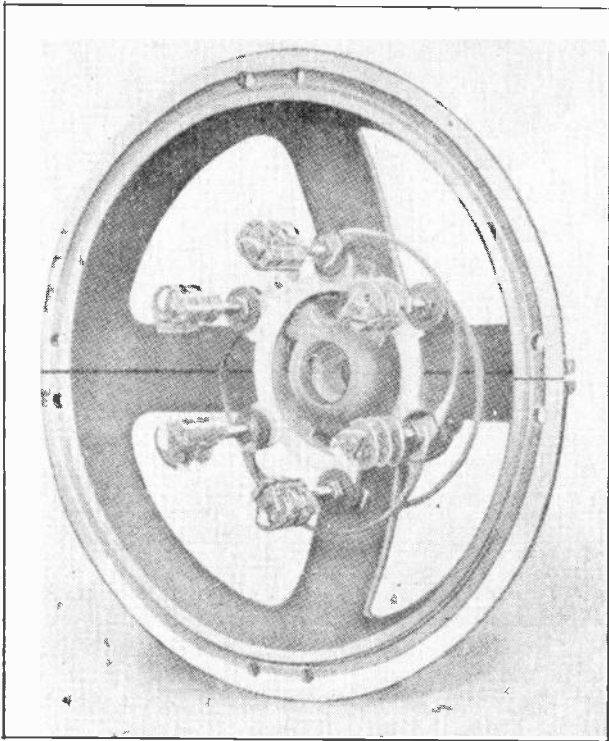


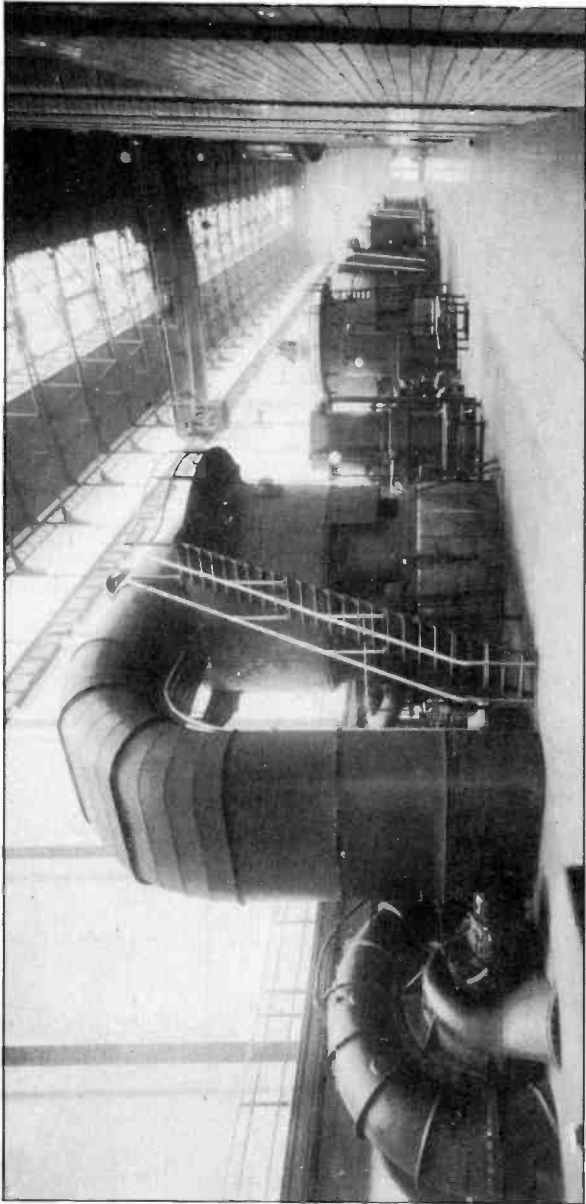
Fig. '21. This view shows a complete set of brushes and holders mounted on the rocker arm, which in turn is fastened in the end bracket of the machine.

A more thorough study of bearings will be given in a later section. The principal point to remember at this time in connection with bearings is the importance of keeping all bearings properly lubricated with clean oil. There should always be enough oil to be sure that the bearings are receiving it; but never oil them excessively and thus cause an overflow which may run into the winding and damage their insulation or get on the commutator and destroy its clean, bright surface.'

**EXAMINATION QUESTIONS**

1. Where are D. C. machines extensively used?
2. What are several advantages of D. C. motors?
3. What speeds and voltages are D. C. generators commonly made for?
4. What are the principal parts of a D. C. motor or generator?
5. Can a D. C. motor be used as a generator?
6. What temperature rise is permissible or safe on D. C. windings with cotton insulation on the windings?
7. What would cause a D. C. Generator or motor to over heat?
8. (a) What is the function' or purpose of the field poles in a D. C. generator?  
(b) Why are field pole faces or shoes often laminated?
9. What is the function of the commutator on a D. C. generator?
10. Name three common types of brush holders. What are several important requirements of a good brush holder?

## D. C. Generators



This photo shows one section of a large turbine room in a generating station—note the overhead crane.

## OPERATING PRINCIPLES OF D. C. GENERATORS

It is important to remember that the electrical generator is a device designed to change mechanical energy into electrical energy. Note that the machine does not **generate** electrical energy; instead it **converts** mechanical energy into electrical energy. Since such a machine is merely a conversion device, it is logical to assume that the conversion can be reversed and the machine used to change electrical energy into mechanical energy. Actually, this is the case. Therefore any electrical generator may be used as a motor, and any electrical motor may be used as a generator.

We have learned that the E. M. F. or voltage in a generator is produced by electro-magnetic induction when the conductors of the armature are rotated through the lines of force of the field.

We also know that the amount of voltage produced depends on the number of lines of force which are cut per second. This in turn depends on the strength of the field, the speed of armature rotation and the number of turns or coils in series between brushes.

The voltage that will be produced by a generator can be calculated by the formula:

$$E = \frac{P \times \phi_p \times Cr \times \text{RPM}}{10^8 \times 60 \times M.}$$

in which.

P = No. of field poles

$\phi_p$  = Total useful flux per pole

Cr = Total No. of inductors on armature

$10^8$  = 100,000,000 lines of flux to be cut per sec.  
by one conductor

60 = 60 sec. per min.

M = No. of parallel conducting paths between the + and — brushes.

For example, suppose we have a machine with 4 poles and with 200 armature inductors (conductors) in four parallel circuits between the brushes. The machine runs at 1200 R.P.M., and we will assume

## D. C. Generators

that the useful flux per pole is 3,000,000 lines.

$$\text{Then } E = \frac{4 \times 3,000,000 \times 200 \times 1200}{100,000,000 \times 60 \times 4}, \text{ or 120 volts.}$$

You may not need to use this formula often, but

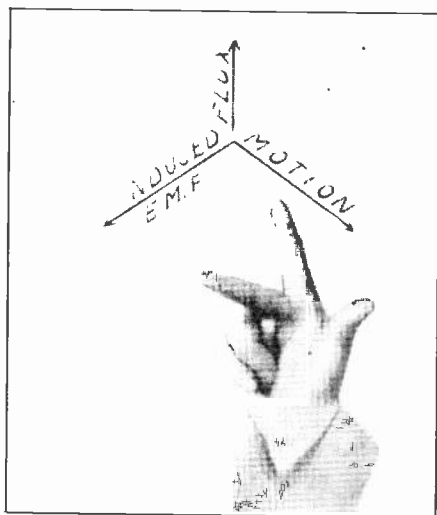


Fig. 1. This figure shows a method of holding the fingers to use the right-hand rule for determining direction of induced voltage in generators.

it serves to show what the voltage of generators depends on in their design and also to illustrate the factors of greatest importance in regulating the voltage of a generator.

Note that once the machine has been constructed the only quantities that can be varied are the R.P.M. and the flux per pole. Therefore, the voltage of a generator can be changed only by varying the speed, or the field strength, or both.

It is an easy matter to determine the direction of induced voltage in the conductors of a generator by the use of **Fleming's Right Hand Rule**, which has been previously stated and explained.

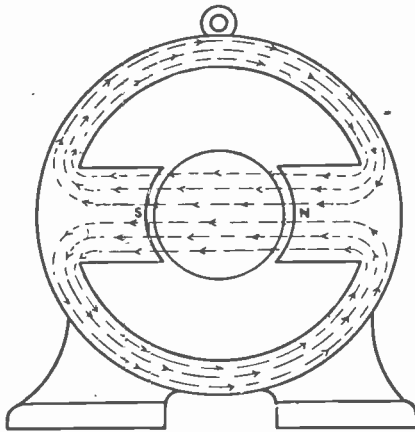
The rule is one that you will have a great deal of use for in connection with generators, so we will repeat it here.



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Place the first finger, thumb, and remaining fingers of the right hand all at right angles to each other. (See Fig. 1.) Let the first finger point in the direction of magnetic flux from the field poles, the thumb in the direction of conductor rotation, and the remaining fingers will indicate the direction of induced voltage.

This rule can be used either with diagrams or at the machine to quickly determine the direction of induced voltage in any conductor, where the direction of conductor movement and field polarity are known.



Magnetic Circuit of 2 Poles.

Fig. 2. The above diagram shows the magnetic circuit or path of the field flux in a simple two-pole machine.

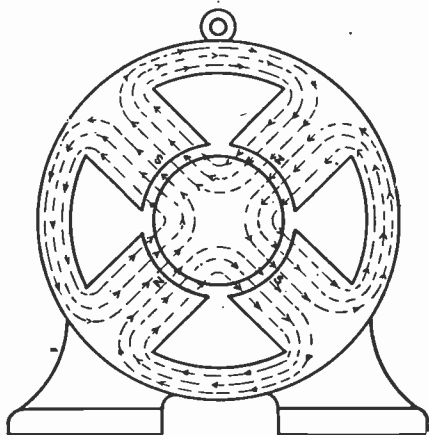
### 1. MAGNETIC CIRCUIT IN A GENERATOR

The number of conductors in the armature of a generator usually remains unchanged once it is built, and while the speed can be varied somewhat, the machine is generally operated at about the speed for which it is designed. So we find that the voltage adjustment or variation during the operation of a generator will depend largely upon the field strength. It would be well, therefore, to consider more in detail some of the factors upon which this field strength depends, and also the methods by which it can be varied.

Every generator or motor has what is called a **Magnetic Circuit**. This is the path followed by the

## D. C. Generators

flux of its field poles through the poles themselves, and through the armature core, and field frame—as shown in Fig. 2.



**Magnetic Circuit of 4 Poles.**

Fig. 3. Magnetic circuits in a four-pole machine. Note the direction of flux from N. to S. poles in the external circuit and from S. to N. poles in the internal circuit of the field.

There are always as many magnetic circuits in a generator as it has poles. That is, a two-pole generator will have two magnetic circuits. A four-pole generator four magnetic circuits, etc. These magnetic paths must be continuous and will complete themselves through air unless iron or steel is provided. It is advisable, therefore, to have as much of the magnetic circuit through iron as possible, in order to reduce the reluctance of the circuit and increase the strength of the field.

The magnetic paths of commercial generators are completed through an all-iron or steel path, with the exception of the 'air gap between the armature core and field poles. Assuming the generator R.P.M. to be constant, increasing this air gap will weaken the strength of the field and reduce the generator voltage proportionately.

Fig. 3 shows a sketch of a four-pole generator frame and the four magnetic circuits which it will have. It is very easy to determine the direction of flux at any pole of a generator if we know which

## Direct Current

ends of the pole are N. and S., and simply remember the rule that magnetic flux always travels from a north to a south pole in the external circuit. Examining Fig. 3 again, we find that the flux from either north pole divides and half of it goes to each of the south poles, then through the air gap and armature core which form the external circuit for the field poles. The internal circuit from the south pole back to the north pole is completed through the field frame. From this we see that each pair of field poles of a generator form a sort of horse-shoe magnet.

The area of the field poles and frame must be great enough to carry the flux without saturation. For highest efficiency, generators are operated at field densities considerably less than saturation, and generally at about 20,000 to 40,000 lines per sq. inch.

### 2. FIELD EXCITATION

We know that the strong magnetic field of the poles in a generator is set up by direct current flowing through the coils on these iron poles. This current is called the **Field Exciting Current**. The strength of the field will, of course, depend on the number of turns in the field coils and the amount of current which is passed through them. So, by **controlling excitation current with a rheostat**, we can readily adjust the strength of the field and the **voltage of the generator**.

Generators are classed as either **Separately Excited** or **Self-Excited**, according to the manner in which the field coils obtain the exciting current.

**A separately excited generator is one that has its field excited from some source other than its own armature.** This source may be either a storage battery or another small D.C. generator. Alternating current cannot be used to excite the field poles of either a D.C. or A.C. generator. So alternators are practically always separately excited by current from storage batteries or D. C. generators. Separately excited D.C. generators are sometimes used for electro-plating machines, and work of this type, and have their field coils wound for a certain voltage. This voltage may range from 6 to 25 for battery excitation; and from 110 to 220 when excited from another generator.

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Fig. 4 shows a sketch of a simple two-pole D.C. generator which has its field separately excited from a storage battery. Note the field rheostat which is provided to vary the field current and the generator voltage.

This type generator may be driven in either direction for the field excitation is independent of the armature polarity. However, the polarity of the brushes will reverse when the armature rotation is reversed, the positive brush becoming negative and vice versa.

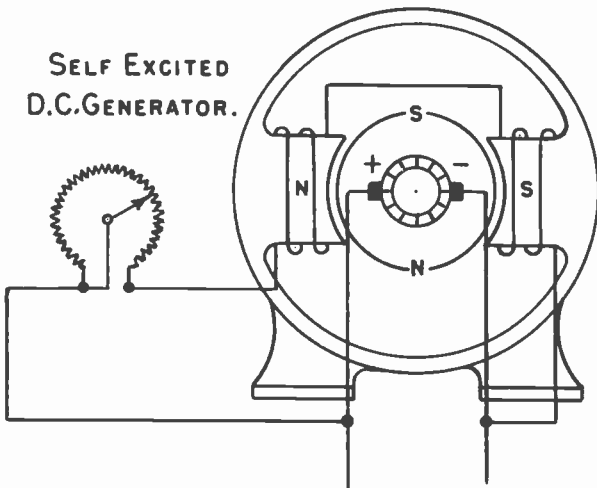


Fig. 4. This diagram shows a simple D. C. generator which has its field separately excited from a storage battery.

A self-excited generator is one that receives its field current from its own armature winding. Fig. 5 shows a sketch of a simple generator of this type. You will note that the field coils are connected across the positive and negative brushes of the armature in parallel with the line and load. Therefore the field has applied to it at all times the voltage generated by the armature, so a current will flow through the field coils as long as the armature is in motion. Most commercial D.C. generators are self-excited.

### 3. BUILDING UP VOLTAGE IN A GENERATOR

With a separately excited generator, as soon as the circuit is closed from the source of direct current for the field, the field will be magnetized at full strength, and the generator voltage will build up rapidly as soon as the machine comes up to full speed.

A self-excited generator must build up its voltage more gradually from the small amount of residual magnetism in the poles when the machine is started. You will recall that residual magnetism is that which remains in or is retained by the iron of the field poles even when their current is shut off. This residual magnetism, of course, produces only a very weak field.

When the machine is first started up and the armature conductors begin to cut this weak residual field, a very low voltage is generated in them. As the field is connected to the armature, this low armature voltage forces a small current through the field coils; this small current slightly increases the strength of the field. Then as the conductors cut through this slightly stronger field a still higher voltage is induced in them. This increases the field strength still more, which in turn builds up a greater voltage in the armature and still further field strength. This continues, and the strength of the field as well as the armature voltage keep on getting greater, until the point of **Saturation** is reached in the field poles.

The saturation point, you will remember, is when a magnetic circuit is carrying its maximum practical load of flux. When this point is reached it would require a considerable increase of current in the field coils to make even a small increase in the flux of the poles. So we find that self-excited generators build up their voltage gradually from residual magnetism as the machine comes up to speed.

Some times it may require a few seconds after the machine has reached full speed for its voltage to come up to normal value.

## D. C. Generators

### 4. FAILURE TO BUILD UP VOLTAGE

With self-excited generators, it is, of course, necessary that the flux lines produced by the field coils be of the same polarity as the residual magnetism in the iron of the poles. Otherwise, the first low voltage applied to the field coils would tend to neutralize the residual magnetism and cause the generator to fail to build up its voltage. For this reason, self-excited generators will build up voltage only when rotated in the proper direction. Generators may, however, be made to build up voltage when rotated in the opposite direction by changing the field connections.

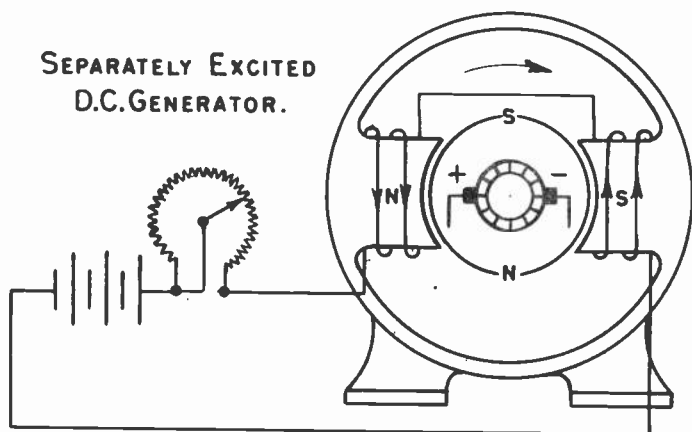


Fig. 5. This simple two-pole machine has its field coils self-excited by connection to its own armature brushes.

After a generator has been idle for quite a period it sometimes loses its residual magnetism to such an extent that it will not build up voltage until it is first separately excited. Some of the causes of a generator failing to build up voltage are as follows: Weak or dead residual magnetism, low speed, poor brush-contact on the commutator, severe overloads, open field circuits, or high resistance connections. Weak or dead residual magnetism, low speed, poor brush-contact on the commutator, severe overloads, open field circuits, or high resistance connections, in the armature or field circuit improper brush position or wrong rotation.

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Removing the cause of the trouble will usually start the machine generating, but if it does not a low voltage storage battery or some other source of direct current applied to the field coils momentarily and in the proper direction will generally cause the machine to promptly build up voltage again.

On some generators it is necessary to cut out part or all of the resistance of the field rheostat before the machines will build up voltage.

### 5. VOLTAGE ADJUSTMENT AND REGULATION

When a generator is running at normal speed, its voltage can be conveniently controlled and adjusted by means of the field rheostat, as shown in Figs. 4 and 5. On most D.C. generators this adjustment is made manually or by the operator, putting resistance in or out of the field circuit by means of this rheostat. In some cases automatic voltage regulators are used to control this voltage according to the load on the machine. This automatic regulating device will be explained later.

The terms "control" and "adjustment" refer to changes made in the voltage by the operator or by the automatic device. The term "voltage regulation" refers to some change in the voltage which the machine makes of its own accord as the load is changed or varied. This change is inherent in the machine and is determined by its design and construction.

### 6. NEUTRAL PLANE

The neutral plane in a generator is that point between adjacent field poles at which the armature conductors are traveling parallel to the lines of force, and in a very weak field. Normally, when the generator is not carrying a load this neutral plane is half way between adjacent poles of opposite polarity, as shown in Fig. 6.

When the conductors are passing through this point they do not generate any voltage, as they are not cutting across the lines of force. It is at this point that the commutator bars attached to the

## D. C. Generators

conductors usually pass under the brushes, where they are momentarily short circuited by the brushes. If the brushes were allowed to short circuit coils while they were passing through a strong flux under a pole, and generating appreciable voltage, it would cause very severe sparking at the brushes. So it is important that the brushes be adjusted properly for this neutral plane.

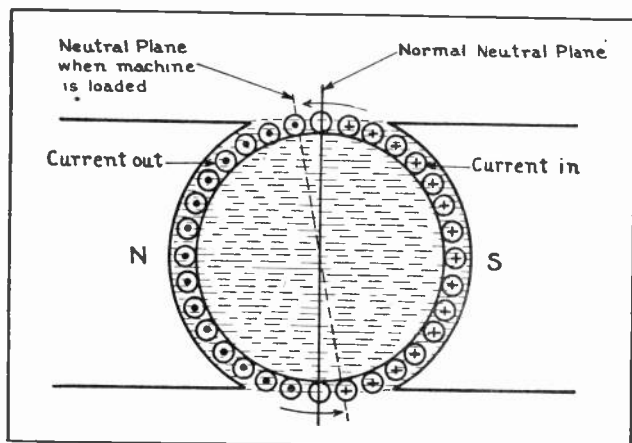


Fig. 6. This diagram shows the normal path of flux through the armature of the generator when the machine is not operating under load. Note the position of the normal neutral plane and also the position this plane takes when a machine is loaded.

## 7. ARMATURE REACTION

In addition to the flux which is set up between the field poles from their coils and exciting current, there is also to be considered the flux around the armature conductors. When a load of any kind is connected to a generator and its voltage begins to send current out through the line and load, this current, of course, flows through the armature conductors of the generator as well.

The greater the load placed on the machine the greater will be the current in the armature conductors and the stronger will be the flux set up around them.

The armature flux is set up at right angles to the flux of the field poles, and therefore tends to distort the field flux out of its straight path between poles. This effect is known as **Armature Reaction**.



## Direct Current

Fig. 7 shows the position of the armature flux as it would be set up by current in the conductors, if there were no field flux to react with it. In actual operation, however, the armature and

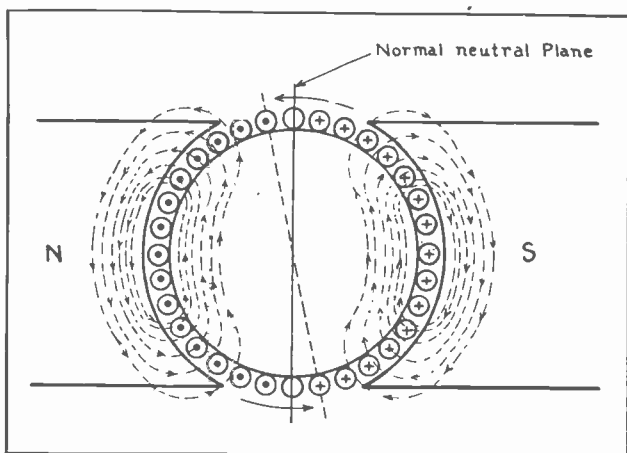


Fig. 7. This sketch shows the magnetic flux set up around the armature conductors of the simple two-pole machine when current is passing through them.

field flux of the generator are more or less mixed together or combined to produce the distorted field shown in Fig. 8. Here we see that the lines of force from the field poles have been shifted slightly out of their normal path and are crowded over toward the tips of the poles which lie in the direction of the rotation of the armature. This causes the field strength to be somewhat uneven over the pole faces, and more dense on the side toward which the armature is rotating.

You will also note that this distortion of the field has shifted the neutral plane, which must remain at right angles to the general path of the field flux.

As the armature flux depends on the amount of current through its conductors, it is evident that the greater the load on the machine, the greater will be the armature reaction and field distortion; and the farther the neutral plane will be shifted from its original position. So unless a generator is provided with some means of overcoming the effect of armature reaction, it will be necessary to shift the

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brushes with varying loads in order to obtain sparkless commutation.

Some machines are provided with commutating

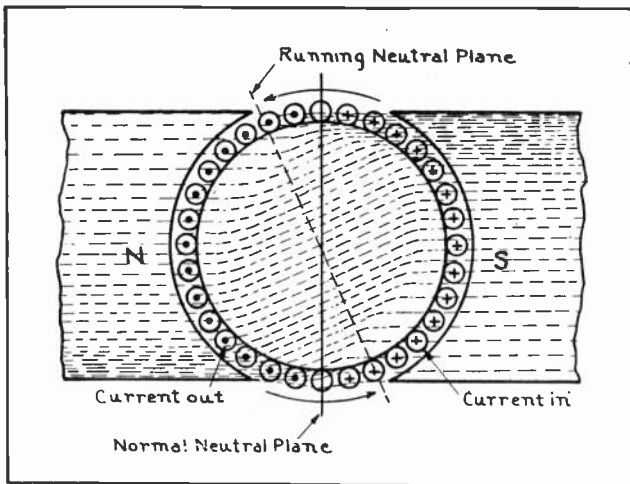


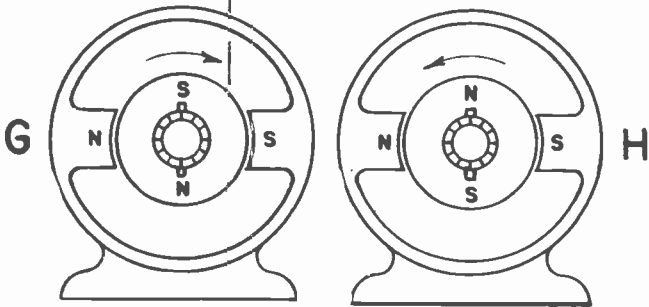
Fig. 8. This view shows the manner in which the magnetic lines of the field are distorted from their normal path by the effect of armature reaction. The neutral plane is shifted counter clockwise, or in the direction of rotation as shown by the dotted line.

poles or interpoles, as they are sometimes called, which are placed between the main field-poles to neutralize this feature of armature reaction and thereby eliminate the necessity of shifting the brushes with changes of load. These poles and their operation will be more fully explained later.

When current flows through the armature wires, magnetic poles are produced on the armature surface and these poles are located midway between the main poles as shown in Fig. G and H. As the current drawn from the generator armature increases, the strength of the armature poles becomes greater in proportion. Note that the relation between the armature poles and the field poles is such that rotation of the armature is opposed. As the electrical load on the generator increases, this opposition to rotation becomes greater; this explains why a generator is harder to drive as the load is increased. Actually the mechanical power provided by

## Direct Current

the prime mover is utilized in overcoming the magnetic effect of the armature and field pole attraction for each other.



## GENERATORS

Diagrams G and H show two generators, one arranged for clockwise and the other for counter clockwise rotation. Note that poles are set up on generator armatures but that in this case the poles **oppose** rotation.

### 8. ARMATURE RESISTANCE AND I. R. LOSS

All armature windings offer some resistance to the flow of the load current through them. While this resistance is very low and usually only a fraction of an ohm, it nevertheless causes a certain amount of voltage drop in the internal circuit of the armature. In other words, a certain small amount of the generated voltage is used to force the load current through the resistance of the armature winding. The greater the load on a generator, the greater will be the voltage drop through the armature.

As we know, this voltage drop is always proportional to the product of the amperes and ohms; and for this reason it is often referred to as **I. R. Drop**.

We can also determine the watts lost in an armature, or converted into heat because of its resistance, by squaring the current and multiplying that by the resistance, according to the watts law formula. Therefore,  $I^2 \times R$  will equal the watts lost in an

## D. C. Generators

armature due to its resistance. In which:

$I =$  the load current

$R =$  the resistance of the armature only.

The armature resistance may be measured with an ohmmeter, a Wheatstone bridge, or by sending a current through the winding and measuring the voltage drop across the armature with a millivoltmeter. Knowing the current flowing through the armature and the voltage drop across it, the resistance of the winding can then be determined by Ohm's Law.

know the size of the wire, the length of the turns in the coils, and the number of paths in parallel in the armature.

### 9. VOLTAGE DROP IN BRUSHES AND LINES

There is also a certain amount of voltage drop at the brushes of a generator which is due to the resistance of the brushes themselves and also the resistance of the contact between the brushes and commutator. This resistance is also very low and will cause a voltage drop of only about one or two volts on ordinary machines under normal load.

In addition to the voltage drop encountered in the generator, we also have the drop in the line which leads from the generator to the devices which use the current produced by the generator.

Knowing that the voltage drop in both the line, or external circuit, and the generator internal circuit will vary with the amount of load in amperes, we can see the desirability and need of some voltage adjustment or regulation at the generator, to keep the voltage constant at the devices using the energy.

### 10. GENERATOR TYPES

Direct current generators can be divided into several classes, according to their field construction and connections. They are called respectively: **Shunt Generators**, **Series Generators**, and **Compound Generators**.

The shunt generator has its field coils connected in shunt or parallel with the armature. Shunt field

## Direct Current

coils consist of a great many turns of small wire and have sufficient resistance so that they can be permanently connected across the brushes and have full armature voltage applied to them at all times during operation. The current through these coils is, therefore, determined by their resistance and the voltage of the armature.

Series generators have their field coils connected in series with the armature, so they carry the full load current. Such coils must, of course, be wound with heavy wire in order to carry this current and they usually consist of only a very few turns.

Compound generators are those which have both a shunt and series field winding.

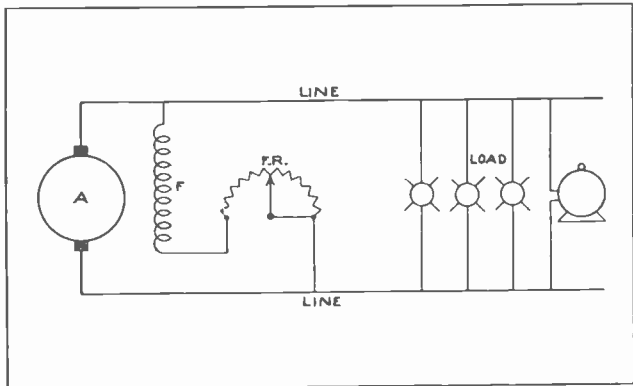


Fig. 10. This diagram shows the connections of a shunt generator. The shunt field winding "F" is connected in series with the field rheostat and then across the brushes. Note that this field winding is also in parallel with the load on the line.

Each of these machines has certain characteristics which are particularly desirable for certain classes of work, as will be explained in detail in the following paragraphs.

### 11. SHUNT GENERATORS

Fig. 10 is a simple sketch showing the method of connecting the field winding of a shunt generator in parallel with its armature. The field rheostat, F.R., is connected in series with the shunt field winding to regulate the field strength, as previously explained.

## D. C. Generators

It is well to note at this point that, in various electrical diagrams, coils of windings are commonly represented by the turns or loops shown for the shunt field at "F", while resistance wires or coils are commonly shown by zigzag lines such as those used for the rheostat at "F.R."

Fig. 11 shows the connections of a shunt generator as they would appear on the machine itself. By comparing this diagram with the one in Fig. 10 and tracing the circuits of the field and armatures, you will find they are connected the same in each case.

The shunt generator, being a self-excited machine, will start to build up its voltage from residual magnetism as soon as the armature commences to rotate. Then, as the armature develops a small amount of voltage, this sends some current through the field, increasing the lines of force and building up the voltage to full value, as previously explained.

However, if there is a low resistance connected across the generator terminals, the generator may fail to build up because this low resistance will shunt most of the armature current away from the field winding and so prevent the increase in field current essential to the normal building up process. This explains why a shunt generator sometimes fails to build up when it is run up to speed with the normal load connected to the armature circuit; it also shows why the voltage of a shunt generator will fall to zero if the machine is short circuited.

As the field circuit and the load circuit are both connected across the generator terminals, any current generated in the armature must divide between these two paths in inverse proportion to their resistance and, as the resistance of the field circuit is relatively high, most of the current goes through the load circuit thereby preventing the increase in field strength essential to the production of normal terminal voltage.

### 12. VOLTAGE CHARACTERISTICS OF SHUNT GENERATORS

The voltage of the shunt generator will vary inversely as the load, due to the same reason men-

## Direct Current

tioned in the preceding article. Increasing the load causes increased voltage drop in the armature circuit, thus reducing the voltage applied to the field. This reduces the field strength and thereby reduces the generator voltage.

If the load on a shunt generator is suddenly increased, the voltage drop may be quite noticeable; while, if the load is almost entirely removed, the

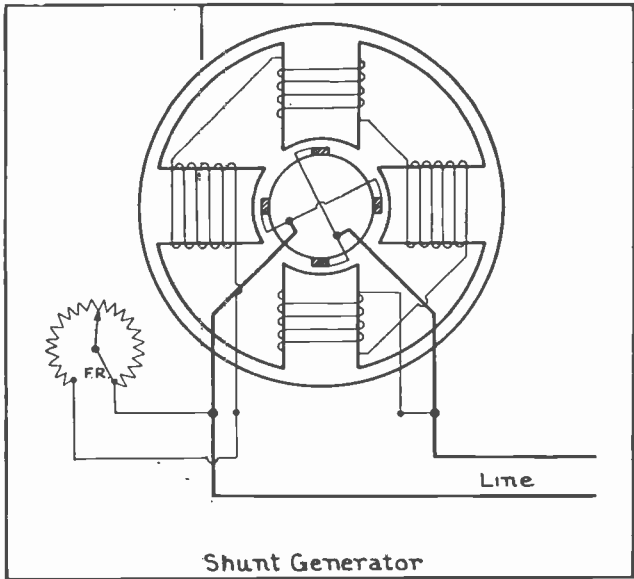


Fig. 11. This sketch shows the wiring and connections of the brushes and field coils for a four-pole, shunt generator.

the voltage regulation of a shunt generator is very poor, because it doesn't inherently regulate or maintain its voltage at a constant value.

The voltage may be maintained fairly constant by adjusting the field rheostat, provided the load variations are not too frequent and too great.

Shunt generators are, therefore, not adapted to heavy power work but they may be used for incandescent lighting or other constant potential devices where the load variations are not too severe.

Shunt generators are difficult to operate in parallel because they don't divide the load equally be-

## D. C. Generators

tween them. Due to these disadvantages shunt generators are very seldom installed in new plants nowadays, as compound generators are much more satisfactory for most purposes.

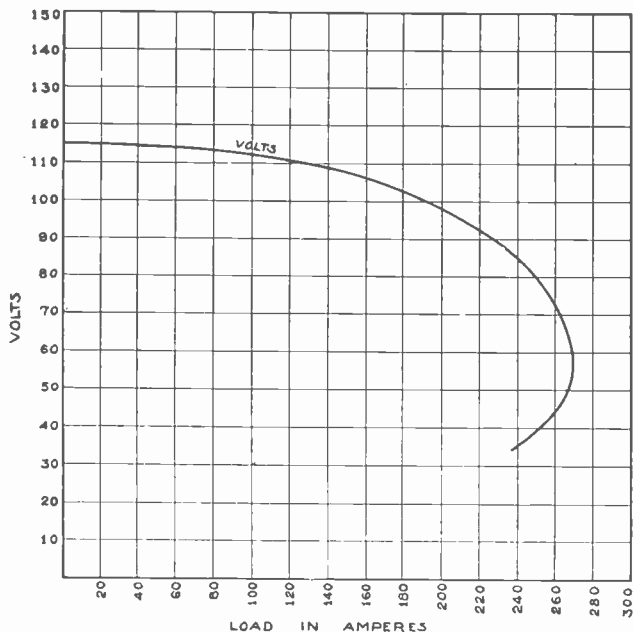


Fig. 12. This curve illustrates the voltage characteristic of a shunt generator. Note how the voltage drops as the load in kilowatts is increased. Full load in this case is 240 amperes.

Fig. 12 shows a voltage curve for a shunt generator and illustrates the manner in which the voltage of these machines varies inversely with the load. You will note that at no load the voltage of the generator is normal or maximum, while as the load in kilowatts increases the generator voltage gradually falls off to a lower and lower value.

### 13. SERIES GENERATORS

These machines have their field coils connected in series with the armature and the load, as shown in Fig. 13. The field winding is usually made of very heavy wire or strip copper, so that it will carry the full load current without overheating.



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By referring to Fig. 13 we can see that with no load connected to the line, it would be impossible for any current to flow through the series field and therefore the generator couldn't build up voltage. So, in order for a series generator to build up voltage when it is started, we must have some load connected to the line circuit.

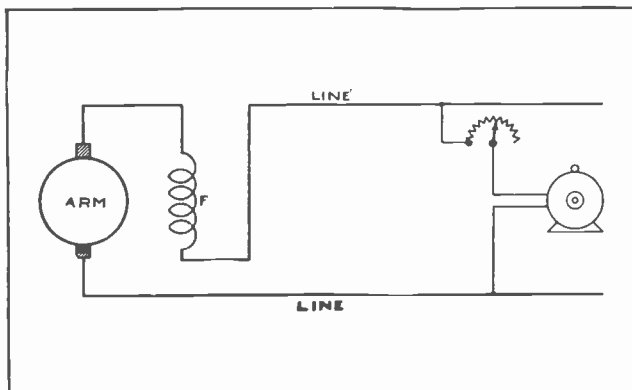


Fig. 13. This sketch shows the connections of a series generator. The series field at "F" is connected in series with the armature and the line. Note that no current could flow through this field if there was no load connected to the line.

### 14. VOLTAGE CHARACTERISTIC OF SERIES GENERATORS

The greater the load connected to such a generator, the heavier will be the current flowing through the field winding and the stronger the field flux. This causes the voltage of a series generator to vary directly with the load; or to increase as the load is increased and decrease as the load decreases. This, you will note, is exactly the opposite characteristic to that of a shunt generator.

As most electrical equipment is to be operated on constant voltage and is connected to the line in parallel, series generators are not used for ordinary power purposes or for incandescent lighting. Their principal use has been in connection with series arc lights for street lighting.

With a load of this kind, the current must always remain at the same value for the series lamps and, therefore, the generator field and voltage will re-

## D. C. Generators

main fairly constant. You can readily see that a series generator would be entirely impractical for ordinary power and light circuits, because, if the load is decreased by disconnecting some of the devices, the voltage on the rest will drop.

### 15. SÉRIES FIELD SHUNTS

Fig. 14 shows a curve illustrating the voltage regulation of a series generator. The voltage of

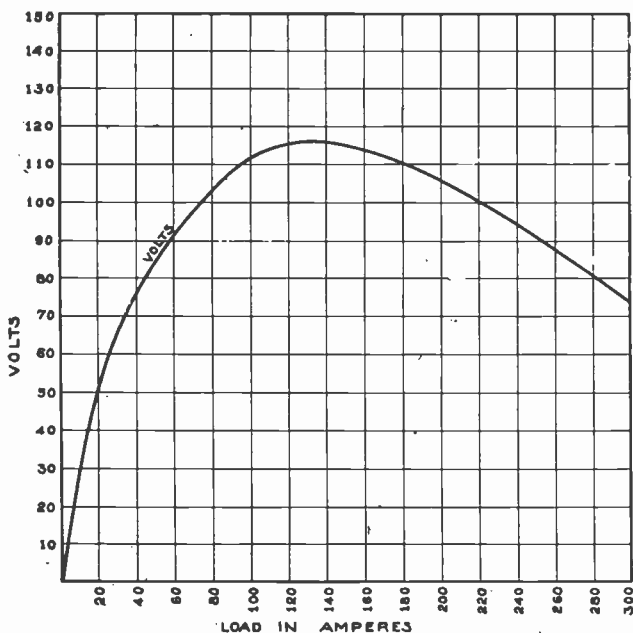


fig. 14. This curve shows the voltage characteristic of a series generator. Note that the voltage increases rapidly as the load on the machine is increased up to about full load. Full load in this case is 125 amperes.

such machines can be adjusted by the use of a low-resistance shunt connected in parallel with the series field coils, as shown in Fig. 15. This figure shows the connections of a series generator as they would appear on the machine. By tracing the circuit you will find that the field coils are connected in series with the armature and load.

The purpose of the shunt is to divide the load current, allowing part of it to flow through the series field and the rest through the shunt. By

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varying the resistance of this shunt, we can cause more or less of the total load current to flow through it, thus either weakening or strengthening the series field.

These shunts are generally made of very low resistance material, such as copper ribbon or strips of metal alloy with higher resistance than copper,

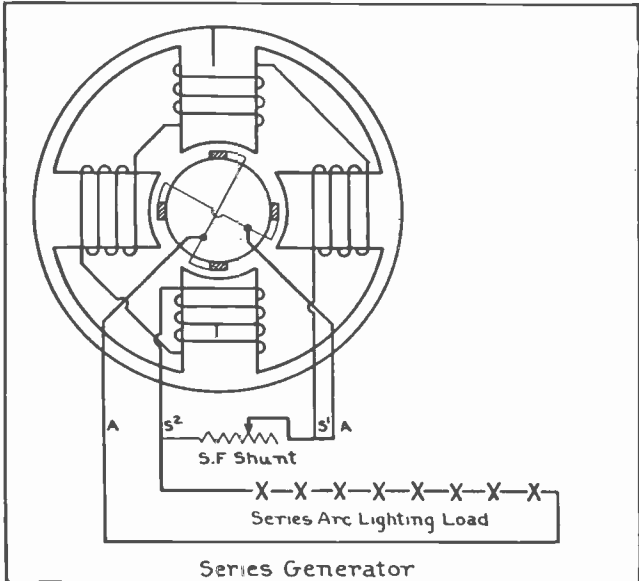


Fig. 15. Connections of brushes and field coils of a four-pole, series generator.

in order to make them short in length and compact in size.

By referring again to the curve in Fig. 14, you can see that the voltage regulation of a series generator is also very poor.

## 16. COMPOUND GENERATORS

The fields of a compound generator are composed of both shunt and series windings, the two separate coils being placed on each pole. Fig. 16 shows the connections of both the series and shunt fields of a compound generator.

The shunt field is connected in parallel with the armature and therefore it maintains a fairly con-

## D. C. Generators

stant strength. The series field, being in series with the armature and load, will have its strength varied as the load varies. These machines will therefore have some of the characteristics of both shunt and series generators.

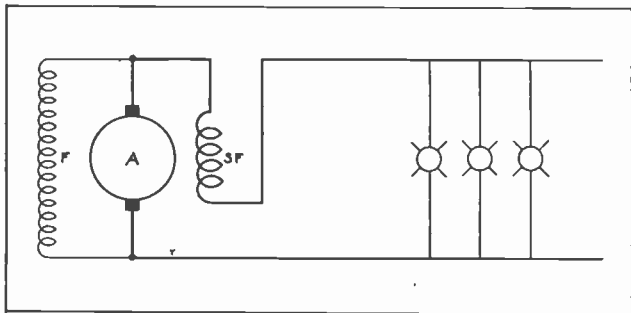


Fig. 16. This sketch shows the connections of a compound generator. The shunt field is connected across the brushes. The series field is connected in series with the line.

We have found that the shunt generator tends to decrease its voltage as the load increases and that the series generator increases its voltage with increases of load. Therefore, by designing a compound generator with the proper proportions of shunt and series fields, we can build a machine that will maintain almost constant voltage with any reasonable variations in load.

The shunt field winding of a compound generator is usually the main winding and produces by far the greater portion of the field flux. The series field windings usually consist of just a few turns, or enough to strengthen the field to compensate for the voltage drop in the armature and brushes as the load increases.

Compound generators can have the shunt field strength adjusted by a rheostat in series with the winding, and may also have a shunt in parallel with the series field for its adjustment. The shunt field rheostat on these machines, however, is not generally used for making frequent adjustments in their voltage, but is intended for establishing the proper adjustment between the series and shunt field strengths when the generators are placed in operation.

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The variation in the strength of the series field, which compensates for the voltage drop with varying load, makes unnecessary the frequent use of the shunt field rheostat employed on these machines, as is done with shunt generators.

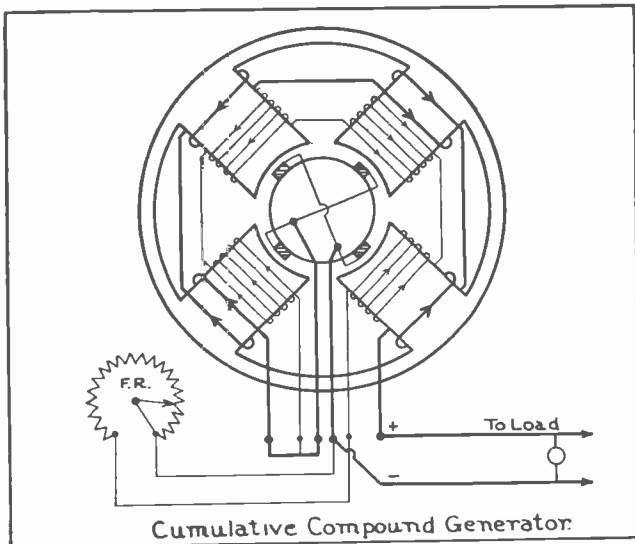


Fig. 17. Connections of brushes and field coils for a four-pole, cumulative compound generator. Note that the direction of current through the series field winding is the same as that through the shunt coils.

Fig. 17 shows the complete connections for the armature and fields of a compound generator. You will note that the series winding is composed of just a few turns of very heavy wire on each pole and is in series with the armature and line. The shunt winding is composed of a far greater number of turns of small wire and is connected in parallel with the armature brushes.

By referring back to Fig. 12, in lesson 33, you will note the series coils wound on the poles over or outside of the shunt winding, which is wound next to the pole cores.

### 17. CUMULATIVE AND DIFFERENTIAL COMPOUND GENERATORS

In the type of generator just described, the shunt and series field coils are so arranged that the cur-

## D. C. Generators

rents flowing in both windings circulate around the poles in the same direction; therefore the windings aid each other in setting up the field flux. Since the action of the fields is cumulative, this type of generator is known as the Cumulative Compound type. The cumulative compound generator is the most widely used type of D.C. machine.

Some compound generators have the series fields wound in the opposite direction, so that their flux opposes that of the shunt field. Such machines are known as **Differential Compound** generators. Their uses will be explained later.

### 18. FLAT COMPOUND GENERATORS. VOLTAGE CHARACTERISTICS

When a compound generator has just enough of series field to compensate for the voltage drop in its own armature and brushes, and to maintain a nearly constant voltage from no load to full load on the generator, it is known as a **Flat Compound** machine.

The voltage regulation of such a machine is very good, as it automatically maintains almost constant voltage at its terminals with all normal load variations. Such machines are very commonly used for supplying current to general power and light circuits where the load is not located too far from the generator and the line drop is small. Fig. 18 shows the voltage curve of a flat compound generator at F.

### 19. OVER COMPOUND GENERATORS. VOLTAGE CHARACTERISTICS

Where the load is located some distance from the generator or power plant and the line drop is sufficient to cause considerable reduction of voltage at the current-consuming devices when the load is heavy, the generators are commonly equipped with series field windings large enough to compensate for this line drop as well as their own armature and brush voltage drop. Such machines are called **Over Compound** generators and are by far the most common type used in power work

The voltage of an over compound generator will increase slightly at the generator terminals with

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every increase of load. Every increase of load increases the current through these series turns, thereby strengthening the field enough to actually raise the voltage a little higher at full load than at no load.

This voltage increase at the generator terminals makes up for the additional voltage drop in the

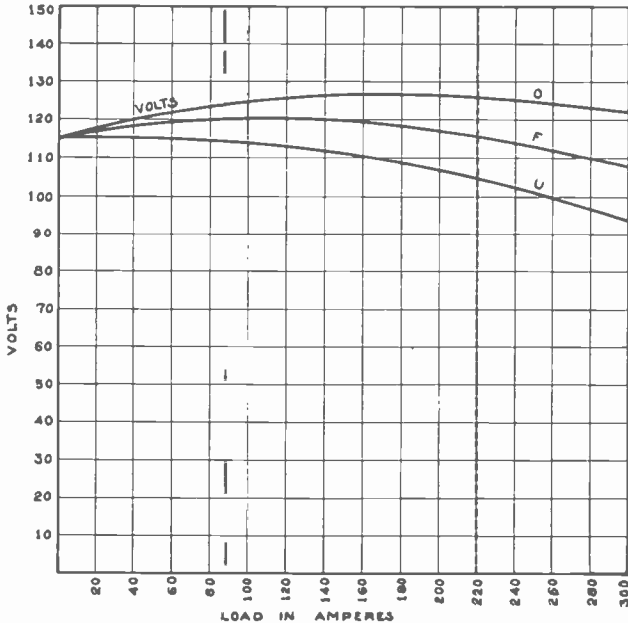


Fig. 18. These curves show the voltage characteristic of a flat compound generator at F, over compound at O, and under compound at U. Full load in this case is 220 amperes.

line when the load is increased. Therefore, if the series and shunt fields of such a machine are properly adjusted, it will maintain a very constant voltage on the equipment at the end of the line.

The adjustment of the shunt and series fields of these machines can be made with the usual shunt field rheostat and series field shunts.

The voltage regulation of an over compound generator is very good, and for ordinary power purposes they don't require frequent adjustment of the rheostat or any special voltage regulating equip-

## D. C. Generators

ment, because this regulation is inherent in the design and operation of the machine. Over compound generators are usually made and adjusted so that the terminal voltage will be from  $4\frac{1}{2}\%$  to  $6\%$  higher at full load than at no load.

### 20. DIFFERENTIAL COMPOUND GENERATORS

Any compound generator can be connected either cumulative or differential, by simply reversing the connections of the series field windings so that these coils will either aid or oppose the flux of the shunt field.

Compound generators are usually designed to operate cumulative unless otherwise ordered for special purposes.

When the series field coils are connected differential, and so that their flux opposes that of the shunt

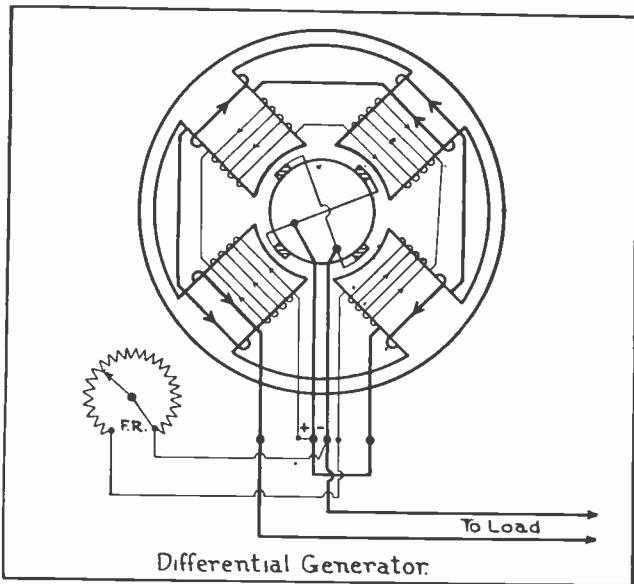


Fig. 19. Connections of brushes and field coils for a four-pole, differential, compound generator. Note that the direction of current through the series field coils is opposite to that in the shunt coils.

field, each increase in the load on the machine will cause quite a decided voltage drop, as it increases



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the current in the differential winding and thereby weakens the field flux.

The voltage of these machines, therefore, will vary inversely with the load and considerably more than it varies with the shunt generator. The voltage regulation of differential compound generators may be classed as very poor, but they have advantages in certain classes of work.

For the generators used in welding, where sudden and severe overloads are placed on the machine in starting the arcs, or for any machines that have frequent severe overloads or the possibility of short

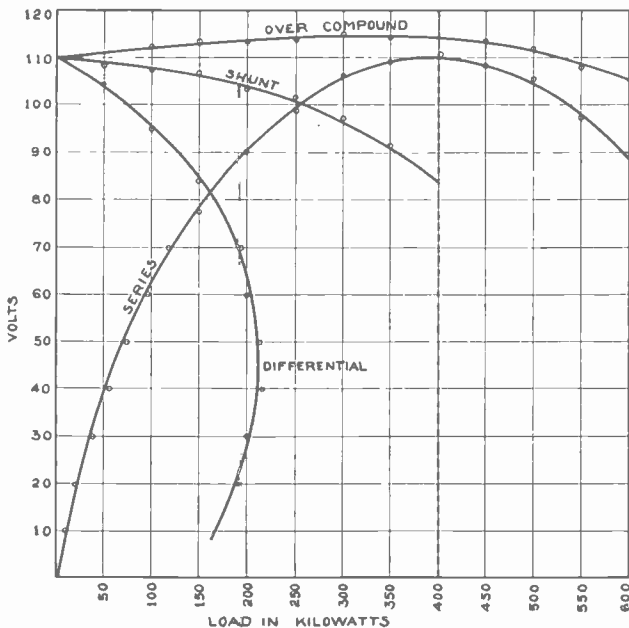


Fig. 20. This chart shows the curves of several types of generators all together so they can be easily compared.

circuits, the differential compound winding is a good protective feature.

When an overload is placed on the line, the additional current in the differential series coils tends to neutralize the shunt field flux and thereby reduces the generator voltage considerably. This also

## D. C. Generators

reduces the amount of current which will flow through the armature, and therefore protects it from overheating.

The shunt field winding of the differential generator should be the main field winding and should determine the polarity of the pole. The series field should at no time determine the polarity of the poles, unless the shunt field circuit is open, or except in a case of a short circuit across the brushes.

Fig. 19 shows the connections of a differential compound generator. Note that the current flows in opposite directions in the shunt and series windings around the field poles.

Fig. 20 shows the curves for the several types of generators just described and provides a good opportunity to compare the voltage characteristics of shunt, series, and compound generators. Note how rapidly the voltage of the differential machine falls off as the kilowatt load increases.

It will be well to keep in mind the different voltage characteristics of these machines and the principles by which their voltage regulation is obtained, because you will encounter all types in various plants in the field. Therefore a knowledge of their field connections and adjustment, and the proper methods by which these connections can be changed to obtain different characteristics, will often be very valuable to you.

### EXAMINATION QUESTIONS

1. On what three factors does the voltage of a D.C. generator depend?
2. Explain the difference between a self excited and a separately excited generator.
3. How can the voltage of a D.C. generator be conveniently controlled or adjusted?
4. a. How does a self excited generator start to build up it's voltage.  
b. What are several possible causes of failure of such a machine to build up voltage?
5. a. What is meant by the term "Armature reaction"?  
b. What is meant by the term "Neutral plane"?
6. What is meant by the term I R drop in a generator armature, and how is it affected by variations in load on the machine?
7. a. Name three common types of D.C. generators as classified according to their field connections.  
b. Which type is most commonly used for general power service?
8. a. How does the voltage of a shunt generator vary with load changes?  
b. Is the voltage regulation of a shunt generator good or poor?
9. For what purpose is a series field shunt used?
10. What is the difference between a "flat compound" and an "over compound" generator?

## D. C. Generators

## GENERATOR OPERATION

In commencing the study of the operation of generators, it will be well to first consider prime movers, or the devices used to drive the generators.

The term **Prime Mover** may apply to any form of mechanical power device, such as a steam engine, steam turbine, gas or oil engine, or water wheel. These devices, when used to drive electric generators, are designed to operate at a constant speed at all loads up to full load. They are usually equipped with governors which maintain this constant speed by allowing the correct amount of power in the form of steam, gas, or water to enter the prime mover, according to the variations of current load on the generator.

The prime mover should always be large enough to drive the generator when it is fully loaded, without any reduction in speed which would be noticeable in the generator voltage output.

It is not our purpose at this time to discuss in detail the design or operation of prime movers, although in a later lesson they will be covered to a greater extent with regard to their operation.

### 1. CALCULATION OF PROPER H. P. FOR PRIME MOVERS

To determine the proper size of engine or prime mover to drive a D.C. generator of a given rating in kilowatts, we can easily calculate the horse power by multiplying the number of kilowatts by 1.34.

You will recall that one h. p. is equal to 746 watts, and one kilowatt, or one thousand watts, is equal to 1.34 h. p.

Multiplying the kilowatt rating of the generator by 1.34 gives the horse power output of the machine. This horse power output can also be determined by the formula:

$$\text{H. P.} = \frac{E \times I}{746}$$

## Horse Power Calculations

In which:

E = the generator voltage

I = the maximum current load rating

746 = the number of watts in one h. p.

In addition to the electrical horse power output of the generator, we must also consider its efficiency, or the loss which takes place in its windings and bearings.

If the efficiency of a generator is known to be 80%, the formula to determine the horse power required to drive it will be as follows:

$$\text{H. P.} = \frac{E \times I}{e \times 746}$$

In which:

e = the efficiency of the generator, expressed decimally.

We should also allow a certain amount for any overload that the generator is expected to carry. A convenient rule for determining the approximate horse power required to drive any generator, is to multiply the kilowatt rating of the machine by 1.5, which will usually allow enough extra power to make up for the loss in the generator.

For example, if we have a generator which is rated at 250 volts and 400 amperes, and this machine has an efficiency of 90%, we can determine the necessary horse power by the formula, as follows:

$$\text{H. P.} = \frac{250 \times 400}{.90 \times 746}, \text{ or } 148.94 \text{ h. p.}$$

The kilowatt rating of this same generator would be 100 KW, as can be proven by multiplying the volts by the amperes. So, if we simply multiply  $100 \times 1.5$ , according to our approximate rule, we find that 150 h. p. will be required. This is approximately the same figure as obtained by the use of the other formula.

If the generator has less than 90% efficiency and if it is known that the load will be up to the full capacity of the generator at practically all times, and occasionally a little overload, then it is better to

## Direct Current

allow slightly greater horse power than in the problem just given.

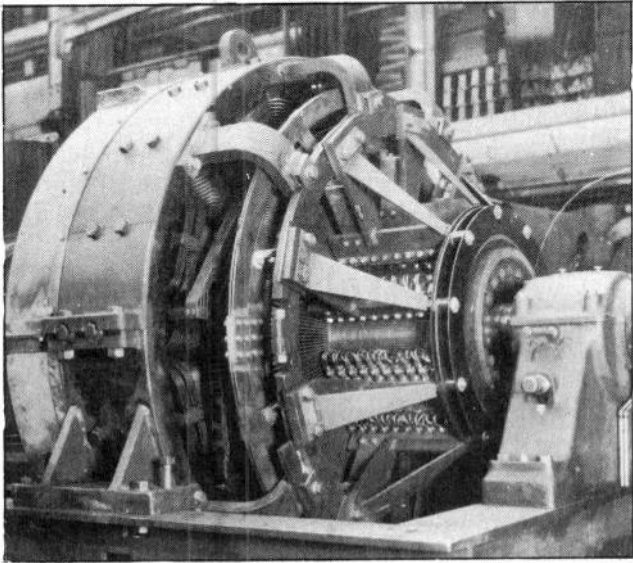


Fig. 1. This photo shows a large modern D. C. generator with a welded frame. The capacity of this generator is 1000 KW. What horse power will be required to drive it and satisfactorily maintain the speed when the generator is 10% overloaded? Assume the efficiency of the generator to be 93%.

Although generators of 5 kilowatt capacity or above will usually have efficiencies of 80 per cent or higher, which means that 80 per cent of the mechanical input to such machines will appear as electrical power at the brushes, it must be noted that in the smaller machines efficiencies of a much lower value will be the rule, for in the fractional horsepower field the efficiencies of both motors and generators will frequently run below 50 per cent. Such machines convert less than half the energy input into useful energy in the output. This will explain why a small D.C. generator with an output of 100 watts may require a one-half H.P. motor to drive it. If both machines have an efficiency of 50 per cent, the overall efficiency of this combination is 25 per cent. This means that every watt output of the generator requires 4 watts input to the driving motor. This combination is encountered frequently when an A.C.

## Starting Generators

motor is used to drive an automobile generator for battery charging purposes.

Prime movers for the operation of generators should be equipped with governors which are quick enough in their response so that they do not allow the generator to slow up noticeably when additional load is applied.

There is generally some adjustment provided on these governors which can be used to set the prime mover to run the generator at the proper speed to maintain the proper voltage.

As the voltage of the generator depends upon its speed, we should keep in mind that its voltage can be adjusted by adjusting the governors or throttle of the prime mover.

## 2. INSPECTION BEFORE STARTING GENERATORS

When starting up a generator we should first make a thorough examination, to make sure that the prime mover and generator are both in proper running order. The oil wells should be examined to see that there is sufficient oil in all main bearings and that the oil rings are free to turn. Be careful, however, not to flood oil wells, because excess oil allowed to get into the windings of the generator is very damaging to the insulation, and may necessitate rewinding the machine.

On small and medium-sized machines only a little oil need be added from time to time, unless the oil wells leak. On large machines, where the armature is very heavy, forced lubrication is necessary to maintain the film of oil between the shaft and bearings. With these machines an oil pump is used to force oil to the bearings at a pressure of 20 to 30 lbs. per square inch to insure proper lubrication. Some bearings are also water cooled, having openings through the metal around the bearing for water to flow through and carry away excessive heat.

If there are auxiliaries of this kind, they should be carefully examined and checked before running the machine.



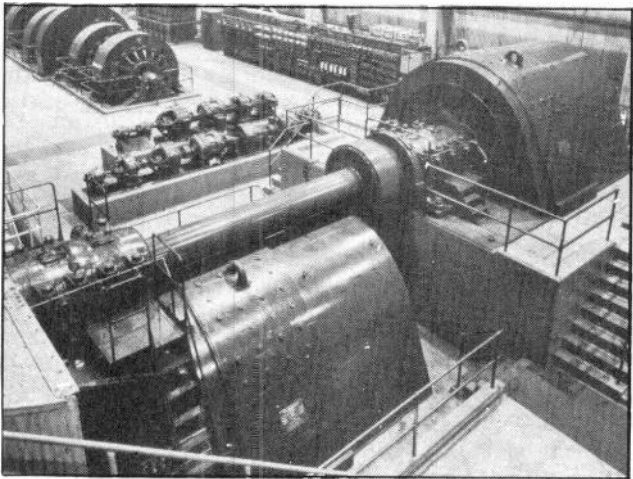
## Direct Current

### 3. STARTING GENERATORS

Before starting up a generator it is usually best to see that the machine is entirely disconnected from the switchboard. This is not always necessary, but it is safest practice. Next start the prime mover and allow the generator armature to come gradually up to full speed. Never apply the power jerkily or irregularly.

Power generators are always rotated at their full speed when operating under load. When the machine is up to full speed the voltage can be adjusted by means of the field rheostat which is connected in series with the shunt field.

The machine voltage can be checked by means of the switchboard voltmeter, and it should be brought up to full operating voltage before any switches are closed to place load on the generator.



This photo shows heavy Direct Current Electric Motors and control equipment.

After the voltage is adjusted properly, the machine may be connected to the switchboard by means of the circuit breakers and switches. Where circuit breakers are used they should always be closed first, as they are overload devices and should be free to drop out in the event there is an overload or short circuit on the line.

## Starting Generators

After closing the circuit breaker the machine switch may be closed, completing the connection of the generator to the switchboard. As the switch is closed the operator should watch the ammeter and voltmeter to see that the load is normal and to make any further necessary adjustments with the field rheostat.

If the generator is operating in parallel with others, the ammeter will indicate whether or not it is carrying its proper share of the load. **The load on any generator should be frequently checked by means of an ammeter or wattmeter to see that the machine is not overloaded.**

The temperature of the machine windings and bearings should also be frequently observed in order to check any overheating before it becomes serious.

### 4. CARE OF GENERATORS DURING OPERATION

After the machine is running, the most important observations to be made frequently are to check the bearing oil and temperature, winding temperatures and ventilation, voltage of the machine as indicated by the volt meter, and the load in amperes shown by the ammeter. Commutator and brushes should also be observed to see that no unusual sparking or heating is occurring.

Commutators should be kept clean and free from dirt, oil or grease at all times. Brushes should be kept properly fitted and renewed when necessary, and the commutator surface kept smooth and even for the best results.

All parts of an electric generator should be kept clean at all times as dust and oil tend to clog the ventilating spaces in the windings, destroying the value of the insulation, and also interfering with proper commutation.

The supply of ventilating air in the generator room should be frequently checked to see that it is not restricted, and that the temperature of the armature is not allowed to become too high. Moisture is very detrimental to the generator winding and water in or around the generator is very dangerous,

## Direct Current

unless confined in the proper pipes for such purposes as cooling bearings, etc. **Never use water to extinguish fire on any electrical equipment.**

### 5. PARALLELING D. C. GENERATORS

When direct current is used in large quantities the power is usually furnished by several generators operating in parallel, rather than by one or two very large machines. The larger machines when operated at full load, are, of course, more efficient than smaller ones, but the use of several machines increases the flexibility and economy of operation in several ways.

If only one large generator is used and the load is small during a considerable part of the time, it is then necessary to operate the machine partly loaded. The efficiency of any generator is generally less when operating at less than full load, as they are designed to operate at highest efficiency when they are fully loaded, or nearly so.

When several machines are used, the required number can be kept in operation to carry the existing load at any time. Then if the load is increased additional machines may be put in operation, or if it is decreased one or more machines may be shut down.

In a plant of this kind if any generator develops trouble it can be taken out of service for repairs, and its load carried by the remaining machines for a short period, if it doesn't overload them more than the amount for which they are designed.

### 6. IMPORTANT RULES FOR PARALLEL OPERATION

As we learned in the previous section on series and parallel circuits, when generators are connected in parallel their voltages will be the same as that of one machine. The current capacity of the number of generators in parallel, however, will be equal to the capacity of all of them, or the sum of their rated capacities in amperes.

To operate generators in parallel, **their voltages must be equal and their polarities must be alike.**

## Paralleling Generators

The positive leads of all machines must connect to the positive bus bar and the negative leads of all machines must connect to the negative bus bar. This is illustrated by the sketch in Fig. 3, which shows two D. C. generators arranged for parallel operation. You will note that if the switches are closed the positive brushes of both machines will connect to the positive bus bar, and the negative brushes are both connected to the negative bus bar.

The voltmeters connected to each machine can be used to check the voltage as the machine is brought up to speed, in order to be sure that it is equal to the voltage of the other machine which may already be running and connected to the bus. If the voltages are unequal to any great extent, the machine of

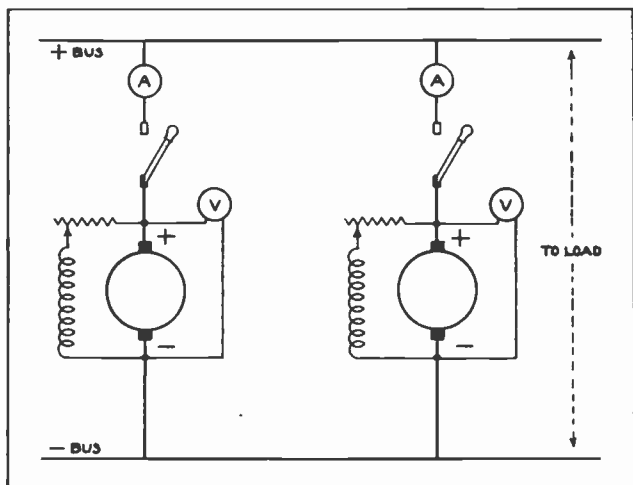


Fig. 3. This simple sketch shows a method of connecting two D. C. generators in parallel. Note the polarity of the generator brushes and bus bars.

higher voltage will force current backward through the one of lower voltage and tend to operate it as a motor.

It is, therefore, very important that the voltage be carefully checked before closing the switch which connects a generator in parallel with others.

If the polarity of one machine were reversed, then when they are connected together it would result

## Direct Current

in a dead short circuit with double voltage or the voltage of both machines applied in series.

Just try making a sketch similar to Fig. 3 and reverse the polarity of one generator and see what would happen. You will find that the positive of one machine feeds directly into the negative of the other, and so on around a complete short circuit.

The resistance of the machine windings, bus bars, ammeters and connections is so low that an enormous current would flow, until circuit breakers or fuses opened the circuit. If no such protective devices were provided, the windings would be burned out or possibly even thrown out of the slots, by the enormous magnetic stresses set up by the severe short circuit currents.

You can readily see that in such matters as these your training on electrical principles and circuits becomes of the greatest importance, as you should at all times know the results of your movements and operations in a power plant, and know the proper methods and precautions to follow.

### 7. CORRECTING WRONG POLARITY

If the polarity of a generator should build up wrong, or in the reverse direction, **it will be indicated by the voltmeter reading in the wrong direction**, and these meters should always be carefully observed when starting up machines.

Sometimes the generator will build up wrong polarity because its residual magnetism has reversed while the machine was shut down. Sometimes stopping and starting the machine again will bring it up in the right polarity. If it doesn't the polarity can be corrected by momentarily applying a low voltage source of direct current to the field coils and sending current through them in the proper direction.

In power plants where several generators are connected to the same switchboard, the polarity of a reversed machine may be easily corrected by raising the brushes on the reversed generator, to open its armature circuit, and then closing the switch which connects this machine in parallel with the operating units. This procedure will allow current to flow

## **Paralleling Generators**

through the generator shunt field in the correct direction, thereby establishing the proper field polarity. The main switch is then opened, the brushes lowered onto the commutator, and the machine paralleled in the usual way.

### **8. COMPOUND MACHINES BEST FOR GENERAL SERVICE**

Shunt wound generators will operate quite satisfactorily in parallel if their voltages are kept carefully adjusted to keep the load divided properly between them. If the voltage of one machine is allowed to rise or fall considerably above or below that of the others, it will cause the machine of lower voltage to motorize and draw excessive reverse current, and trip open the circuit breakers.

If the voltage of one machine falls only a little below that of the others, the back current may not be sufficient to open the breakers, but would be indicated by the ammeter of this machine reading in the reverse direction.

Shunt generators are not very often used in large power plants, because of their very poor voltage regulation and the considerable drop in their voltage when a heavy load is applied. A plain shunt generator can usually be changed for compound operation by simply adding a few turns of heavy wire around the field poles, and connecting them in series with the armature, with the right polarity to aid the shunt field flux.

The compound generator is best suited to most loads and circuits for power and lighting service and is the type generally used where machines are operated in parallel in D. C. power plants.

Series generators are not operated in parallel and in fact they are very little used, except for welders, test work or in older street lighting installations.

### **9. SIMILAR VOLTAGE CHARACTERISTICS NECESSARY FOR PARALLEL OPERATION**

Compound generators can be readily paralleled if they are of the same design and voltage. They usu-

ally have similar electrical and voltage characteristics and should be made with the same compounding ratios. That is the compounding effects of the machines must be equal even though they are of unequal size.

Machines of different kilowatt ratings can be satisfactorily operated in parallel, if they are made by the same manufacturer or of the same general design, so that each will tend to carry its own share of the load. If their compounding is properly proportioned, the voltage rise of each generator should be the same for a similar increase of load.

When a D. C. generator is operated in parallel with others and its voltage is increased, it will immediately start to carry a greater share of the current load. **We can, therefore, adjust the load on the various machines by increasing or decreasing their voltages the proper amount.**

### 10. TESTING AND ADJUSTING COMPOUNDING OF GENERATORS

The compounding effects of different generators can be tested or compared by separately loading them different amounts and observing their voltmeters. This can be done by connecting one of the machines to the switchboard, or to a special loading rheostat, and operating the machine under normal voltage. Then apply a certain amount of load to it and observe the voltmeter closely, to note the amount of increase in the voltage due to the compounding effect.

It will probably be well to check the voltage increase as the load is changed from one-fourth to one-half, and then to three-fourths and full load values. By testing each generator in this manner we can determine which of them has the greatest overcompounding effect, or produces the highest increase in voltage for the various increases in load.

If this compounding is found to be different on the various machines, it can be adjusted by means of the series field shunt, which will allow more or less of the total load current to flow through the series winding of the compound field.

## Paralleling Generators

When a number of machines of similar design are thus properly adjusted they should operate satisfactorily in parallel under all normal load changes.

In case the machines do not properly divide their loads and one is found to be taking more than its share of any load increases, this can be corrected by very slightly increasing the resistance of its series field circuit by adding a few feet of cable in the series field connection.

The series field windings may be connected to either the positive or negative brush leads of the armature; but where compound generators are operated in parallel, the series field lead of each machine must be connected to the same armature lead, either positive or negative, on all generators.

### 11. EQUALIZER CONNECTIONS

When compound generators are operated in parallel, an equalizer connection should be used to equalize the proportion of currents through their series fields and to balance their compounding effects.

This equalizer connection, or bus, is attached to the end of the series field next to the armature. Its purpose is to connect the series fields of all generators directly in parallel by a short path of very low resistance, and to allow the load to divide properly between them. When this connection is properly made the current load will divide between the series fields of the several machines in proportion to their capacity.

The equalizer allows the total load current to divide through all series fields in inverse proportion to their resistance, independently of the load on the armature of the machine and of the armature resistance and voltage drop. This causes an increase of voltage on one machine to build up the voltage of the others at the same time, so that no one machine can take all the increased load.

The connecting cables or busses used for equalizer connections between compound generators should be of very low resistance and also of equal resistance. This also applies to the series field connections from the generators to the main buss, if machines are of the same type.



## Direct Current

If the machines are located at different distances from the switchboard, bus cables of slightly different size can be used, or an additional low resistance unit can be inserted in the lower resistance leads.

Whenever possible, leads of equal length should be used; and, in the case of cables, it is sometimes advisable to loop them or have several turns in the cable to make up the proper length. If these cables or busses were of unequal resistance on machines of the same size, there would be an unequal division of the load through the machines, and the machine having the lowest resistance in its series field circuit would take more than its share of the load. When machines of unequal size are to be paralleled the resistance of the series field leads should be in proportion to the resistance of the series windings.

Fig. 5 shows a wiring diagram for two compound generators to be operated in parallel. Note the series and shunt field windings, and also the series field shunts and shunt field rheostat. The equalizer connections are shown properly made at the point between the series field lead and the negative brush. From this point they are attached to the equalizer bus on the switchboard. The voltmeters are connected directly across the positive and negative leads of each generator, and the ammeters are connected across ammeter shunts which are in series with the positive leads of each machine. These shunts will be explained later.

The machine switches for connecting the generators to the bus bars are also shown in this diagram; but the circuit breakers, which would be connected in series with these switches, are not shown.

### 12. LOCATION OF EQUALIZER SWITCHES

On machines of small or medium sizes and up to about 1,000 amperes capacity, the equalizer switch is often the center pole of the three-pole switch, as shown in Fig. 5.

The two outside switch blades are in the positive and negative leads of the machine. For machines requiring larger switches, three separate single-pole switches may be used for greater ease of operation.

## Paralleling Generators

In this case the center one is usually the equalizer switch.

It is quite common practice to mount all of these switches on the switchboard, although in some installations the equalizer switch is mounted on a pedestal near the generator. In this case, the equal-

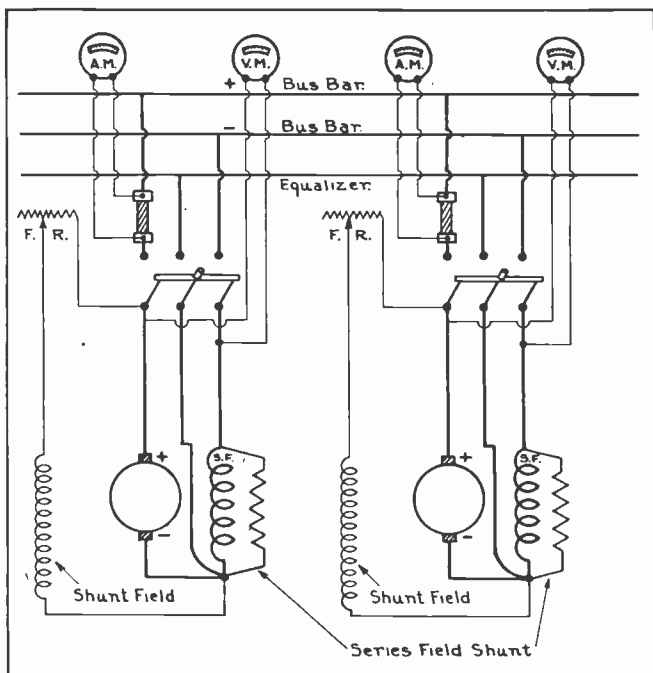


Fig. 5. This diagram shows the connections for two compound D. C. generators to be operated in parallel. Note carefully the connections of the equalizer leads, series and shunt fields and instruments.

izer cable or bus is not taken to the switchboard but is run directly between the two machines.

Regardless of the location of the equalizer switches, **they should be closed at the same time or before the positive and negative machine switches are closed.**

Where three-pole switches are used, all of the poles are, of course, closed at the same time; but, if three single-pole switches are used, the equalizer should be closed first. If the positive and negative switches are closed one at a time, the switch on the

## Direct Current

same side of the armature from which the equalizer connection is taken should be closed second.

The series field should always be paralleled before or at the same instant that the generator armature is paralleled with the main bus, in order to insure equalization of the compounding effects and to allow the machine to take its proper share of the load at once.

### 13. INSTRUMENT CONNECTIONS WITH PARALLEL GENERATORS

Current instruments and devices—such as ammeters, overload coils on circuit breakers, current coils of wattmeters, etc.—should always be connected in the armature lead which doesn't contain the series field winding. This is shown by the ammeter shunts in Fig. 5, which are properly connected in the positive lead.

If these devices are connected in the lead which has the series field in it, the current indications will not be accurate, because current from this side of the machine can divide and flow through either the equalizer bus or the armature.

Ammeters and other current devices should indicate the amount of current through the armature of the machine. It is not necessary to measure the current through the series fields, since they are all in parallel with each other.

The voltage generated in the armature will determine the amount of current which is carried through it, and it is possible to control the armature voltage of any machine by the adjustment of the shunt field rheostat and thus vary the load carried by each generator.

Voltmeters should be connected, as shown in Fig. 5, at a point between the generator brushes and the main switch, so that the voltage readings can be obtained before this switch is closed. This is necessary because we must know the voltage of the generator before it is connected in parallel with the others

## Paralleling Generators

### 14. STARTING, PARALLELING and ADJUSTING LOAD ON GENERATORS

In starting up a generator plant with several machines, the first generator can be started by the procedure previously described and connected to the bus as soon as its voltage is normal. The second generator should then be brought up to speed and its voltage then carefully checked and adjusted to be equal to that of the first machine. Then this second machine can be connected to the bus. The ammeters of both machines should then be read to see that they are dividing the load equally or in proportion to their sizes.

By adjusting the voltage of any generator with its field rheostat, it can be made to take its proper share of the load. After this adjustment is made, the same procedure can be followed on the remaining machines. If there are a number of branch circuits and switchboard panels feeding to the lines and load, the switches on these panels can be closed one at a time, applying the load to the generators gradually.

To shut down any machine adjust its shunt field rheostat to cut in resistance and weaken its field, lowering the voltage of that generator until its ammeter shows that it has dropped practically all of its load. The circuit breaker can then be opened and the machine shut down.

### THREE-WIRE D. C. SYSTEMS

The Edison three-wire D.C. system is used chiefly where the generating equipment is to supply energy for both power and lighting. The advantages of this system are that it supplies 110 volts for lights and 220 volts for motors and also saves considerably in the amounts and cost of copper, by the use of the higher voltage and balancing of the lighting circuits. Some of these features of the three-wire system were also explained in lesson 19.

One of the most simple and common methods of obtaining the two voltages on three-wire D. C. circuits is by connecting two 110-volt generators in series, as shown in Fig. 6.

We know that when generators are connected in series in this manner their voltages add together, so these two 110-volt machines will produce 220 volts between the outside or positive and negative wires. The third, or neutral, wire is connected to the point between the two generators where the positive of one and negative of the other are connected together. The voltage between the neutral wire and either outside wire will be 110 volts, or the voltage of one machine.

Generators for this purpose may be either shunt or compound, but the **compound machines are more generally used**. They can be driven by separate prime movers or both driven by the same prime mover if desired; and the drive may be either by belt or direct coupling.

In general the operation of a three-wire system is practically the same as for a two-wire machine. The voltage of each generator may be adjusted by means of the shunt field rheostat.

As these machines are operated in series instead of parallel, it is not necessary to have their voltage exactly even; but they should be kept properly adjusted in order to maintain balanced voltages on the two sides of the three-wire system.

There is no division of the current load between these generators—as in the case of parallel machines—as the main current flows through both machines in series. When the voltage of both machines

## Three-Wire Systems

is properly adjusted, they can be connected to the switchboard busses. The ammeters should then be observed to note the current in each wire.

### 15. DIRECTION AND AMOUNT OF CURRENT IN THE NEUTRAL WIRE

The ammeter in the neutral wire is of the double-reading type, with the zero mark in the center of the scale, and it will read the amount of current flowing in either direction.

When the load on a three-wire system is perfectly balanced, the neutral wire will carry no current and the set operates on 220 volts. In this case the two outside ammeters will read the same and the center ammeter will read zero. When there is an unequal amount of load in watts on each side of the system it is said to be unbalanced, and the neutral wire will carry current equal to the difference between the current required by the load on one side and that on the other.

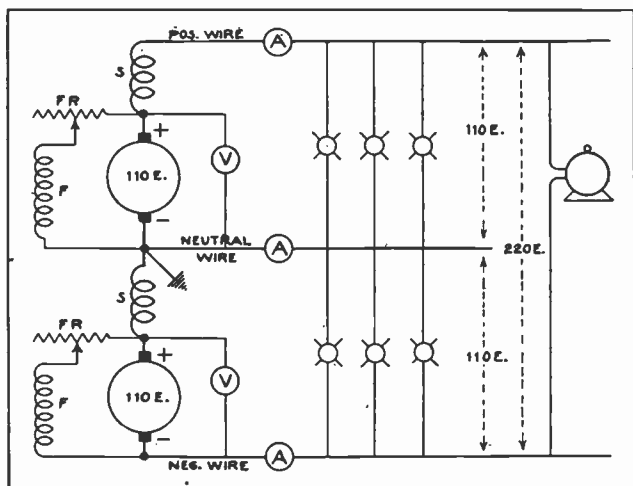


Fig. 6. This sketch shows two D. C. generators connected in series for providing three-wire, 110 and 220 volt service.

This current may, therefore, flow in either direction, according to which side of the system has the heaviest load. Referring to Fig. 6—if the greater

## Direct Current

load were on the lower side, the extra current required would be furnished by the lower generator; and the current in the neutral wire would be flowing to the right, or away from the generators. If the heavier load were placed on the upper side of the system, the extra current would be supplied by the upper machine, flowing out on its positive wire and back to the line on the neutral wire.

### 16. BALANCED SYSTEM MORE ECONOMICAL

For efficient operation, the amount of unbalance should not exceed 10% of the total load. In many cases, however, it is allowed to exceed 15% or more. If the load could always be kept perfectly balanced, no neutral wire would be required as all of the load devices would be operated two in series on 220 volts.

Without the neutral wire, if one or more of the lamps or devices should be disconnected, the remaining ones on the other side of the system would operate at more than normal voltage.

In most systems it is practically impossible to keep the load balanced at all times, and, therefore, the neutral wire is necessary to carry the unbalanced load and keep the voltages equal on both sides of the system. It is very seldom, however, that the neutral wire will have to carry as much current as the outside wires. Therefore, it may be made smaller than the positive and negative wires.

Quite often the neutral wire is made one-half the size of either of the outer wires, unless local rulings require it to be of the same size. If the neutral wire is made one-half the size of the outer ones, a three-wire system of this type will require only 31.3% of the copper required for the same load on a two-wire, 110-volt system.

The neutral wire is generally grounded, as shown in Fig. 6.

### 7. THREE-WIRE GENERATORS

In some cases a special three-wire generator is used, instead of the two machines in series, to produce a three-wire D.C. system. An early type of three-wire generator, and one which is still used for

## Three-Wire Systems

certain installations, consists of a 220-volt armature equipped with both a commutator and slip rings.

The armature coil connections are made to the commutator in the usual manner, and 220 volts is obtained from the brushes on the commutator. In addition to the leads from each coil to the commutator bars, other leads are taken from points spaced  $180^\circ$  apart around the winding and are connected to a pair of slip rings mounted on the shaft near the end of the commutator. This supplies single-phase alternating current at 220 volts to the slip rings.

From the brushes on these slip rings two leads are taken to opposite ends of a choke coil, which consists of a number of turns of heavy wire wound on an iron core similar to a transformer core. This connection is shown in Fig. 7.

A tap is made at the exact center of this choke coil for the third or neutral wire. In some cases a choke coil is mounted on the armature shaft and rotated with it; but in most cases this coil is stationary and outside of the machine, having its connections made through the slip rings and brushes. These coils are often referred to as three-wire transformers or compensators.

### 18. PRINCIPLE OF THE BALANCE COIL

The neutral wire, being connected to the center of the coil, is always at a voltage about one-half that between the positive and negative brushes. Therefore, if 220 volts are obtained between these brushes, 110 volts are obtained between either the positive and negative wire and the neutral.

When the load on a three-wire generator of this type is perfectly balanced, no current flows in the neutral wire and all of the load current is supplied from the commutator by the positive and negative D. C. brushes. There is, however, a small amount of alternating current flowing through the **choke or balance coil** at all times, as there is an alternating voltage applied to it from the slip rings as long as the machine is operating. This current will be very small, as a choke coil of this type offers a very high



## Direct Current

impedance or opposition to the flow of alternating current.

This impedance, or opposition, is composed of the ohmic resistance of the conductors in the coil, and also of the counter-voltage generated by self-induction whenever alternating current is passed through such turns of wire wound on an iron core.

Direct current, however, can flow through a coil of this type with only the opposition of the copper resistance, as the flux of direct current is not constantly expanding and contracting like that of alternating current, and so doesn't induce the high counter-voltage of self-induction.

### 19. UNBALANCED LOAD ON THREE-WIRE GENERATORS

When a system such as that shown in Fig. 7 is

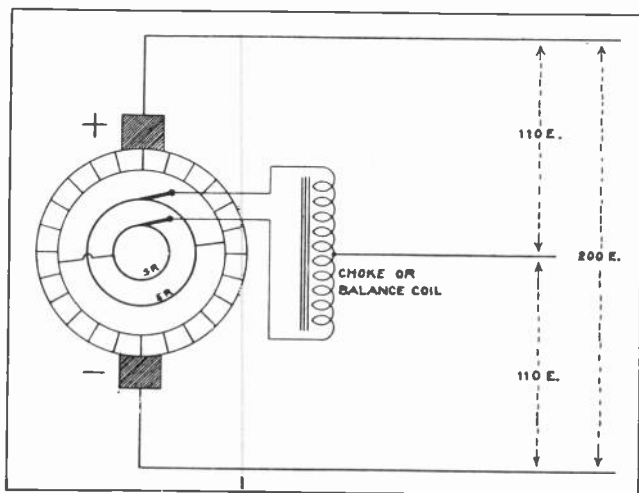


Fig. 7. The above diagram shows the commutator, slip rings, and balance coil of a three-wire D. C. generator.

unbalanced and has, we will say, a heavier load between the positive wire and neutral, the unbalanced current flowing in the neutral wire will return to the center tap of the choke coil. From this point it will flow first in one direction and then in the other, as the alternating current reverses in direction through the coil. Thus it returns to the armature

## Three-Wire Systems

winding, through first one slip ring and then the other.

If the lower side of the circuit is loaded the heaviest the unbalanced current will flow out through the choke coil in the same manner, passing first through one half and then the other, to reach the neutral wire.

The choke coil must, of course, be wound with wire large enough to carry the maximum unbalanced current that the neutral wire is expected to carry. It must also have a sufficient number of turns to limit the flow of alternating current from the slip rings to a very low value, in order to prevent a large waste of current through this coil.

Three-wire generators of this type can stand considerable unbalanced load without much effect on the voltage regulation. They are very compact and economical and are used to some extent in small isolated D.C. plants, where the circuits carry a load of 110-volt lamps and equipment, and also 220-volt motors.

### 20. THREE-WIRE MOTOR GENERATORS OR BALANCER SETS

Three-wire circuits may also be obtained by means of a 220-volt D.C. generator in combination with a motor-generator or balancer set. These balancer sets consist of two 110-volt machines mounted on the same bed plate and directly connected together by their shafts. See Fig. 11. The armatures of both machines are connected in series with each other, and across the positive and negative leads of the 220-volt generator, as shown in Fig. 10.

This allows 110 volts to be applied to each armature and operates both machines as motors when the load is perfectly balanced. Either machine can, however, be operated either as a motor or as a generator, if the load on the system becomes unbalanced.

If one side of the system has a heavier load connected to it, the machine on this side automatically starts to operate as a generator and is driven by the machine on the other side, which then operates as

## Direct Current

a motor. This condition will immediately reverse if the greater load is placed on the opposite side of the system. A balancer set of this type will, therefore, supply the unbalanced current in either direction, and will maintain 110 volts between the neutral and either outside wire.

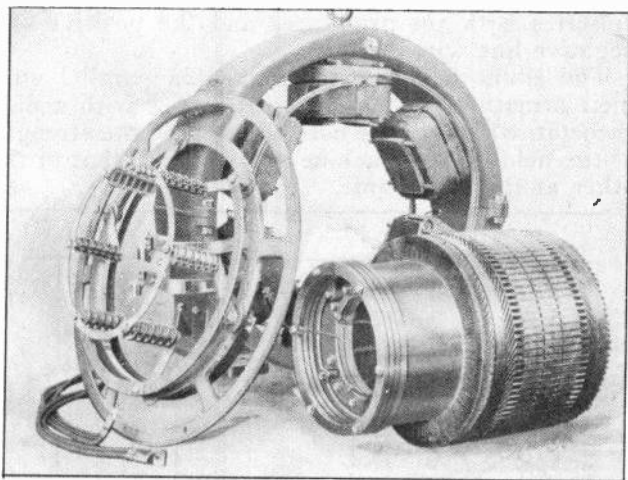


Fig. 8. This view shows a three-wire generator disassembled. You will note the slip rings mounted on the end of the commutator.

Where these machines are larger than one or two kilowatts, a starting rheostat should be used to limit the flow of current through their armatures until the machines attain full speed. After they reach full speed, they generate sufficient counter-voltage to limit the current flow through their armatures while operating as motors.

The neutral wire is connected between the armatures of the motor generator set where their positive and negative leads connect together.

### 21. EFFECTS OF SHUNT AND SERIES FIELDS OF BALANCER GENERATORS

Either shunt or compound machines may be used for these equalizers, but compound machines are used more extensively. The number of turns in the series field coils must be carefully selected to provide the proper compounding effects. Generally the

## Three-Wire Systems

number of turns is very small, so that the voltage rise due to compounding will not be very great.

If this series field produces too great a voltage rise on either machine, that machine will be apt to take more than the unbalanced part of the load. The machines shown in Fig. 10 are of the compound type and have their series fields connected in series with the armatures and the positive and negative line wires.

The shunt fields are connected in parallel with their armatures and are both in series with a field rheostat, which can be used to increase the strength of the field of one machine and decrease that of the other at the same time.

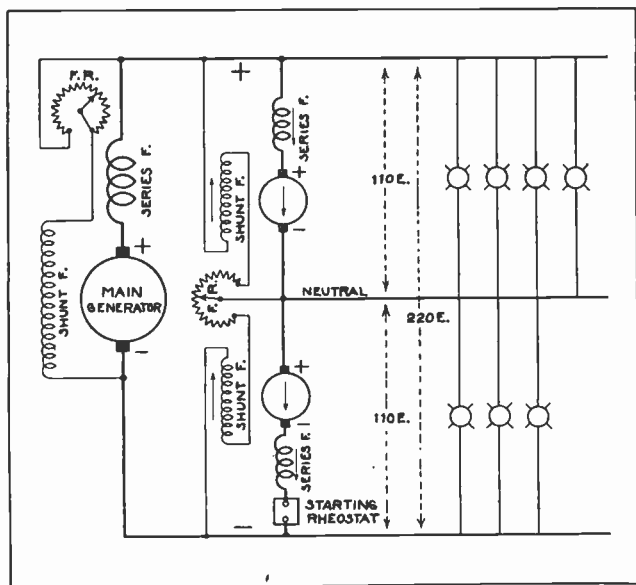


Fig. 10. This diagram shows the connections for the main generator and two balancer machines of a three-wire system.

The series fields are connected so that they increase the field strength when either machine is operating as a generator, but tend to decrease or oppose the flux of the shunt field on either machine when it operates as a motor. This is caused by the reversal of the direction of current through the series field and armatures as the unbalanced load

## Direct Current

is shifted from one side of the system to the other. Current through the shunt fields, however, continues to flow in the same direction at all times, because they are connected across the positive and negative leads from the main generator.

If the compounding effect of the balancer machines tends to strengthen the field of either one operating as a generator, the voltage of that machine will rise slightly; while the compound effect on the machine operating as a motor weakens its field and tends to make it speed up.

As long as the load on the system is perfectly balanced, both machines operate as differential motors without any mechanical load. The current through their armatures at such times is very small, being only sufficient to keep the armatures turning against the bearing and friction losses and to supply the small electric losses in the machines.

### 22. BALANCING OF UNEQUAL LOADS

When a system is unbalanced, the neutral current divides between the two armatures, driving the one on the lightly loaded side as a motor and passing through the other as a generator. In Fig. 10 the upper side of the system has the heaviest load, and the lower side has the highest resistance. This will cause the excess current from the greater load to flow back through the neutral wire and through the series of the lower machine, in a direction opposing its shunt field. This weakens the field flux and causes this machine to speed up and tend to act as a motor to drive the upper machine as a generator.

As the voltage of the generator unit rises slightly with the increased speed, it causes part of the unbalanced load to flow through it, and its series field, in a direction aiding the flux of the shunt field.

This increases its voltage still more, which enables it to take its proper share of the unbalanced current and to compensate for the voltage drop on the heavily loaded side of the system.

If the heaviest load is placed on the other side of the system, the current through the series fields of both machines will reverse, and cause the one which

## Three-Wire Systems

was operating as a generator to speed up and operate as a motor.

The motor armature must take enough more than one-half of the neutral current to supply the losses of both armatures.

Referring again to Fig. 10, we find that the connections of the field rheostat, F. R., are such that when the handle or sliding contact is moved upward it will cut resistance out of the shunt field of the upper machine and add resistance in series with the shunt of the lower machine. This would pro-

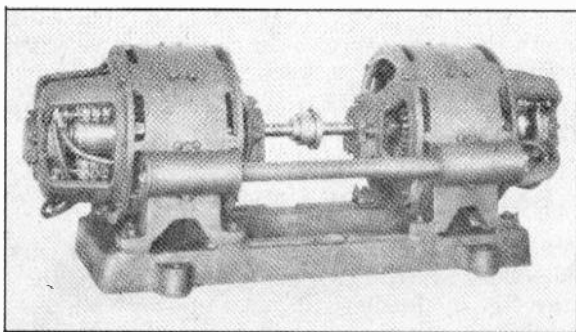


Fig. 11. Photo of a motor-generator balancer set used for three-wire system machines of this type are used considerably, where the unbalanced load is small compared to the total load on the main generator.

duce the desired effects when the upper machine is operating as a generator and the lower one as a motor.

As this change of resistance increases the field strength voltage of the generator, it weakens the field strength and increases the speed of the motor.

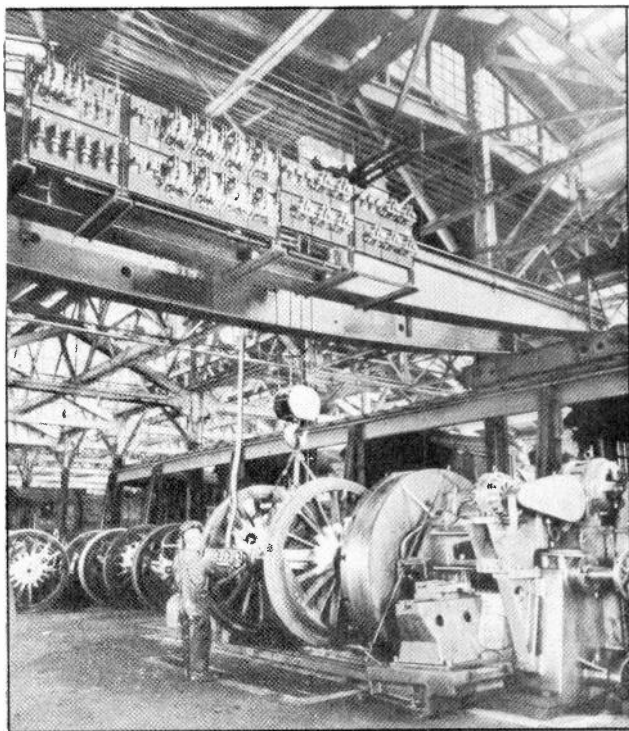
The shunt fields can be controlled separately, if desired, by connecting a separate rheostat in series with each field. In Fig. 6 the shunt fields of each machine are connected in parallel with their own armatures. By changing these connections so that the shunt field of each machine is connected across the armature of the other machine, the machine which is operating as a generator will increase the current flow through the motor field and improve the torque of the motor armature.

## Direct Current

### EXAMINATION QUESTIONS

1. For what purpose is a Prime Mover used?
2. What size engine in H. P. rating would be required to operate a 110 volt generator capable of furnishing current at the rate of 30 amperes? Assume the generator to be 80% efficient.
3. a. In what order are the circuit breakers and switches closed when connecting the generator to the switch board?  
Why?
4. What are two advantages in operating two or more generators in parallel rather than using one generator large enough to carry the entire load?
5. What effect does a parallel connection of generators have on the combined voltage and current capacity?
6. In what respect must generators be alike when they are connected in parallel?
7. What is the purpose of an equalizer connection when paralleling compound generators?
8. In what three ways may a three wire D.C. system be produced?
9. Does current flow in the neutral wire when a three wire system is operating with a balanced load?
10. What may happen on a three wire system if the neutral wire is broken?

## Three-Wire Systems



On this 10-Ton railroad repair shop floor-operated crane, Dynamic Lowering Control gives extreme accuracy, enabling the machine operator to guide the work carefully into position on the machine tool centers.



# COMMUTATION AND INTERPOLES

The term "Commutation" applies to the process of reversing the connections of the coils to the brushes, as the coils pass from one pole to another in rotation.

The function of the commutator, as we already know, is to constantly deliver to the brushes voltage in one direction only, and thereby rectify or change the alternating current generated in the winding to direct current for the line.

We have also learned that commutation for the various coils, or the contact of their bars with the brushes, should take place when the coils are in the neutral plane between adjacent poles; at which point there is practically no voltage generated in them.

The reason for having commutation take place while the coils are in the neutral plane is to prevent short-circuiting them while they have a high voltage generated in them. This would cause severe sparking, as will be more fully explained later.

## 1. PROCESS OF COMMUTATION

The process of commutation, or shifting of coils in and out of contact with the brushes, is illustrated in Fig. 1. Here we have a sketch of a simple ring-type armature with the ends of the coils shown connected to adjacent commutator bars. This winding is not the kind used on modern power generators, but it illustrates the principles of commutation very well, and is very easily traced.

We will assume that the armature in this figure is rotating clockwise. All of the coils which are in front of the north and south poles will be generating voltage, which we will assume is in the direction shown by the arrows inside the coils.

As the coils are all connected in series through their connections to the commutator bars, the voltage of all of the coils on each side of the armature will add together. The voltages from both halves of the winding cause current to flow to the positive brush, out through the line and load, and

## Commutation

back in at the negative brush where it again divides through both sides of the winding.

Now let us follow the movement of one coil through positions A, B, and C; and see what action takes place in the coil during commutation.

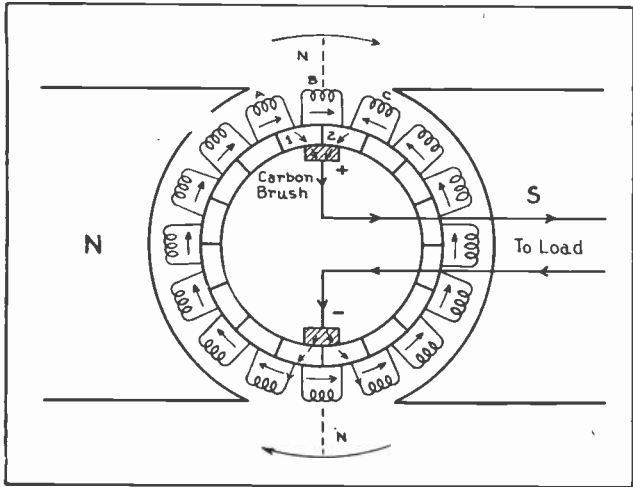


Fig. 1. This diagram illustrates the principles of commutation in a generator. Examine each part of it very carefully while reading the explanation given on these pages.

We will first consider the coil in position A, which is approaching the positive brush. This coil is carrying the full current of the left half of the winding, as this current is still flowing through it to commutator bar 1 and to the positive brush. The coil at "A" also has a voltage generated in it, because it is still under the edge of the north field-pole.

An instant later when the coil has moved into position B, it will be short-circuited by the brush coming in contact with bars 1 and 2.

## 2. SELF INDUCTION IN COILS SHORTED BY BRUSHES

As soon as this coil is shorted by the brush, the armature current stops flowing through it, and flows directly through the commutator bar to the brush. When this current stops flowing through

## Direct Current

the coil, the flux around the coil collapses and cuts across the turns of its winding, inducing a voltage in this shorted coil. This is called **voltage of self-induction**, and it sets up a considerable current flow in the shorted coil, as its resistance is so low. Note that the **voltage of self-induction** always tends to maintain current in an armature coil in the direction it was last flowing when generated from the field pole.

As long as the coil remains shorted, the current set up by self-induction flows around through the coil, bars, and brush. But as the coil moves far enough so bar 2 breaks contact with the brush, this interrupts the self-induced current and causes an arc. Arcing or sparking will tend to burn and pit the commutator, and is very detrimental to the commutator surface and brushes. Methods of preventing arcing will be explained later.

As the coil which we are considering moves on into position C, its short circuit has been removed and it is now cutting flux under a north pole. This will generate a voltage in the opposite direction to what it formerly had, and it still feeds its current back to the positive brush through bar 2.

So we find that, by shifting the contact from one end of the coils to the other as they pass from pole to pole and have their voltages reversed, the same brush always remains positive.

### 3. IMPORTANCE OF PROPER BRUSH SETTING FOR NEUTRAL PLANE

The time allowed for commutation is extremely short, because when a motor armature is turning at high speed, the bars attached to any coil are in contact with a brush for only a very small fraction of a second.

The reversal of the coil leads to the brushes must take place very rapidly as the coils are revolved at high speed from one pole to the next. On an ordinary four-pole generator each coil must pass through the process of commutation several thousand times per minute. Therefore, it is very important that commutation be accomplished without

## Commutation

sparkling, if we are to preserve a smooth surface on the commutator and prevent rapid wear of the brushes.

Brushes are made in different widths according to the type of winding used in the machine; but, regardless of how narrow the brushes may be, there will always be a short period during which adjacent commutator bars will be shorted together by the brushes as they pass under them.

We have found that, in order to avoid severe sparking during commutation, the coils must be shorted only while they are in the neutral plane, when the coil itself is not generating voltage from the flux of the field poles. Therefore, the brushes must be accurately set so they will short circuit the coils only while they are in this neutral plane.

### 4. SHIFTING BRUSHES WITH VARYING LOAD ON MACHINES WITHOUT INTERPOLES

The neutral plane tends to shift as the load on a generator is increased or decreased. This is due to the fact that increased load increases the current through the armature winding and the additional armature flux will cause greater distortion of the field flux. The greater the load, the further the neutral plane will move in the direction of armature rotation.

If the brushes are shifted to follow the movement of this neutral plane with increased load, commutation can still be accomplished without severe sparking. For this reason, the brushes are usually mounted on a rocker arm which allows them to be shifted or rotated a short distance in either direction around the commutator.

In addition to the sparking which is caused by shorting coils which are not in the neutral plane, the other principal cause of sparking is the self-induced current which is set up in the coils by the collapse of their own flux when the armature current through them is interrupted.

We have previously stated that this self-induction will set up a considerable flow of current in the

## Direct Current

shorted coils. Then, when the coil moves on and one of its bars moves out from under the brush and thus opens the short circuit, this current forms an arc as it is interrupted.

Sparking from this cause can be prevented to a large extent by generating in the coil a voltage which is equal and opposite to that of self-induction.

Shifting the brushes also helps to accomplish this, by allowing commutation to take place as the coil is actually approaching the next field pole.

This is illustrated in Fig. 2. In this figure you will note that the brushes have been shifted so that they do not short circuit the coils until they are actually entering the flux of the next pole beyond the normal neutral plane.

The voltage of self-induction always tends to set up current in the same direction as the current induced by the field pole which the coil is just leaving. If, at the time the short circuit on the

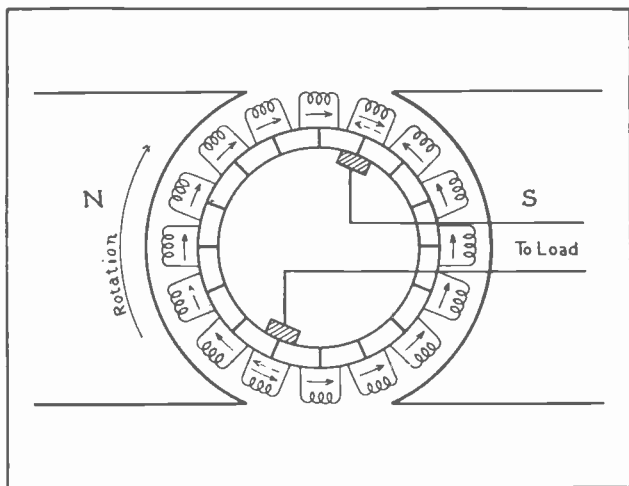


Fig. 2. This sketch shows the method of shifting the brushes to short circuit coils in a position where they will be generating the voltage to neutralize that of self-induction.

coil is broken, the coil is entering the flux of the next pole, this flux will induce in the coil a voltage in the opposite direction to that of self-induction. This will tend to neutralize the voltage and currents

## Commutation

of self-induction and enable the short circuit to be broken when there is practically no voltage or current in the shorted coil.

Keep in mind that this is the required condition for most satisfactory commutation.

If the load on generators doesn't change often or suddenly, manual shifting of the brushes with each change of load and new position of the neutral plane, may be all that is required to prevent sparking; but when the load changes are frequent and considerable, it would be very difficult to maintain this adjustment by hand.

Where the manual method is used to maintain proper commutation, it is common practice to adjust the brushes to a position where they will spark the least for the average load. Then, even though a certain amount of sparking results when the load rises above or falls below this value, the brushes are not changed unless the sparking becomes too severe.

Fig. 3 shows a D.C. generator without the shaft or bearing post. The brushes of this machine are all attached to the ring framework as shown, and this entire assembly can be rotated to shift the brushes, by means of the hand wheel at the left.

Referring again to Fig. 2, the solid arrows show the direction of the voltage of self-induction, and the dotted arrows show the direction of the voltage which is induced by the flux of the field pole which the coil is approaching. These two voltages, being in opposite directions, tend to neutralize each other, as has previously been explained.

### 5. USE OF COMMUTATING POLES TO PREVENT SPARKING

On the more modern D.C. machines commutating poles, or *interpoles*, are employed to hold the neutral plane in its normal position between the main poles, and to neutralize the effects of self-induction in the shorted coils. These interpoles are smaller field poles which are mounted in between the main poles of the machine, as shown in Fig. 4.

The interpoles are wound and connected so they will set up flux of proper polarity to generate

## Direct Current

voltage in the opposite direction to that of self-induction, as the armature coils pass under them. Fig. 5 shows a sketch of a simple generator with interpoles, or commutating poles, placed between the main field poles.

We will assume that this armature is rotated in a clockwise direction, and that its armature conductors have generated in them voltage which tends to send current in through the conductors on the left side, and out through those on the right side

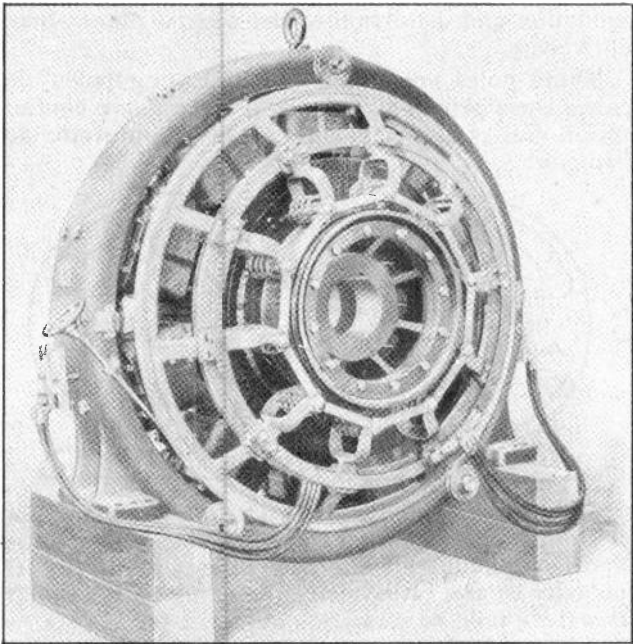


Fig. 3. This end view of a generator with the pedestals, bearings, and shaft removed shows very clearly the brush ring mounted in grooved rollers on the side of the field frame. The hand-wheel at the left can be used for rotating this ring to shift the brushes to the proper neutral plane.

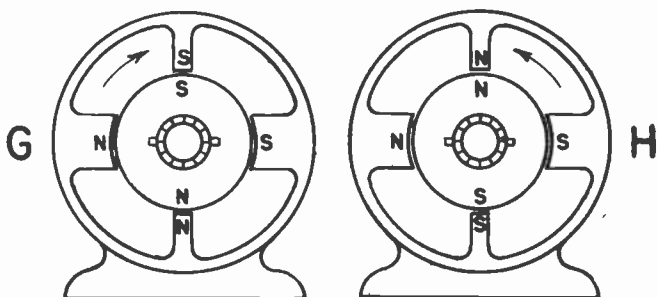
of the winding. Recalling that the voltage of self-induction tends to maintain current in the same direction in the conductor as it was under the last field pole, we find that this voltage is generated "in" at the top conductor in the neutral plane and "out" at the lower one.

## Interpoles

### 6. POLARITY OF INTERPOLES FOR A GENERATOR

If you will check the polarity of the interpoles, you will find that their flux would be in a direction to induce voltages opposite to those of self-induction in each of these two conductors. The direction of these voltages is shown by the symbols placed just outside of the conductor circles. So we find that, if these commutating poles are made to set up flux of the right polarity and in the right amount, they can be caused to neutralize the effects of self-induction and distortion of the neutral plane almost entirely.

These poles are called "commutating poles" because their principal purpose is to improve commutation and reduce sparking at the commutator and brushes.



Diagrams G and H show two generators equipped with interpoles. G is arranged for clockwise rotation and H for counter clockwise rotation. Note that the polarity of the interpole is the same as that of the armature pole immediately adjacent to it. This rule applies to both generators and motors and is true regardless of the number of poles, the type of machine, or the direction of rotation. Note too, that the armature poles on the generators oppose rotation and thus produce the force against which the prime mover must work to maintain rotation.

### 7. STRENGTH OF COMMUTATING FIELD VARIES WITH LOAD

In order that these commutating poles may produce fields of the proper strength for the varying



## Direct Current

loads on the generator armature, **their windings are connected in series with the armature**, so that their strength will at all times be proportional to the load current. In this manner, the strength and neutralizing effect of the interpoles increases as the load increases, and thereby tends to counteract the effect of increased load on field distortion and self-induction.

In this manner, interpoles can be made to maintain sparkless commutation at all loads and thus make unnecessary the shifting of the brushes for varying loads.

Referring again to Fig. 4, you will note that the windings on the interpoles consist of a few turns of very heavy cable, so that they will be able to carry the armature current of the machine. The strength of the interpoles can be varied by the use of an **interpole shunt**, which is connected in parallel with the commutating field to shunt part

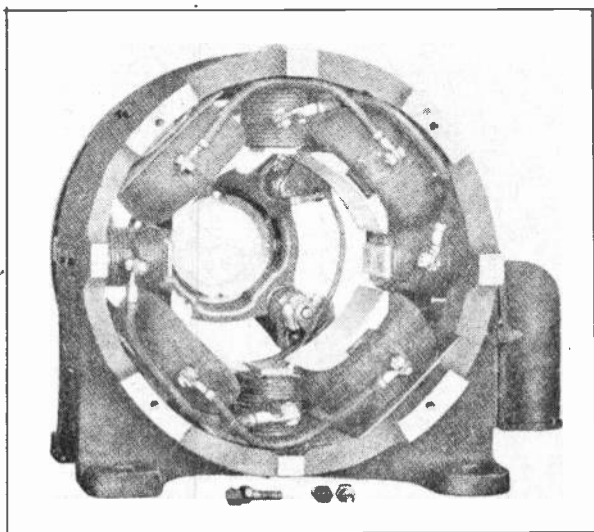


Fig. 4. This photo shows a four-pole, D. C. generator with commutating poles. These commutating poles or interpoles are the smaller ones shown between the main field poles.

of the armature current around these coils. The connections of this shunt are shown in Fig. 6-A. The interpole shunt is usually made of low re-

## Interpoles

sistance materials, such as bronze or copper, so it will carry the current readily without undue heating.

This method of weakening the strength of the commutating field is quite commonly used on the larger machines. The terminals of the commutating field are usually connected directly to the brushes, to eliminate confusion when making external connections to the machine.

### 8. ADJUSTMENT OF BRUSHES ON INTERPOLE MACHINES

On machines of small and medium sizes, the end plate or bracket on the generator is sometimes

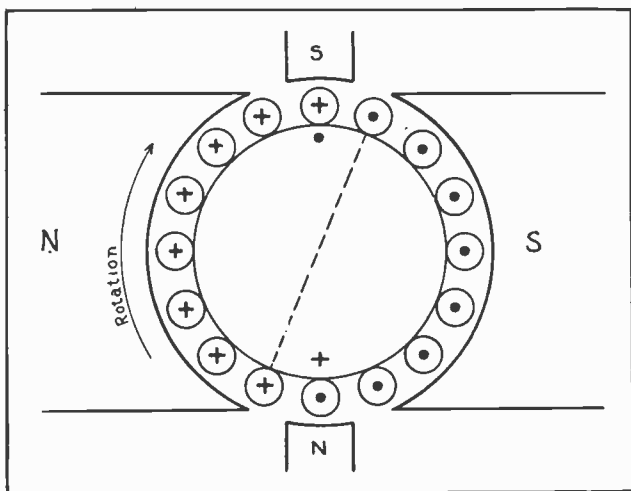


Fig. 5. This sketch illustrates the manner in which interpoles generate voltage opposite to that of self-induction in the conductors which are shorted by the brushes.

slotted, as shown in Fig. 6-B, to allow the brushes to be rotated or shifted within a very limited range. With such machines, the brush-holder studs are mounted rigidly in the bracket but are, of course, insulated from the metal with fibre sleeves and washers.

When the brushes are to be rotated the bolts which hold the end plate to the field frame are loosened slightly and the entire end plate is shifted.

## Direct Current

This allows the armature coils to be commutated at a point where the effects of the interpole are just great enough to neutralize or balance self-induction.

Before removing the end plate to make repairs on a machine of this type, it is well to mark its position, so that you can be sure to get it replaced in the correct position. This can be done by making one or two small marks in line with each other on both the field frame and the end plate. The marks can be made with a file or prick punch.

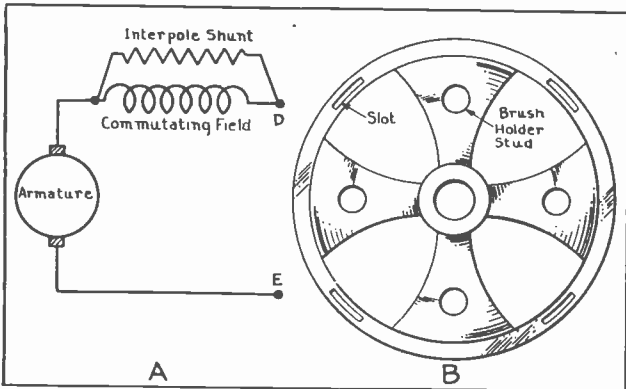


Fig. 6. At "A" is shown the connection of an interpole shunt for varying the strength of the commutating field. "B" shows an end bracket with slots to allow it to be rotated slightly to shift the brushes. The brush holders on this machine would be mounted on this end bracket.

### 9. ADJUSTING INTERPOLES BY CHANGING THE AIR GAP

If the position of the brushes is in question on a generator, connect a voltmeter from the positive to the negative brush and operate the machine. Move the brushes carefully back and forth across the neutral plane until the position is found that gives the highest reading on the voltmeter; lock the brush rigging in that position.

A simple test for determining the proper brush position on a motor is to run the machine with an ammeter connected in series with it and move the brushes to the position that gives the lowest reading on the ammeter.

## Interpoles

In the field analysis it should be remembered that the brushes are to set in a position that results in minimum sparking under load; therefore, if a slight departure from the brush position as found above provides less sparking when the machine is in operation, then that is the position in which the brushes should be set.

The strength of interpoles can also be varied by placing iron shims or thin strips between the interpole and the field frame of the machine, as shown in Fig. 7. It is possible in this manner to vary the width of the air gap between the face of the interpoles and the armature core.

Decreasing the air gap reduces the magnetic reluctance of the interpole field path, thereby strengthening its flux and increasing its effect on commutation. This method can be used on machines of any size and when no other visible means of varying the interpole strength is provided, shims are probably used.

On some machines, the number of interpoles may only be one-half the number of main field poles; in which case they will be placed in every other neutral plane and will all be of the same polarity. By making these interpoles of twice the strength as would be used when a machine has one for each main pole, we can still effectively neutralize the

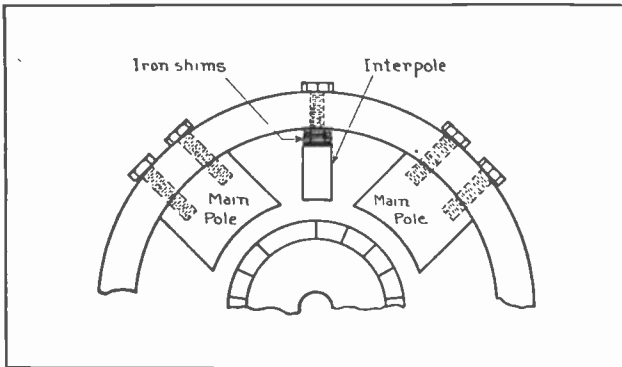


Fig. 7. Thin iron shims can be used under an interpole to vary its strength by changing the air gap between the pole and the armature.

self-induction in the coils. This is true because, with a modern drum-wound armature, when one

## Direct Current

side of any coil is in one neutral plane the other side will be in the adjacent neutral plane.

For this reason, if interpoles are placed in every other neutral plane, one side of any coil will always be under the interpole while this coil is undergoing commutation. This is illustrated by the sketch in Fig. 8, which shows a four-pole generator with only two interpoles.

As both sides of any coil are in series, the double strength of the interpoles over one side will neutralize the effects of self-induction in the entire coil. This type of construction reduces the cost of the generator considerably and is often used on machines ranging up to six-pole size.

### 10. COMMUTATION ON MOTORS

The problem of obtaining sparkless commutation on D. C. motors is practically the same as with D.C. generators.

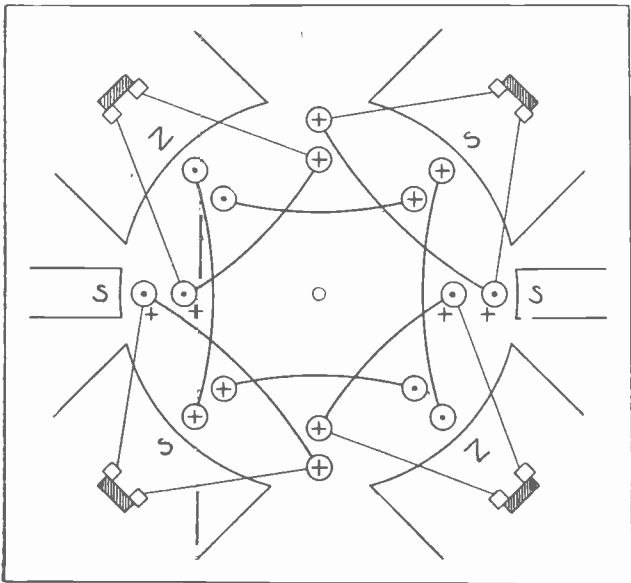


Fig. 8. This simple sketch illustrates the manner in which two interpoles can be used to neutralize self-induction in the coils of a four-pole machine.

Motors as well as generators must have the connections from the brushes to the coils reversed as

## Interpoles

the coils pass from one pole to another of opposite polarity. This is necessary to keep the current from the line flowing in the right direction in all coils in order to produce torque in the same direction under all field poles.

During commutation, the coils of a motor armature are momentarily short circuited by the brushes, the same as with a generator.

This shorting and commutation should take place while the coils are in the neutral plane between the field poles, where they are doing the least work or producing the least torque.

We also know that the coils of any motor armature have a high counter-voltage generated in them as they rotate under the field poles. This counter-voltage will be at its lowest value while the coils are passing through the neutral planes; which is another reason for having commutation take place at this point in a motor.

### 11. POSITION OF NEUTRAL PLANE IN MOTORS

The neutral plane of a D.C. motor will also shift with load variations and changes in armature current, but this shift will be in the opposite direction to what it is in a generator. This is due to the fact that the rotation of a motor will be opposite to that of a generator if the current direction is the same in the motor armature as in the generator armature.

Motor coils also have counter-voltage of self-induction produced in them when they are shorted by the brushes. In a motor, the direction of this self-induced voltage will be opposite to that in a generator, as the motor armature currents are in the opposite direction to those in a generator armature of the same direction of rotation.

We can, therefore, improve commutation on a motor by shifting the brushes in the opposite direction to that used for a generator. **Motor brushes should be shifted against the direction of rotation, when the load is increased.**

## Direct Current

Fig. 9 is a sketch of the armature conductors and field poles of a simple D.C. motor, showing the position of the neutral plane with respect to the direction of rotation.

The heavy symbols in the six armature conductors on each side show the direction of the applied current from the line, which is flowing "in" on the conductors at the right and "out" on those on the left side. The lighter symbols in the single conductors at the top and bottom show the direction

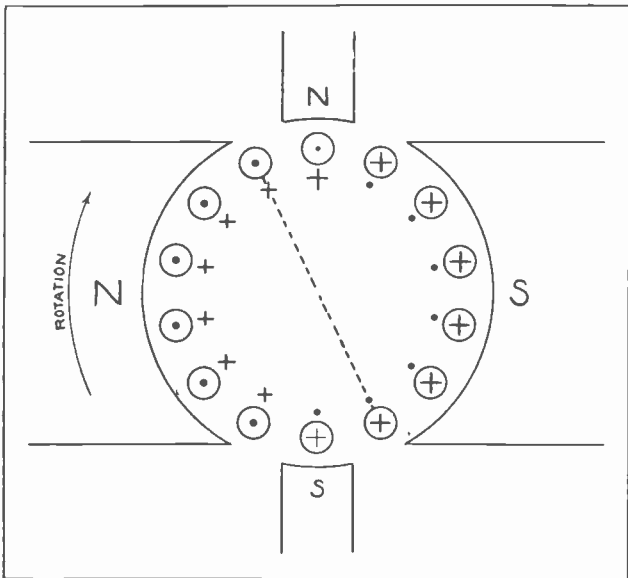


Fig. 9, This sketch shows the position of the neutral plane with respect to rotation in a motor. Compare this with Fig. 5 for a generator.

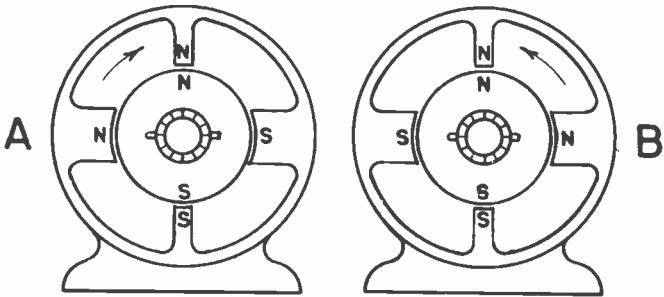
of the currents set up in this coil by self-induction when the coil is shorted. The symbols shown outside of the conductor circles indicate the direction of the counter E.M.F. produced in the motor winding: This counter-voltage always opposes the direction of the applied line voltage.

### 12. POLARITY OF INTERPOLES FOR MOTORS

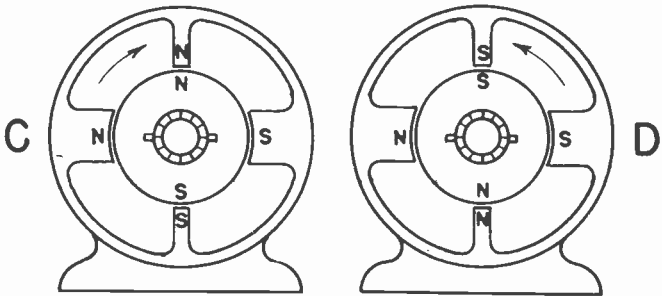
To minimize sparking at the brushes, most D.C. motors are equipped with small poles placed mid-

## Interpoles

way between the main poles and called interpoles or commutating poles. For proper operation, these small poles must have the correct polarity. Ref-



erence to any of the diagrams will show that the polarity of the interpole is always the same as the armature pole adjacent to it.



## REVERSING ROTATION

The windings on the interpoles are always connected in series with the armature winding and are considered a part of the armature circuit. Therefore, when current through the armature is reversed, the interpole polarity is also reversed. This arrangement automatically preserves the proper relation between the armature poles and the interpoles when the armature current is reversed.

## NUMBER OF INTERPOLES

Machines equipped with interpoles may have as many interpoles as main poles or one-half as many



## Direct Current

interpoles as main poles. As the interpole winding is always connected in series with the armature, the interpole strength will vary with the value of armature current.

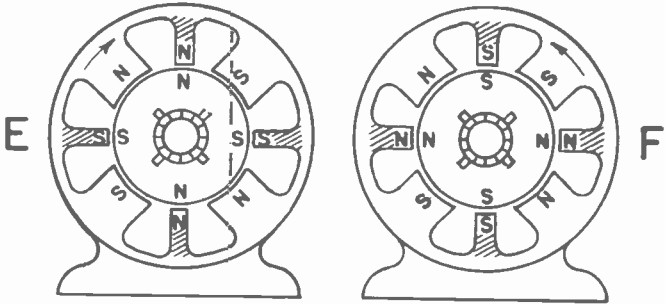


Fig. 10 shows the connections of the interpoles for a two-pole D.C. motor. You will note that one line or armature lead is connected directly to the negative brush, while the other lead connects first to the commutating field and then, through these poles, to the positive brush.

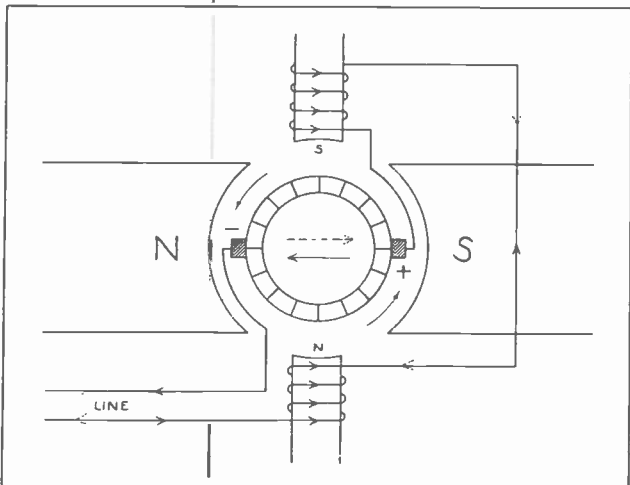


Fig. 10. This diagram shows the connections of the interpoles for a two-pole generator or motor.

If this connection is properly made when the machine is assembled, it is not necessary to make any change in the connections of the commutating

## Carbon Brushes

field when the motor is reversed. Either the armature current or field poles must be reversed to reverse the rotation, so that the relation of the commutating poles will still be correct.

This connection can be the same whether the machine is operated as a motor or generator, because a generator rotated in the same direction as a motor will generate current in the opposite direction through the armature. This is shown by the dotted arrows in Fig. 10 while the solid arrows show the direction of motor current.

As the commutating poles are in series with the armature, this reversed current will also reverse the polarity of the commutating field, and maintain the proper polarity for generator operation.

These principles of commutation and interpoles should be kept well in mind, as an efficient maintenance electrician or power plant operator will never allow unnecessary sparking to damage the brushes and commutator of machines he has charge of.

## CARBON BRUSHES

The brushes play a very important part in the operation of any D. C. motor or generator, and are well worth a little special attention and study at this time.

The purpose of the brushes, as we already know, is to provide a sliding contact with the commutator and to convey the current from a generator armature to the line, or from the line to a motor armature, as the case may be. We should also keep in mind that the type of brush used can have a great effect on the wear on commutators and in producing good or bad commutation.

It should not be assumed, just because any brush will carry current, that any piece of carbon or any type of brush will do for the replacement of worn brushes on a D.C. generator or motor. This is too often done by untrained maintenance men, and it frequently results in poor commutation and sometimes serious damage to commutators and machines.

## Direct Current

Many different grades of brushes are made for use on machines of various voltages and commutator speeds and with different current loads.

In order to avoid sparking, heating, and possible damage to commutators, it is very important when replacing worn brushes to select the same type of brushes or brush materials as those which are removed.

In some special cases, brushes other than those supplied by the manufacturers for that particular machine, may not work satisfactorily. In case the brushes supplied by the manufacturers are not available and difficulty is encountered in obtaining the proper brushes, it may be advisable to get in touch with some dependable brush manufacturing company. They will be able to render valuable assistance in the selection of proper brushes for any machine.

The information contained in the following paragraphs should be carefully studied in order that you will be able to select the proper brushes for various uses.

### 13. BRUSH REQUIREMENTS

A good brush should be of low enough resistance lengthwise and of great enough cross-sectional area to carry the load current of the machine without excessive heating. The brush should also be of high enough resistance at the face or contact with the commutator to keep down excessive currents due to shorting the armature coils during commutation. In addition, the brush should have just enough abrasive property to keep the surface of the commutator bright and the mica worn down, but not enough to cut or wear the commutator surface unnecessarily fast.

Figs. 11 and 12 show several carbon brushes of different shapes, with the "pigtail" connections used for carrying the current to the brush-holder studs.

### 14. BRUSH MATERIALS

The most commonly used brushes are made of powdered carbon and graphite, mixed with tarry pitch for a binder, and molded under high pressure into the shapes desired. This material can be

## Carbon Brushes

molded into brushes of a certain size, or into blocks of a standard size from which the brushes can be cut.

The molded material is then baked at high temperatures to give it the proper strength and hardness and to bake out the pitch and volatile matter.

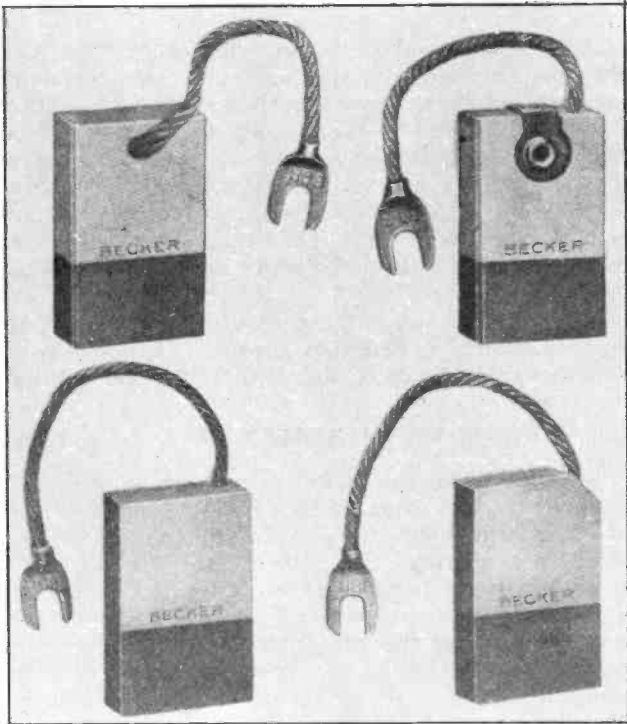


Fig. 11. Above are shown several carbon brushes of common types, such as used on D. C. motors and generators.

Carbon is a very good brush material because it is of low enough resistance to carry the load currents without too great losses, and yet its resistance is high enough to limit the short circuit currents between commutator bars to a fairly low value. Carbon also possesses sufficient abrasiveness to keep commutator mica cut down as the commutator wears.

## Direct Current

Graphite mixed with carbon in the brushes provides a sort of lubricant to reduce friction with the commutator surface. It also provides a brush of lower contact resistance and lower general resistance, and one with greater current capacity.

Powdered copper is sometimes added or mixed with graphite to produce brushes of very high current capacity and very low resistance. These brushes are used on low-voltage machines such as automobile starting motors, electro-plating generators, etc. They often contain from 30 to 80 per cent of copper, and such brushes will carry from 75 to 200 amperes per sq. in.

Lamp-black is added to some brushes to increase

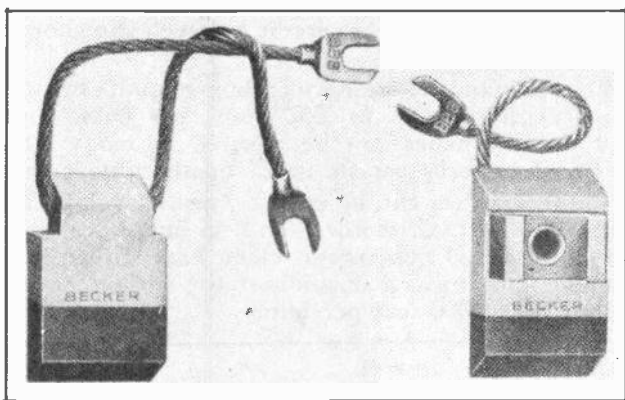


Fig. 12. Two carbon brushes of slightly different shapes, such as used with reaction type brush holders.

their resistance for special brushes on high-voltage machines.

### 15. COMMON BRUSH MATERIAL. BRUSH RESISTANCE

A very common grade of carbon-graphite brush is made of 60% coke carbon and 40% graphite, and is known as the "utility grade". Brush material of this grade can be purchased in standard blocks 4" wide and 9" long, and in various thicknesses.

Brushes for repairs and replacements can then be cut from these blocks. They should always be cut so that the thickness of the block forms the

## Carbon Brushes

thickness of the brush, as the resistance per inch through these blocks is higher from side to side than it is from end to end or edge to edge. This is due to the manner in which the brush material is molded and the way the molding pressure is applied, so that it forms a sort of layer effect or "grain" in the carbon particles.

This higher "cross resistance" or lateral resistance is a decided advantage if the brushes are properly cut to utilize it, as it helps to reduce short-circuit currents between commutator bars when they are shorted by the end of the brush.

Fig. 13 shows how brush measurements should be taken and illustrates why it is an advantage to have the highest resistance through the thickness of the brush and in the circuit between the shorted commutator bars.

The resistance of ordinary carbon-graphite brushes usually ranges .001 to .002 ohms per cubic inch, and these brushes can be allowed to carry from 30 to 50 amperes per sq. in. of brush contact area.

These brushes can be used on ordinary 110, 220, and 440-volt D.C. motors; and on small, medium, and large sized generators which have either flush or undercut mica, and commutator surface speeds of not over 4000 feet per min.

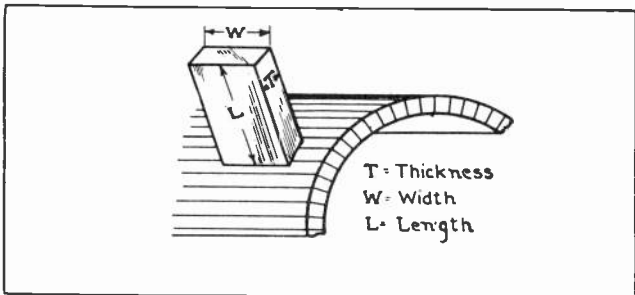


Fig. 13. This sketch illustrates the method of taking measurement for the length, width, and thickness of carbon brushes.

### 16. HARDER BRUSHES FOR SEVERE SERVICE

These utility grade carbon-graphite brushes can be obtained in a harder grade, produced by special

## Direct Current

processing, and suitable for use on machines which get more severe service and require slightly more abrasiveness. These harder brushes are used for steel mill motors, crane motors, elevator motors, mine and mine locomotive motors, etc.

Brushes with a higher percentage of carbon can be used where necessary to cut down high mica, and on machines up to 500 volts and with commutator speeds not over 2500 feet per minute. This type of brush is usually not allowed to carry over 35 amperes per square inch, and is generally used on machines under 10 h. p. in size.

### 17. GRAPHITE USED TO INCREASE CURRENT CAPACITY

Brushes of higher graphite content are used where high mica is not encountered, and for heavier current capacity. Such brushes are generally used only on machines which have the mica undercut; and are particularly adapted for use on older types of generators and motors, exhaust fans, vacuum cleaners, washing machines, and drill motors.

Brushes with the higher percentage of graphite do not wear or cut the commutators much, but they usually provide a highly-polished surface on both the commutator and brush face. After a period of operation with these brushes the surface of the commutator will usually take on a sort of brown or chocolate-colored glaze which is very desirable for long wear and good commutation.

### 18. SPECIAL BRUSHES

Some brushes are made of practically pure graphite and have very low contact resistance and high current-carrying capacity. Brushes of this nature will carry from 60 to 75 amperes per square inch and they can be used very satisfactorily on machines of 110 or 220 volts, or on high-speed slip rings with speeds even as high as 10,000 feet per minute.

The greater amount of graphite offers the necessary lubrication properties to keep down friction at this high speed.

## Carbon Brushes

Another type of brush consisting of graphite and lamp-black, and known as the electro-graphitic brush, is made for use with high-voltage machines which have very high commutator speeds. These brushes have very high contact resistance, which promotes good commutation. They can be used to carry up to 35 amperes per square inch and on commutators with surface speeds of 3000 to 5000 feet per minute.

These brushes are made in several grades, according to their hardness; the harder ones are well adapted for use on high-speed fan motors, vacuum cleaners, drill-motors with soft mica, D. C. generators, industrial motors, and the D.C. side of rotary converters. They are also used for street railway motors and automobile generators, and those of a special grade are used for high-speed turbine-driven generators and high-speed converters.

### 19. BRUSH PRESSURE OR TENSION

It is very important to keep the springs of brush holders or brush hammers properly adjusted so they will apply an even amount of pressure on all brushes. If the pressure is higher on one brush than on another, the brush with the higher pressure makes the best contact to the commutator surface and will carry more than its share of the current. This will probably cause that brush to become overheated.

To remedy this, the spring tension should be increased on the brushes which are operating cool, until they carry their share of the load.

Brush pressure should usually be from  $1\frac{1}{4}$  to 3 lbs. per square inch of brush contact surface. This brush tension can be tested and adjusted by the use of a small spring scale attached to the end of the brush spring or hammer, directly over the top of the brush. Then adjust the brush holder spring until it requires the right amount of pull on the scale to lift the spring or hammer from the head of the brush. One can usually tell merely by lifting the brushes by hand, whether or not there are some brushes with very light tension and others with too heavy tension or pressure.



## Direct Current

Motors used on street cars, trucks, and moving vehicles, or in places where they are subject to severe vibration, will usually require a higher brush-pressure to keep the brushes well seated. On such motors the pressure required may even range as high as 4 lbs. per square inch.

### 20. BRUSH LEADS OR SHUNTS

All brushes should be provided with flexible copper leads, which are often called "pigtails" or brush shunts. These leads should be securely connected to the brushes and also to the terminal screws or

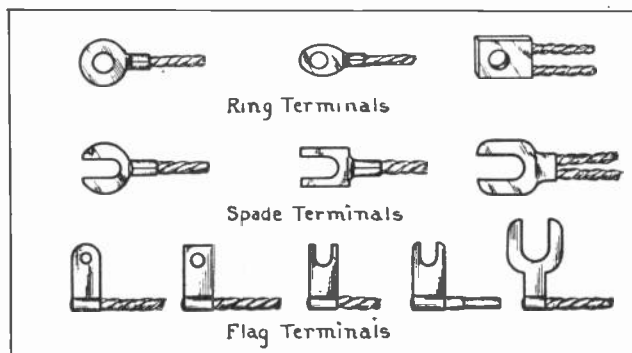


Fig. 14. Above are shown several types of terminals for brush shunts or leads.

bolts on the brush holders, and their purpose is to provide a low-resistance path to carry the current from the brush to the holder studs.

If these brush shunts or leads become loose or broken, the current will then have to flow from the brush through the holder or brush hammers and springs. This will often cause arcing that will damage the brush and holder and, in many cases will overheat the springs so that they become softened and weakened and don't apply the proper tension on the brushes.

The brushes shown in Figs. 11 and 12 are equipped with leads or brush shunts of this type and Fig. 14 shows a number of the types of copper terminals or clips that are used to attach these leads

## Carbon Brushes

to the brush holders by means of terminal screws or bolts.

When new brushes are cut from standard blocks of brush material, the pigtails can be attached by drilling a hole in the brush and either screwing the end of the pigtail into threads in this hole or packing the strands of wire in the hole with a special contact cement.

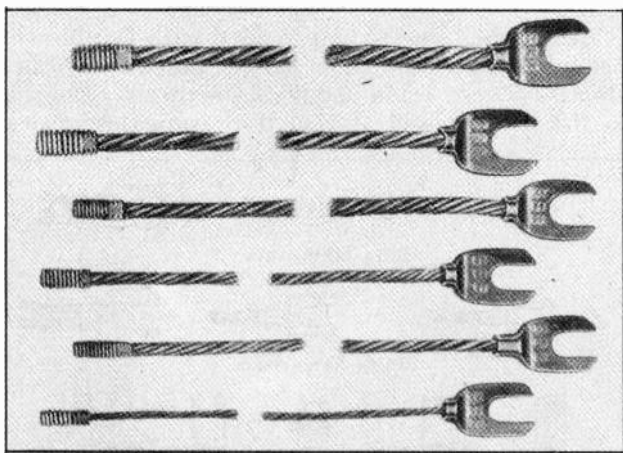


Fig. 15. Brush shunts can be obtained with threaded plugs on their ends for securely attaching them to the brushes.

Fig. 15 shows a number of brush shunts or leads with threaded plugs attached to them. These leads can be purchased in different sizes already equipped with threaded end plugs.

Fig. 16 illustrates the method of preparing a brush and inserting the threaded ends of the brush shunts. The top view shows a bar of brush stock from which the brushes may be cut, and in the center is shown the manner of drilling a hole in the corner of the brush.

Carbon graphite brushes are soft enough to be drilled easily with an ordinary metal drill, and they are then tapped with a hand tap, as shown in the left view in Fig. 16. The threaded plug on the end of the copper lead can then be screwed into this hole in the brush by means of pliers, as shown in the lower right-hand view of the same figure.

## Direct Current

Brush leads of this type save considerable time in preparing new brushes, and insure a good low resistance connection to the brush. These leads can be unscrewed and removed from worn brushes, and used over a number of times.

### 21. CEMENT FOR ATTACHING LEADS TO BRUSHES

When brush leads with threaded tips are not available, a special compound or cement can be made by mixing powdered bronze and mercury. The bronze powder should first be soaked in muriatic or hydrochloric acid, to thoroughly clean it.

The acid should then be washed from the powder with lukewarm water. The bronze powder can then be mixed with mercury to form a thick paste. This paste is tamped solidly around the copper strands of the brush lead in the hole in the carbon brush, and will very soon harden and make a secure connection of low resistance.

Care must be used not to make this cement too thick or it may harden before it can be tamped in place. It is usually advisable to mix only a very small quantity of the paste at one time, because it may require a little experimenting to get it just the right consistency.

### 22. DUPLICATING AND ORDERING BRUSHES

Worn or broken brushes should always be promptly replaced, before they cause severe sparking and damage to the commutator. Always replace brushes with others of the same grade of material if possible. The new brushes should also be carefully cut to the same size, so they will span just the same width on the commutator bar and will not fit too tight or too loose in the holders.

If it is necessary in emergencies to replace one or more brushes with others of a slightly different grade, place all those of one grade in the positive brush holders, and those of the other grade in the negative holders. If brushes of different grades are placed in the same set of holders, the current will divide unequally through them and cause heating of certain ones, and it may also cause unequal wear on the commutator.

## Carbon Brushes

When ordering new brushes for any certain machine, careful measurements should be taken of the brush width, thickness, and length. The brush thickness is measured in the direction of travel of the commutator or slip rings; the width is measured parallel to the armature shaft or commutator bars; and the length is measured perpendicularly to the commutator or slip rings surface. These measurements are shown in Fig. 13. Any other special measurements should also be given, and in some cases it is well to send the old brush as a sample.

The length of brush leads or shunts should also be specified when ordering new brushes. They are usually provided in standard lengths of five inches, but can be furnished shorter or longer where required.

The style of terminal or end-clip should also be given, along with the diameter of the slot or hole by which they are attached to the bolts on the brush-holder studs.

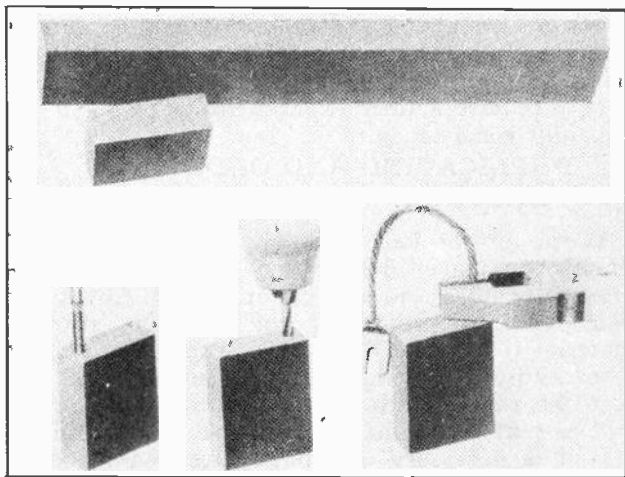


Fig. 16. These views illustrate the method of preparing a carbon brush to attach the threaded end of the brush lead or pigtail.

It is generally advisable to have on hand a few of the brushes most commonly required for replacement on any machines you may be maintaining. It is also well to have a catalogue of some

reliable brush manufacturer, to simplify ordering by giving the number and exact specifications of the brushes required.

### 23. FITTING NEW BRUSHES TO THE COMMUTATOR

New brushes should always be carefully fitted to the surface or curvature of the commutator. This can be done by setting the brush in the holder with the spring tension applied, and then drawing a piece of sandpaper under the contact surface or face of the brush, as shown in the center view in Fig. 17. Note: Never use emery cloth because the metallic nature of the emery tends to short circuit the commutator.

The sandpaper should be laid on the commutator with the smooth side next to the bars and the rough or sanded side against the face of the brush. Then, with the brush held against the paper by the brush spring, draw the paper back and forth until the face of the brush is cut to the same shape as the commutator surface.

Be sure to hold the ends of the sandpaper down along the commutator surface so these ends will not cut the edges of the brush up away from the commutator bars.

On small machines where it is difficult to use sandpaper in the manner just described, a **brush-seater stone** can be used. These stones consist of fine sand pressed in block or stick form with a cement binder.

The brush seater is held against the surface of the commutator in front of the brush, as shown on the left in Fig. 17, and as the commutator revolves it wears off sharp particles of sand and carries them under the brush, thus cutting out the end of the brush until it fits the commutator.

When fitting a number of brushes, a brush jig such as shown on the right in Fig. 17 can be used to save considerable time. This jig can be made of either metal or wood, and in the form of a box into which the brush will fit. The open end of the box or jig has its sides cut to the same curve as the commutator surface.

## Carbon Brushes

A new brush can then be dropped in this box and its face cut out to the curve or edge of the box by means of a file. The bulk of the carbon can be cut out very quickly in this manner, and the brush can then be set in the holder and given a little final shaping with sandpaper as previously explained.

Graphite brushes should generally be used on iron slip rings on three-wire generators, and metal-graphite brushes on copper rings.

On certain very low voltage machines where heavy currents are handled, "copper leaf" brushes

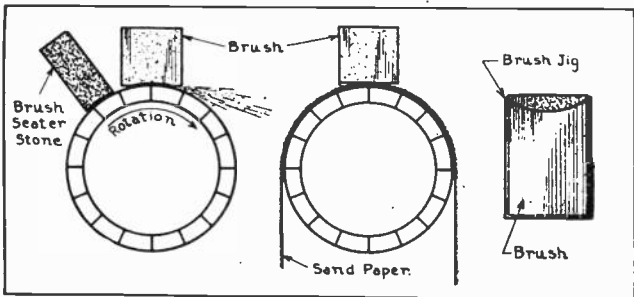


Fig. 17. The above sketches show several methods of cutting brush faces to fit the commutator surface. Each is explained in the accompanying paragraphs.

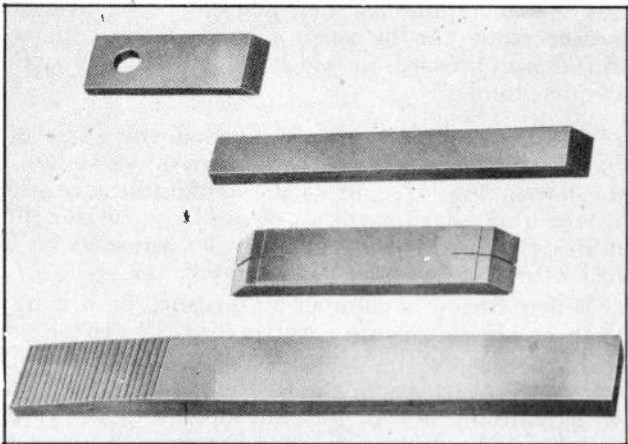


Fig. 18. Brushes made of copper strips or copper "leaf" construction are often used for low voltage machines which handle very heavy currents.

## Direct Current

are used. These are made of a number of thin flat strips of hard drawn copper, with the end of the group beveled as shown in Fig. 18.

When brushes of too low resistance are used, they will generally cause long, yellow, trailing sparks at the commutator surface behind the brushes.

Brushes of too high resistance will cause blue sparks and will also cause the brushes to overheat.

If the commutator mica is not being cut down by the brushes and becomes too high, it will cause sparking and burned spaces to the rear of the mica segments, on the leading edges of the commutator bars.

The proper type of brushes and their proper fitting, well deserve thorough attention on the part of any electrical maintenance man or power plant operator; as a great many troubles in motors and generators can be prevented or cured by intelligent selection and care of brushes.

## EXPERIMENTS

Some valuable experience in making brushes can be obtained by using an old piece of carbon, such as may be taken from an old worn out dry cell.

We do not recommend the use of this carbon for brushes to be used on regular jobs, but the experience gained in working on carbon of this kind will be just as good as when using expensive brush carbon.

Brushes of several different dimensions may be cut from an old battery carbon. As an example, if you wish to make a brush  $\frac{1}{2}$ " thick by  $\frac{3}{4}$ " wide by  $\frac{3}{4}$ " long, you would first cut a  $\frac{1}{2}$ " piece from the end of the rod and then it would be a simple matter to lay this piece flat on the bench and measure off the proper width and length. A hack saw should be used in making the cuts and then the piece may be smoothed up with a piece of sand paper or a file.

After the pieces are cut to the proper size, they should be drilled and tapped for the "pigtail" leads (sometimes called shunts or leaders).

The next step is to practice fitting the brush to the commutator. If a commutator is not at hand,

## Carbon Brushes

you may use any round object such as a bottle or a tomato can.

The instructions given in the lesson should be carefully followed until you are capable of doing a good job of making and fitting a new brush.

You are then ready to use a good grade of brush carbon and construct brushes for actual use on motors or generators.

### EXAMINATION QUESTIONS

1. Why should commutation take place while the coils are in the neutral plane?
2. What happens to the position of the neutral plane on a generator as the load is increased?
3. Why are interpoles used on D.C. machines?
4. How does the polarity of generator interpoles compare to the polarity of adjacent main poles?
5. How are interpoles connected so that their strength will be proportional to the load current?
6. In what two ways may the strength of interpoles be varied?
7. Which direction should motor brushes be shifted to improve commutation when the load is increased?
8. Give three requirements for a good brush.
9. What is the resistance per cu. inch of an ordinary carbon brush?
10. In cases where threaded "pigtail" leads are not available, how may the wire be fastened to the brush?



## Direct Current

### D. C. SWITCHBOARDS

In power plants, substations, and industrial plants where large amounts of electric power are generated or used, it is necessary to have some central point from which to control and measure this power. For this purpose switchboards are used.

The function of the switchboard is to provide a convenient mounting for the knife switches, circuit breakers, rheostats, and meters which are used to control and measure the current. The equipment located on the switchboard is generally called **switchgear**.

#### 1. TYPES OF SWITCHBOARDS

Switchboards are of two common types, known as **panel boards** and **bench boards**. The latter are also called **Desk-type** boards.

Panel-type boards consist of vertical panels of the proper height and width, on the face of which the switchgear is mounted. On the rear of the board are located the bus bars and wires which connect the switches, circuit breakers, and meters to the various power circuits. Fig. 10 on pages 18 and 19 shows a panel-type switchboard for a D. C. power plant. Examine it carefully and note its construction and the arrangement of the equipment mounted on it.

Bench-type switchboards have the lower section built like a bench with a sloping top, and above the rear edge of the bench section is a vertical panel which contains the instruments.

The sketch in Fig. 1 shows an end view of a bench-type switchboard with the panels mounted on a pipework frame. Boards of this type are used mostly for remote-control switchboards, where the switches and circuit breakers are operated by electro-magnets and solenoids, which are controlled by small push-button or knife switches on the bench portion of the board.

#### 2. SWITCHBOARD PANEL MATERIALS

Switchboard panels are sometimes made of slate

## Generator Panels

or marble, as these materials are good insulators and have good mechanical strength as supports for the switchgear.

Slate is cheaper than marble and is easier to drill and cut for mounting on the frames and for mounting the switchgear. Slate is not quite as good an insulator, however, and is usually not used for voltages over 500 or 750.

Marble is a better insulator and can be used on voltages up to 1100. Marble presents an excellent appearance, but it is more difficult to keep clean. It is also very hard to drill or cut.

A newer material recently developed for switchboard panels, and known as **ebony asbestos**, has a number of very important advantages for this work. It is made of a composition material in which asbestos fibre and electrical insulating compounds are mixed and formed under great pressure into smooth-surfaced panels.

This material has a beautiful natural black finish, is lighter in weight, and has better insulating qualities and mechanical strength than either slate or marble. In addition to these advantages, ebony asbestos is also much easier to drill and cut, which makes it easy and economical to install.

Steel panels are also coming into use for switchboards, and have the advantage of great strength and durability. The switchgear on steel panels must, of course, be insulated from the metal at all points.

### 3. GENERATOR AND FEEDER PANELS

The common panel-type switchboards are usually made about ninety inches high, and as wide as necessary to provide the required space for the equipment needed. They are practically always built up in vertical sections or panels, each of which is used for the control of separate circuits. Panels of greater width are used for the main circuits or generator circuit control, and sub-panels of narrower width are used to control the separate feeder **circuits**, which supply the energy to the various lines or power circuits controlled from the switchboard.

## Direct Current

Fig. 10 shows two generator panels on the right, and six feeder panels on the left. Note the difference in the size of the switches and circuit breakers on the main panels and sub-panels. By referring to this same figure, you will also note that each vertical panel is divided into three sections. This type of construction facilitates repairs and changes of certain equipment, without disturbing the rest of the equipment on that panel.

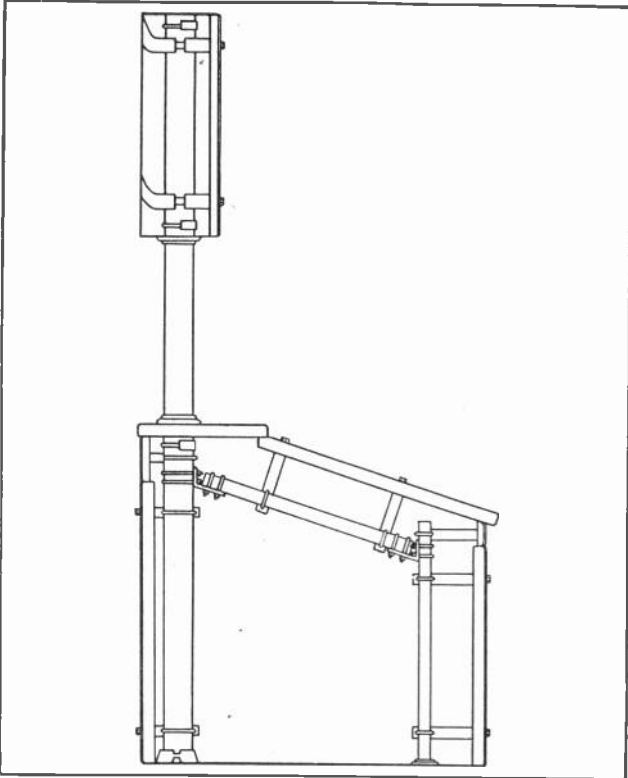


Fig. 1. The above diagram shows an end-view of a "bench-type" switchboard mounted on pipe frame work. This type of board is often referred to as "desk type".

For example, if the switches on a panel are to be changed to others of different size or type, the section containing them can be removed and a new one drilled and inserted. It is not necessary to disturb

## Switchboard Frames

the other two sections, or to leave unsightly holes in the board where the old switches were removed.

Sectional construction of panels also reduces the danger of cracked panels which might result from mechanical strains or vibration if larger single panels were used.

Switchboard panel material can be obtained in thicknesses from  $\frac{1}{2}$ " for very small boards for light duty, to 2" or more for large heavy-duty boards. These panels are usually beveled on the corners of the front side, for better appearance.

### 4. SWITCHBOARD FRAMES

Switchboard panels are commonly mounted on either angle iron or pipe-work frames.

Where angle iron is used, it should be of the proper size to give the required strength and rigidity for proper support of the panels and switchgear.

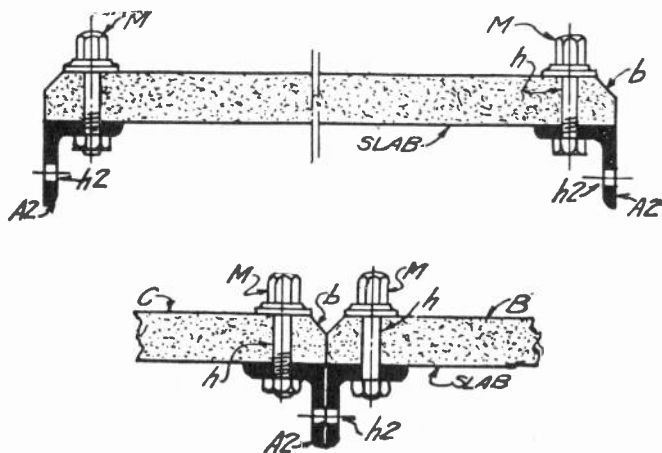


Fig. 3. The above sketches show the method of attaching switch board panels to the angle iron frame work. Note how the panels are bolted to angle irons, and the angles bolted together between panels. Also note the type of bolts, nuts, and washers used with this construction.

The board should not bend or vibrate noticeably during operation of heavy knife-switches or circuit-breakers.

Angle iron of  $1\frac{1}{2}$ " to 3" is commonly used. It can be cut to proper length by means of a hack saw,

## Direct Current

and drilled for the bolts with which the panels are attached, and also for the bolts which hold the angle irons of adjoining panels together.

Fig. 3 shows how the panels should be bolted to the angle irons at *h*, and the method of bolting the angle irons together at "h2". The panels should be carefully marked for drilling, so they will line up neatly and give the proper appearance when finished.

Short bolts of the proper length, with washers and nickle-plated cap nuts, can be used to provide good appearance of the front surface of the board.

These bolts and nuts should be tightened sufficiently to hold the panels securely, but not tight enough to crack the corners of the panels.

The bolt holes can be drilled in the panels with ordinary metal drills used in a breast drill or yankee drill. Where a large number of holes are to be drilled an electric drill is faster and more convenient. Slate and marbles are hard and should, therefore, be drilled slowly or the drill should be cooled while it is cutting. Ebony asbestos is very easy to drill; in fact, nearly as easy as hardwood.

The lower ends of the angle irons should have "feet" bent in them or attached with bolts, for secure anchorage to the floor. The upper ends should be braced to keep the switchboard rigid.

### 5. PIPE FRAMES AND THEIR ADVANTAGES

Pipe-work frames are very convenient to install, as they do not require drilling as angle iron does. The pipe frame-work is held together by special clamps, as shown in Fig. 1. Fittings with holes for the panel bolts are also provided to clamp on the pipes. The pipes are attached to the floor with threaded floor-flanges.

Standard pipe sizes can be used; the common sizes being  $1\frac{1}{4}$ " to 2", or larger for very heavy boards. Special clamp fittings can be obtained for mounting bus insulators and various devices on the rear of the board. Other fittings are used for attaching brace pipes to secure the framework and board in a vertical position.

## Switchboard Frames

Pipe-work frames are very popular and are extensively used, as they provide a very flexible frame which can easily be adjusted to fit various panels and devices by merely sliding the clamp fittings. One of the pipes of the frame can be seen on the left end of the board shown in Fig. 10.

### 6. KNIFE SWITCHES. TYPES

Knife switches, used for controlling the various

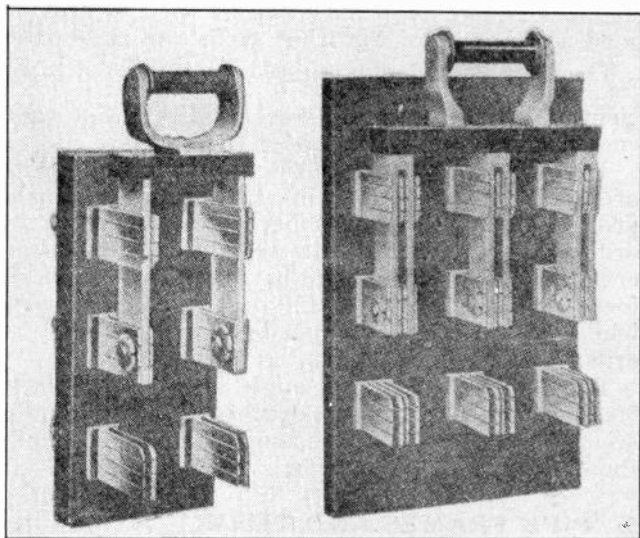


Fig. 4. Above are shown a double-pole and three-pole knife switch. Note carefully the construction of the switch plates, hinges, and clips.

circuits on switchboards, are made in single, double, and three-pole types. The smaller and medium sizes are generally two or three-pole; but the larger ones are generally single-pole, for greater ease of operation. Three-pole switches or three single-pole switches are used to control the circuits of compound generators, the three poles being used in the positive, negative, and equalizer leads.

Three-pole switches are also used for circuits of the Edison three-wire system. Other D. C. circuits are usually two-wire, and they use either one two-pole or two single-pole switches.

## Direct Current

Equalizer switches are sometimes mounted on small panels on pedestals near the generators, to eliminate the necessity of running equalizer busses to the switchboard. In such cases, the main panels for compound generators will also use two-pole switches.

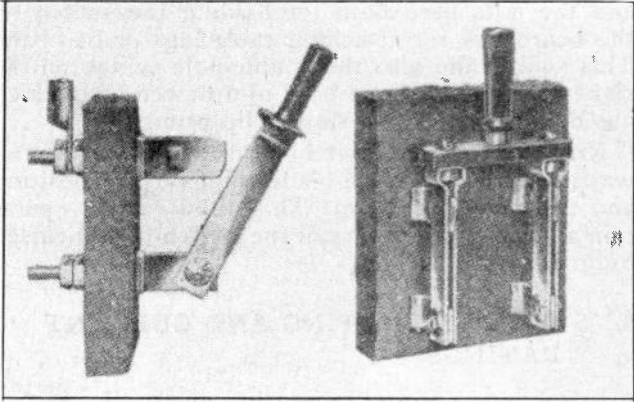


Fig. 5. Single-pole and double-pole switches of a modern type. Note the manner in which the hinges and clips are attached to the board and the method of making cable or bus connections to the studs on the back of the board.

## 7. CONSTRUCTION OF SWITCHES

Knife switches consist of three essential parts called the **blade**, **hinge**, and **clips**. The blades are made of flat copper bus bar material and are attached to the hinges by means of short bolts and spring washers. This fastening gives the required tension for good contact between the blades and hinges, and yet allows freedom of operation. See Fig. 4.

Switch clips are made of two or more thin, springy pieces of copper, mounted in a block. The blades are inserted between these clips when the switch is closed. The clips are usually slotted to make them more flexible and allow them to make better contact with the blade of the switch. These details of construction can be observed by examination of the switches shown in Fig. 4, and also those on the switchboard in Fig. 10.

Switch blades are equipped with insulating handles and guards on their free ends. The hinges

## Knife Switches

and clips usually have threaded studs of copper attached directly to them, for convenient mounting on the switchboard panels. Bus bars or cable lugs on the rear of the board are attached to these studs by means of extra nuts provided with them.

The switch at the left in Fig. 5 shows the studs and the nuts used both for holding the switch on the board and for attaching cable lugs or bus bars. This switch and also the double-pole switch on the right in this figure, are both of a newer type which has double blades and single clip prongs.

Knife switches on switchboards are practically always mounted with the blades in a vertical position and the clips at the top. This allows easier operation and prevents danger of the switch falling closed by gravity.

### 8. SWITCH MOUNTING AND CURRENT RATINGS

In mounting switches on the panels, the hinges and clips should be carefully lined up so that the blades will fit well and make good electrical contact.

All knife switches are rated in amperes according to the copper area of their blades and the contact area of clips and hinges. They are commonly made in sizes from 50 amperes to one thousand ampere capacity; and for heavy power circuits they are made to carry 6000 amperes or more.

You will note that a number of the switches on the right-hand side of the switchboard in Fig. 10 have multiple blades in each pole. This gives a much greater contact area between the blade surfaces and hinges and clips, and also allows air to circulate through the switches to cool them.

Switches should never be loaded above their rated capacity in amperes for any great length of time, or they will overheat. Hinges or clips which are loose or poorly fitted will also cause overheating of the switch at these points. If switches are allowed to overheat too much, the copper will become soft and lose the springy qualities which are necessary for tight fitting of the clips. Overheated switches often



## Direct Current

cause the copper clips or blades to turn a bluish color. Switches that have been heated to this extent will probably need to be replaced.

### 9. CARE AND OPERATION OF SWITCHES

New switches should be carefully fitted and "ground in" before loading. "Grinding in" can be done by coating the switch-blades with vaseline or oil mixed with abrasive powder, and then opening and closing the switch a number of times. This grinds and polishes the sides of the blades and clips to make their surfaces perfectly parallel and provide a good contact between them.

Never open knife-switches under heavy load, if they have a circuit-breaker in series with them. Opening the switch under load will draw an arc at the point where the blades leave the clips. These arcs tend to burn and roughen the blades and clips, making the switch hard to operate and also destroying the good contact between the blade and clips.

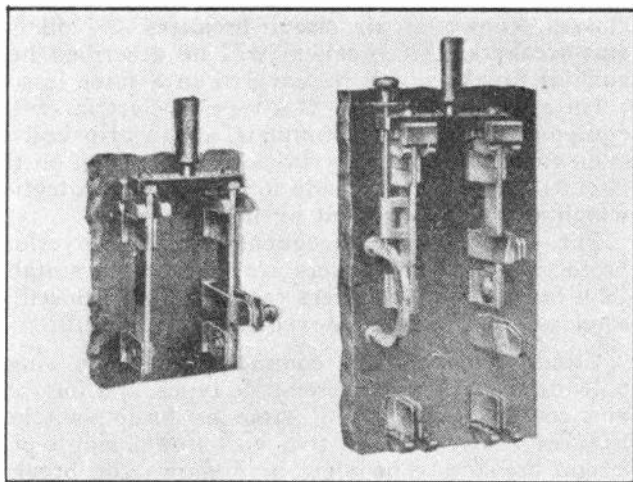


Fig. 6. A number of special types of knife switches are made with auxiliary clips and blades, as shown above. These two switches are used as field discharge switches for generators.

Where circuit-breakers are provided they should always be tripped open first and the knife-switch opened afterward. This prevents arcing at the

## Current Breakers

switch and is also much safer for the operator, as the arcs drawn by opening switches under heavy current load may be very dangerous.

Knife-switches should be kept lubricated with a thin film of petroleum jelly or light vaseline.

Special types of knife-switches, with snap-action blades operated by springs, are made for use in the shunt field circuits of generators. Field circuit switches often have auxiliary blades to close the field across a resistance just before the main blades open. Such switches are called **field discharge switches**. Two types of these switches are shown in Fig. 6. Their purpose is to prevent the setting up of high voltages by self-induction due to the collapse of the flux around the shunt field coils when this circuit is opened.

### 10. CIRCUIT BREAKERS

For opening heavy power-circuits in case of overload or short circuits, automatic circuit breakers are commonly used. These are divided into two general classes, known as **air circuit-breakers** and **oil circuit-breakers**. Air breakers will be described here and oil breakers will be covered in a later lesson.

An air circuit-breaker is a type of electric switch equipped with special contacts and a trip coil to open them automatically in case of overload on the circuit. Thus they provide for the same protection which would be afforded by fuses.

For circuits which frequently require overload protection, circuit-breakers are much more suitable than fuses, as the breakers can be quickly closed as soon as the fault is removed from the circuit.

Circuit breakers are commonly made in single pole, double-pole, and three-pole types, and for various current ratings, the same as knife switches. Figures 7 and 8 show two views of a single-pole circuit-breaker. The view in 7 shows the breaker in closed position, and in 8 it is shown open.

The main current-carrying element or bridging contact is made of a number of thin strips of copper curved in the form of an arch and fitted closely together. This copper leaf construction permits the ends of this main contact to fit evenly over the sur-

## Direct Current

face of the two lugs, or stationary contacts, which are mounted in the switchboard and attached to the bus bars.

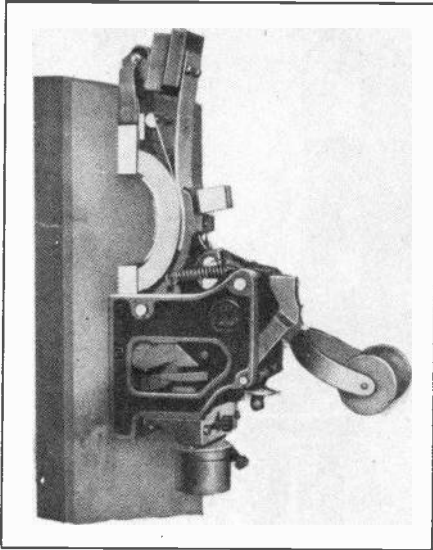


Fig. 7. This photo shows a common type of air circuit breaker in closed position. Note the manner in which the main contacts and auxiliary contacts connect with the stationary contacts on the panel.

### 11. CIRCUIT-BREAKER OPERATION

When the breaker is closed by means of the handle, a lever action is used to force the main contact tightly against the stationery contacts under considerable pressure.

Auxiliary arcing contacts and tips are provided above the main contact, as shown in the figures. The intermediate contact, or the one directly above the main contact, consists of the heavy copper spring with a removable copper tip. The top arcing contact on the movable element is carried by a long copper spring and has a removable carbon tip.

## Current Breakers

When the breaker is opened, the main contact opens first and allows the current to continue flowing momentarily through the auxiliary contacts. This prevents drawing an arc at the surface of the

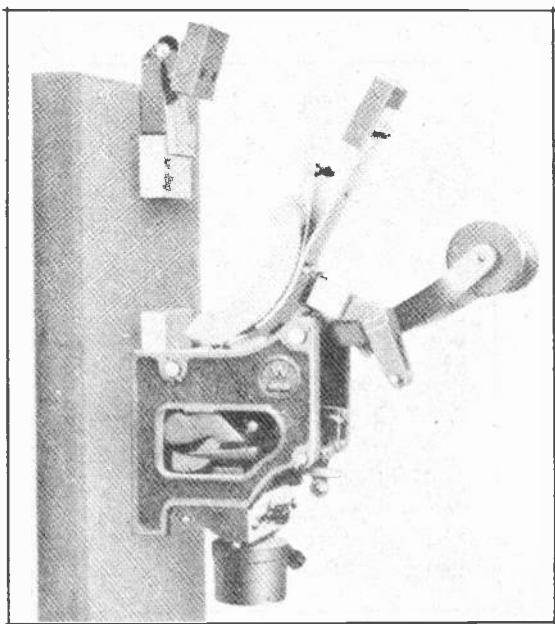


Fig. 8. This view shows the same circuit breaker as in Fig. 7, except that it is now in open position. Again note carefully the construction and position of the main contacts and arcing contacts. Also note the trip adjustment on the bottom of the breaker.

main contact and eliminates possible damage to this contact surface, which must be kept bright and smooth and of low resistance, in order to carry the full load current without loss.

The intermediate contact opens next and it may draw a small arc, because the remaining circuit through the carbon tips is of rather high resistance.

The carbon contacts open last and the most severe arc is always drawn from these points. Carbon withstands the heat of the arc fairly well, and these contacts are easily and cheaply renewed whenever they have been burned too badly by repeated arcs.

Circuit-breakers of this type can usually be tripped open by means of a small lever or button, as well as by the automatic trip coil. When released

## Direct Current

they are thrown quickly open by the action of springs or gravity on their moving parts.

Fig. 9 is a sketch showing a side view of an air breaker in which can be seen the leaf construction of the main contact, and also the bus stubs to which the connections are made at the rear of the board.

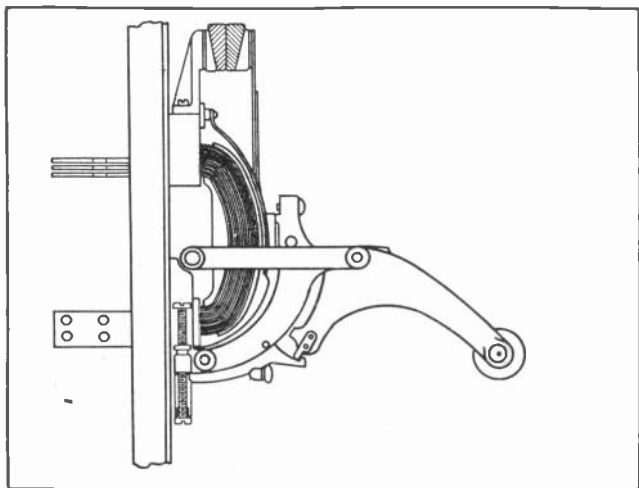


Fig. 9. This sketch shows a side-view of a circuit breaker in closed position and illustrates the copper "leaf" construction of the main contact. Note the copper stubs which project through the board for connections to bus bars.

When a circuit-breaker is closed the contacts close in the reverse order, the carbon tips closing first, intermediate contact second, and the main contact last. This construction and operation eliminates practically all arcing and danger of pitting at the ends of the main contacts. It is very important, however, to keep the auxiliary contacts and carbon arcing tips properly adjusted and occasionally renewed, so that they make and break contact in the proper order.

### 12. CIRCUIT-BREAKER TRIP COILS OR OVERLOAD RELEASE

Fig. 11 shows a single-pole and a double-pole circuit breaker which are both in closed position. The overload coils, or trip coils, can be seen on each of the breakers in this figure. These coils are of the

## Circuit Breakers

series type and consist of a very few turns of heavy copper bar or cable, inside of which is located an iron plunger.

When the coil is connected in series with the line and breaker contacts, any overload of current will increase its strength and cause it to draw up the plunger. The plunger then strikes the release latch and allows the breaker to open.

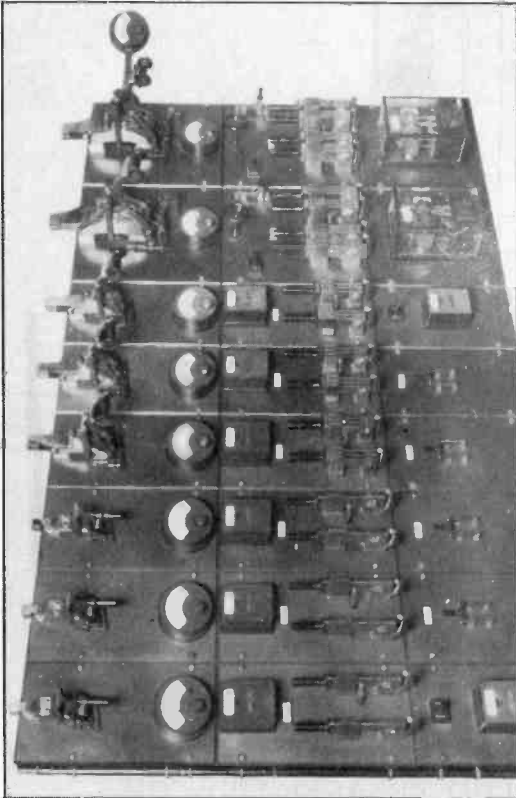


Fig. 10. This photo shows a modern panel type switchboard equipped with knife switches, meters, and circuit breakers. The two large panels on the right are the main generator panels and are equipped with field rheostats and instrument switches and much larger circuit breakers. The six smaller panels on the left are feeder or distribution panels. Examine all the parts and details of construction of this board very carefully, and refer to this figure frequently while reading the accompanying pages.

An adjustment is provided for raising and lowering the normal or idle position of the plunger so that the breaker can be set to trip at different currents and loads. Trip coils of this type are known as **series-type overload release coils** and are com-

## Direct Current

monly used on breakers up to 500 amperes capacity. The circuit-breakers shown in Figures 7 and 8 have electro-magnets and armatures which trip the holding latches, and also an oil dash-pot to delay the opening of the breaker on light overloads. The adjustments for these devices can be seen below the breaker in the figures.

### 13. SHUNT TRIP COILS AND OVERLOAD RELAYS

For circuit breakers of 500 amperes and more, it is not usually practical to use series overload-coils, because of the large sized conductor which would be needed to carry the current.

On these larger breaker, **shunt trip coils** are used, and these coils are wound with a greater number of turns of small wire and are operated from an ammeter shunt. Shunt trip coils are not connected directly to the ammeter shunts, but are operated by a relay which obtains from the ammeter shunt the small amount of energy needed for its coil.

The greater the current flow through ammeter shunts, the greater will be the voltage drop in them.

This voltage drop is usually only a few milli-volts, and as it is difficult to wind the shunt trip coils to operate on this small fraction of a volt, so **overload relays** are generally used to close a circuit to these coils.

The overload relay is a very sensitive instrument, having a small coil designed to operate on a very low voltage of 50 to 100 milli-volts; and this coil is connected across the ammeter shunt.

The tension spring on the armatures of these relays is adjustable so the relay can be made to close its contact and energize the shunt trip coil on the breaker, at any desired current load within the range for which the relay and breaker are designed.

### 14. REVERSE CURRENT RELAYS

Some circuit-breakers are also equipped with reverse current protection to cause them to open in case of reversed polarity of a generator or reversed current flow in the line.

## Circuit Breakers

**Reverse-current relays** are used to trip the breakers to obtain this protection. These relays have two elements or windings similar to the field and armature of a simple motor. One is called the **potential or voltage element**, and the other the **current element**.

The current coil or element is connected across the terminals of the ammeter shunt. The potential coil is connected directly across the positive and negative leads or busses and serves to maintain a constant field flux.

The direction of current through the current element or moving coil of the relay is determined by the direction of current through the ammeter shunt. When the current through the ammeter shunt is in the normal direction, the moving coil tends to hold the relay contacts open and keep the shunt trip-coil of the circuit-breaker de-energized.

If the current through the ammeter shunt is reversed this will reverse the polarity of the voltage drop across the shunt and send current through the movable elements of the relay in the opposite direction. This reverses its torque and causes the coil to turn in a direction which closes the relay contacts and energizes the shunt trip-coil which trips the breaker.

These relays are also adjustable so they can be set to open the circuit-breaker at the desired amount of reversed current.

### 15. CIRCUIT-BREAKER CARE AND MOUNTING

Circuit-breakers are one of the most important pieces of switchgear and afford a great deal of protection to the electrical machinery on their circuits as well as to operators. They should be kept in good repair and adjustment, and should be frequently tested to be sure that they will open freely and quickly when necessary. The main contacts should be kept clean and well fitted, and arcing contacts should be renewed when badly burned. Operating springs and trip coils should be kept carefully adjusted.



## Direct Current

Heavy-duty circuit-breakers require considerable force on the handle to close them, and also deliver quite a shock to the switchboard when they fly open. For this reason, switchboard panels carrying heavy breakers should be thick enough and sufficiently well braced to provide a rugged mounting for the breaker, and to prevent vibration of the board when the breaker is operated.

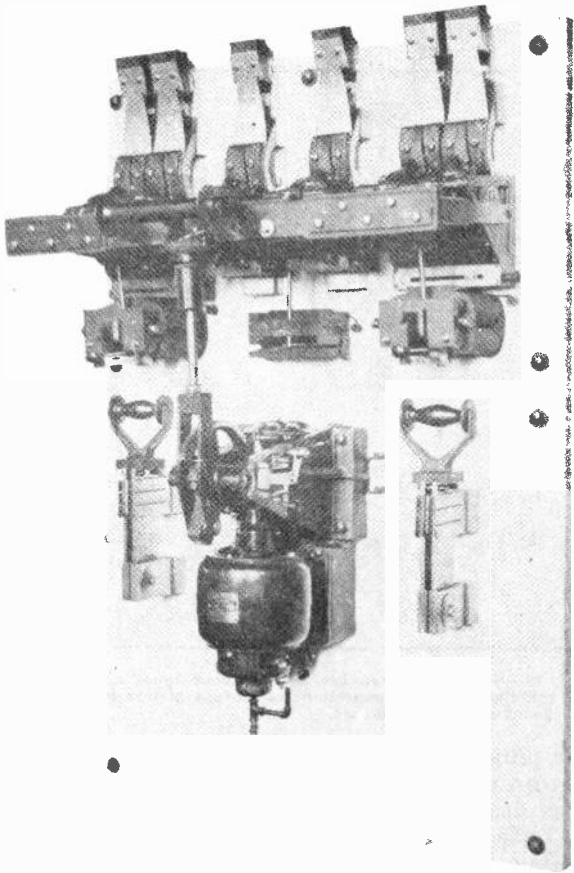


Fig. 12. Large, heavy duty circuit breaker, equipped with a motor for automatic reclosing, after it has been tripped either by an overload, or by remote control.

Fig. 12 shows a large circuit-breaker which also has a motor for automatically reclosing it. Such

## Circuit Breakers

breakers can be equipped for remote control by the operator or for automatic reclosing by a time element or relay, after the breaker has been tripped open for a certain definite period.

### 16. INSTRUMENT SWITCHES

In addition to the knife switches and circuit-breakers, special switches are used for the switching and control of motor circuits. These may be of

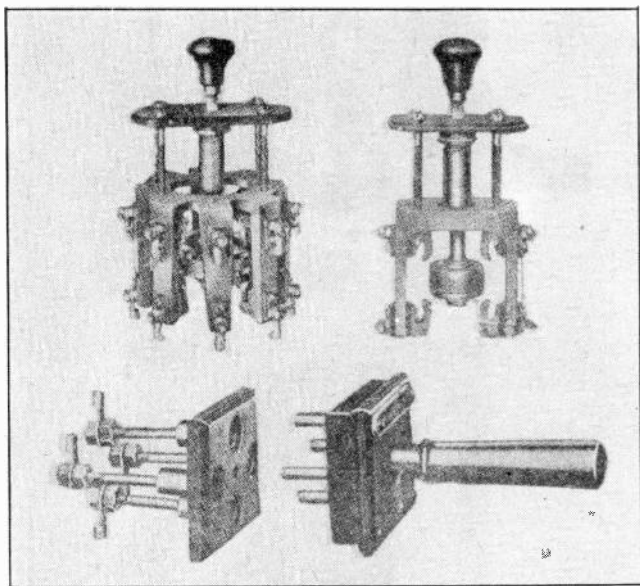


Fig. 13. Instrument switches of the above types are frequently used for changing the connections of various meters to different switch-board panels and busses.

the plug type, pull and push button type, or rotary button type. These switches are mounted in openings drilled through the board, so that the handles or buttons project from the face of the board; and the switch element is mounted on the rear for convenient connections to the smaller wires of instruments and relays.

Fig. 13 shows two instrument switches of the pull and push type in the upper view and one of the plug type in the lower view.

## Direct Current

### 17. BUS BARS, MATERIALS AND MOUNTING

Copper bus bars are commonly used for connecting together the various switches, circuit breakers, and heavy power circuits on switchboards. Long

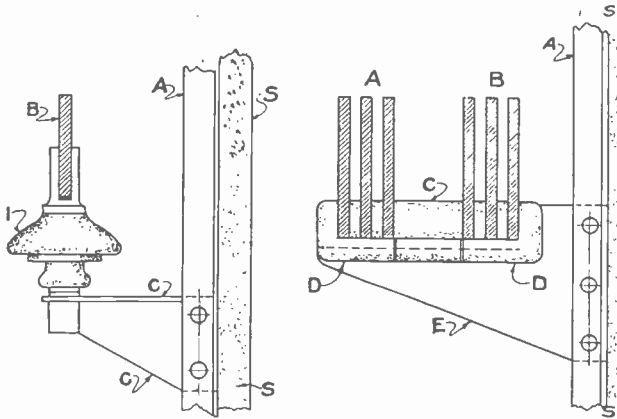


Fig. 14. The above diagrams show methods of mounting and installing bus bars on the back of switchboards.

busses are usually mounted on insulators attached to the rear of the switchboard frame or panels, while short lengths may be supported by the studs or bolts to which they connect.

Bus bars are generally run bare for the lower voltages up to 750 or, in some plants, even higher. Busses for higher voltages can be wrapped with varnished cloth or friction tape after they are installed.

Copper bus bar materials can usually be obtained in sizes from  $\frac{1}{8}$ " to  $\frac{1}{2}$ " in thickness, and from 1" to 4", or even 6" wide. When very heavy currents are to be carried, several bus bars are usually run in parallel and mounted with their flat sides vertical, as shown in the right-hand view in Fig. 14.

This arrangement of the busses allows air to circulate freely through them and helps to keep them cool. The view on the right in Fig. 14 shows two separate busses, "A" and "B", each consisting of three bars. One set is the positive bus and one is negative. Both sets are mounted in a base of insulating material, shown at "C", and supported by metal brackets attached to the switchboard frame.

## Bus Bars

The insulation used for mounting and spacing the bars can be hard fibre, slate, bakelite, or ebony asbestos.

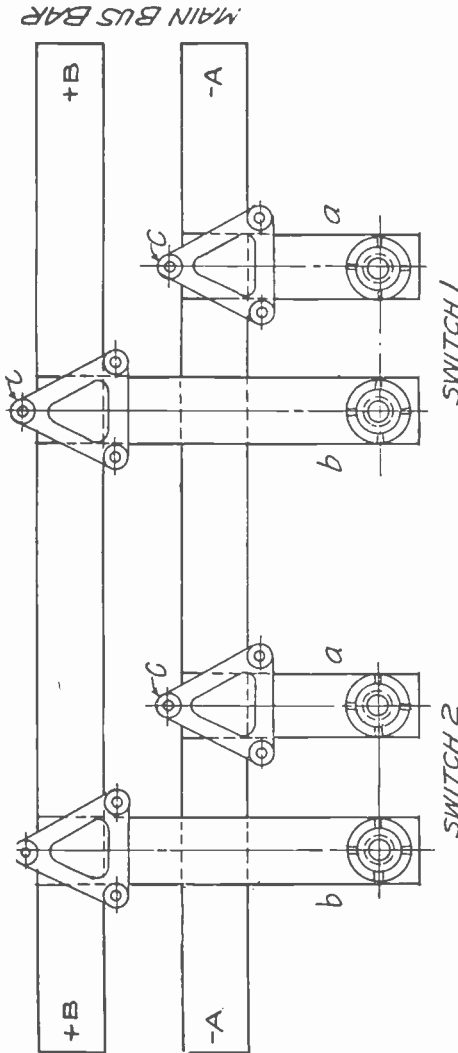


Fig. 15. Bus bars can be connected together by means of special clamps as shown above. These clamp pieces are held securely gripped to the busses by means of short bolts through the holes in their three corners. Clamps of this type save the trouble of drilling the copper busses.

In the left view in Fig. 14 is shown a single bus bar supported by a porcelain bus insulator.

## Direct Current

Busses opposite polarity and for voltages up to 750 should be spaced several inches apart wherever possible. When they are run closer together they should be well mounted and braced so they cannot easily be bent or vibrated together.

### 18. CONNECTING BUS BARS TOGETHER

Where bus bars are joined together, they can be fastened either by means of bolts through holes drilled in the copper or by bus clamps which do not require drilling the bars.

Fig. 15 illustrates the use of a common type bus clamp, consisting of two triangular pieces with three holes for the bolts which draw the parts of the clamp up tightly and grip the bars together. These clamps are very easy to install, as they do not require any drilling of the bars.

Copper bus bars can be cut to the proper length with a hack saw; and where bolts are used for connections the bars can be drilled with an ordinary metal drill.

Fig. 16 shows the method of connecting bus bars to the studs of switches or circuit-breakers, by means of two nuts and a short strip of bar connected to the main bus by a clamp. All joints and connections in bus bars should be made tight and secure, to avoid overheating when the current flows through them. Where the sections join the copper should be well cleaned of all dirt and oxide.

Copper bus bars of the smaller medium sizes can be easily bent to various angles when necessary, but care should be used not to bend the corners too sharply and cause the bar to crack.

In locations where the busses are well ventilated it is common practice to allow about 1000 amperes per square inch of cross-sectional area of the bars.

### 19. EXPANSION JOINTS OR LOOPS IN BUSSES

Where long busses are run, some allowance should be made for expansion and contraction with changes in temperature, or sufficient strains may be

## Switchboard Circuits

set up to warp the busses or crack the switchboard panels by twisting the studs.

A special loop or "U"-bend is sometimes put in a long bus to absorb this expansion in the spring of the bend. In other cases, bus ends can be overlapped and held fairly tight with two bus clamps, but not tight enough to prevent the lapped ends from sliding on each other under heavy strains. One or more short pieces of flexible cable can then be connected around this joint to carry the current without heating. The cable ends should be soldered into copper lugs, and these securely bolted to the bus on each side of the slip joint.

### 20. SWITCHBOARD LAYOUT AND CIRCUITS

It is not a difficult matter to lay out and erect an ordinary switchboard for a small power plant or distribution center.

A plan should be laid out on paper for the required number of circuits. The desired switches, circuit-breakers, and meters for the control and measurement of the power, should be included in this sketch or plan.

After the load has been determined for the various circuits, the size of the switches and devices for the proper current ratings can be obtained from the manufacturer's specifications.

Panels can then be selected large enough to hold these devices in neat, uncrowded arrangement.

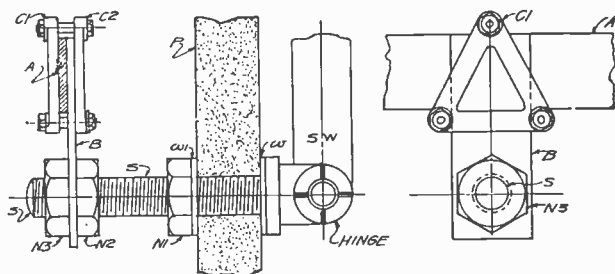


Fig. 16. Two views showing the method of connecting bus bars to the studs of switches and circuit breakers.

The simplest type of switchboard would at least contain switches for each of the main circuits and

## Direct Current

feeder circuits. There should also be on each of these circuits some form of overload protection, such as fuses or circuit-breakers.

On circuits of not over 500 amperes capacity and which are very seldom subject to overload, cartridge fuses will provide economical overload protection.

On heavy power circuits or any circuits which are subject to frequent overloads or occasional short circuits, circuit-breakers should be used. Circuit-breakers eliminate the replacement of fuse links and enable the circuit to be closed back into operation more quickly.

Usually it will be desired to measure the load in amperes on some of the circuits, if not on all of them. Ammeters of the proper size should be used for this purpose.

Where only one generator is used, one voltmeter may be sufficient to check the voltage of the main busses. Where several generators are operated in parallel, we will need one voltmeter for the main bus and probably one for each generator, in order to check their voltages before connecting them in parallel.

Sometimes one extra voltmeter is used for checking the voltage of any one of the generators which is being started up. This is done by the use of a voltmeter bus and plug switches for connecting the meter to whichever machine is being started up. A meter used in this manner is often mounted on a hinged bracket at the end of the switchboard, as shown in Fig. 10.

Wattmeters are often used to obtain instantaneous readings of the power in certain circuits. Watt-hour meters may be installed for showing the total power consumed per hour, per day, or per month, on any circuit.

In medium and larger sized plants, recording voltmeters and ammeters are often used to keep a daily record of the voltage and current variations. These instruments will be explained in a later lesson on D.C. meters.

## Switchboard Wiring

### 21. SWITCHBOARD WIRING

Fig. 17 shows a wiring diagram for a simple D.C. switchboard with three panels, as shown by the dotted lines. The main generator-control panel is on the left, and contains the main switch, circuit-breaker, voltmeter, ammeter and shunt, and the shunt field rheostat.

The two feeder panels on the right merely have switches and circuit-breakers in each circuit.

Note that the circuit-breakers and knife switches are in series in each circuit; so that, when the breaker in any circuit is tripped, there will be no current flowing through the switch.

The coils in series with each pole of the circuit-breakers are the series overload-relay coils, which trip the breakers in case of an overload of current.

Note that the voltmeter is connected on the generator side of the main switch, so a reading of the

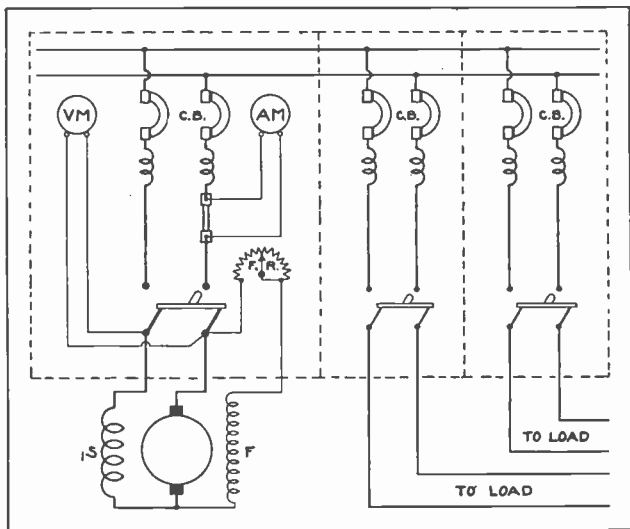


Fig. 17. The above diagram shows the wiring and equipment for a simple switchboard with one generator panel and two distribution panels.

generator voltage can be obtained before the machine is connected to the busses.



## Direct Current

Fig. 18 shows a wiring diagram for a switchboard with two generator panels and two sub-panels or feeder panels. A number of feeder panels could be added to either side of this board if necessary.

Equalizer connections are shown for the generators, which are compound and are to be operated in parallel.

The circuit-breaker trip-coils are not shown in this diagram.

Circuits for switchboard instruments and meters which do not require heavy current, are usually made with No. 12 or No. 14 switchboard wire, which has white colored slow-burning insulation. These wires can be held on the back of the board with small metal clamps and screws.

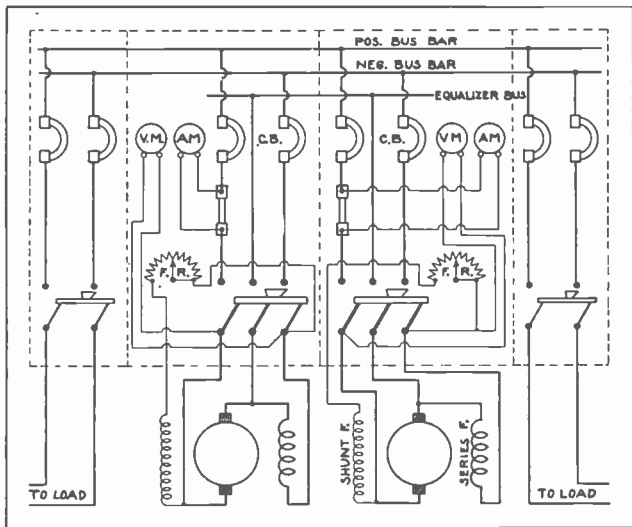


Fig. 18. Wiring diagram for a D. C. switchboard with two main generator panels and two or more feeder panels. Additional feeder panels would be connected to the board and busses the same as the two which are shown. Note carefully the arrangement of all of the parts and circuits shown in this diagram.

Examine the wiring and check the locations and connections of the various devices shown in Fig. 18.

## 22. LOCATION OF METERS AND SWITCH-GEAR

Refer again to Fig. 10 and note the positions and arrangement of the various switch-gear and devices

## Switchboard Wiring

on the board. Knife switches are usually mounted so their handles come about in the center of the board height, or a little lower, as this height is very convenient for their operation. Watthour and recording meters are frequently mounted along the lower panel-sections, underneath the knife switches.

Voltmeters and ammeters are usually placed above the knife switches, at about eye level or a little above, so they can be easily read.

Circuit-breakers are commonly placed at the top of the board, so any smoke or flame from their arcs cannot reach other instruments or blacken and burn the switchboard.

When air circuit-breakers open under severe over-loads or short circuits, they often draw long, hot arcs. The flame, heat, and smoke from these arcs are driven upward by their own heat. Therefore, if meters or instruments were located above the breakers and close to them, they would be likely to be damaged.

Mounting the breakers at the top of the boards also places them up high enough so operators are not likely to be bumped or burned when the breakers fly open or, as we say, "kick-out."

## Direct Current

### EXAMINATION QUESTIONS

1. Name three common types of switchboards.
2. What four materials are commonly used for switchboard panels?
3. In what position are knife switches generally mounted on switchboards?
4. a. Explain what is meant by "grinding in" a switch.  
b. How should this be done?
5. a. Name two common types of circuit-breakers.  
b. What is the function and advantage of circuit-breakers?
6. a. What is the purpose of the overload trip coil on a circuit-breaker?  
b. A reverse current relay?  
c. The arcing contact?
7. What care and attention should circuit-breakers receive?
8. a. How are bus bars generally mounted and attached to switchboards?  
b. Why should expansion joints be used on long busses?
9. How many  $\frac{1}{4} \times 2$ " copper buss bars should be used in parallel to carry 1500 amperes on a switchboard circuit?
10. Draw a switchboard circuit diagram similar to the one in Fig. 17, but with two generators and four feeder panels, and include the equalizer connections.

## Switchboard Wiring

# DIRECT CURRENT METERS

Electrical meters are used for accurately measuring the pressure, current, and power in various electrical circuits. There are a great number of types of meters, some of which are used only in laboratory work and others that are more commonly used in every-day work by the practical man.

These latter types are the ones which we will principally consider in this section. The meters most frequently used by electricians and operators are the **voltmeter**, **ammeter**, and **wattmeter**. These instruments are made both in portable types and for switchboard mounting.

## 1. TYPES OF METERS

The portable meters are used for convenient testing of machines and equipment wherever they are located, while the switchboard types are permanently mounted on switchboards for measuring the energy of certain circuits on these boards.

Voltmeters and ammeters are also made in recording types, which keep a record of their various reading throughout certain periods of time.

Wattmeters are divided into two general classes, called **indicating** and **integrating**.

The indicating instrument merely indicates the power in the circuit at any instant at which it is read. Integrating wattmeters, or watt-hour meters, as they are commonly called, keep summing up the total amount of energy in kilowatt hours which is used throughout any certain period of their operation.

## 2. PARTS AND CONSTRUCTION OF D. C. METERS

Most meters operate on magnetic principles or use the magnetic effect of electric currents to produce the movement of the meter needle.

## D. C. Meters

Ordinary D. C. voltmeters and ammeters consist of a permanent magnet of horse-shoe shape which supplies a magnetic flux or field, a delicately balanced coil of fine wire which is rotated in this field, a pointer, scale, and case.

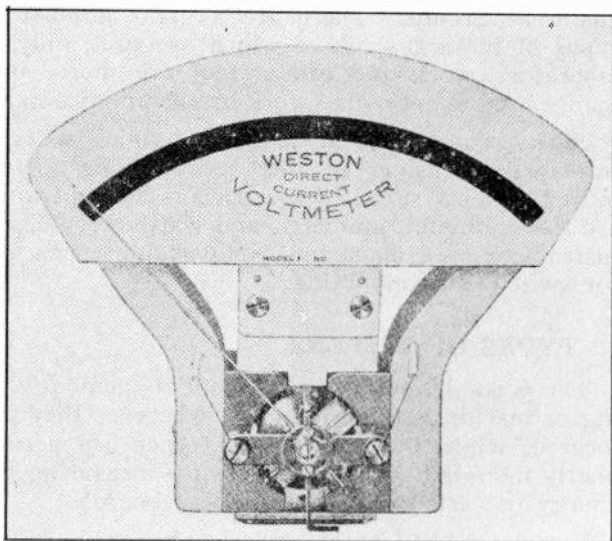


Fig. 1. The above view shows the important parts of a D. C. voltmeter. Note the horse-shoe magnet which provides the magnetic field in which the movable coil rotates. The movable coil with the pointer attached can also be seen between the magnet poles.

Fig. 1 shows the principal parts of a meter of this type, with the case or cover removed. The poles of the permanent magnet are equipped with pole shoes which have curved faces to distribute the flux evenly over the rotating element. In the center of the space between the magnet poles can be seen a round soft iron core which aids in concentrating and distributing the magnetic field over the space in which the coil moves. The needle is attached to the rotating or moving element so it will swing across the scale when the coil is rotated. This type of construction is known as the D'Arsonval, because it was first developed by a Frenchman named D'Arsonval. The D'Arsonval or moving coil type

## Direct Current

meter is one of the most accurate and commonly used types of D. C. Meters.

Fig. 2 shows a separate view of the moving coil with the needle attached. You will also note the small coil-spring on each end of the moving coil. This coil is usually wound with very fine wire on a light-weight aluminum frame, the shaft of which is then set in jeweled pivots made of first-grade sapphires. These pivots make it possible for the coil to move with an extremely small amount of energy which makes the instrument very sensitive and accurate.

### 3. OPERATING PRINCIPLES OF D. C. VOLTMETERS AND AMMETERS

The operating principles of meters of this type are very similar to those of a D. C. motor. When a small amount of current is sent through the turns of the moving coil, it sets up around this coil a flux which reacts with the flux of the permanent magnet field and exerts torque to turn the moving coil against the action of the fine coil springs. The coil springs tend to hold the needle, or pointer, in normal or zero position, usually at the left side of the scale.

These springs are often called counter torque springs as they tend to oppose the torque or turning effort of the moving coil. These two springs are wound in opposite directions to compensate for temperature changes. When an increase of temperature increases the tension of one spring, it reduces the tension on the other one and thus keeps the meter more accurate under varying temperatures.

The greater the current passed through the moving coil, the stronger will be its flux; and the reaction between this flux and that of the permanent magnet will tend to move the needle across the

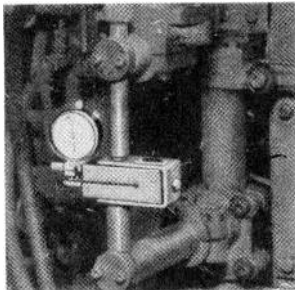
## D. C. Meters

scale, until the magnetic force is balanced by the force of the springs.

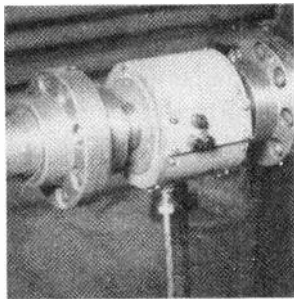
### HOW TO MAKE SPECIAL MEASUREMENTS



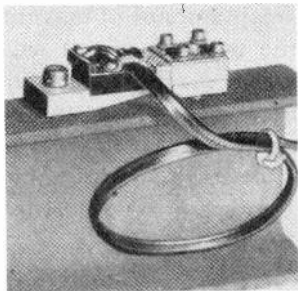
**Portable dynamic-balancer** permits balancing of rotors in their own or other bearings, at speeds from 600 to 5000 rpm. Simple to operate, and readings can be taken quickly.



**Electrode-pressure gage** measures force between electrodes of resistance-welding machines. Range: 0 to 4500 lb. Easy to use. Also used for checking springs in compression, weighing, etc.



**Torque meter** measures torque, in pound-feet, transmitted by a calibrated shaft without absorbing power. It measures twist in the shaft by electric strain gages. Ranges to 10,000 lb-ft.



**Strain gage** measures static strains caused by steady compressive, tensile, or bending loads, or dynamic strains caused by rapidly changing loads, such as vibration in machines or airplanes.

The amount of voltage applied to the coil will determine the amount of current flow through it. So the distance that the needle is moved across the scale will be an indication of the amount of voltage or current in the circuit to which the meter is attached.

The same type of meter element can be used for either a voltmeter or ammeter, according to the



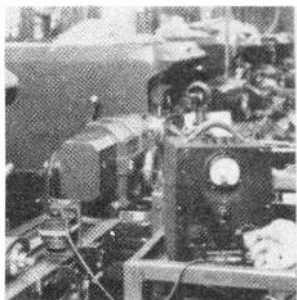
## Direct Current

manner in which the instrument is connected to the circuit to be measured.

The permanent magnets used with good-grade meters are made of the best quality of steel, and are usually aged before they are used in the meters. This aging process leaves them with a certain amount of magnetic strength, which they will retain for very long periods without noticeable weakening.

The pole shoes are made of good-grade soft iron

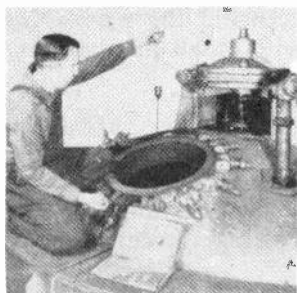
## HOW TO MAKE SPECIAL MEASUREMENTS



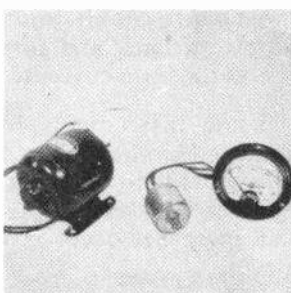
**Vibration-velocity meter** for measuring vibration velocity and displacement. Frequency range is 10 to 4000 vibrations per second, and velocity range 1 to 40,000 mils per second.



**Film-thickness gage** measures thickness of nonmagnetic materials—such as enamel, lacquers, glass, mica—when placed on steel. Standard scale range is 0 to 0.1 inch.



**Viscosimeter** measures viscosity of liquids such as paint, varnish, lacquer, japan, and oil. Time required is approx 30 seconds for one measurement. Its range is 10 to 1200 centipoises.



**Electric tachometer** is used to indicate rpm. Can also be calibrated in "feet per minute" of circumference. Indicating meter can be mounted away from the machine to facilitate reading.

to provide a low reluctance path for the flux of the permanent magnets. An additional stationary core

## D. C. Meters

of soft iron is often placed within the rotating coil, to provide a better magnetic path between the pole shoes, and to more evenly distribute the flux.

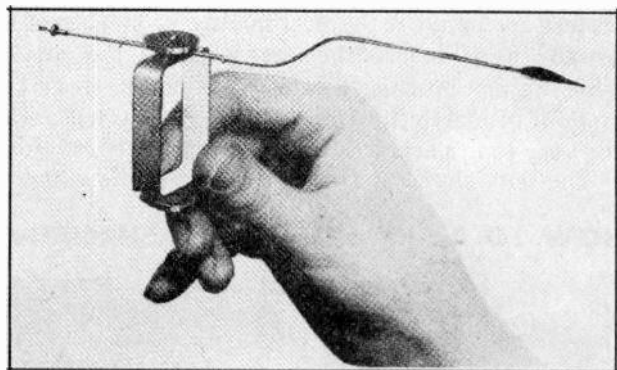


Fig. 2. An excellent view of the movable coil, pointer and spring of a D. C. meter.

### 4. DAMPING OF METER NEEDLES OR POINTERS

As the aluminum coil-frame is rotated through the flux of a meter of this type, small eddy currents are induced in the frame. These tend to set up a **damping** effect which slows or retards the rapid movement of the coil and needle, making the instrument more stable and preventing the needle from vibrating back and forth with small fluctuations in the voltage or current.

Some instruments have a light-weight air-vane attached to the needle, to provide a further damping effect and to prevent the needle from striking against the case at the end of the scale when sudden increases occur in the voltage or current of the circuit.

Small rubber cushions, or "stops," mounted on light wire springs are usually provided on each side of the needle, to limit its travel and prevent it from striking against the case. These stops can be seen in Fig. 1.

## Direct Current

Meter scales are usually printed in black on a white cardboard background, and are located directly behind the pointers, as shown in Fig. 4.

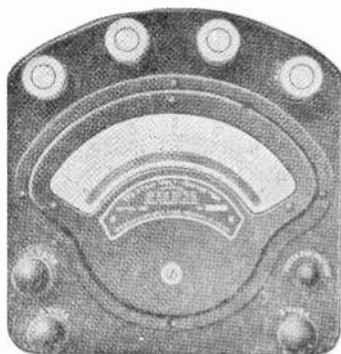


Fig. 3. A very convenient portable combination ammeter and triple range voltmeter. Circuits of different voltages can be tested by connecting to proper marked terminals.

To obtain very accurate readings, some instruments have a mirror strip parallel to the scale and directly behind the pointer. In reading a meter of this type, one should stand in such a position that the pointer covers its own reflection on the mirror. This eliminates viewing the meter from an angle and perhaps reading the voltage or current at a scale line which is not directly under the pointer.

The instrument shown in Fig. 4 is one for switchboard use and is designed to be mounted flush with the surface of the board by setting the case in an opening cut in the switchboard panel. This meter is provided with a marker, or additional black needle with a round head, which can be set in any desired position on the scale by turning the button on the front of the case. This makes it easy to tell when the voltage of the generator or circuit has reached normal value, as the moving needle would then be directly over the marker.

## D. C. Meters

### 5. CARE AND ADJUSTMENT OF METERS

Because of the delicate construction of the moving coils and the manner in which they are mounted in jeweled bearings, electric meters should be very carefully handled when they are being moved

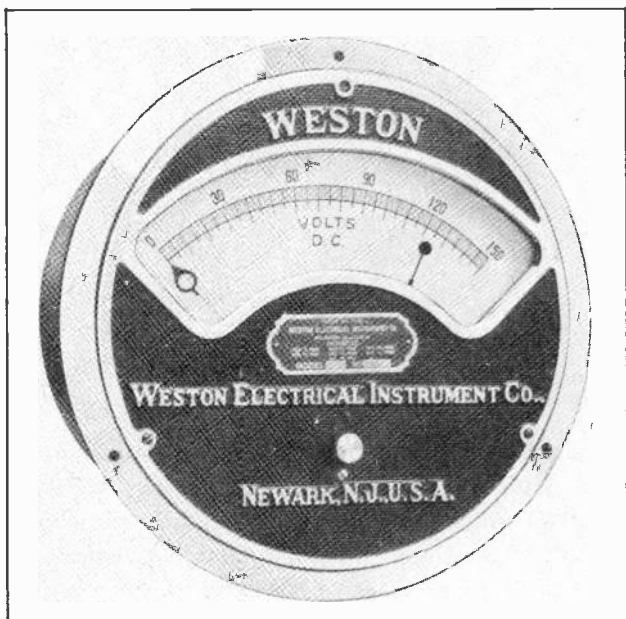


Fig. 4. Switchboard type voltmeter for mounting flush with the surface of the board. Note the stationary index pointer or marker, to indicate when full voltage is reached by the movable pointer.

about; because, if they are dropped or severely jarred it may damage the mechanism and cause their readings to be inaccurate. Jarring also tends to weaken the permanent magnets. Meters should not be mounted where they are subject to severe vibration or mechanical shocks.

On many meters adjustments are provided by means of which the tension on the coil spring can be regulated by a small screw, thereby correcting any slight inaccuracies in the meter reading. Pivot

## Direct Current

screws should be kept tight enough to prevent too much end play of the shaft and coil, but never tight enough to keep the coil from moving freely.

### 6. VOLTMETERS

When meter elements of the type just described are used for voltmeters, the moving coil is connected in parallel, or across the positive and negative wires of the circuit on which the voltage is to be measured.

It is difficult to wind a sufficient number of turns on the moving coil to have high enough resistance to stand the full line voltage on ordinary power and light circuits. For this reason, special resistance coils are connected in series with the moving coil element and the meter terminals, as shown in Fig. 5.

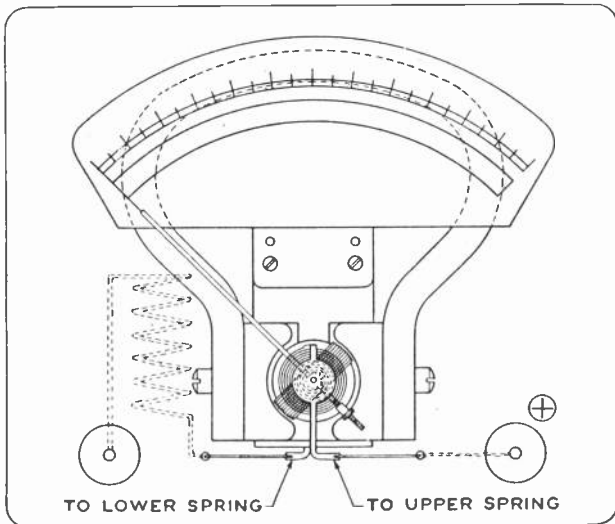


Fig. 5. This diagram shows the parts also the connections for a D. C. voltmeter.

These resistance coils limit the current flow through the meter to a very small fraction of an ampere, and thereby allow the meter element to

## D. C. Meters

be constructed of light weight and as delicately balanced as required for accuracy. Voltmeter resistance coils can be located either inside the case or outside. Portable instruments usually have them located within the case, while with switchboard instruments the resistance coils are sometimes mounted on the back of the switchboard behind the instrument.

By changing the number of these coils in series, or by changing their size and resistance, we can often adapt the same meter element for use on circuits of different voltages. When a meter is changed in this manner to operate on a different

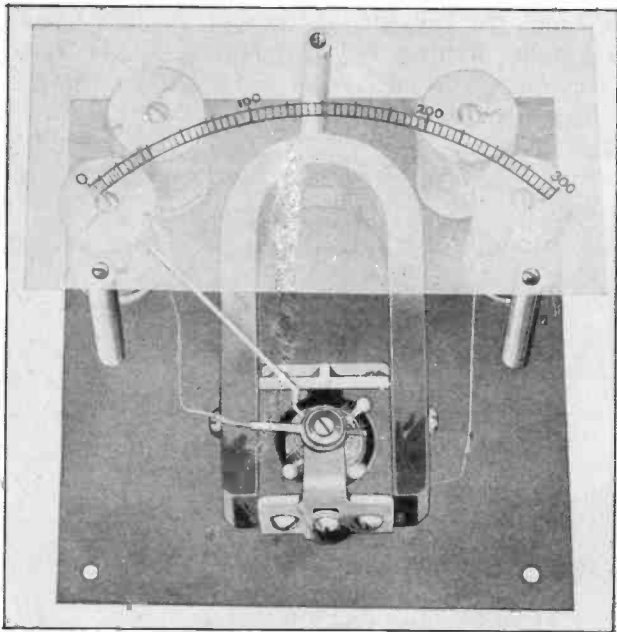


Fig. 6. The above view shows a D. C. voltmeter of a slightly different type, with the case removed to show the resistance coils which are connected in series with the movable element.

voltage, a different scale will probably also be required.

Fig. 6 shows a view of the inside of a voltmeter in which are mounted four resistance coils that are

## Direct Current

connected in series with a meter element.

Fig. 7 shows two types of external voltmeter resistance coils that can be used for mounting on the rear of the boards with voltmeters for switchboard use. With these resistance coils in series with the voltmeter element, it requires only a few milli-volts across the terminals of the moving coil

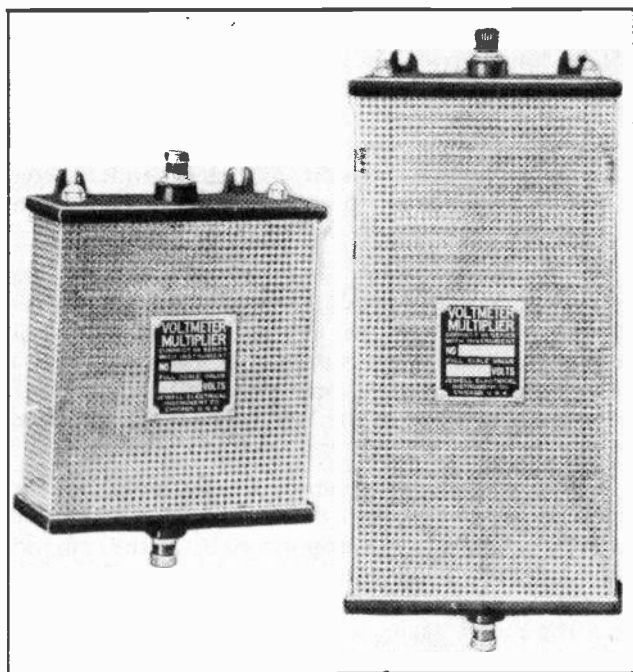


Fig. 7. External resistors for use with voltmeters and wattmeters. Resistors of this type are to be mounted outside the meter case, and usually on the rear of the switchboard.

itself to send through it enough current to operate the meter. Therefore, when the instrument is used without the resistance coils it can be connected directly to very low voltage circuits of one volt or less, and used as a milli-volt meter.

Whether it is used with or without the resistance coils, the strength of the flux of the moving coil

## D. C. Meters

and the amount of movement of the needle will depend entirely upon the voltage applied, because the current through the coil is directly proportional to this voltage.

**Any tye of voltmeter, whether for portable or switchboard use, should always be connected across the circuit, as shown in Fig. 8 at "A."**

### 7. AMMETERS AND AMMETER SHUNTS

The construction and parts of an ordinary D.C. ammeter are the same as those of the voltmeter. When the instrument is used as an ammeter, the terminals of the moving coil are connected in parallel with an ammeter shunt, and this shunt is connected in series with the one side of the circuit to be measured, as shown in Fig. 8-B.

The ammeter shunt is simply a piece of low resistance metal, the resistance of which has a fixed relation to that of the ammeter coil. The load current in flowing through this shunt causes a voltage drop of just a few milli-volts and this is the voltage applied to the terminals of the ammeter coil.

In other words, the meter element simply measures the milli-volt drop across the shunt; but, as this drop is always proportional to the current flowing through the shunt, the meter can be made so that the load in amperes can be read directly from the meter scale.

This principle can be explained by another method, as follows: We know that electric current will always divide through any number of parallel paths which it is given. As the ammeter shunt is connected in parallel with the instrument coil and is of much lower resistance than this coil, the greater part of the load current passes through the shunt, and only a very small fraction of the current flows through the meter coil.

The use of a shunt in this manner eliminates the necessity of constructing meter coils large enough



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to carry the load current. This would be practically impossible on meters of this style for heavy duty circuits. Shunts also make possible the use of the same type of moving coil element for either ammeters or voltmeters.

Ammeter shunts for portable instruments are usually mounted inside the instrument case; and for switchboard instruments on heavy power circuits, the shunt is usually mounted on the rear of the switchboard.

To obtain accurate readings on the meters, ammeter shunts should be made of material the resistance of which will not change materially with ordinary changes in temperature, as the shunt may become heated to a certain extent by the flow of the load current through it. The material commonly used for these shunts is an alloy of copper, manganese, and nickel, and is called "manganin." This

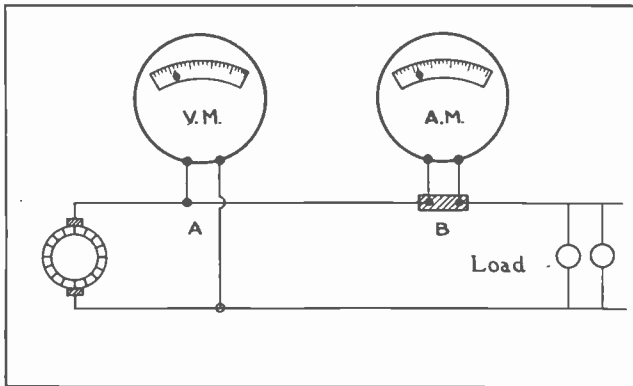


Fig. 8. This diagram shows the proper methods of connecting voltmeters and ammeters to electric circuits. Note carefully the manner of connecting voltmeters in parallel with the line and ammeters or their shunts in series with the line.

alloy has a temperature co-efficient of almost zero; in other words, its resistance doesn't vary any appreciable amount with changes in its temperature. **Manganin** is used also because it doesn't develop

## D. C. Meters

thermo-electric currents from its contact with the copper terminals at its ends.

Ammeter shunts for use with D.C. ammeters are made in sizes up to several thousand amperes capacity. Fig. 9 shows several sizes and types of these shunts. Note the manner in which the strips of alloy are assembled in parallel between the bus connector stubs. This allows air circulation through the shunt to cool it.

### 8. CONNECTION OF AMMETERS AND SHUNTS

Remember that **ammeter shunts or ammeters must always be connected in series with the line**

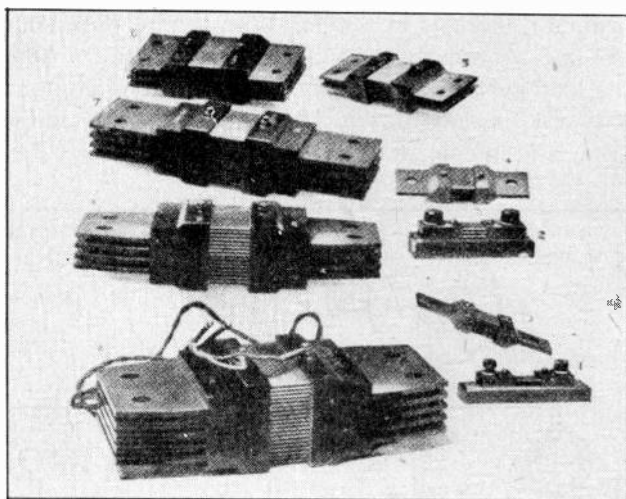


Fig. 9. The above photo shows several sizes and types of ammeter shunts which are generally used with ammeters where heavy loads are to be measured.

and **never in parallel**. The resistance of shunts is very low and if they were connected in parallel across positive and negative wires of a circuit, it would produce a severe short circuit, which on heavy circuits would be dangerous to the person connecting the meter and would at least blow the

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fuse and kick out circuit breakers. It would also probably burn out the meter or destroy the shunt.

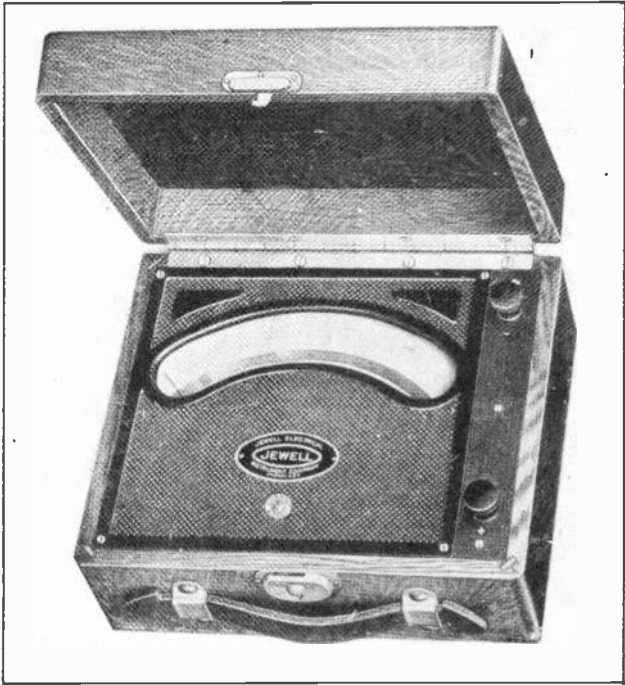


Fig. 10. Portable meters of the above type are very convenient and necessary devices for the practical electrician to use in testing various machines and circuits.

Fig. 10. shows a common type of portable meter, such as is used in testing various electrical machines and circuits. The protective case and convenient carrying handle make these instruments very handy for use on the job. **Voltmeters, ammeters, and wattmeters** of this type are very essential in any plant where a large number of electric machines are to be maintained.

Testing the voltage and current of motors of different sizes will often disclose an overload or defective condition in time to prevent a complete burnout or serious damage to the machine windings.

Some portable instruments have two separate

## Meters

elements in the case and two separate scales, one for a voltmeter and one for an ammeter. Portable instruments of this type are very convenient for tests, but extreme care must be used to be sure to connect the voltmeter terminals in parallel and the ammeter terminals in series with any circuit to be tested.

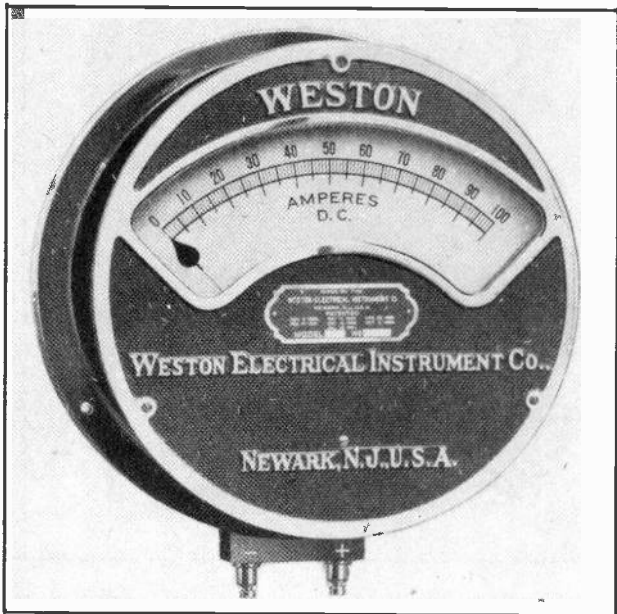


Fig. 11. Switchboard type ammeter for surface mounting. This meter does not require any large opening to be cut in the switchboard panel.

D. C. meters must be connected to the line with the proper polarity, and their terminals are usually marked "positive" and "negative," as shown in Fig. 11. If meters of this type are connected to the line with wrong polarity, the needle will tend to move backwards and will be forced against the stop wire or case at the zero end of the scale.

The meter shown in Fig. 11 is another type of switchboard meter for surface mounting. This instrument doesn't require cutting any opening in

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the switchboard panel, since the meter is mounted flat against the front surface of the panel.



Fig. 13. This photo shows a high grade portable combination voltmeter and ammeter combined in one convenient carrying case. Such instruments are very handy for maintenance electricians.

These meters are often mounted on a hinged bracket at the end of the switchboard so that they can be seen from any point along the board.

### 9. CHANGING METERS FOR HIGHER OR LOWER READINGS

In certain cases an electrician may not have suitable meters for testing all of the various circuit voltages and current loads in the plant, and in such cases it is often very convenient to know how to change the meters on hand to indicate voltages or currents other than those for which they were designed. This can be quite easily done by changing the resistors on voltmeters, or the shunts used with ammeters.

In recent years instrument manufacturers have begun to standardize on the construction of essential parts of meters. This not only reduces original

## D. C. Meters

costs and makes it easier to secure repair parts, but it also makes certain meters more flexible or adaptable to a wider range of service. For example, many voltmeters and ammeters are now made with a standard moving coil having a resistance of  $2\frac{1}{2}$  ohms and designed to give full scale deflection of the pointer with a current of 20 milliamperes, or .020 ampere. According to Ohms law formula  $I \times R = E$ , or  $.020I \times 2.5R = .050E$ , or 50 millivolts drop, or pressure applied to force full scale current through this coil. A coil having  $2\frac{1}{2}$  Ohms for a 50 millivolt reading would be on a basis of 50 OHMS PER VOLT. As one volt or 1,000 m. v.  $\div 50$  m. v. = 20, and  $20 \times 2.5 = 50$ .

Now if we wish to use this 50 m. v. meter to measure 100 m. v. or double the present voltage rating we should simply double the resistance of the meter circuit or add  $2\frac{1}{2}$  ohms more resistance in series with the  $2\frac{1}{2}$  ohm moving coil. Then  $2\frac{1}{2} + 2\frac{1}{2} = 5$  ohms total resistance, which when connected across a 100 m. v. circuit would draw  $.100 \div 5$  or .020 ampere and again give full scale deflection. If we now re-mark or recalibrate the scale for 100 m. v. we have doubled the range of the meter.

You can readily see that if the  $2\frac{1}{2}$  ohm coil were connected on a circuit of double its rated voltage without increasing the resistance the coil would receive double current and be burned out. Therefore in changing voltmeter resistances to adapt the meter for correct readings of higher voltage values we simply use the following formula to determine the correct resistors to use in series with the meter coil:—

$$\frac{\text{Desired voltage range}}{\text{full scale meter coil current}} = \frac{\text{total resistance}}{\text{for meter circuit.}}$$

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Then by subtracting the resistance of the moving coil from this total resistance we can determine the amount of extra resistance to use in series for the higher readings. For example, suppose we wish to adapt this same meter element for a full scale reading of 150 volts, and for safe use on a 150 volt circuit.

$$\text{Then } \frac{150 \text{ E}}{.020 \text{ I}} = 7500 \text{ R. total resistance.}$$

Then  $7500 - 2.5 = 7497.5$  ohms of additional resistance to be used.

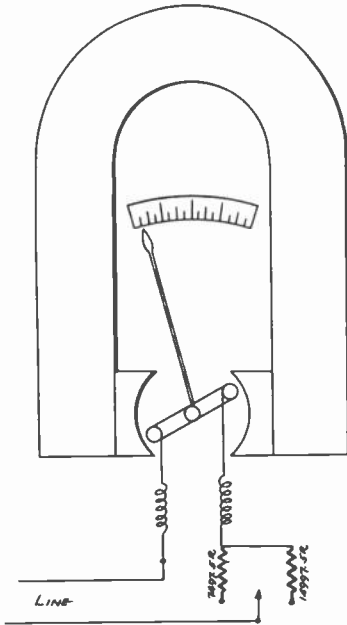


Fig. 14. This diagram shows a meter designed for reading two different voltages.

If we wish to use the same meter for dual service or 150 and 300 volt circuits we can arrange another resistor of 14997.5 ohms as shown in Fig. 14.

## D. C. Meters

Then by connecting the wires of the circuits to be tested to the proper terminals or resistors we can measure either voltage. Some multiple range meters have these extra resistors located inside the case and connected to proper terminals. These meters may also have the scale marked for 3 or more voltage ranges as in Fig. 3.

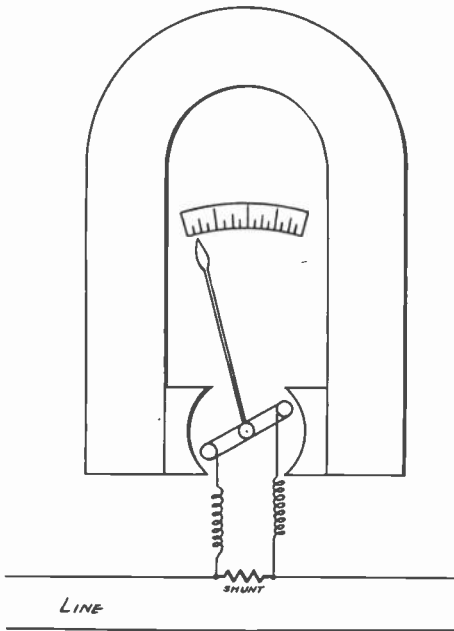


Fig. 15. This figure shows how the ammeter shunt is connected in parallel with the meter coil.

The same changes can be applied to ammeters to adapt them for other ranges by changing the resistance of the shunts which are used with this same standard meter element and  $2\frac{1}{2}$  ohm moving coil. Using only the meter coil without any shunt the instrument's capacity and full scale reading would be only 20 milliamperes. If we wish to change it to measure current up to 100 M. A. or 5 times its former rating, we would place in parallel with the moving coil a shunt having a resistance  $\frac{1}{4}$ th



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that of the coil or,  $2.5 \div 4 = .625$  Ohms resistance for the shunt.

With this shunt connected in parallel with the meter as shown in Fig. 15, the current will divide in inverse proportion to the resistance of the two parallel paths, and  $4/5$  of the current or 80 M. A. will pass through the shunt, while  $1/5$  of the current or 20 M. A. will pass through the meter coil.

When making such changes for scale readings of 2 amperes or less, we should determine the shunt resistance according to the desired division of current between the meter coil and the shunt, as we have just done in the foregoing problem. This is due to the fact that in order to obtain readings which are accurate at least within one per cent on such small current loads we must consider the amount of current which flows through the meter element. However for changes over 2 amperes the following simple formula can be used to determine the shunt resistance:

voltage rating of meter coil  
----- = resistance of shunt.  
desired current capacity

Then if we want to change this same type of meter with the 50 millivolt coil to measure currents

up to 10 amperes at full scale reading  $\frac{.050}{10} = .005$

ohm shunt to be used in parallel with the meter element. Note that the shunt resistance is  $1/500$  of the meter coil resistance, and the meter coil current of .020 is  $1/500$  of the new full scale current of 10 amperes.

If we desire to change this type of meter to read 200 amperes, then  $\frac{.050}{200} = .00025$  ohm shunt.

Meters which use these standard coils of  $2\frac{1}{2}$  ohms resistance for 20 M. A. current at 50 ohms

## D. C. Meters

per volt are guaranteed by the manufacturers for accuracy within one per cent. This is accurate enough for all ordinary shop tests. When a higher degree of accuracy is required for laboratory measurements, etc., meters with higher resistance moving elements are used. The more resistance per volt which is used in the meter coil, the higher the degree of accuracy will be.

### 10. INDICATING WATTMETERS

Wattmeters, as previously mentioned, are used for measuring the power of circuits in watts. As this power is proportional to both the voltage and amperage of the circuit, wattmeters use two coils, one of which is known as the voltage or potential element, and the other as the current element.

The potential element is connected across the line, similarly to a voltmeter coil; while the current element is connected in series with one side of the line, similarly to an ammeter coil.

A diagram of the internal wiring and the connections of a wattmeter is shown in Fig. 16.

The potential coil is the movable element and is wound with very fine wire and connected in series with resistance coils, similarly to those used in the voltmeter. As this coil is connected across the line, the strength of its flux will always be proportional to the line voltage.

The current element is stationary and consists of a few turns of larger wire. As this coil is connected in series with the line, its strength will be proportional to the load and the current which is flowing. This current element supplies the field and takes the place of the permanent magnet used in voltmeters and ammeters.

As the turning effort, or torque, exerted on the

## Direct Current

movable coil is the result of reaction between its flux and the flux of the current element, the pointer movement will always be proportional to the

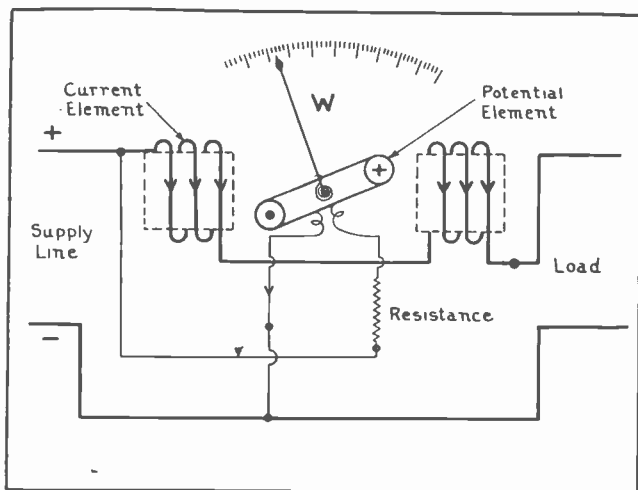


Fig. 16. This diagram shows the potential and current coils of a wattmeter. Note the manner in which each of these elements are connected in the circuit. The movable coil is shown in a sectional view so you can observe the direction of current through its turns and note how the flux of this movable coil will react with that of the current coils and cause the pointer to move.

product of these two fields and will, therefore, read the power in watts directly from the scale.

The coils of these instruments are not wound on iron cores but are wound on non-magnetic spools or in some cases the wires are stiff enough to hold their own shape in the coils. Wattmeters of this design can be used on either D.C. or A.C., as they will read correctly on A.C. circuits if the reactances of both the moving and stationary coils are equal.

Wattmeters are designed for different amounts of voltage and current and should never be used on circuits with a greater amount of power in watts than they are rated for, nor circuits with higher voltage or heavier currents than the instruments are designed for.

The terminals for the potential and current elements can be distinguished by their size, as those

## D. C. Meters

of the current element are usually much larger than those of the potential element. Extreme care should

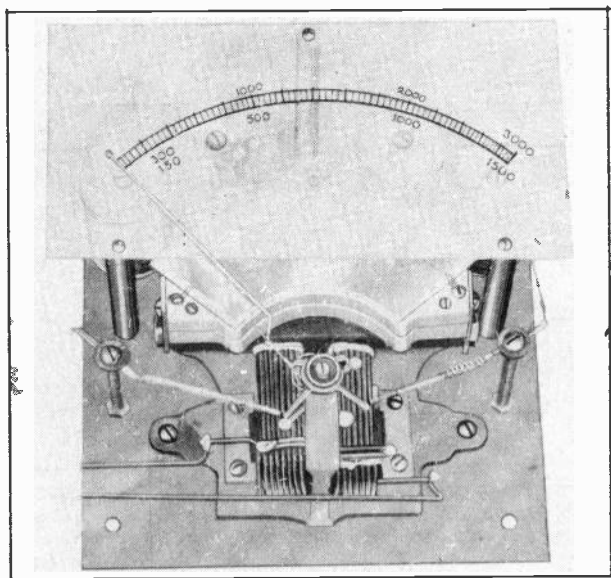


Fig. 17. This view shows the current coils, resistor coils, and general construction of a common type wattmeter.

be used never to connect these in the wrong relation to the circuit, because if the current coil is connected across the line, a short circuit will result.

Fig. 17 shows the internal construction of a D.C. wattmeter. In this view the current coils, consisting of a few turns of heavy wire, can be plainly seen. The potential coil cannot be seen, however, as it is inside of the current coil.

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### EXAMINATION QUESTIONS

1. Name three important parts of an ordinary D.C. voltmeter or ammeter.
2. Describe two methods by which the meter needle is protected against striking the case when sudden increases of voltage or current take place through the instrument.
3. Why are mirrors used in certain meters?
4. How does the resistance of a voltmeter including the resistance coils compare with the resistance of an ammeter including the shunt?
5. How are voltmeters and ammeters connected with relation to the line and load?
6. a. Are voltmeter resistances connected in series or parallel with the meter element?  
b. Are ammeter shunts connected in series or parallel with the meter element?
7. On a certain voltmeter with a coil resistance of 2.5 ohms, and a full scale current of .020 amperes, what resistance must be connected in series with the coil to adapt the meter for use in measuring voltages up to 220 volts?
8. Give the formula to be used in figuring the shunt resistance on meters of over 2 amperes rating.
9. How many coils are used in Wattmeters? Name them.
10. How are Wattmeter coils connected with relation to the line?

## D. C. Meters

## Direct Current

# WATTHOUR METERS

The common type of meter used in homes, factories, and power plants for measuring in kilowatt hours the **total amount of power used during any certain period**, is known as a **watthour meter**.

These meters have a current and potential element somewhat similar to those in the indicating wattmeter. The potential element, however, is allowed to revolve continuously, like the armature of a D.C. motor, as long as there is any load on the circuit or line to which the meter is attached.

This element is not limited to a fraction of a turn by the coil springs, as in the case of indicating meters, but is mounted on a vertical shaft set in jeweled bearings and is free to revolve completely around, with the application of a very small torque.

This rotating element is connected to a series of gears which operate the hands or pointers on the clock-like dials of these instruments. The current element consists of a few turns of large wire and is connected in series with the line, or in parallel with an ammeter shunt which is connected in series with the line. This stationary current coil provides a magnetic field similar to that of a D.C. motor, and in which the potential coil or armature element rotates.

### 1. PRINCIPLES OF WATTHOUR METERS

The potential element, being connected across the positive and negative leads of the line, is always excited and has a very small current flowing through it as long as it is connected to the circuit. This coil, usually has additional resistance coils placed in series with it, to limit the current flow to a very small value. Therefore, it doesn't waste any appreciable amount of current by being permanently connected across the line.

As long as no load current is flowing through the line and the current element of the meter, there is no field flux for the flux of the potential coil to react with, and so it doesn't turn. As soon as load is applied to the line and current starts to flow

## Watt-hour Meters

through the stationary coils, it sets up a field which reacts with that of the potential coil, causing the latter to start to turn.

The greater the load of current, the stronger will

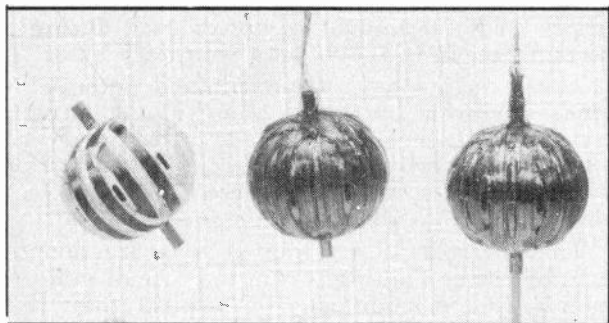


Fig. 1. The above photo shows several potential or armature coils of watt-hour meters and illustrates the manner in which they are wound.

be this field and the faster will be the rotation of the potential element or armature. This will cause the pointers on the dials to revolve faster and total up power more rapidly. The longer the load is left on the circuit, the farther these pointers will be revolved and the greater will be the total power reading.

## 2. CONSTRUCTION OF POTENTIAL AND CURRENT COILS

Fig. 1 shows three views of the armature or potential element of a watt-hour meter, both partly wound and completely wound. The coils of fine wire are wound on a drum or hollow ball of light weight non-magnetic material and are held in place by a coating of insulating compound. You will note that they are wound similarly to the coils of a simple D.C. motor armature. The leads of the coils are brought up to a very small commutator located on the top end of the shaft at the right.

Fig. 2 shows both the current coils and potential coil of a watt-hour meter. The current coils are wound of heavy copper strip and are each divided into two sections. They are mounted close



## Direct Current

to the potential or rotating element, which can be seen just inside of them. You will note at the top of this figure the very small metal brushes mounted on wire springs and in contact with the small commutator to which the leads of the potential element are attached. Directly above this commutator is the small wormgear which drives the series of small gears that operate the dials. The brushes of the meter are connected in series with the proper resistance coils and then across the line wires, and they complete the circuit through the potential element, or armature, of the meter.

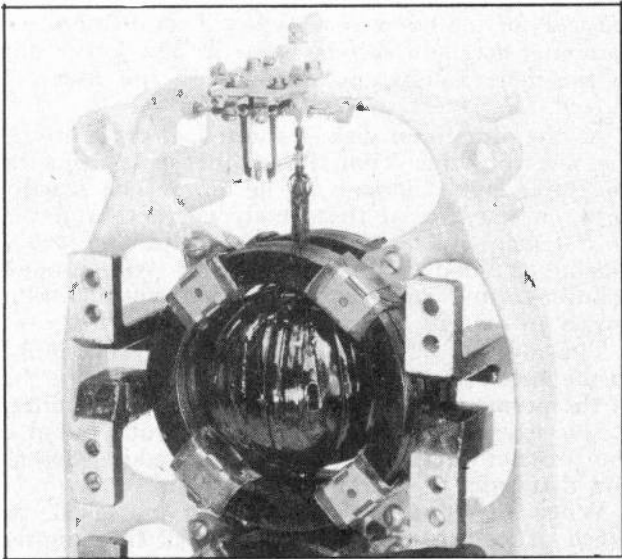


Fig. 2. This view shows the potential and current coils and also the commutator and brushes of a watt-hour meter.

These brushes are commonly made of silver or some very good conducting material, in order to prevent resistance and voltage drop at the brush contact with the commutator.

### 3. DAMPING DISK AND MAGNETS

The speed at which the armature of the watt-hour meter will rotate depends upon the voltage applied to the potential element and the current flowing

## Watt-hour Meters

through the current element. Because of the very slow speed at which this armature revolves, its speed is not regulated by counter-E.M.F., as armatures of direct current motors are.

In order to prevent over-speeding and to make the driving torque remain proportional to the power applied, the motor armature must have some damping or retarding effect to oppose the torque exerted by the magnetic fields. This counter-torque is obtained by mounting a thin aluminum disk upon the lower end of the armature shaft, and allowing it to rotate in the field of one or more permanent magnets of the horse-shoe type. This disk and the damping magnets can be seen in the lower part of the meter, shown in Fig. 3 with the cover removed.

As the aluminum disk is rotated, it cuts through the lines of force from the magnet poles and this generates eddy currents in the disk. The reaction between the flux of these eddy currents and that of the magnets tends to oppose rotation, just as placing a load upon a generator will produce counter-torque and require effort from the prime mover to turn it.

The induced eddy currents will be proportional to the speed of rotation of the disk and, as the flux of the permanent magnets is constant, the counter-torque exerted by the disk will be proportional to the product of the flux from these eddy currents and that from the permanent magnets.

When the load on the meter is increased, the speed of its armature increases, until the counter-torque developed by the disk just balances the torque exerted by the armature. In this manner, the armature speed is maintained proportional to whatever load is applied to the meter, causing the pointers on the dials to read the correct power in kilowatt hours.

This type of meter is often referred to as a watt-hour meter, but the gears and speed of most of them are so adjusted and of the proper ratio so that the readings will be in kilowatt hours, instead of watt-hours.

### 4. ADJUSTING DAMPING EFFECT

The amount of damping effect produced by the

## Direct Current

disk can be adjusted by moving the poles of the permanent magnets in or out along the disk. If the poles are moved closer to the outer edge of the disk where it will cut their flux at higher speed, a greater amount of eddy current will be induced and cause a greater damping effect, and if the magnet poles are moved closer to the shaft where the disk is traveling at lower speed the induced eddy currents will be less, and the damping effect will be reduced.

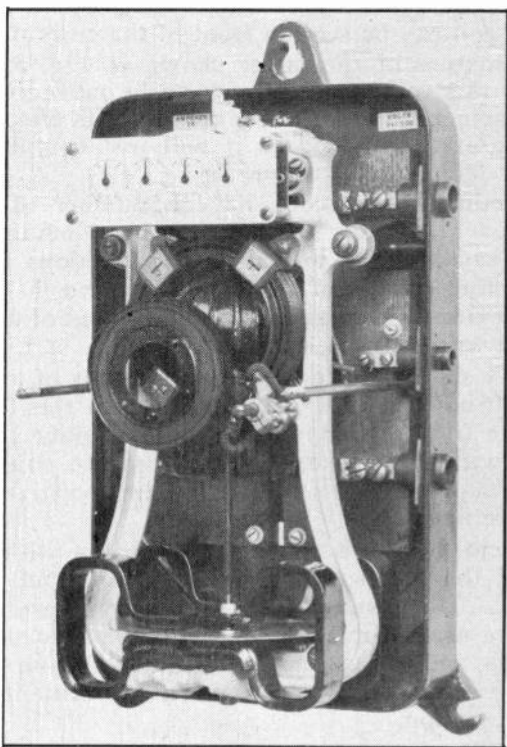


Fig. 3. Complete view of a KW-hour meter with the cover removed clearly showing the dials, current and potential coils, compensating coil, damping disk, and drag magnets.

### 5. COMPENSATING COIL

No matter how carefully the armature of a meter of this type may be mounted, there is always a slight amount of friction to offer resistance to its

## Watt-hour Meters

rotation. Some of the energy produced by the meter coils will be required to overcome this friction and the friction of the gears on the dials.

In order to make a meter register accurately on light loads, this friction should be compensated for. This is done by means of a coil consisting of many turns of fine wire, connected in series with the armature or voltage coil of the meter. This **compensating coil** is mounted on an adjustable bracket in a position where its flux will react with that of the potential and current coils.

This coil can be seen in front of the current coils and armature of the meter shown in Fig. 3. By having this coil adjustable, it can be moved closer to or farther from the meter coils and its effect can be accurately adjusted so it will just compensate for the friction, and no more.

Sometimes these coils have a number of taps provided at various sections of the winding and also a small switch to shift the connections to include more or less of the turns of the coil. This also provides an adjustment of the amount of torque the coil will exert to overcome friction.

Fig. 4 shows the coils and connections of a D.C. kilowatt-hour meter. You will note in this figure that the friction compensating coil is connected in series with the armature and resistance coil, and this group are connected across the positive and negative line wires.

Current coils are connected in series with one side of the line so they will carry the full load current. The terminals of a watt-hour meter of this type are usually marked for the line and load connections, and these connections must, of course, be properly made so that the meter will run in the right direction.

### 6. WATTHOUR CONSTANT AND TIME ELEMENT

A given amount of power in watts must pass through a watt-hour meter to produce one revolution of the armature and disk. For example, it may require a flow of energy representing 6 watt-

## Direct Current

hours, or the equivalent of 6 watts for one hour, to produce one revolution of the meter armature. This amount would be termed the **watthour constant** of the meter.

Knowing the number of watts per revolution, it only remains to get the total number of revolutions during a certain period of time, in order to know or measure the total amount of energy passed through the meter during that time. As each revolution of the armature is transmitted to the gears which operate the pointers on the dials, the total power in kilowatt hours can be read directly from these dials.

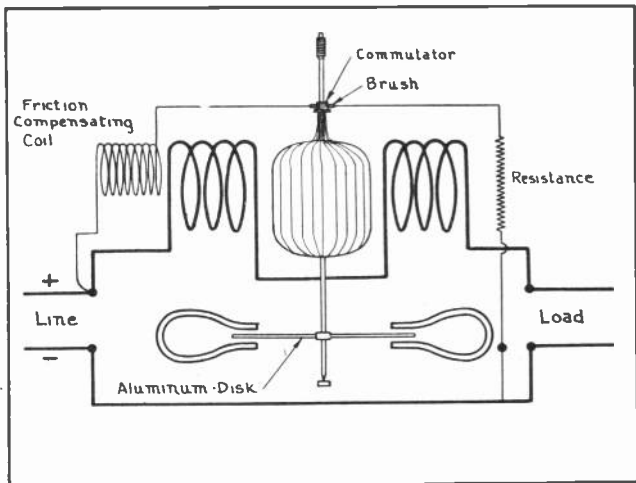


Fig. 4. This diagram shows the coils and circuits of a KW-hour meter and the manner in which they are connected to the line and load.

The operation of the gears and dials or registering mechanism is very simple. The worm-gear on the upper end of the armature shaft is meshed with the teeth of a gear which is the first of a row or chain of gears all coupled together. This gear has attached to it a small pinion which meshes with the teeth of the next gear and drives it at  $1/10$  the speed of the first one. This second gear, in turn, drives the third gear  $1/10$  as fast as it runs, and the third drives a fourth, the speed of which is again reduced to ten times lower than the third one.

## Wathour Meters

Referring to Fig. 3, when the pointer on the right has made one complete revolution, the pointer on the next dial to the left will have travelled just one division or one-tenth of a revolution.

When the first pointer has made ten revolutions, the second one will have completed one revolution, and the third pointer will have moved one point. When the first pointer completes 100 revolutions, the second will have completed 10; and the third will have completed one revolution.

In this manner the first dial will have to make 1000 revolutions to cause the left-hand dial to complete one revolution.

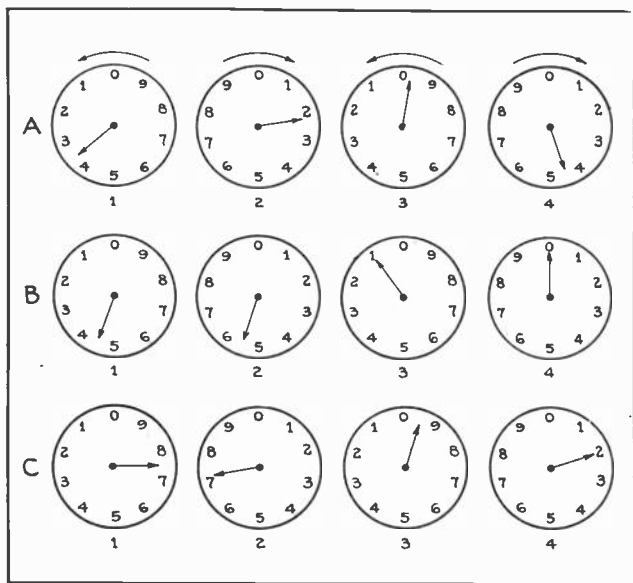


Fig. 5. The above sketches, A, B, C, shows the dials of a kilowatt-hour meter in three different positions. If you will practice reading each set of these dials with the instructions here given, you will be able to easily and accurately read any KW-hour meter.

### 7. READING WATTHOUR METERS

By noting the figures at which the pointers stand, in order from left to right, we can read the kilowatt hours indicated by the meter. Some meters used on larger power circuits are adjusted so that their dials and pointers don't show the amount of

## Direct Current

power directly, but provide a reading which must be multiplied by some certain figure, such as 10, 20, or 50, to obtain the correct total reading. This figure is called a **constant** or **multiplier**, and it should be used whenever reading a meter of this type. This constant, or multiplier, is usually marked beneath the dials of the meter.

When reading kilowatt-hour meters, **we should always read the last number which has been passed by the pointer on any dial.** Some care is required in doing this until one has had enough practice to do it automatically. If each dial is not carefully observed, mistakes will be made; because **each adjacent pointer revolves in the opposite direction to the last**, as can be seen by the numbers marked on the dials shown in Fig. 5-A.

When the pointer is almost directly over one of the numbers, there may be a question as to whether the pointer has actually passed this number or is still approaching it. This should always be determined by referring to the next dial to the right to see whether or not its pointer has completed its revolution. If it has completed the revolution or passed zero on its dial, the pointer to the left should be read as having passed its number.

If the pointer to the right has not completed its last revolution, the one next to the left should not be read as having passed its number, even though it may appear to be beyond the number.

If the readings are carefully checked in this manner there is very little chance of mistakes.

On the second dial from the left in Fig. 5-A, the pointer revolves in a clockwise direction, and it might easily appear that it has passed the No. 2. By checking with the dial next to the right, however, we find that this pointer, which revolves counter-clockwise, has not quite completed its revolution or passed zero. Therefore, the dial at the left should still be read as No. 1. The correct reading for a meter with the pointers in the position shown in Fig. 5-A would be 3194 kilowatt hours.

## Watthour Meters

The reading for the pointers in Fig. 5-B should be 4510 kilowatt hours. Here again the pointer on dial No. 3 appears to be on figure No. 1; and, by checking with dial No. 4, we find that its pointer is on zero or has just completed a revolution; so it is correct to read dial No. 3 as No. 1.

The reading for the set of dials in Fig. 5-C should be 7692. The pointer on dial No. 2 in this case appears to have passed No. 7; but, by checking with dial No. 3 to the right, we find its pointer has not quite completed its revolution; therefore, the dial to the left should be read as No. 6.

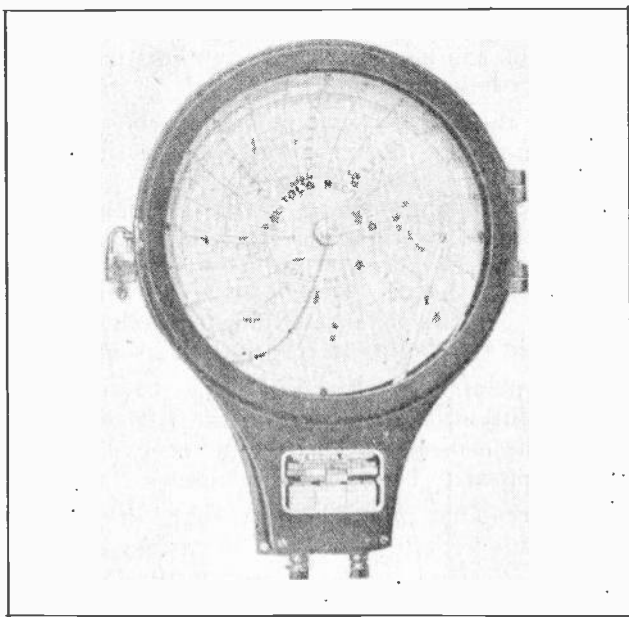


Fig. 6. Common type of recording voltmeter used for keeping an hourly and daily record of the voltages on the system to which it is attached.

### 8. "CREEPING"

The armature of a watthour meter will sometimes be found to be rotating slowly, even when all load is disconnected from the circuits. This is commonly called **creeping** of the meter. It may be caused by a high resistance ground or a short



## Direct Current

on the line. The resistance of such a ground or short may not be low enough to cause the fuse to blow, and yet there may be a small amount of current flowing through it at all times.

If the load wires are entirely disconnected from the meter and the disk is still creeping, it may be due to the effects of stray magnetic fields from large conductors which are located near the meter and carrying heavy currents, or it may be caused by the fields from large electrical machines located near by.

For this reason, watt-hour meters, or for that matter any other electric meters, should not be located within a few feet of large machines, unless they are magnetically shielded, and they should be kept at least a few inches away from large conductors carrying heavy currents.

Large bus bars or cables carrying currents of several hundred or several thousand amperes set up quite strong magnetic fields around them for distances of several feet, and very strong fields a few inches away from them.

Sometimes a very small load such as a bell transformer or electric clock may cause the meter to rotate very slowly, but this is actual load and not creeping.

Vibration of the building or panel to which the meter is attached may sometimes be the cause of creeping. In some cases this may be stopped by proper adjustment of the compensating coil; or a small iron clip can be placed on the edge of the aluminum disk, if the clip does not rub the damping magnets as the disk revolves.

When this iron clip comes under the poles of the permanent magnets, their attraction for the iron will stop the disk and prevent it from creeping. As long as this clip doesn't touch the permanent magnets, it will not interfere with the accuracy of the meter; because its retarding effect when leaving the poles of the magnets is balanced by its accelerating effect when approaching the poles.

## 9. TESTING KILOWATT-HOUR METERS

Kilowatt-hour meters can be tested for accuracy,

## Watt-hour Meters

or calibrated, by comparison with standard portable test instruments.

A known load consisting of a resistance box can be connected to the load terminals of the meter when all other load is off. Then, by counting the revolutions per min. of the disk and comparing this number with the revolutions made by the disk of a "rotating standard" test instrument, the accuracy of the meter can be determined.

When no standard load box or test instrument is available, a test can be conveniently made with a known load of several lamps or some device of which the wattage is known.

For this test the following formula should be used:

$$\frac{\text{WHK} \times 3600 \times R}{W} = \text{seconds}$$

In which:

WHK = the watt-hour constant marked on the meter disk.

3600 = number of seconds in an hour.

R = any chosen number of revolutions of the disk.

W = known load in watts which is connected to the meter.

For example, suppose we wish to test a meter which has a constant of .6, marked on its disk. We can connect a new 200-watt lamp, or two 100-watt lamps across the load terminals of the meter, after all other load has been disconnected. At the instant the lamp load is connected, start counting the revolutions of the meter and observe accurately the amount of time it requires to make a certain number of revolutions. Let us say it is 5 revolutions.

Then, according to the formula, the time required for the disk to make these 5 revolutions should be:

$$\frac{.6 \times 3600 \times 5}{200}, \text{ or } 54 \text{ seconds}$$

If it actually requires longer than this, the meter is running too slow. If the time required to make

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the 5 revolutions is less than 54 sec., the meter is running too fast.

Remember where to find this formula for future reference, as it may often be very convenient to use.

### 10. RECORDING INSTRUMENTS

In power plants or substations where large amounts of power are generated and handled, it is often very important to keep accurate records of the voltage, current, and power on principal circuits at all hours of the day and night.

Records of this kind will show any unusual variations in load or voltage and they are often the means of effecting great savings and improvements in the operation of power plants and industrial electric machinery.

It is usually not practical for an operator or elec-

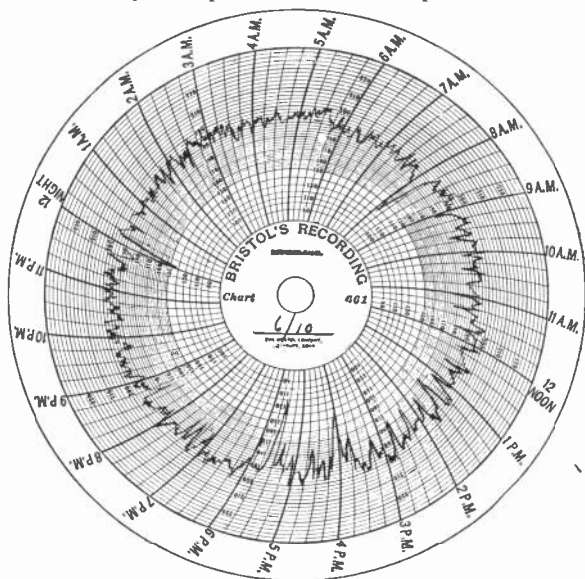


Fig. 7. Paper disk or chart from a direct acting recording meter. The irregular black line shows the voltage curve traced by the pointer and pen throughout each hour of the day and night.

trician to keep constant watch of meters to obtain a record of their readings hourly or more often.

## Recording Instruments

Recording meters which will mark a continuous record of their readings on a paper chart or disk can be used for this purpose.

### 11. DIRECT-ACTING RECORDING METERS

One of the simplest types of recording instruments uses the ordinary meter element and has a case quite similar to that used for D.C. voltmeters or ammeters, and has a small ink cup and pen attached to the end of the needle or pointer. This pen rests lightly on a paper disk which is rotated once around every 24 hrs. by a clock-work mechanism inside the meter. See Fig. 6.

As the disk slowly revolves, the pointer pen traces on it a line which shows the movements of the pointer and the variations in voltage or current, whichever the instrument is used to measure.

The paper disks have on them circular lines which represent the voltage or current scale. By the position of the ink line on this scale the voltage or amperage at any point can be determined. Around the outer edge of the disk is marked the time in hours, so the readings for any period of the day can be quickly determined. Fig. 7 shows a disk from a meter of this type.

Recording meters of the type just described are called **Direct-Acting** instruments. One of the disadvantages of meters of this type is that the friction of the pen on the paper chart does not allow the pointer and pen to move freely enough to make the meter very sensitive or accurate on small variations in the voltage or current. They also require frequent winding, replacing of charts, and refilling of the pen, but they are low in cost and very satisfactory for certain requirements.

### 12. RELAY TYPE RECORDING METERS

Another type of recording instrument in very common use is the **Relay Type**, which operates on the electro-dynamometer, or Kelvin balance, principle.

The Kelvin balance consists of a set of stationary

## Direct Current

coils and a set of movable coils. These coils can be seen at the top of the instrument shown in Fig. 8, which is a relay-type recording meter.

The thin moving coils are shown balanced between the larger stationary coils, and are equipped with a torsion spring which tends to oppose their movements in either direction.

Any change of voltage or current in these coils changes the repulsion or attraction between the

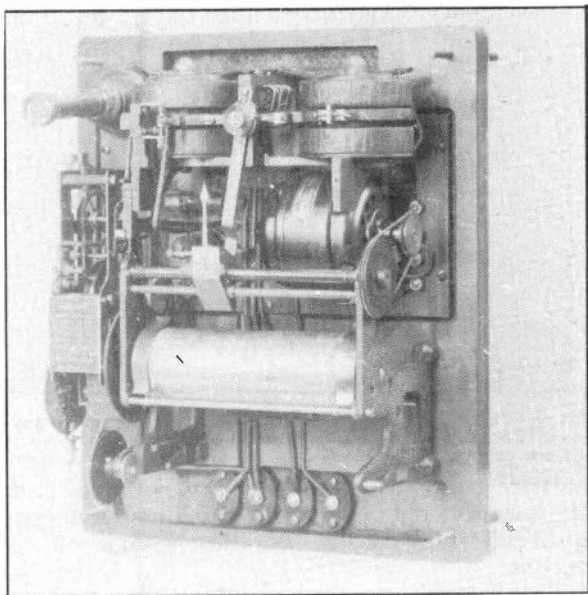


Fig. 8. This photo shows a complete recording instrument of the relay type with the cover removed. Note the stationary coils and balance coils at the top, and the roll for carrying the paper chart beneath the pointer.

fields of the moving and stationary elements, and will force the coils of the moving element up or down. This moving element then operates a set of relay contacts which close a circuit to the solenoids or small operating motor which moves the pen.

The instrument shown in Fig. 8 uses a motor for the operation of the pen and pointer. The motor,

## Recording Instruments

which can be seen above the chart roll, revolves a worm shaft which moves the pen. The movement of the pen also readjusts the counter-torque spring on the movable coil so that it is balanced properly for the new position of the pen. This causes the

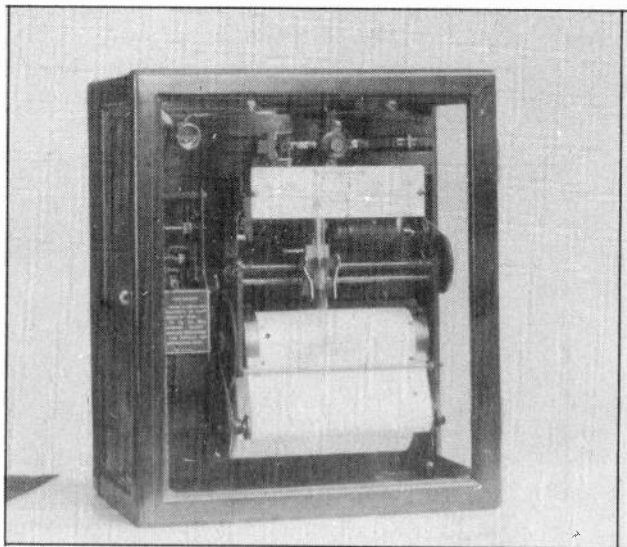


Fig. 9. This view shows the recording instrument which was shown in Fig. 8, with the paper chart in place. The glass ink cup and pen can be dimly attached to the lower part of the pointer.

balance coils to open the relay contacts and stop the motor; so the pen will remain in this position until another change of the voltage or current occurs.

The "clock" mechanism which drives the paper chart in this type of instrument is electrically wound and therefore does not require frequent attention.

Fig. 9 shows a recording instrument of this type, with the chart roll in place. This paper chart is continuous throughout the roll. So, as the roll travels and the pen moves sidewise across it, a continuous record of the voltage or power is kept. When the end of one roll is reached, a new one can be inserted.

Fig. 10 shows the connections for a recording meter of the type just described. Terminals 1 and

## Direct Current

2 are for the motor circuit, and 3 and 4 are for the control circuit.

### 13. LOAD DEMAND INDICATORS

Power and lighting loads which are of a steady or constant nature and do not vary greatly throughout the day are most desirable to power companies. Loads which have high "peaks" in proportion to the average hourly load, require the operation and maintenance of generating equipment which is sufficient for these peak periods, and may be either idle or lightly loaded at other periods. This tends to reduce the operating efficiency and economy in the power plant, and power companies will often give a customer lower rates per KW hr, on his power if his peak load is not over a certain percentage higher than his average load.

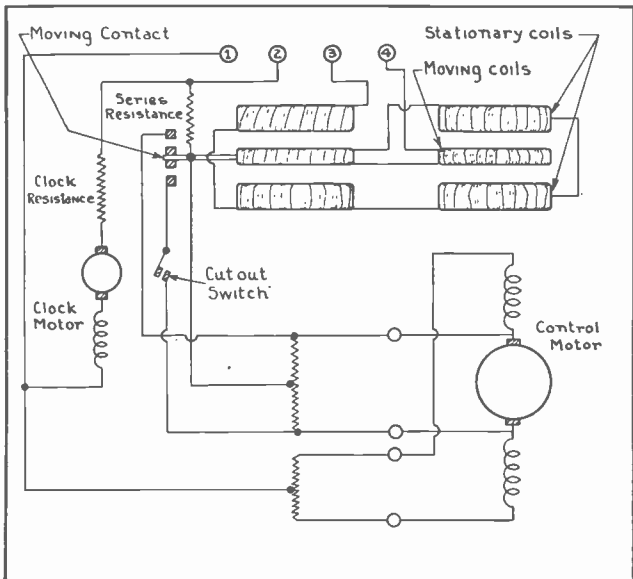


Fig. 10. This diagram shows the coils and winding of a recording meter such as shown in Figs. 8 and 9

To determine the maximum load, or peak, for any period during the day or week, **Maximum Demand Indicators** are used. They are sometimes called "max. meters".

## Demand Indicators

One type of demand indicator is the Wright maximum ampere-demand indicator, which operates on the thermal or heat expansion principle.

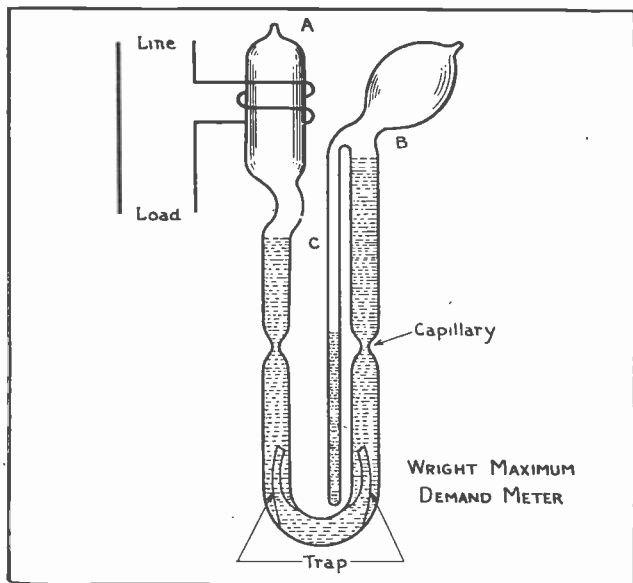


Fig. 11. This sketch illustrates the principle of a common type maximum demand meter which operates by expansion of the air in the bulb "A", when current is passed through the coil around this bulb.

This instrument consists of a specially shaped sealed glass tube, as shown in Fig. 11. In this tube is sealed a certain amount of colored liquid, usually sulphuric acid, and a certain amount of air.

A resistance coil of platinoid metal is wound around the bulb as shown at "A" in the figure. This coil is connected in series with the line and load, or in parallel with an ammeter shunt. When current passes through the coil it causes it to become slightly heated and this heat expands the air in the bulb "A".

This expansion increases the air pressure and forces more of the liquid over into the right-hand part of the tube. If the liquid is forced high enough in this tube, some of it will run over into the small Index Tube, "C".



## Direct Current

As the heat developed in the resistance coil is proportional to the square of the current passing through it, the index tube "C" can be graduated or equipped with a graduated scale behind it; so the maximum current in amperes can be read from the height of the liquid in this tube.

A momentary increase in load will not register on an indicator of this type, because it requires a little time for the heat in the coil to expand the air inside the tube. This is a desirable feature, as it usually is not desired to measure peak loads that last only an instant.

A load increase which lasts for 30 minutes will register the full amount, or 100%, of the increase.

After a reading, this type of instrument can be reset by tilting the tube and allowing the liquid to flow back into tube "B".

Small, inverted, glass funnels are fastened inside the bottom of each side of the tube, to prevent the passage of air from one side of the tube to the other. These are called traps. When the tube is tilted to reset the indicator, these traps remain covered with liquid and prevent air from passing through.

Recording wattmeters or ammeters also serve as maximum-demand meters, as they show all load variations.

Another type of maximum-demand meter uses a combination of a wattmeter element and pointer and a watthour meter time element, to allow the watt-meter pointer to register only over certain time periods.

Some demand meters use a thermostatic strip to move the pointer as the strip is expanded and warped by the heat of the load current.

### 14. WHEATSTONE BRIDGE

This instrument is a very convenient device for measuring the resistance of electric circuits or devices, by comparison with standard resistances of known value.

## Wheatstone Bridge

You have already learned that electric current will tend to follow the path of lowest resistance, and will divide through parallel paths in inverse proportion to their resistance.

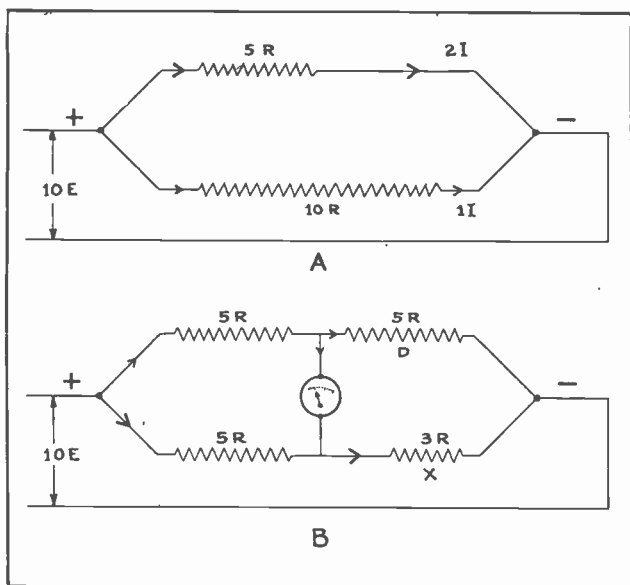


Fig. 13. The sketch at "A" shows the manner in which current will divide in inverse proportion to the resistance of two parallel circuits. At "B" is shown the manner in which current will flow through a galvanometer placed between four resistances, one of which is of a different value than the rest.

For example, suppose we have one resistance coil of 5 ohms and one of 10 ohms connected in parallel, as shown in Fig. 13-A. If we apply 10 volts to the end terminals, 2 amperes will flow through the 5-ohm coil and 1 ampere through the 10-ohm coil.

Now let us connect a group of four coils as shown in Fig. 13-B. Here we have two coils of 5 ohms each in series on one path, and a 5-ohm coil and a 3-ohm coil in series on the other path.

If we now connect a sensitive galvanometer across the center of the paths between the coils, as shown, it will indicate a flow of current from the

## Direct Current

upper path to the lower when voltage is applied to the terminals of the group.

Tracing from the positive terminal to the center of the group, the resistance of each path is equal, but from this point on to the negative terminal the lower path or coil "X" has the lowest resistance. For this reason, some of the current tends to flow down through the galvanometer wire to the lower coil or easier path.

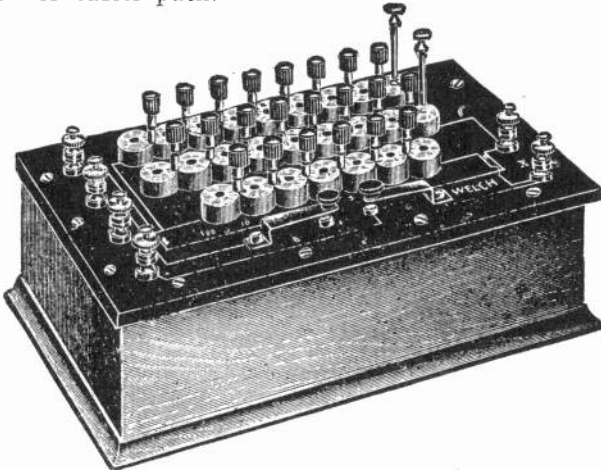


Fig. 14. Resistance box of a common Wheatstone bridge. Note the plugs which are used for varying the amount of resistance in the circuit.

If we changed the coil "D" to one of 3 ohms, both sides of the circuit would again be balanced and no current would flow through the galvanometer.

On this same principle, if the resistance of coil "X" is not known, we can determine it by varying the resistance of coil "D" in known amounts until the galvanometer indicates zero, or a balanced circuit. We would then know that the resistance of coil "X" is equal to whatever amount of resistance we have in coil "D" to secure the balance.

### 15. OPERATION AND CIRCUIT OF WHEATSTONE BRIDGE

The Wheatstone Bridge operates on the same

## Wheatstone Bridge

general principle first described. It consist of a box of resistance coils with convenient plugs for cutting coils of various resistance in and out of the balancing circuits. Fig. 14 shows the resistance box of a bridge of this type.

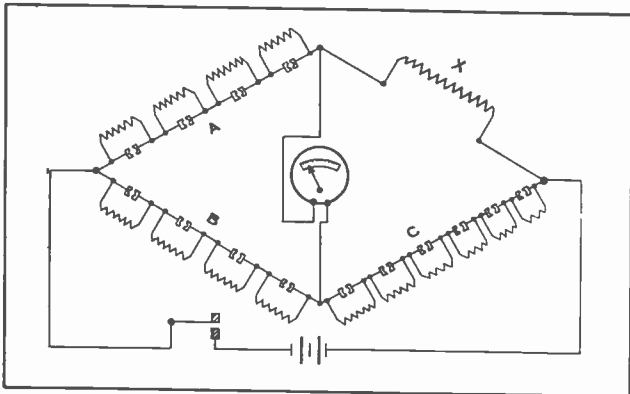


Fig. 15. This diagram shows the connections and principle of a Wheatstone bridge or resistance balancer. Note how the split metal sockets can be used to short out various resistance coils when a metal plug is inserted in these sockets. Study this diagram carefully while referring to the explanations on these pages.

Some bridges have knobs and dial switches instead of plugs for switching the resistance units; and some have the galvanometer built in the top of the box, and the dry cells inside.

Fig. 15 shows a diagram of a common type of bridge and the methods by which the coils can be left in the various circuits or shorted out by inserting metal plugs in the round holes between metal blocks, attached to the ends of each resistance-coil.

The coil or line of which the resistance is to be measured is connected at X. The circuits A, B, and C are called **Bridge Arms**. A and B are called **Ratio Arms**, or **balance arms**; and C is called the **Rheostat Arm**.

Arms A and B usually have the same number of resistor units of similar values in ohms. Arm C has a number of resistors of different values.

When the unknown resistance, X, has been connected in and the bridge arms so balanced that the galvanometer shows no reading when the button

## Direct Current

is pressed, the resistance of X in ohms can be determined by the use of the following formula:

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

In which:

- X = resistance in ohms of device under test.
- A = known resistance in ratio arm A.
- B = known resistance in ratio arm B.
- C = known resistance in rheostat arm C.



Fig. 16. The above photo shows a "Megger", or device used for measuring the resistance of insulation and high resistance circuits. This instrument contains its own D. C. generator as well as meter element.

The Wheatstone bridge is a very convenient device for testing the resistance of coils or windings of electrical equipment; of lines, cables and circuits; and of the insulation on various wires or devices.

There are a number of types of bridges for resistance measurement, most of which are supplied

## Meggers

with a connection chart and instructions for operation. So, with a knowledge of their general principles as covered here, you should be able to use and operate any ordinary bridge.

### 16. "MEGGER"

Another testing instrument frequently used by the practical electrician for testing the resistance of insulation on electrical machinery is known as a **Megger**. This name comes from the fact that this instrument is commonly used to measure resistances of millions of ohms; and a million ohms is called one meg-ohm.

The megger consists of a small hand-operated D.C. generator and one or more meter elements, mounted in a portable box, as shown in Fig. 16. When the crank is turned, the D.C. generator will produce from 100 to 1000 volts D.C., according to the speed at which the generator is rotated and the number of turns in its winding.

Normal operating voltage is usually from 300 to 500 volts, and is marked on the meter scale.

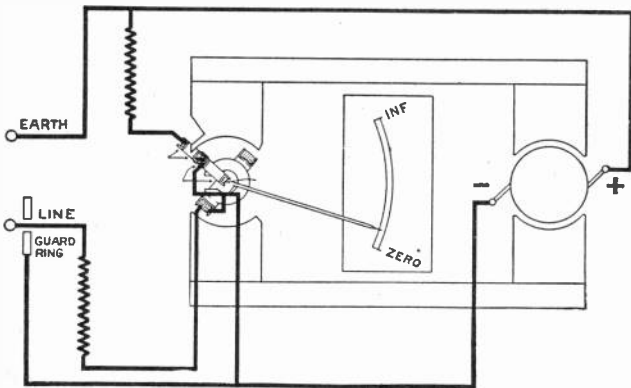


Fig. 17. Simple circuit showing the connection and principles of a "Megger". Note the arrangement of the D. C. generator armature and meter element at opposite ends of the magnet poles and the connections of this device to the line or that test terminals.

of these instruments have a voltmeter to show the generator voltage, and an ohm-meter to indicate the insulation resistance of the device under test.

## Direct Current

The terminals of the instrument can be connected to one terminal of a machine winding and to the machine frame. Then, when the crank is rotated the insulation resistance in meg-ohms can be read directly from the scale.

Fig. 17 shows the internal connections of a megger and the terminals for connections to the equipment to be tested. As the insulation of electrical machines or lines become aged, or in some cases where it has been oil or water-soaked, its resistance in ohms is considerably reduced. Therefore, the resistance test with the megger is a good indication of the condition or quality of the insulation.

Periodic megger tests of electrical equipment and records of the insulation resistance will often show up approaching trouble before the insulation breaks down completely and burns out the equipment.

Either the Wheatsone bridge or the megger can be used to determine the approximate location of grounds or faults in cables and long lines, by measuring the resistance from the end of the line to the fault, through the cable and its sheath or the earth. Then, by comparing this resistance with the known resistance total of the line or with its resistance per foot or per 1000 ft., the distance to the fault can easily be calculated.

### 17. METERS ESSENTIAL IN ELECTRICAL WORK

A number of simple and practical tests of resistance can also be made with voltmeters and ammeters, and the use of ohms law formulas. By applying voltage of a known value to any device and accurately measuring the current flow set up by this voltage, we can readily calculate the resistance of the circuit or device by the simple formula:

$$R = \frac{E}{I}$$

While on the subject of meters, it will be well to mention that very sensitive relays are often made

## Meggers

from regular meter elements, using a short armature or moving contact in place of the regular pointer or needle. Fig. 18 shows a relay of this type. In this figure you can see the short contact needle attached to the moving coil, and the adjustable contacts on each side of this needle.

By proper adjustment of the contacts of relays of this type, they can be made to close or open circuits when the voltage or current values rise above or fall below any certain values.

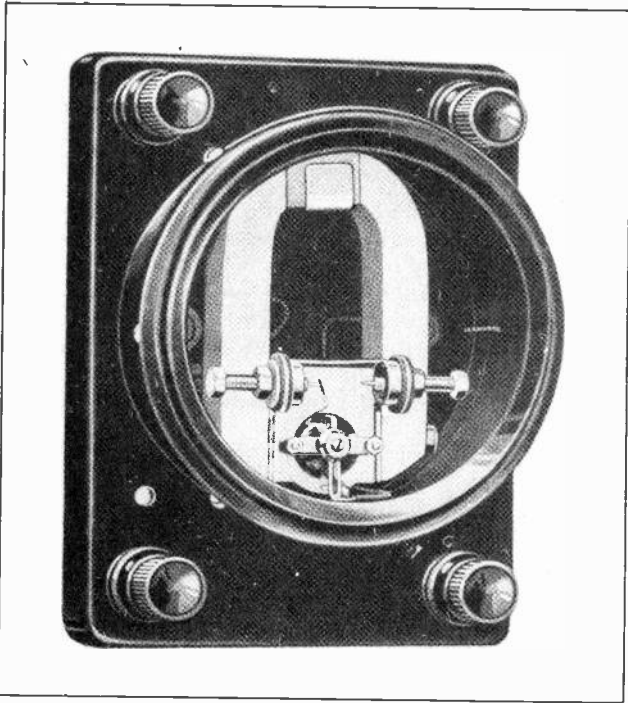


Fig. 18. Very sensitive relays such as shown above are commonly made with the same principle elements used in voltmeters or ammeters. Relays of this type can be used to open or close various circuits at any set voltage or current values.

Keep well in mind the importance of ordinary electric meters in the work of any practical, up-to-date electrician, and remember that great savings



## Direct Current

in power or equipment can often be made by the proper use of electrical meters and instruments.

For testing the efficiency of machines, checking operations in power plants, inspection of electrical equipment, and for trouble shooting and fault location, electrical meters of the proper types are of enormous value.

The trained practical man should never overlook an opportunity to effect a saving or improve operation by the selection and use of the proper meters.

## Meggers

### EXAMINATION QUESTIONS

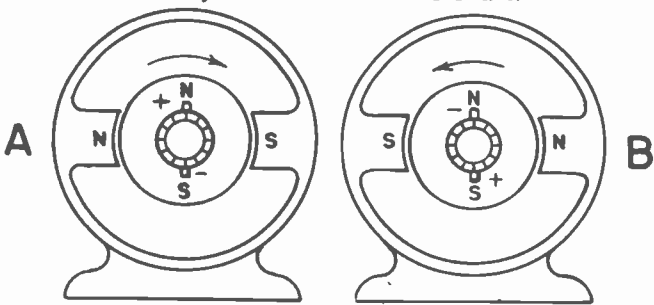
1. For what purpose are watthour meters used?
2. What method is used to prevent the Watt-meter motor armature from overspeeding?
3. Name two troubles which may cause "creeping" in a Watthour meter.
4. Give the formula for use in testing a kilowatt-hour meter with a known load.
5. How many seconds would be required for the disk on a watt-hour meter with a constant of .6 to make 10 revolutions with a connected load of 300 watts?
6. For what purpose are recording instruments used?
7. Name two types of recording instruments.
8. a. On what principle does the Wright maximum demand meter operate?  
b. How much time is required before this meter will record 100% of the increase in load?
9. For what purpose is the wheatstone bridge used?
10. What would be the resistance at X as shown by Fig. 15 when the resistance A is 10 R, B 15 R, and C 6 R, and the galvanometer reading is zero?

## Direct Current

### DIRECT CURRENT MOTORS

An electric motor, as you have already learned, is a device for converting electrical energy into mechanical energy, or to perform just the opposite function to that of a generator. Motors supply mechanical energy to drive various machines and equipment by means of belts, gears, and direct shaft connections.

When electricity from the line is supplied to terminals of the motor, it develops mechanical force which tends to rotate its armature and any equipment which may be attached to its shaft.



#### OPERATION

The D.C. motor operates on the first law of magnetism which states that **like poles repel** and **unlike poles attract**. Current flowing through the field coils produces the field poles, and current through the armature coils develops armature poles midway between the field poles. Attraction and repulsion between these two sets of poles produces rotation.

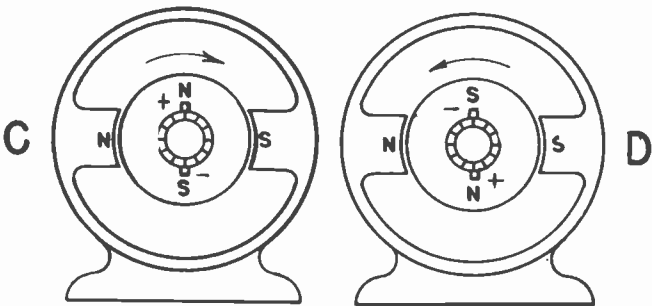
In order that the attractive and repulsive forces between the armature poles and the field poles be maintained, the armature poles must remain **stationary in space**. This condition is made possible by the action of the commutator and brushes for, as the armature moves forward a different set of commutator segments come under the brushes and current is consequently fed to the armature at the same point in space at all times; therefore, the armature poles remain stationary in space even though the armature itself rotates.

It is this magnetic action between the armature

## Motors

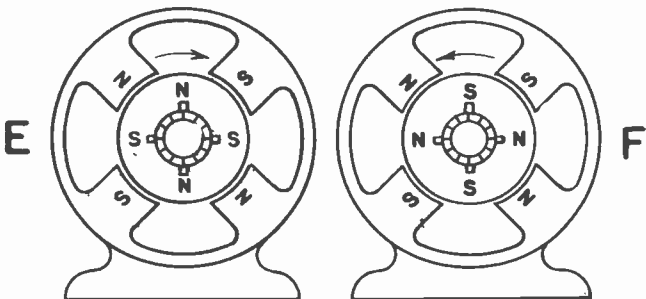
poles and the field poles that develops the twisting force at the motor shaft that enables it to revolve the loads mechanically connected to it. This twisting effort is called **torque**. A motor capable of exerting a relatively high twisting effort per ampere when it is starting is said to have a relatively high starting torque; one that generates a low twisting effort per ampere when starting is said to have a relatively low starting torque.

The torque per ampere that any given motor will develop depends upon the type of motor: series, shunt, or compound, and how well the machine is designed. In general, the starting torque per ampere will be greatest for the series motor, somewhat less for the compound motor, and least of all for the shunt motor.



### ROTATION

By reversing the direction of current flow through the fields or through the armature, the field poles or the armature poles will be reversed, and the direction of rotation changed. Compare A with B and C with D.



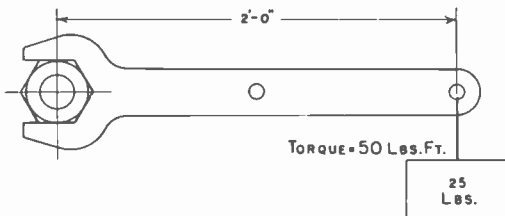
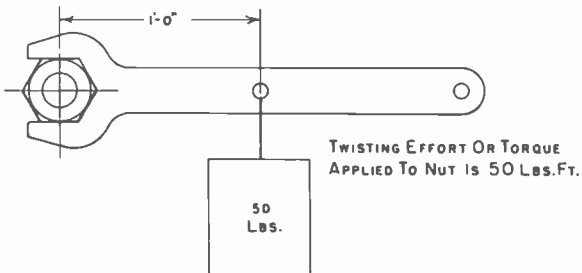
## Direct Current

### ARMATURE POLES

Diagrams E and F show a 4 pole motor. Note that the number of armature poles always equals the number of field poles, and that the armature poles are located midway between the field poles. From the above it is obvious that a 2 pole armature will not work in a 4 pole field. Note also that when the direction of armature current flow is reversed, all poles are reversed.

### TORQUE

As previously stated, torque is defined as twisting effort. When a mechanic places a wrench on a nut and pulls, he applies torque to the nut, and the amount of torque applied will depend upon the length of the wrench and the magnitude of the pull employed. If the wrench is one foot long and the pull applied 50 pounds, then the torque applied to the nut is 50 pounds-feet. If the nut does not turn



under these conditions, more torque is necessary. The mechanic may increase the torque applied either by pulling harder on the foot-long wrench, or by using the same pull on a longer wrench. In the

## Motor Speeds

first case he is increasing the force used on the wrench; in the second case he is increasing the leverage with the same force; in either case, the net result would be an increase in the torque on the nut. It should be noted here that applying torque to a movable body (the nut in this instance) does not necessarily mean that the body will move. Motion will take place only if the torque applied to produce motion is greater than the resisting torque which opposes the motion. In the case of the nut, the resisting torque is practically all due to friction, and motion will not take place until the applied torque is great enough to overcome this frictional opposition.

From the above it is evident that the twisting effort applied to any body depends upon two things; the force applied to the lever; and the length of the lever used. The handle on a grindstone, for example, represents a lever. If this handle is one foot distant from the shaft of the grindstone, then this arrangement is equivalent to a lever one foot long. Assuming a force of 20 pounds be applied to this handle, then a torque of 20 pounds times one foot or 20 pounds-feet is tending to rotate the grindstone. If the force applied to the handle is raised, the applied torque will increase in proportion. Therefore it is seen that torque is proportional to the product of the applied force (in pounds) and the length of the lever (in feet). Consequently, torque is found by merely multiplying these two values together and expressing the result in pounds-feet. For example, if a motor, equipped with a pulley 2 feet in diameter is found to exert a pull at the surface of the pulley of 100 pounds then the torque developed equals  $100 \times 1$  or 100 pounds-feet. It will be noted that a pulley 2 feet in diameter has its surface or rim only one foot from the shaft; consequently the leverage is only one foot and the torque 100 pounds-feet.

From the above it is evident that the revolving of any rotatable body requires application of a twisting effort or driving torque. In the case of the D.C. motor this torque is produced by the magnetic action between armature poles and the field poles.

## Direct Current

If the armature is 2 feet in diameter and the magnetic force applied at the armature surface is 30 pounds, then the torque that the shaft of the motor could exert would be  $30 \times 1$  or 30 pounds-feet. In this way the magnetic attraction and repulsion between the armature poles and the field poles is converted in mechanical torque at the motor shaft.

For a rotatable body, such as the armature of a motor, to be put into motion, it is essential that the magnetic driving torque developed by it be greater than the mechanical resisting torque applied to the shaft. Once the armature is in motion it will accelerate until the driving torque and the resisting torque becomes equal; when this condition is established, the speed will become constant.

If the driving torque is assumed to be constant and the resisting torque increases, the motor speed will decrease steadily until it stops. If the resisting torque is less than the driving torque, the motor will continue to accelerate until the driving torques and resisting torques become equal. If the operating conditions are such that the resisting torque can never equal the driving torque, the motor will accelerate to destruction.

It will later be shown that the electric motor tends to be self regulating with regard to the adjustment of the driving torque to the resisting torque. Whenever the resisting torque resulting from the motor load changes, a change in the motor speed will occur, and this change in speed will be in a direction that will cause the driving torque and the resisting torque to become equal again.

When considering the action of a given type of motor under varying load conditions, application of the above information concerning the action of rotating bodies represents the logical starting point. If the relation between the resisting and the driving torque is understood, the effect of a change in load on motor speed can readily be determined.

### 1. TYPES OF D.C. MOTORS

Direct current motors can be divided into three general classes, the same as D.C. generators were, namely, **Shunt**, **Series**, and **Compound** motors. These motors are classified according to their field

## Motor Type

connections with respect to the armature, in the same manner in which the generators were classified.

Compound motors can be connected either cumulative or differential. With generators we find that the shunt, series, and compound types each have different voltage characteristics. With motors, the effect of these different field connections is to produce different speed and torque characteristics.

Motors are made with various types of frames, known as **Open Type**, **Semi-enclosed**, and **Closed Type** frames.

Fig. 1 shows a modern D.C. motor with an open type frame. A frame of this type allows easy access to the commutator, brushes and parts, for adjustment, cleaning and repairs; and also allows good ventilation. Open type motors are generally used

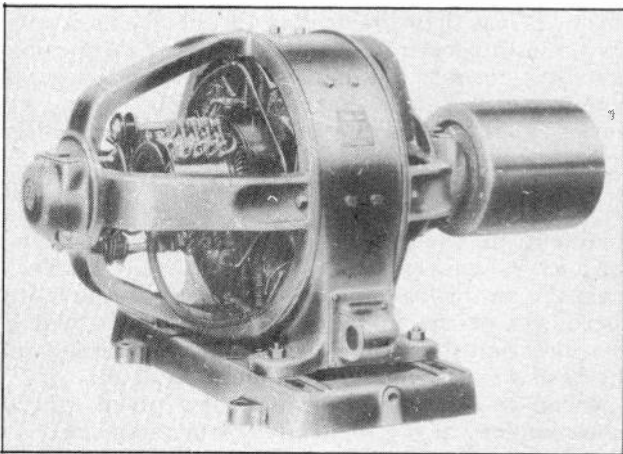


Fig. 1. This photo shows a modern D.C. motor with an open type frame. Note the easy access a frame of this construction provides to the commutator, brushes, and field coils.

where they are to be operated in clean places, and where there is no danger of employees coming in contact with their live parts; and no danger of fire or explosions which might be caused by sparks at the brushes.

Fig. 3 shows a motor with a completely enclosed frame. Motors of this type are often built larger



## Direct Current

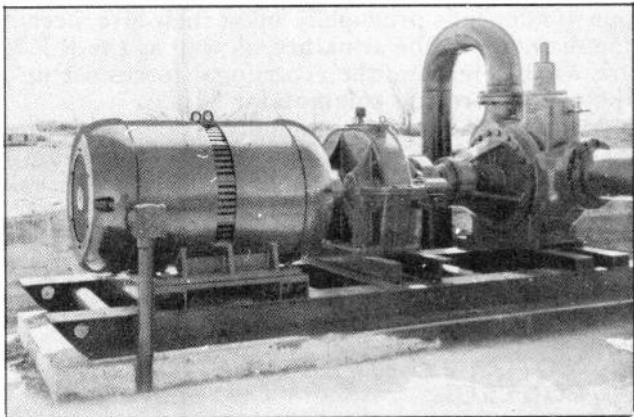
and wound with larger wire, so they do not develop as much heat. In some cases they are practically air-tight, and have ventilating tubes attached to their casings to bring cooling air from another room.

Motors with enclosed frames of this type can be used in places where the air is filled with dust and dirt, or possibly vapors or explosive gases.

Enclosed frame motors should always be used where abrasive dust or metal dust is present in the air, or in mills where wood or grain dust might be exploded by any possible sparks from brushes.

### 2. MOTOR SPEEDS AND H.P.

D.C. motors are always rated in horse power and range in size from those of a small fraction of one horse power to those of several thousand horse power each. The smaller motors are used for driving household appliances, laboratory equipment, and small individual shop machines, such as drill presses, small lathes, etc. Medium-sized motors, ranging from one horse power to several hundred horse power each, are used for driving machinery in factories and industrial plants, for street railways and electrical locomotives, and for elevator ma-



This pump unit is used to load gasoline on ships. The Louis Allis Company of Milwaukee pioneered and developed the first types of fan cooled explosion proof motors.

chinery. The larger types, ranging from several hundred to several thousand horse power each, are used principally in steel mills and on electrically-driven ships.

## Motor Speed

The horsepower ratings of motors refer to the maximum continuous output they can deliver without overheating.

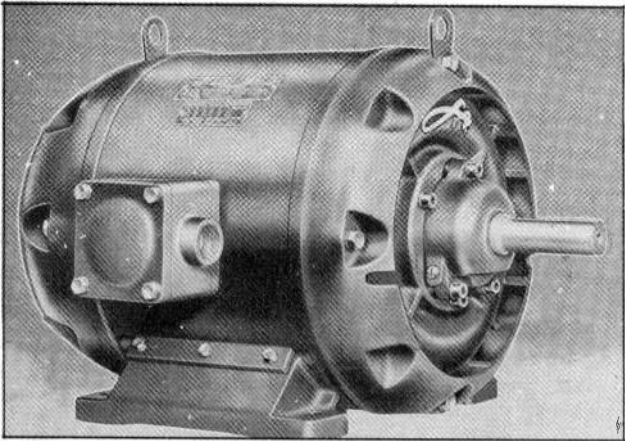


Fig. 3. The above motor has a frame of the enclosed type. Motors of this type are particularly well suited for operation in places where the air is full of dust or vapor.

The speed at which D.C. motors are designed to operate depends principally upon their size, because the diameter of the armature, as well as the R.P.M., are what determine the centrifugal forces set up in the conductors and commutator bars.

Very small motors commonly have speeds from 2000 to 4000 R. P. M., while motors of medium or average size, ranging from 1 to 25 H.P., usually rotate at speeds from 1000 to 2000 R. P. M.

Very large motors operate at much lower speeds, generally ranging from 100 to 500 R. P. M.; although some large steel-mill motors have speeds as low as 40 R. P. M.

### 3. MOTOR SPEED REGULATION AND CONTROL

In referring to the characteristics and operation of electric motors, we frequently use the terms **Speed Regulation** and **Speed Control**. These terms have entirely separate meanings, and their difference is very important.

**Speed Regulation** refers to changes in speed

## Direct Current

which are automatically made by the motor itself, as the load on the machine is varied. Speed regulation is largely determined by the construction of the motor and its windings and is a very important factor in the selection of motors for different classes of work. The speed regulation of a motor is usually expressed in percentage and refers to the difference in the speed of the machine at no load and full load. It can be determined by the following formula:

$$\text{Speed regulation} = \frac{\text{No load R. P. M.} - \text{full load R. P. M.}}{\text{Full load R. P. M.}}$$

For example, if we have a motor that operates at 1800 R. P. M. when no load is connected to it and slows down to 1720 R. P. M. when it is fully loaded, its speed regulation would be:

$$\frac{1800 - 1720}{1720}, \text{ or } .046 +$$

This would be expressed as 4.6%.

Motor speed regulation is entirely automatic and is performed by the motor itself, as the load varies.

The term **Speed Control** refers to changes which are made in the motor speed by the use of manual or automatic control devices. These speed control devices are usually external to the motor and consist of some form of variable resistance. They will be fully explained in the following pages.

#### 4. MOTOR RATINGS IN VOLTS AMPERES, AND H.P.

The rating of a D.C. motor in horse power, amperes, and volts depends on the same factors in their design as the rating of generators does. The motor ratings in horse power are also based on the same factor of the temperature increase in their windings when operated at full rated load.

For example, a 10 H.P. motor is one that when supplied with the proper voltage for which it is designed will drive a 10 H.P. mechanical load continuously without overheating its windings. The current required by a motor is, of course, proportional to the mechanical load in H.P. which it is driving:

## Motor Torque

In addition to carrying the load without heating the windings, the motor must also be able to carry its full load current without excessive heating or sparking at the brushes and commutator.

Motors are generally designed to carry overloads of a greater amount and for longer periods of time than generators are. Most D.C. motors can carry a 25% overload for a period of two hours, without serious overheating.

We have already learned that D.C. motors are similar to D.C. generators in all details of their mechanical construction. In fact, manufacturers frequently use the same D.C. machines either as motors or generators, by merely changing the name plates on them and making a few minor changes in the connections of the field windings and setting of the brushes.

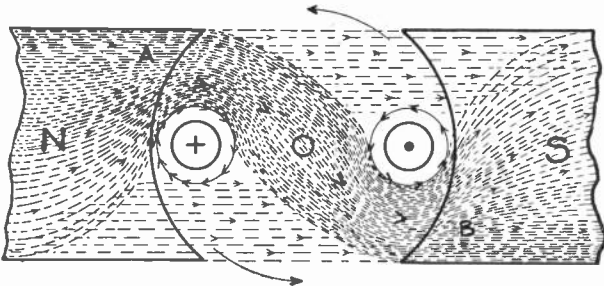


Fig. 4. The above diagram illustrates the manner in which the reaction between the lines of force from the armature and field windings set up the torque or turning effort in a motor.

## 6. MOTOR TORQUE, SPEED AND H.P.

The torque exerted by such a motor will, of course, depend on the strength of the magnetic flux from the field poles and the strength of the armature flux. Therefore, the torque exerted by a motor can be increased by increasing either the field strength or the armature current, or both.

The horse power or mechanical power output of a D.C. motor is proportional to the product of its torque and speed. The higher the speed at which a motor is operated while maintaining the same amount of torque, the greater will be its horse power.

## Direct Current

D.C. motors rated at higher speeds will produce the same horse power with smaller frames and armatures. The cost of high speed motors is therefore much less per H.P. A motor frame that is rated a 5 H.P. at 900 R. P. M. will deliver 10 H.P. at 1800 R.P.M.

### 7. DIRECTION OF MOTOR ROTATION

The direction of rotation of a D.C. motor can be easily determined by the use of Fleming's left-hand rule. This rule is similar to the right-hand rule which we have learned to use for generators.

Hold the first finger, thumb, and remaining fingers of the left hand all at right angles to each other. Let the first finger point in the direction of flux from the field poles, the remaining fingers in the direction of current through the armature conductors, and the thumb will then indicate the direction of rotation of the armature.

This rule can be quickly and easily applied to diagrams such as shown in Fig. 4 and can also be used on the actual machines, when the armature conductors and connections to the commutator can be seen and the polarity of the field poles is known.

The direction of rotation can also be easily determined with diagrams such as shown in Fig. 4, by simply remembering that the repelling or crowding force on the armature conductor will be on the side where its flux lines join with those of the field flux.

From this study of the direction of rotation of motors, you can see that any D.C. motor can be reversed either by reversing the direction of current through the armature winding or by reversing the field connections to change the polarity of the field poles. Refer to Fig. 4, and using the left-hand rule, note the direction in which these conductors would rotate if their current were reversed or the poles of the motor were reversed.

### 8. COUNTER-E. M. F. IN MOTORS

You have already learned that a voltage will be induced or generated in the armature conductors of a motor whenever the machine is running, and that

## Counter-E. M. F.

this voltage is called **Counter-E. M. F.** As the armature of the motor rotates, its conductors will be going through the field flux and so will produce counter-voltage in the same direction as that of the voltage of a generator rotated in the same direction as the motor. Therefore, this counter-E. M. F. induced in a motor is always in a direction opposing the applied line voltage, but of course is normally not quite as great as the applied voltage.

The amount of counter-voltage which will be generated depends upon the number of conductors in the armature, the strength of the motor field, and the speed at which the machine is operated.

Keep this rule well in mind, because the effects of counter-voltage are extremely important in the operation of D.C. motors and control equipment.

In Fig. 5, the direction of the current and voltage applied to the armature conductors from the line is shown by the solid black symbols in the two armature conductors, and the direction of the counter-voltage generated in these conductors with the polarity and rotation shown, is indicated by the lighter symbols above the conductors.

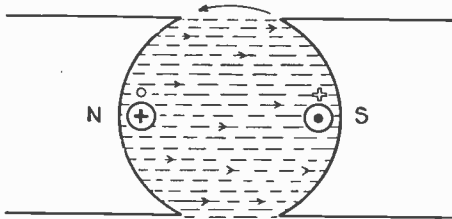


Fig. 5. The above sketch illustrates the manner in which the counter-voltage is generated in the opposite direction to the applied voltage in a motor armature.

As the counter-voltage is generated in the opposite direction to the applied line voltage, we can readily see how it limits or regulates the current which will flow through the armature and thereby acts to control the motor speed.

The voltage applied to a D.C. motor armature must always be equal to the voltage drop in the winding plus the C. E. M. F., or

$$E_a = R_a I_a + C E_a$$

in which

$$E_a = \text{Applied voltage}$$

## Direct Current

$R_a$  = Resistance of armature

$I_a$  = Current in armature

$CE_a$  = Counter voltage of armature

Then, for example, the applied voltage of a certain 110-volt motor might be used as follows:

	Ex.	$R_a$	$I_a$	$CE_a$
No load:	110 =		1	+ 109
Full load:	110 =		5	+ 105

### 9. ARMATURE RESISTANCE NECESSARY WHEN STARTING D.C. MOTORS

When the motor armature is idle or at rest no counter-voltage is produced, and the current which would then flow through the armature would be determined entirely by its resistance and the voltage applied; according to the formula:

$$I = E \div R.$$

The resistance of D.C. motor armatures is very low, usually less than one ohm. Therefore, excessive currents would flow through them if we were to apply the full line voltage to start the machine.

For this reason, when starting D.C. motors of any but the very smallest sizes, it is necessary to place some resistance in series with the armature to limit the current until the machine comes up to speed. As the motor increases its speed the counter-voltage becomes higher and higher, until it limits the current to such an extent that the motor speed cannot further increase. At this point the difference between the counter-voltage and the line-voltage may be only a few volts, even on motors of quite high voltage.

The voltage effective in forcing current through the armature of a motor when it is running will be just that amount of the line voltage which is not neutralized by counter-voltage. In other words, the value of the voltage used to force current through the armature winding will be line voltage minus counter-voltage. This is illustrated in Fig. 6, which shows the amount of the applied voltage which is neutralized by the counter-voltage developed in the armature. For this illustration we have used even and convenient figures, but in actual operation of a

## Counter-E. M. F.

motor running without load the counter-voltage would be almost equal to the line voltage.

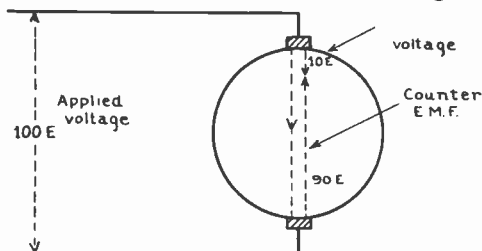


Fig. 6. From the above illustration you will note that the counter-voltage is often nearly as high as the applied voltage. This sketch illustrates the extent to which counter-voltage regulates or limits the current flow through a motor armature.

If we assume the resistance of the armature in this figure to be .2 of an ohm, the current which would flow through its winding if full line voltage were applied would be  $100 \div .2$ , or 500 amperes. That is, of course, provided that no external resistance were used in series with the armature.

If this same armature develops 90 volts C.E.M.F. when rotating at full speed under full load conditions, the difference between the applied voltage and the counter-voltage would be  $100 - 90$  or 10 volts. This 10 volts would be available for forcing current through the armature. So, when running at this speed, the armature current would be  $10 \div .2$ , or 50 amperes. From this example you can see what a great effect counter-voltage has upon the current flow in a motor armature.

### 10. EFFECT OF COUNTER-VOLTAGE ON MOTOR SPEED

The current required to operate a D.C. motor when no load is connected to it is comparatively small. Let us say that the armature shown in Fig. 4 requires 50 amperes to operate it at full load, and only 5 amperes to operate it when the load is disconnected. As the resistance of the armature is only .2 of an ohm, the net voltage applied to run the machine at full speed and at no load would be  $.2 \times 5$ , or 1 volt. So the counter-E. M. F. during the time this motor is running idle should be  $100 - 1$ , or 99 volts.

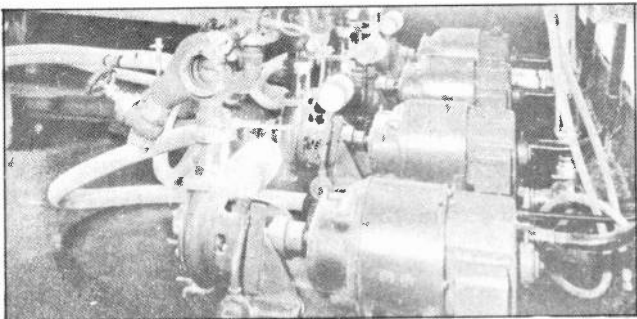


## Direct Current

When the mechanical load is removed from a motor, its armature tends to speed up because the driving torque is then considerably greater than the resisting torque and, as previously indicated, this state of affairs results in acceleration. However, as the armature speed increases, the C.E.M.F. rises; this results in diminishing the current through the armature and decreasing the driving torque. These actions continue until the two torques become equal again. The increase in speed required to bring about this equality will depend upon the speed regulation of the motor in question, and the magnitude of the change in the resisting torque.

### 11. D.C. MOTOR CHARACTERISTICS

In selecting D.C. motors for any particular work or application we must, of course, use a machine of the proper horse-power rating to start and carry the load the motor is intended to drive. In addition to the **Horse Power Rating** of the motor, the other essential points to be considered are its **Starting Torque** and **Speed Regulation** characteristics. These characteristics vary widely for shunt, series, and compound motors, which will be thoroughly explained in the following paragraphs. Make a careful study of this section because it may often be of great advantage to you on a job to be able to select the proper motors for different applications.



A battery of DIRECT-CURRENT Splash-Proof Motors in a prominent midwestern brewery.

### 12. SHUNT MOTORS

The field winding of a shunt motor is connected directly across the line or source of current supply,

## Shunt Motors

in parallel with its armature. This shunt field winding is made up of many turns of small wire and has sufficient ohmic resistance to limit the current through the coils to the safe carrying capacity of the conductors they are wound with. As the resistance of the shunt field winding is practically constant, this current and the strength of the field it sets up will be determined by the line voltage which is applied to the motor.

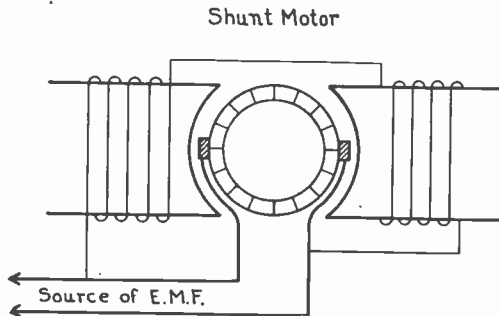


Fig. 7. Diagram of the connections for a simple shunt motor.

A simple diagram of the connections of the armature and field of a two-pole shunt motor is shown in Fig. 7.

### 13. STARTING TORQUE OF SHUNT MOTORS

The starting torque of shunt motors is only fair and they cannot start very heavy loads because their field strength remains approximately constant as long as the applied voltage is constant.

While a motor is starting the armature flux is very dense, because of the heavier currents flowing through the armature at this time.

This increased armature flux of course increases the motor torque, but it also weakens the field by distorting it and forcing it to take a path of higher reluctance; so shunt motors cannot build up as good starting torque as series or compound machines do.

As the torque of the motor depends upon its field strength as well as upon the armature current, we can see that the starting torque of a shunt motor will not be very good.

## Direct Current

### 14. STALLING TORQUE OF SHUNT MOTORS

If a shunt motor is overloaded to too great an extent it will slow down and possibly be stopped entirely if the overload is great enough. A motor

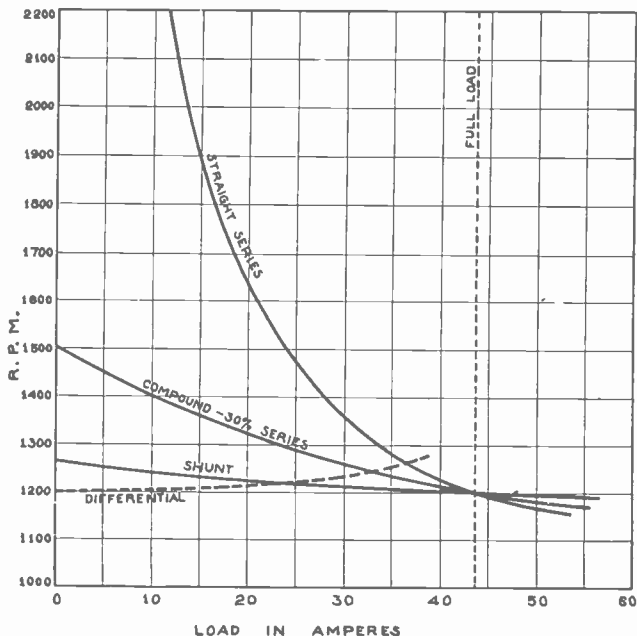


Fig. 8. The above diagram shows the characteristic speed curves for several types of D.C. motors. Note carefully the manner in which the speed varies with increase of load.

should never be allowed to remain connected to the line when in this stalled condition, or its windings will be burned out. This is due to the fact that when the armature is stopped it is generating no counter-voltage, and the applied line voltage will send a severe overload of current through the low resistance armature. Fuses or circuit breakers should be provided to open the line circuit to the motor in a case of this kind.

The ability of a motor to carry overload without stalling is often referred to as the **Stalling Torque** of the motor.

Shunt motors will carry their full, rated load but should not be overloaded to any great extent, as their stalling torque is not very high.

## Shunt Motors

### 15. SPEED REGULATION OF SHUNT MOTORS

The speed regulation of shunt motors is excellent, as the strength of their field remains practically constant, and as long as the proper line voltage is applied they will maintain practically constant speed under wide variations of the load.

The shunt motors will of course slow down a little when the load is increased; but, as soon as the armature speed is reduced even slightly, this reduces the counter-voltage generated and immediately allows more current to flow through the armature, thereby increasing the torque and maintaining approximately the same speed.

The speed of shunt motors ordinarily should not vary more than three to five per cent from no load to full load. Fig. 8 shows a set of curves which illustrate the speed regulation of series, shunt, and compound motors. Note that the speed of the shunt motor only falls off very gradually as the load is increased.

### 16. SPEED CONTROL AND APPLICATIONS OF SHUNT MOTORS

The speed of shunt motors can easily be varied or controlled by inserting a rheostat in series with their field. If the field is weakened, the motor speed will increase, because the reduced counter-voltage allows more current to flow through the armature. If the field is strengthened, the motor speed will decrease, because this stronger field allows the normal counter-voltage to be generated at lower speed.

The uses and applications of shunt motors are many and varied. They may be used on any job where more than full-load torque is not required for starting and where practically constant speed is essential. They are extensively used for pumps, elevators, motor-generator sets, and for the operation of lathes and various machines used in manufacturing appliances.

### 17. SERIES MOTORS

Series motors have their field coils connected in series with the armature and the line, as shown in

## Direct Current

Fig. 9. The windings for the fields of series motors are made of heavy copper wire or strap copper, and may consist of anywhere from a few dozen to a few hundred turns.

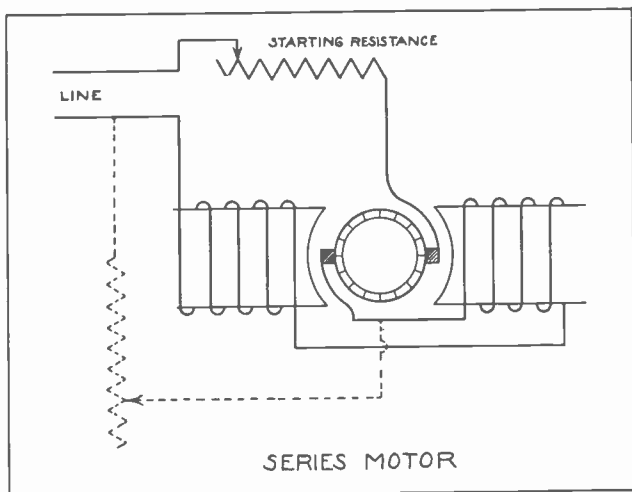


Fig. 9. Diagram of the connections for a simple series motor. The dotted lines show where a shunt can be connected in parallel with the field coils for varying the speed.

The strength of the field of the series motor depends upon the amount of current flowing through the armature and series field coils.

As the armature current depends upon the motor load and speed, the field strength of a series motor will be much greater at heavy loads and low speeds than at light loads and higher speeds, when the armature is developing a greater counter-E. M. F.

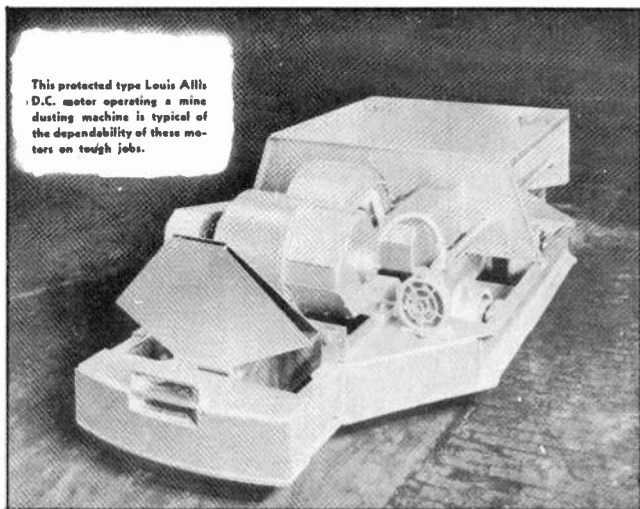
### 18. STARTING TORQUE

The armature current is usually at its greatest value when starting a motor because when the armature is idle or rotating at low speeds it doesn't generate much counter-E. M. F., and very heavy currents will flow through the armature until it comes up to speed. For this reason the starting torque of series motors is excellent.

The torque of motors of this type varies directly with the square of the armature current, because any increase of current through the armature also increases the field strength, as the two windings are in series.

## Series Motors

Series motors are capable of starting very heavy loads, and this makes them particularly adaptable for use on street cars and electric railways, and other special applications where the machinery to be driven is difficult to start.



### 19. STALLING TORQUE

Series motors also have excellent stalling torque, because, when they are overloaded, their speed is reduced and less counter-voltage will be generated in the armature. This allows more current to flow both through the armature and field coils, greatly increasing the flux around the armature conductors and from the field poles.

It is almost impossible to stall a series motor with any reasonable load, because the slower the speed becomes, the more current will flow through the armature and field of the motor, and the greater its torque becomes.

Of course, it is possible to burn out a series motor by overloading it in this manner, if the overload is left on it too long.

### 20. SPEED REGULATION

The speed regulation of series motors is very poor, because their speed varies inversely with the load applied. Any increase of load actually strength-

## Direct Current

ens the field flux of the series motor. This causes a higher counter-voltage to be generated and momentarily reduces the armature current, until the speed of the motor drops enough lower to bring the counter-voltage back to normal or less than normal, to allow the increased current flow required for the additional load.

If some of the load is removed from the series motor, this decreases the flow of current and weakens its field. The weaker field develops less counter-voltage and momentarily allows more current to flow, until the speed is increased enough to build the counter-voltage up again somewhat above normal value.

Thus, series motors will operate at very high speeds when the load is light and they will overspeed if the load is entirely disconnected. For this reason **series motors should never be operated without load**, or the speed will increase to a point where centrifugal force may throw the armature apart.

Series motors should always be attached to their load by gears or direct shaft connection, and never by belts, because if the belt should break or slip off the pulleys, the motor might dangerously overspeed before it could be stopped.

In Fig. 8, the speed curve for a series motor is shown, and you will note how rapidly the speed decreases with any increase of load.

There are certain applications for motors, however, where the decrease of speed with increase of load is very desirable.

### 21. SPEED CONTROL

The speed of a series motor can be controlled or varied at will by the use of resistance in series with the motor. Increasing this resistance will reduce the voltage applied to the armature and series field, thereby momentarily reducing the current flow and the torque, until the machine reduces its speed and counter-E. M. F., to a point where the counter-E. M. F., and effective voltage again balance the reduced applied voltage.

This is one of the methods used to vary the speed of electric street cars, by cutting resistance in or out

## Series Motors

of the motor circuit with the drum controller. When the resistance in series with the machine is varied the voltage across the armature is varied accordingly, and the armature slows down or speeds up correspondingly until the counter-E. M. F. and effective voltage again equal the applied voltage.

The speed of series motors can also be varied by connecting a shunt in parallel with their field coils, as shown by the dotted lines in Fig. 9. This shunt merely passes a certain amount of the armature current around the field winding, and thereby weakens the field strength and increases the speed of the motor. These shunts can not be used to decrease the motor speed below normal.



A modern motor room equipped with the latest type Louis Allis explosion proof motors and equipment.

## 22. USES OF SERIES MOTORS

The uses and applications of series motors are somewhat limited because of their wide variation in speed when the load is varied, and their tendency to overspeed when the load is removed. Series motors are not adapted to driving machinery or equipment which places a variable load on the motor and require practically constant speed.

Series motors are used principally for electric cranes, hoists, and railway service, and are well suited to this work because of their high torque de-



## Direct Current

veloped at low speeds. They are particularly well adapted to electrical traction work because of their splendid starting torque, which enables them to start heavy cars quickly and also climb hills with heavy loads. Their speed characteristic is also an advantage in this case, because it is possible to obtain high speeds with cars operated by this type of motor when the cars are running on the level or with light loads.

### 23. COMPOUND MOTORS

Compound D. C. motors have some of the characteristics of both the shunt and series motors, as they have both a shunt and series field winding on each pole. The shunt field of the ordinary machine is made up of many turns of small wire and is connected in parallel with the armature and line, as shown in Fig. 10. The strength of the shunt field flux will therefore be proportional to the applied line voltage and will be practically constant as long as this voltage is not varied.

The series field winding is usually made of very heavy copper wires or strap copper and may vary from a few turns to 100 turns or more per pole. This winding is connected in series with the armature, as shown in Fig. 10, and carries the full load current which passes through the armature.

The strength of the series field will therefore be proportional to the load applied to the motor. The shunt field, however, is the one that always determines the polarity of the machine under ordinary conditions and, therefore, it is called the main field winding.

Compound motors can be connected either cumulative or differential, by simply reversing the connections of their series field windings. The connections shown in Fig. 10 are for a cumulative compound motor, and most D.C. motors are understood to be connected in this manner, unless they are marked or designated as differential-compound.

With the series field connected for cumulative-compound operation, the current flows through these coils in the same direction that it does through the shunt coils, and therefore aids in setting up a stronger field when there is any load on the motor.

## Compound Motors

### 24. STARTING AND STALLING TORQUE

Cumulative-compound motors have a very much better starting-torque than shunt motors, because the heavier armature currents which flow during starting also pass through the series field and greatly strengthen its flux, thereby increasing the motor torque.

Motors of this type can be used for starting very

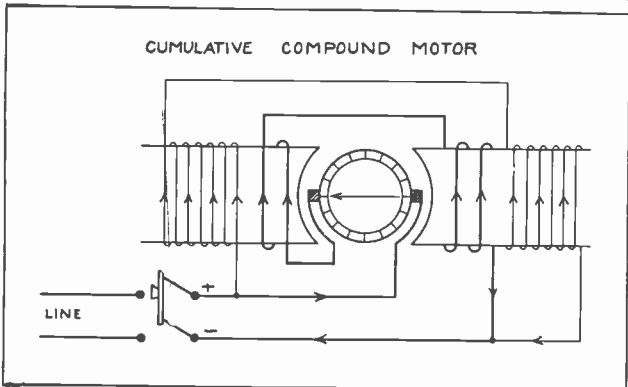


Fig. 10. Diagram of connections for a cumulative compound motor. Note that the series field winding is connected so it will aid the shunt field winding in providing a strong field.

heavy loads, or machinery that is difficult to start and bring up to speed.

The stalling torque of cumulative compound motors is also quite high, because any increase of load on the machine will increase its armature current and the current through the series field. This increases the flux of the field poles, which in turn increases the motor torque and enables it to carry the additional load at slightly reduced speed.

Such motors can be allowed to carry reasonable overloads of 15 to 25 per cent. as long as they don't overheat enough to damage their insulation.

### 25. SPEED REGULATION AND APPLICATIONS

The speed regulation of cumulative-compound motors can be considered as fair. Their speed will vary inversely with the load, because any increase of load also increases the field flux due to the action of the series winding; and when the field flux is increased, the armature speed must decrease, in order

## Direct Current

to lower the counter-E. M. F. sufficiently to allow enough current to flow to carry the load. The stronger the field of any motor, the lower will be the speed at which it can generate the normal counter-E. M. F.

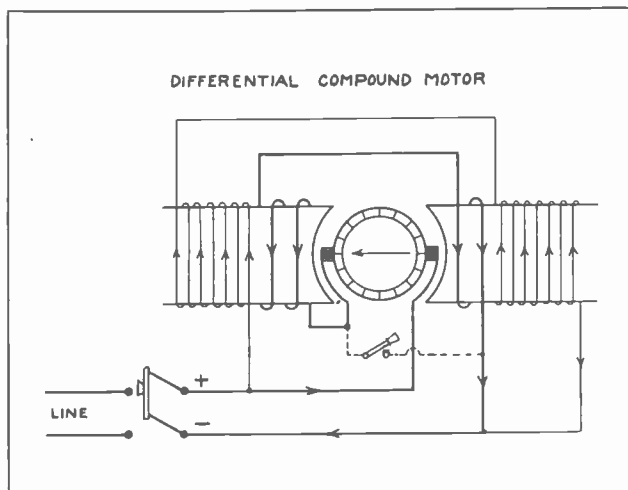


Fig. 11. Differential compound motor connections. Note that the series field is connected so it will oppose and weaken the effect of the shunt field.

Compound motors are used extensively to drive power shears, the rolls of steel mills, and in factories and industrial plants for running machines which require good starting and stalling torque and don't require very close speed regulation.

### 26. DIFFERENTIAL COMPOUND MOTORS

When compound motors are connected for differential operation their characteristics change considerably from those of cumulative machines.

A differential compound motor has its series field so connected that the current will flow through it in the opposite direction to that of the current in the shunt field windings, as shown in Fig. 11. This tends to weaken the field flux whenever any load is being carried by the motor.

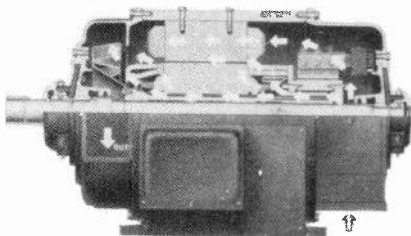
The shunt field winding is the main winding and under ordinary conditions it determines the polarity of the field poles. Occasionally, however, when these motors are started up rather suddenly and

## Compound Motors

under heavy load, the current flow through the differential series winding becomes very strong; and due to its strong flux and the inductive effect which it has on the shunt field coils during the time this flux is building up around the series winding, it may overcome the shunt field flux and reverse the polarity of the field poles. This will cause the motor to start up in the wrong direction.

To avoid this, the series field of a differential motor should be short-circuited when starting. This can be done by the use of a single-pole knife switch of the proper size, connected across the series field terminals, as shown in Fig. 11.

Cutaway view of G-E Type CD "1000 Series" dripproof, direct-current motor, showing ventilating system which is designed for reversible rotation. This design gives you a motor of less height, reduced weight, and higher rating per frame size than heretofore possible.



### 27. STARTING TORQUE AND STALLING TORQUE

The starting torque of an ordinary differential-compound motor is very poor, even poorer than that of a shunt motor. This is due to the effect of the heavy starting currents flowing through this field and weakening the flux of the shunt field to such an extent that the motor has very poor starting torque. Motors of this type are usually started without any load connected to them.

A reversing switch can be used to reverse the polarity of the differential field and make the motor operate cumulative during starting, and thereby improve the starting torque of this motor.

Differential motors will not carry overload without stalling. In fact they will usually only carry about 75% of the full rated load of a shunt motor of the same size. Whenever the load on such a machine is increased, the series field current is increased and, because it flows in the opposite direction of that in the shunt winding, it tends to neu-

## Direct Current

tralize and weaken the total field flux and also weaken the load-pulling torque.

### 28. SPEED REGULATION AND APPLICATIONS

Differential-compound motors have excellent speed regulation up to a certain amount of load. As the load is slightly increased, the motor tends to slow down, but the increased current through the differential series field immediately weakens the shunt field flux and thereby causes the counter-E. M. F. in the armature to be reduced.

This allows more current flow through the armature and maintains the speed at normal value. With just the proper number of turns on a differential series field, the tendency of the motor to slow down with increased load and the tendency to speed up with weakened field can be so balanced that they will neutralize each other, and the speed will remain almost perfectly constant if the load change is not too great.

Note the speed curve shown for this type of motor in Fig. 8.

Differential-compound motors are not used very extensively, because of their very poor starting torque; but they have certain applications where very little starting torque is required and good speed regulation is essential. The operation of textile mill machinery is a good example of this application.

A convenient, practical method for determining whether a compound motor has its series field connected differential or cumulative is to operate the motor and note its speed. Then reverse the series field connection and again note the speed. Which-ever connection gives the most speed is the differential connection of the series field winding.

The table on characteristics and applications of D.C. motors provides some useful information on torque, speed regulation and application of the different types of motors. Note that the change in speed from no-load to full-load is least for the shunt motor and greatest for the series motor. In other words, the shunt motor has the best speed regulation.

## Compound Motors

### Characteristics\* and Applications of D-c Motors, 1 to 300 Hp

Type	Starting Duty	Maximum Momentary Running Torque	Speed Regulation	Speed Control †	Applications
Shunt-wound, constant-speed	Medium starting torque. Varies with voltage supplied to armature, and is limited by starting resistor to 125 to 200 per cent full-load torque	125 to 200 per cent Limited by commutation	8 to 12 per cent	Basic speed to 200 per cent basic speed by field control	Drives where starting requirements are not severe. Use constant-speed or adjustable-speed, depending on speed required. Centrifugal pumps, fans, blowers, conveyors, elevators, wood- and metal-working machines
Shunt-wound, adjustable-speed			10 to 20 per cent, increases with weak fields	Basic speed to 600 per cent basic speed (lower for some ratings) by field control	
Compound-wound, constant speed	Heavy starting torque. Limited by starting resistor to 130 to 260 per cent of full-load torque	130 to 260 per cent. Limited by commutation	Standard compound-winding 25 per cent. Depends on amount of series winding	Basic speed to 125 per cent basic speed by field control	Drives requiring high starting torque and fairly constant speed. Pulsating loads. Shears, bending rolls, plunger pumps, conveyor crushers, etc.
Series-wound, varying-speed	Very heavy starting torque. Limited to 300 per cent full-load torque	300 to 350 per cent. Limited by commutation	Very high. Infinite no-load speed	From zero to maximum speed, depending on control and load	Drives where very high starting torque is required and speed can be regulated. Cranes, hoists, gates, bridges, car dumpers, etc.

\* Table shows average values for standard motors.

† Minimum speed below basic speed by armature control limited by heating.

## Direct Current

The maximum overload that a motor can carry for a brief interval of time is limited by sparking at the brushes. This is indicated by the statements on maximum momentary torque given in the third column of the table. Note that due to sparking difficulties, the series motor cannot be allowed to carry more than 350 per cent of the normal full load torque. If the load demanded it, the series motor could actually develop a much higher torque than indicated; however, such a high value of torque would result in severe flashing at the commutator.

The last column shows that each motor is suited to a particular application or series of applications and some of the more frequently encountered ones are listed. This brings out the fact that no motor is suitable for all types of drives, and it indicates the need for analyzing the drive requirements before selecting a motor for any given application.

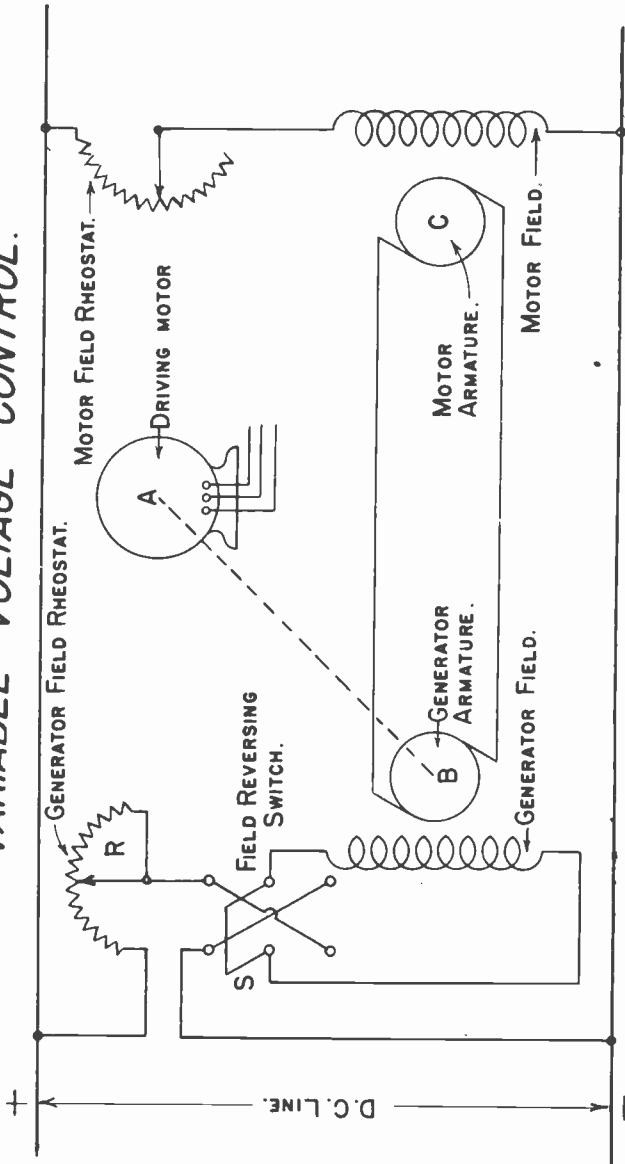
The variation in speed obtainable by field control on the ordinary D.C. motor will not, in the average case, exceed 4 to 1 due to the sparking difficulties experienced with very weak fields. Although the range may be increased by inserting resistance in series with the armature, this can be done only at the expense of efficiency and speed regulation.

With constant voltage applied to the field, the speed of a D.C. motor varies directly with the armature voltage; therefore, such a motor may be steplessly varied from zero to maximum operating speed by increasing the voltage applied to its armature. The sketch shows the arrangement of machines and the connections used in the Ward Leonard type of variable voltage control designed to change speed and reverse rotation. The constant speed D.C. generator (B) is usually driven by an A.C. motor (A) and its voltage is controlled by means of rheostat R. Note that the fields of both generator (B) and driving motor (C) are energized from a separate D.C. supply or by an auxiliary exciter driven off the generator shaft. Thus the strength of the motor field is held constant, while the generator field may be varied widely by rheostat R.

With the set in operation generator (B) is driven at a constant speed by prime mover A. Voltage

# Compound Motors

## VARIABLE VOLTAGE CONTROL.





## Direct Current

from B is applied to the D.C. motor (C) which is connected to the machine to be driven. By proper manipulation of rheostat R and field reversing switch S the D.C. motor may be gradually started, brought up to and held at any speed, or reversed. As all of these changes may be accomplished without breaking lines to the main motor, the control mechanism is small, relatively inexpensive, and less likely to give trouble than the equipments designed for heavier currents.

The advantages of this system lie in the flexibility of the control, the complete elimination of resistor losses, the relatively great range over which the speed can be varied, the excellent speed regulation on each setting, and the fact that changing the armature voltage does not diminish the maximum torque which the motor is capable of exerting since the field flux is constant.

By means of the arrangement shown, speed ranges of 20 to 1—as compared to 4 to 1 for shunt field control—may be secured. Speeds above the rated normal full load speed may be obtained by inserting resistance in the motor shunt field. This represents a modification of the variable voltage control method which was originally designed for the operation of constant torque loads up to the rated normal full load speed.

As three machines are usually required, this type of speed control finds application only where great variations in speed and unusually smooth control are desired. Steel mill rolls, electric shovels, passenger elevators, machine tools, turntables, large ventilating fans and similar equipments represent the type of machinery to which this method of speed control has been applied.

### 29. BRAKE HORSE-POWER TEST FOR MOTORS

Occasionally it may be desirable to make an actual test of the horse-power output of a motor, in order to determine its condition or efficiency. This can be done by arranging a brake or clamp to apply load to the pulley of the motor and thereby measure the pull in pounds or the torque exerted by the motor.

## Prony Brake

This method is known as the **Prony Brake Test**.

Fig. 12 shows the equipment and method of its use for making this test. The brake can be made of wood blocks cut to shape to fit the pulley and

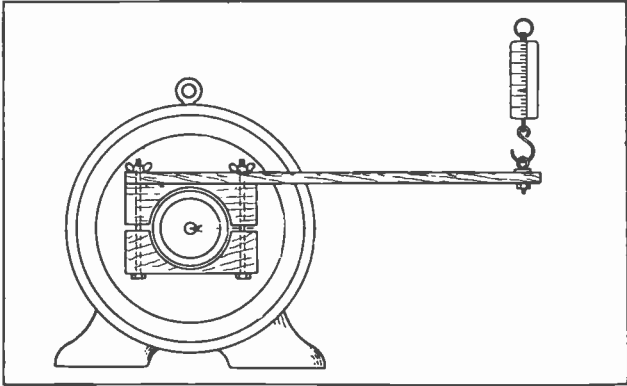


Fig. 12. The above diagram illustrates the method of making a brake-h.p. test on a motor.

fitted with bolts and wing nuts so the grip or tension of the blocks on the pulley can be adjusted. When making a number of these tests, it is also a good plan to line the curved faces of the block with ordinary brake lining such as used on automobiles. This makes it possible to apply a smoother braking effect without generating too much heat due to the friction.

An arm or bar, of either wood or metal, can be attached to the brake blocks as shown in the figure, and fitted with a bolt or screw eyes for attaching the scales to the end of the bar. A spring scale, such as shown in Fig. 12, can be used, or the bolt on the underside of the arm can be allowed to rest on the top of a platform scale.

The brake arm should preferably be of some even length, such as 2 ft. or 3 ft., in order to simplify the horse-power calculation. The arm length is measured from the center of the shaft to the point at which the scale is attached.

With a device of this kind, load can be gradually applied to the motor by tightening the brake shoes or clamps until the motor is fully loaded.

An ammeter can be used in series with one of the line leads to the motor to determine when the ma-

## Direct Current

chine has been loaded to its rated current capacity. In case an ammeter is used, a voltmeter should also be used, to see that the proper line voltage is applied to the motor at the time of the test. A wattmeter can be used instead of the voltmeter and ammeter if desired.

When the brake has been adjusted so that the motor is drawing its full rated load in watts, the pound pull on the scale should be noted and the speed of the motor in revolutions per minute should be carefully checked.

The adjustment on the brake should be maintained to keep the motor pulling the same amount on the scales and drawing the same load in watts during the time the speed is being checked.

The motor speed can easily be checked by means of a speed counter or tachometer applied to the end of its shaft while running. A watch with a second-hand should be used for gauging the time accurately.

### 30. HORSE POWER CALCULATION

The horse power of a motor is proportional to the product of its torque and speed. Therefore, when we know the length of the lever arm in feet, the pull in lbs. on the scales, and the speed of the motor in R. P. M., we can easily determine the horse-power output by the following simple formula:

$$\text{h.p.} = \frac{2 \times \pi \times \text{R.P.M.} \times P \times L}{33,000}$$

In which:

h. p. = the horse power developed by the motor

$\pi$  = 3.1416, or the ratio between the diameter and circumference of a circle.  
( $2 \times \pi = 6.28$ )

R. P. M. = Speed of the motor in revolutions per minute.

P = Lbs. pull on the scale.

L = Length of lever arm in feet.

33,000 = Number of foot-pounds required per minute for one h.p.

As an example, suppose we have made a test on a motor using a brake arm two ft. in length, and have found that when the motor is fully loaded ac-

## Efficiency

According to the electrical instruments, it applies 9 lbs. pull on the end of the arm and revolves at a speed of 1500 R. P. M. Then, according to our formula:

$$\text{h. p.} = \frac{6.28 \times 1500 \times 9 \times 2}{33,000} \text{ or } 5.1 \text{ h. p.}$$

### 31. EFFICIENCY TESTS

The efficiency of a motor is, of course, an important item, especially where a large number of motors are being chosen for continuous operation of certain equipment. The higher the efficiency of any motor, the greater the h. p. it will produce from a given amount of electrical energy in watts, and the less power will be wasted in losses within the machine.

These losses are partly mechanical, such as bearing friction and "windage" due to the armature revolving through the air at high speed. They are also partly electrical, such as losses in the armature and field windings due to resistance and to a certain amount of energy being transformed into heat, and the slight magnetic losses due to hysteresis and eddy currents.

The efficiency of D.C. motors may vary from 50%

EFFICIENCY OF 230VOLT COMPOUND D.C. MOTORS			
SIZE IN H.P.	AT ½ LOAD	AT ¾ LOAD	AT FULL LOAD
5	73 %	78 %	80 %
10	79 %	82.5 %	85 %
25	84 %	87 %	87.5 %
50	85 %	87.5 %	88.5 %
200	87 %	89 %	91.5 %

Fig. 13. This table gives the approximate efficiencies of various sized D.C. motors at various percentages of load.

or less for the very small fractional horse power machines up to 90% for the larger ones, and even higher than this for extremely large motors.

The efficiency of ordinary motors from 5 to 50 h. p. will usually range between 75 and 90 per cent ;

## Direct Current

so, when the efficiency of a machine is not known, a good average figure to use is 80% or 85%.

As a general rule, the larger the motor, the higher will be its efficiency. Fig. 13 shows a table in which are given the efficiencies of several sizes of motors, from 5 to 200 h. p. You will also note by examining this table that the efficiency of any motor is better at full or nearly full load. Therefore, it does not pay to operate motors lightly loaded whenever it can be avoided by the selection and use of motors of the proper size. In many cases, motors which are larger than necessary have been installed to operate certain machines, because these machines require considerable starting torque. In a case of this kind, the selection of a different type motor with a better starting torque can often effect considerable power saving.

### 32. EFFICIENCY CALCULATION

The efficiency of any motor can be found by dividing its output in watts by the input in watts. This is stated by the following formula:

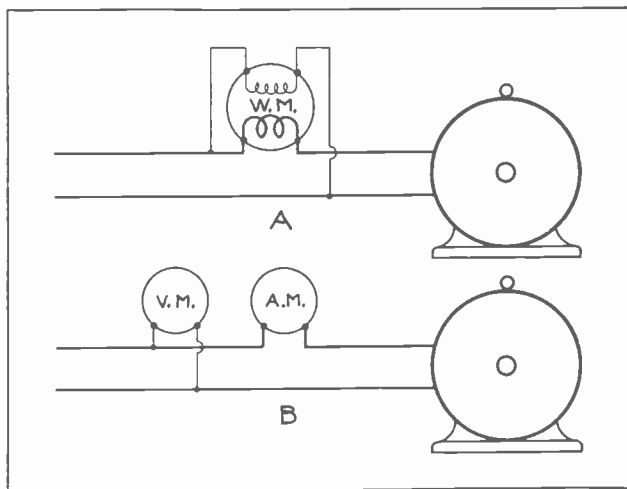


Fig. 14. The above diagram shows the method of connecting a wattmeter or voltmeter and ammeter, to determine the KW or h. p. input to a motor.

$$e = \frac{W O}{W I}$$

## Efficiency

In which :

- $e$  = the efficiency of the motor in per cent.  
W O = watts output  
W I = watts input

The output and input can both be determined in horse power or kilowatts, if preferred, and used in the same manner in the formula.

When we have made a test of the horse power of a motor by the Prony brake method and have measured the electrical power input either with a wattmeter or a voltmeter and ammeter, it is then an easy matter to determine the efficiency of the machine with the formula just given.

For example, suppose we have tested a machine and found its full load output to be 35.5 h. p. During this test the wattmeter connected to the motor leads indicated that it was consuming 31,150 watts.

To obtain the output in watts, we multiply 35.5 by 746, as there are 746 watts in each h. p., and we find that the output is 26,483 watts.

Then, according to the formula, the efficiency of this motor will be found as follows:

$$e = \frac{26,483}{31,150}, \text{ or } 85 + \% \text{ efficiency}$$

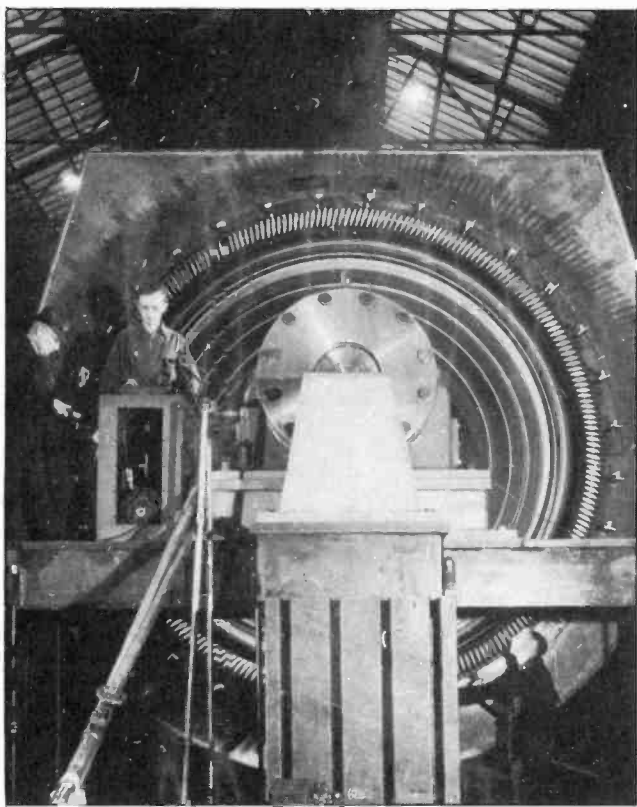
Fig. 14 shows the method of connecting a wattmeter to the terminals of a motor for determining the input or energy consumed. At "B" in this same figure are shown the proper connections for a voltmeter and ammeter used to determine the input of the motor. Watts equal volts multiplied by amperes.

## Direct Current

### EXAMINATION QUESTIONS

1. What determines the speed of any D.C. motor?
2. What is the difference between the term "Speed Control" and "Speed Regulation" when used in connection with D.C. motors?
3. How does the horsepower output of a high speed motor compare to the H.P. output of a low speed motor of the same size?
4. Give Fleming's rule for determining the direction of rotation for a D.C. motor?
5. How is the field winding of a shunt motor connected in relation to the armature?
6. Is there any danger in operating a series motor without a load? Why?
7. Draw a simple sketch of a two pole cumulative compound motor.
8. Which type motor would you select for each of the following uses?  
a. Power shears? b. lathe? c. cranes?
9. Give the formula for determining the brake horsepower of a motor.
10. What would be the efficiency of a motor operating on 1800 W and developing 2 horsepower?

## Efficiency



**A motor almost big enough to live in. This gigantic and inspected motor is being tested by the two workmen in upper left corner before being shipped.**



### D. C. MOTOR STARTERS AND CONTROLS

There are two general types of D. C. motor control equipment. One of these is used for starting duty only, and the other can be used both for starting and for controlling or regulating the speed of the motors while running.

Motors of  $\frac{1}{4}$  H. P. or less can be started by connecting them directly across the line, as their armatures are so small and light in weight that they come up to full speed almost instantly. Therefore, the heavy rush of starting current does not last long enough to overheat their windings.

**Medium-sized and larger D. C. motors should never be connected directly across the full line voltage to start them, as their heavier armatures require more time to speed up and develop the necessary counter-voltage to protect them from excessive starting current.**

If these armatures are connected directly across full line voltage when they are at rest, the rush of starting current through them is likely to be more than 10 times full-load current. This excessive current will overheat the winding, and also possibly damage the insulation of the coils by the powerful magnetic field it sets up and the mechanical forces the coils exert on the slots in trying to practically jerk the armature up to full speed.

So, for this reason, a starting resistance should always be connected in series with the armature of a D. C. motor when starting it, and left in the circuit until the motor armature has reached full speed and has built up its own protective counter-voltage.

When the current flows through this resistance, it causes sufficient voltage drop so that only about one-fourth of the line voltage is applied to the armature. Fig. 1 shows the method of connecting the starting resistance in series with the motor armature.

These starting resistances are usually arranged so

## Starters and Controllers

they can be gradually cut out of the armature circuit as the motor comes up to speed, and when full speed is reached the resistance is all cut out.

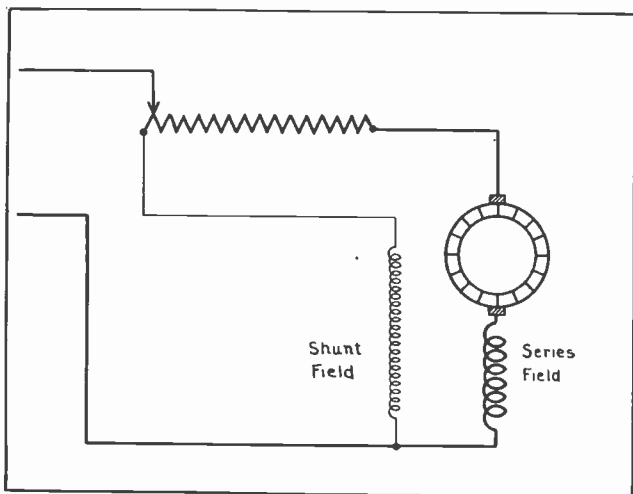


Fig. 1. This simple sketch shows the manner in which a resistance is used in series with the armature when starting a D. C. motor.

The starting current for D. C. motors should be limited to about  $1\frac{1}{2}$  to  $2\frac{1}{2}$  times full-load current. It is therefore necessary that starting rheostats have the proper resistance value and current capacity for the motors with which they are used.

### 1. TIME ALLOWED FOR STARTING MOTORS

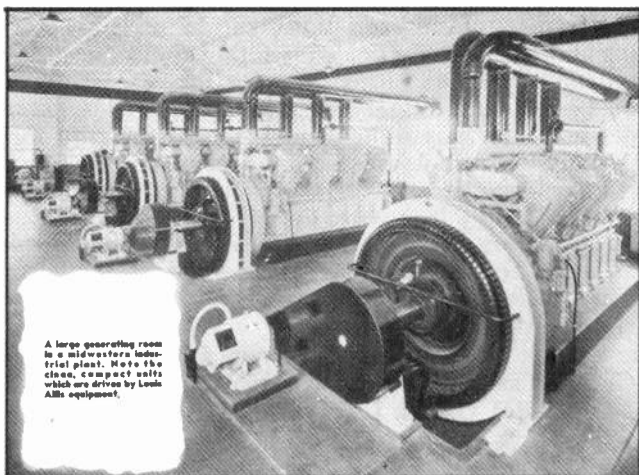
The period of time for which the starter resistance should be left in series with the motor when starting, depends upon the size of the motor and the nature of the load attached to it. A motor connected to a heavy load, of course, requires more time to come up to full speed, and the larger the armature of a motor, the more time is required for it to reach full speed.

Usually from 15 to 30 seconds will be required on ordinary motors. This rule, however, cannot be strictly followed, as the time allowed for starting a motor must be largely a matter of observation and

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good judgment on the part of the operator. One can readily tell by the sound of the motor when it has reached full speed.

While starting and operating various motors you will gain considerable practice in judging the time required for different motors. Always watch and listen to the motor closely when starting it up, and never leave the resistance in the circuit any longer than necessary, or it is likely to become damaged by overheating.



A large generating room in a midwestern industrial plant. Note the close, compact units which are driven by Lewis Allis equipment.

## 2. MOTOR STARTING RHEOSTATS

Starting resistances or **Rheostats**, as they are called, should never be used to regulate the speed of a motor after it is running. Starting rheostats are designed to carry the armature current only for a very short period and should then be cut out of the circuit. If they are used for speed regulation and left in the circuit for longer periods, they are very likely to become overheated to a point where the resistance metal will burn in two and result in an open circuit in the rheostat.

Armature starting resistances for small machines are usually made up of iron wire, or wire consisting of an alloy of nickel and iron. This resistance wire is wound on an insulating base, or form of asbestos

## Starters and Controllers

or slate. The turns of the coil are so spaced that they don't short together.

Taps are made at various points along the coil and are connected to segments or stationary contacts which are mounted on the face-plate of the starter. A lever arm with a sliding contact is then used to cut out the resistance gradually as the motor comes up to speed.

### 3. SPEED CONTROL RHEOSTATS

Speed-regulating resistance can be used for starting motors and also for controlling their speed over indefinite periods. Rheostats for this use are made of larger and longer resistance material and are designed to carry the armature current for long periods without damage from overheating.

Speed-regulating resistances are in some cases made of heavy iron wire, but for medium and larger sized motors are generally made of cast iron grids, or grids consisting of an alloy of nickle and iron. The nickle alloy is generally preferred in the better class controls.

### 4. METHODS OF CONTROLLING THE SPEED OF D. C. MOTORS

The speed of shunt or compound motors may easily be controlled by the use of a rheostat in series with the shunt field, as shown in Fig. 2. By varying the resistance of the field rheostat, we can vary the current through the field of the motor. If the field is weakened, the counter-E. M. F. generated in the armature is momentarily reduced and more current is allowed to flow through the machine.

This will cause the machine to speed up until the counter-voltage produced in this weaker field is again normal. If the motor field is strengthened, the counter-voltage developed in the armature will be increased, and this will cause the current flowing through the machine to be reduced, allowing the speed to decrease until the counter-voltage developed in this stronger field is again normal.

It is possible to vary the speed of a motor only above its normal speed by the use of shunt field rheostats.

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The torque of a motor armature will vary inversely with the speed when the field is weakened in the manner just described. The output in h. p., however, will remain approximately the same, as the h. p. is proportional to the product of the speed and torque.

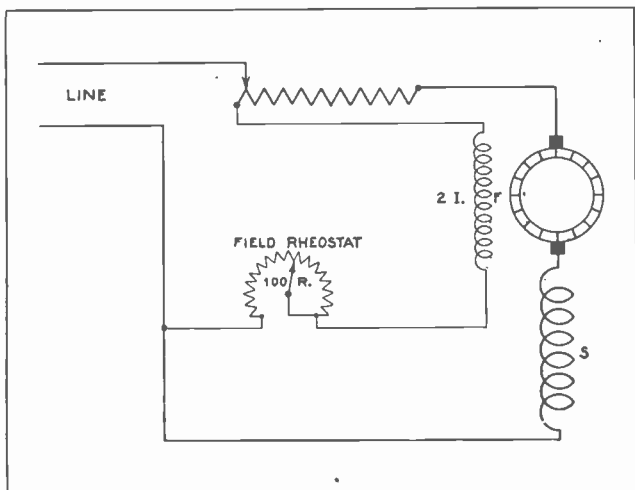


Fig. 2. This diagram shows the armature starting resistance and also a shunt field rheostat for varying the speed of the motor.

For example, if a certain motor normally rotates at 1000 R. P. M. and develops 10 lbs. torque at the end of a brake arm, the product of this speed and torque is  $1000 \times 10$ , or 10,000.

Now, if we were to increase the speed of this motor to 2000 R. P. M., or double its normal speed, the torque, which varies inversely with the speed, will be reduced to 5 lbs., or one-half its former value. In this case, the speed times the torque equals  $2000 \times 5$ , or 10,000 as before.

Motors that do not have interpoles should not ordinarily be operated at speeds greater than 65 to 70 per cent above their normal speed ratings. On motors that have interpoles, it is possible to obtain speed variations as great as 6 to 1 ratio.

Field control is a very economical means of speed variation for D. C. motors, since the output of the motor in horse power remains practically unchanged

## Starters and Controllers

and the power lost in the field rheostat is very small.

The power lost due to heating in any resistance is equal to the square of the current multiplied by the resistance, or  $I^2 \times R = W$ .

For example, let us assume that the resistance of the field rheostat shown in Fig. 2 is 100 ohms, and that the field current required by this motor is 2 amperes; then the power lost in the field rheostat would be  $2^2 \times 100$ , or 400 watts.

### 5. SPEED CONTROL BY USE OF ARMATURE RESISTANCE

The speed of shunt, series, and compound motors can also be regulated or varied by means of a rheostat in series with the armature, as shown in Fig. 3. An armature resistance used in this manner merely produces a voltage drop as the machine current flows through it, and thus it varies the voltage applied to the armature.

When this method of speed control is used, the strength of the shunt field of the motor is not varied, as it is connected directly across the line so it is not affected by the armature resistance. Observe this method of connection in Fig. 3.

When the voltage applied to the armature is decreased by cutting in the resistance of the armature rheostat, this will decrease the armature current and the speed of the motor. Since the torque of any motor varies with the product of the armature current and field flux, any change of this armature current produces a corresponding change in the torque and speed developed by the machine. When the machine slows down to a speed at which its counter E. M. F.; and effective armature voltage again balance the applied voltage, the current and torque will again be the same as before changing the speed.

### 6. SPEED CONTROL BY FIELD RESISTANCE MOST ECONOMICAL GENERALLY

Speed control by means of armature resistance is very wasteful of power because of the very heavy

## Direct Current

armature current which must be passed through the rheostat, and the losses due to heat and I R drop in the rheostat.

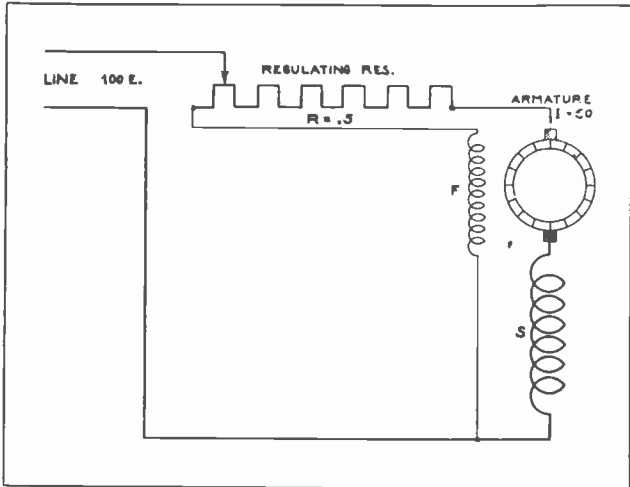


Fig. 3. Rheostats for speed regulating duty use heavier resistance units to stand the continued current load without overheating.

If the armature shown in Fig. 3 requires 50 amperes for full load operation and the speed regulating rheostat has .5 of an ohm resistance, then the energy lost due to heat in the rheostat will be  $I^2 \times R$ , or  $50^2 \times .5$ , which equals 1250 watts.

If the field resistance were used for speed control of this motor, the losses would be much less. We will assume the field current to be 2 amperes, and the field rheostat resistance 100 ohms. Then the loss with this form of speed control would only be  $2^2 \times 100$ , or 400 watts.

The speed regulation of the motor which is controlled by armature resistance is very poor when the machine is operated below normal speed, while the speed regulation of a motor controlled by the field rheostat is very good, because the armature in this case is always operated at the same voltage.

Shunt field rheostats for ordinary motors are small compact devices, because they don't need to carry a great amount of current or to have a large heat radiating surface.

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Armature rheostats are much larger and usually made of heavy cast iron grids, or, in the case of some of the latest type controls, they are made from alloy of manganese and copper.

From the foregoing material, it is easy to see that the use of the field rheostat provides a much more economical method of motor speed control than the use of armature resistance, and it should therefore be used whenever possible.

The three principal advantages of field control over armature control are as follows:

1. The horse power output remains practically unchanged with field control but decreases considerably with armature control.
2. Power lost in the field rheostat is much lower than in armature rheostats, which must carry the heavier armature current.
3. The speed regulation of a motor which is controlled by field rheostats is much better than that of a machine controlled by armature resistance.

Resistance should never be cut in to both armature and field circuits at the same time on any motor, because resistance in the armature circuit tends to reduce the speed, while resistance in the field circuit tends to increase speed. So each one would tend to defeat the purpose of the other.

Both armature and field control are often used together on the same motor, however, **cutting out** resistance from the armature circuit to bring the speed from zero up to normal, and **cutting in** resistance in the field circuit to raise the speed above normal.

### 7. D. C. MOTOR CONTROLLERS

There are many types of D.C. motor starters and speed controllers, but the general principles of practically all of them are very much the same. Their function is usually to place resistance in series with the motor armature when the machine is started, and gradually cut out this resistance as the machine comes up to speed.

Some controllers also make a slight variation in the resistance in the shunt field circuit at the same



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time the armature resistance is cut out. Some types of controls have reversing switches or contacts in addition to the rheostat element, so they can be used for starting and reversing of motors.

The operation of controllers may be either **Manual or Automatic**. In the manual types the lever arm or sliding contact which cuts out the resistance is operated by hand; while, in automatic types, the movement of the sliding contact or switches which cut out the resistance is accomplished by means of electro-magnets or solenoids, which may be operated by a small push button switch located either at the controller or some distance from it. Because of this feature, certain controllers are known as **Automatic Remote-Control** devices.

The design of the various controllers depends in each case upon the size of the motors they are to operate and upon the class of duty they are to perform.

### 8. CONSTRUCTION FEATURES

Common small motor controls consist of a box or panel on which are mounted the stationary contacts and sliding contact or controller arm; and usually some form of latch or holding magnet to hold the arm in running position, and frequently some form of line switch or, possibly, reversing switch.

On some of the smaller type controllers these contacts, coils, and switches are on the outside of the box or on what is called a "face plate," made of slate or insulating material.

Controllers used for small motors frequently have the resistance coils mounted inside the box, directly behind the face plate. In such cases the box is usually of well-ventilated construction, to allow the heat to escape.

On larger controllers, the resistance coils or grids are frequently located in a separate box or on a panel, and have copper leads run from the contacts on the panel to the resistance element.

Modern automatic types of controls frequently have their entire assembly of magnets, switches, and

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contacts enclosed in a metal safety cabinet.

Regardless of the type or application of the controller, you should be able to easily understand their circuits and principles, with the knowledge you already have of electrical circuits, electro-magnets, switches and rheostats.

### 9. THREE AND FOUR POINT STARTERS

Some of the most simple and common types of controls used with shunt and compound motors are called 3-point and 4-point controllers. The names 3-point and 4-point are derived from the number of connections or terminals on the face plate of these

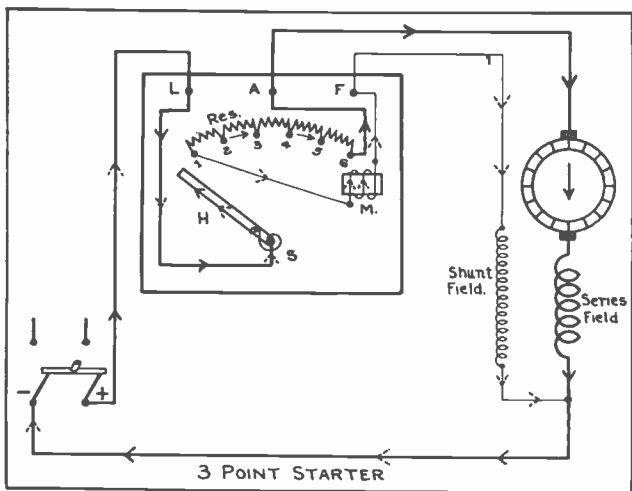


Fig. 4. This diagram shows the connections for a simple 3-point D. C. motor starter. Trace the circuit carefully with the accompanying instructions.

controllers. The 3-point control is usually arranged for starting duty only, but in some cases it may also be used for speed control, if it is properly designed.

Fig. 4 shows the wiring and electrical connections of a simple 3-point starter. In this diagram all parts and connections are in plain view and the path of the armature current is marked with solid black arrows, while the field circuit is shown by the dotted arrows. Trace this circuit out thoroughly

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and become familiar with the principles and operation of this fundamental type of starter.

To operate a controller of this type and start the motor, the first step will be to close the line switch to apply the line voltage to the controller and motor.

You will note that one side of the line connects directly to the motor and that the controller is inserted in the other line wire, so that its resistance will affect both the armature and field circuits during starting.

The first step after closing the line switch is to move the lever arm "H" to the first point or contact attached to the left end of the controller resistance. Current will then start to flow from the opposite line wire, through the controller arm, and through the entire resistance to the motor armature and series field, and then back to the negative line wire, as shown by the solid arrows.

Another circuit can also be traced from the lever arm when it is in contact with point No. 1, as the current divides at this point and a small amount flows through the holding magnet "M", then through the shunt field winding and back to the negative line wire, as shown by the dotted arrows.

As soon as the motor starts to turn, the controller arm can be moved slowly across the contacts in order, 1, 2, 3, etc. This cuts out the resistance from the armature circuit step by step as the armature develops speed and begins to generate counter-voltage.

When the last contact point is reached, all resistance has been cut out of the armature circuit, and the lever arm will be held in this running position by the holding magnet "M", which is in series with the shunt field circuit.

### 10. "NO VOLTAGE" and "NO FIELD" RELEASE COIL

The reason for connecting this holding magnet in series with the motor field is to provide what is known as "no field" protection.

We have learned that a motor with a very weak field is likely to overspeed dangerously. This would

## Starters and Controllers

probably be the case if an open circuit should occur in the shunt field coils or connections of a motor of this type, when it is not loaded.

However, with the holding magnet, "M", connected in series with the shunt field, if any break occurs in this circuit the magnet, "M", will be de-energized and allow the controller arm to be thrown back to the "off" position by means of a spring. This will stop the motor before it has a chance to overspeed.

This holding magnet also acts as a "no voltage" release, so that if the voltage or power supplied at the line should fail, the starter arm will be released and return to normal position and thus stop the motor.

If this protection were not provided and the controller arm were left in running position, the motor might be burned out or injured when the power came back on the line, because there would then be no resistance in series with the motor armature.

This holding magnet is often referred to as a **no-field or no-voltage release coil**, and provides this very important protection to the motor, in addition to serving its function of holding the starter arm in place.

### 11. ALL RESISTANCE OUT OF FIELD CIRCUIT DURING STARTING

You will note by tracing the circuit when the starter arm is in the running position, that the field current will then have to pass back through the entire starter resistance, through coil "M", and the shunt field. We find, therefore, that as the controller cuts the resistance out of the armature circuit, it places the same resistance in the shunt field circuit. The advantage of this is that it provides maximum strength of the shunt field during starting of the motor, when it is naturally desired to provide the best possible starting torque.

As the motor comes up to speed, the shunt field strength can be reduced to normal by causing its current to flow through the starter resistance.

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The value of the starter resistance in ohms is very low and it therefore doesn't affect the shunt field as much as it does the armature, because the very small current required by the shunt field doesn't create much voltage drop when flowing through this resistance.

### 12. STOPPING A MOTOR

To stop the motor, we should always open the line switch, which will interrupt the current flow through the armature and field, and also allow the controller arm to fall back to starting position.

Never attempt to stop a motor by pulling the controller arm back across the contacts while the line switch is closed.

This would cause severe arcing and damage to the controller contacts, which should always be kept smooth and in good condition.

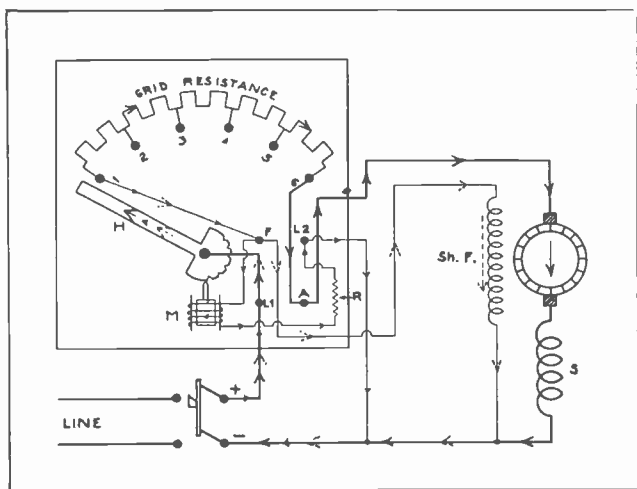


Fig. 5. Wiring diagram of a 4-point starter for speed regulating. Observe the connections and operating principle carefully.

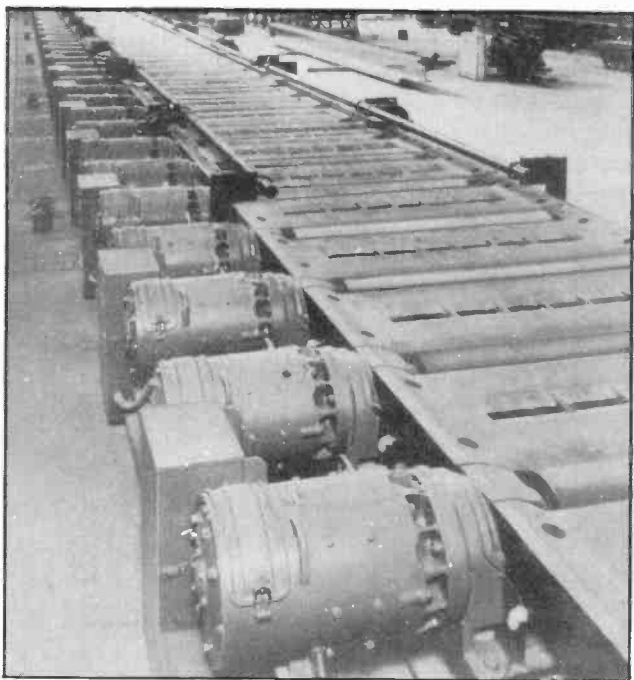
### 13. STARTER TERMINALS AND CONNECTIONS

You will note in Fig. 4 that the terminals on the starter are marked L, A, and F, to indicate the con-

## Starters and Controllers

nections for the line, armature, and field. This makes it a very simple matter to connect up controllers of this type to the line and motor.

The principal point to keep in mind is that one line wire should connect directly to the motor, being attached to both the shunt field and armature, or series field leads. The other side of the line should connect to the line terminal on the controller, and the remaining armature and field leads of the motor should connect respectively to the armature and field terminals on the controller. These terminals are usually marked on the controller or on the blue print supplied with it by the manufacturers.



54-inch hot-strip mill. General view of runout table from finishing mill. Each 12-inch table roller driven by G-E shunt-wound d-c motor, type MD-441, 4 HP, 750 RPM, 250 Volts. Protective cabinets, one per each pair of motors, mounted at table. Installed in 1939.

### 14. SPEED REGULATING CONTROLLERS

Fig. 5 shows a 4-point controller of the type which can be used both for starting and speed regu-

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lation of D. C. motors. The resistance element of this controller is made of heavier grids of iron or nickle alloy, and is designed to carry the full armature current of the motor for indefinite periods.

The principal differences between this controller and the one shown in Fig. 4 are the larger resistance element, the use of 4 terminal points instead of 3, and the arrangement of the holding magnet, "M". With this speed-regulating controller, the lever arm and holding magnet are mechanically arranged so that the arm can be held in any position between No. 1 and 6 on the resistance contacts.

This allows the arm to be set for any desired speed of the motor. In this case, both line wires are connected to the controller terminals marked "L-1" and "L-2". The reason for connecting the negative line wire to the controller at "L-2" is

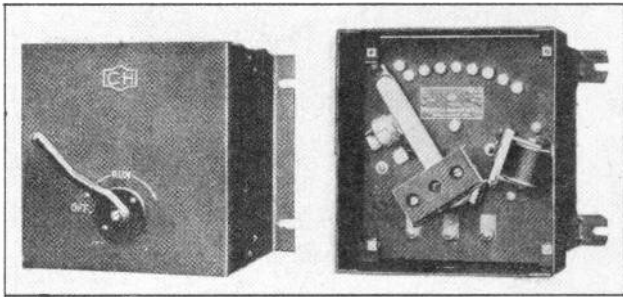


Fig. 6. Photo of a simple 3-point starter enclosed in a metal safety box.

merely to complete the circuit of the holding coil "M", directly across the line.

The small resistance "R" is placed in series with the magnet coil to keep it from overheating.

The armature path of current in Fig. 5 is shown by the large solid arrows, the shunt field current by the dotted arrows, and the current through the holding coil "M", by the small solid arrows. Trace each of these circuits out very carefully to be sure you thoroughly understand the operation of this controller.

Fig. 6 shows two views of a simple motor starter of the 3-point type. The view on the left shows

## Starters and Controllers

the starter completely enclosed in the safety box with just the handle projecting from the front cover. When the cover is closed this handle connects with the sliding contact arm inside the box. The view on the right shows this arm as well as the stationary contacts and holding magnet.

Where small, low priced starters of the type just described are used, fuses are generally used with them to provide overload protection for the motors. Sometimes these fuses as well as the line switch are enclosed in the same box with the starter, as shown in Fig. 7.

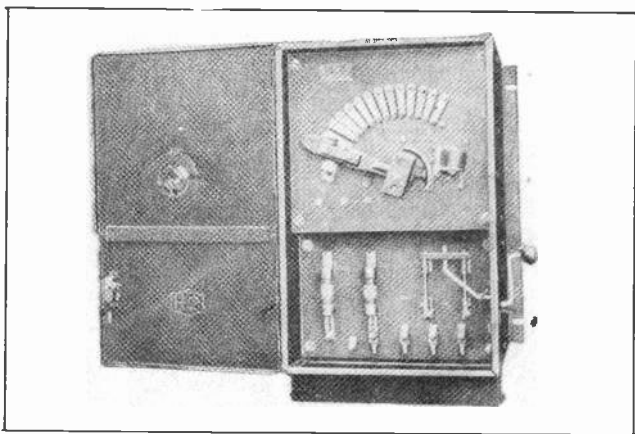


Fig. 7. Speed regulating controller with fuses and line switch enclosed in a controller box.

The switch in this case is also operated by a safety handle on the outside of the box.

Fig. 8 shows three forms of resistance elements such as are commonly used with motor starters. In the lower view, the resistance wire is wound on insulating forms of heat-resisting material, and then coated over with a plaster-like substance of the same nature. Note how a number of these coils can be mounted on a rack and spaced to allow ventilation. We can then connect several such units or coils in series or parallel, as desired, to obtain the proper resistance with convenient standard units.



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The view on the upper right shows a heavy-duty resistor made in the form of grids. These grids are clamped together with bolts as shown, and are spaced with washers of porcelain or some other insulating and heat resisting material.

Resistance coils are frequently wound on tubular shapes or forms, and mounted in the starter box, as shown at the upper left in Fig. 8. The copper wires or leads shown attached to these coils are

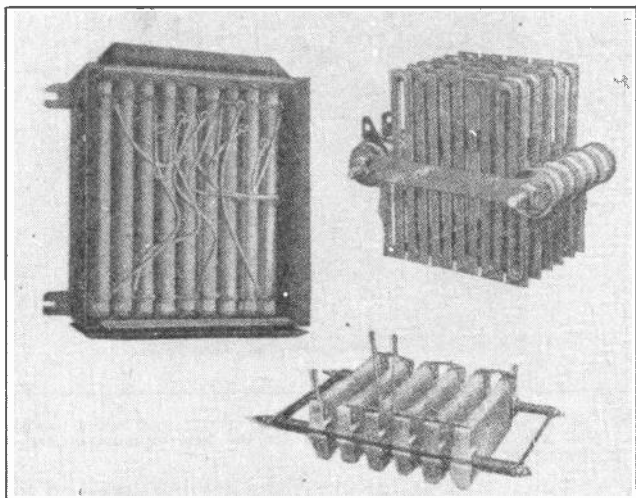


Fig. 8. Several styles of resistance units commonly used with motor starters and speed controls.

used for connecting them to the stationary segments or contacts on the starter plate.

### 15. CARBON PILE STARTERS

In some classes of work, such as the operation of textile mill machinery and certain other equipment, it is desirable to have very gradual application of the starting torque of the motor when the machines are first put in motion.

To accomplish this, it would, of course, be necessary to start the motor with extremely high resistance in the armature circuit, so that the starting current could be limited to only a very small frac-

## Starters and Controllers

tion of the load current. For this purpose, some starters are made with resistance elements consisting of small carbon disks stacked in tubes of non-combustible material with an insulating lining, as shown in the left-hand view in Fig. 10.

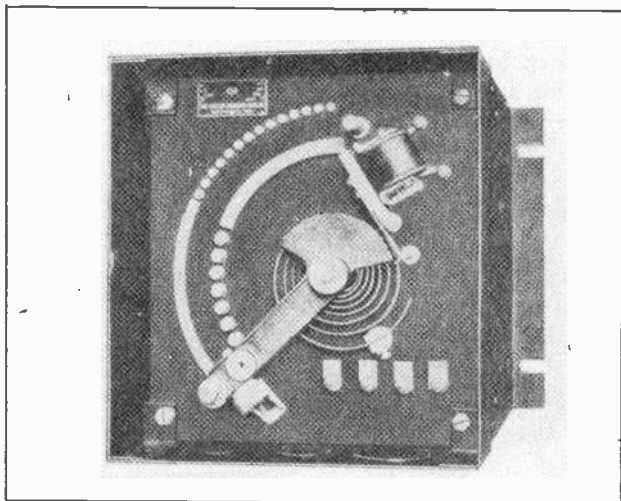


Fig. 9. A simple type of D. C. motor starter and speed control. Note the extra sets of contacts for the field resistance used in varying the speed.

As long as these carbon disks are left loose in the column or tube, the resistance through them is very high, because of the loose contact between each disk and the next. If pressure is gradually applied to the ends of this column by means of a lever and spring, this tightens the contacts between the disk and very gradually reduces the resistance through the pile.

One or more of these tubular piles or resistance elements can be arranged in a starter as shown in the right-hand view of Fig. 10; so that pressure can be smoothly applied to them by means of the lever shown in this view. Starters of this type are known as **carbon pile starters**, and they afford a means of starting motors more gradually and smoothly than with practically any other device on the market.

### 16. SMOOTH STARTING OF MOTORS WITH CARBON STARTERS

When using a starter of this type, there is prac-

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tically no sudden increase in the starting current through the motor, as there is when the lever arm of the "step by step" starter is shifted from one contact to the next.

In addition to the pressure-applying device in

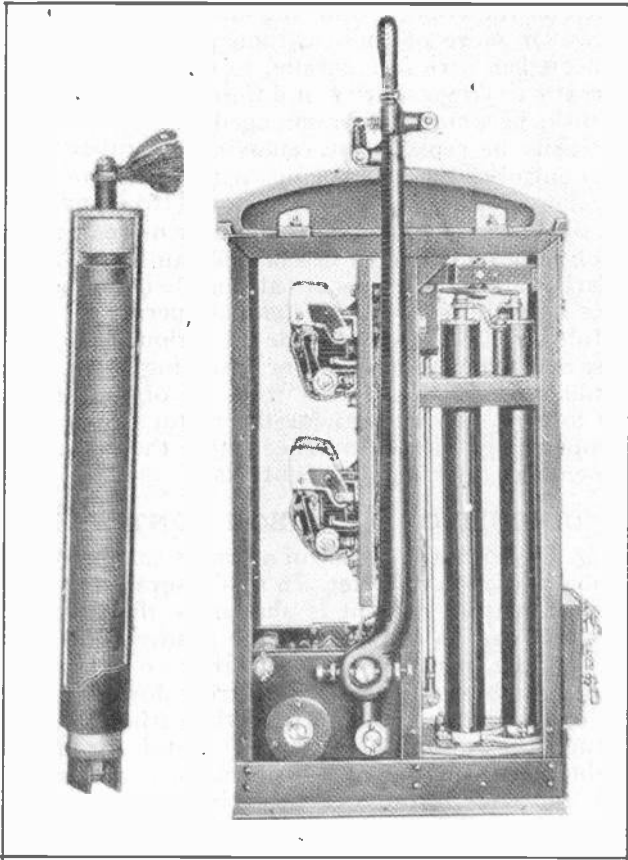


Fig. 10. Carbon-pile rheostat for starting D. C. motors very gradually. On the left is shown one of the carbon resistance elements used with such starters.

starters of this type, there must also be some form of switch or contactor to short circuit the carbon piles entirely out of the armature circuit after full pressure has been applied and the machine is up to speed. The reason for using this short-circuiting

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switch is that the resistance of the carbon pile is still too high to leave in the motor circuit, even when the disks are under maximum pressure; and they would tend to overheat if left in the circuit too long.

Tubes with larger disks are provided, however, for use with speed-regulating controllers, and these can be left in the circuit while the motor is running.

Two or more of these carbon pile tubes can be connected in series or parallel to obtain the proper current-carrying capacity of different controllers. If the disks become worn or damaged at any time, they can easily be replaced by removing the tubes from the controller and replacing with complete new tubes; or the end plug can be removed from any tube and the disks taken out, so that one or more of those which may be damaged or cracked can be replaced.

Carbon pile controllers are also made in automatic types as well as those for manual operation.

Motor controllers are made in various h. p. ratings, and when purchasing or installing them, care should be used to see that they are of the proper size to carry the current for the motor which they are operating, without overheating of the resistance elements or burning the contacts.

### 17. CIRCUIT OF A CARBON CONTROLLER

Fig. 11 shows the circuit of a simple, manual-type, carbon pile, motor starter. In this diagram the path of the armature current is shown by the solid arrows and can be traced from the positive line wire through the armature of the starter to contact 1. From this point, the armature current flows through the lower wire to the bottom of the carbon pile, up through the carbon disks, out at the top through a flexible lead, on through the armature and series field, and back through the negative line wire.

As soon as the starter arm makes contact with 1, field current can also flow, as shown by the dotted arrows from the positive line, through the starter arm; and from contact 1 the current flows up through the curved brass strip, through the holding coil, "M"; through the shunt field; and then back through the negative line wire.

As the starter arm is moved slowly upward, it applies more and more pressure to the carbon disks by

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means of the hook and spring shown in the figure. When the starter arm reaches contact 2, full pressure has been applied to the carbon disks; and the arm, upon touching contact 2, short-circuits the carbon pile out of the armature circuit.

The current then flows from the starter arm to contact 2, out at the armature terminal "A" through the motor, and then to the negative line wire.

### 18. AUTOMATIC STARTERS

As previously mentioned, a great number of motor starters and controllers are equipped with solenoids or electro-magnets which operate the switches or arms which cut out the starting resistance as the motor comes up to speed. This type of construction eliminates manual operation of the controller and reduces liability of damage to motors and controllers by improper use when controllers are operated manually by careless operators.

If a manual starter is operated too rapidly and all of the resistance is cut out before the motor comes up to speed, or if the starter is operated too slowly thus leaving the armature resistance in the circuit too long, it is likely to damage both the controller and the motor.

Automatic controllers which are operated by solenoids or electro-magnets usually have a time control device, in the form of a dash-pot attached to the solenoid or starter arm. By the proper adjustment of the dash-pot, the controller can be set so that it will start the motor in the same period of time at each operation.

Other controllers have the time period which they are left in the circuit regulated by the armature current of the motor so that the resistance cannot all be cut out of the circuit until the starting current has been sufficiently reduced by the increased speed of the motor.

### 19. REMOTE CONTROL

Another great advantage of magnetically operated controllers is that they can be controlled or operated from a distance by means of push-button switches

## Starters and Controllers

which close the circuit to the operating solenoids or magnets.

For example, a motor located in one room or on a certain floor of a building can be controlled from any other room or floor of the building. Elevator controls are a good example of the use of remote

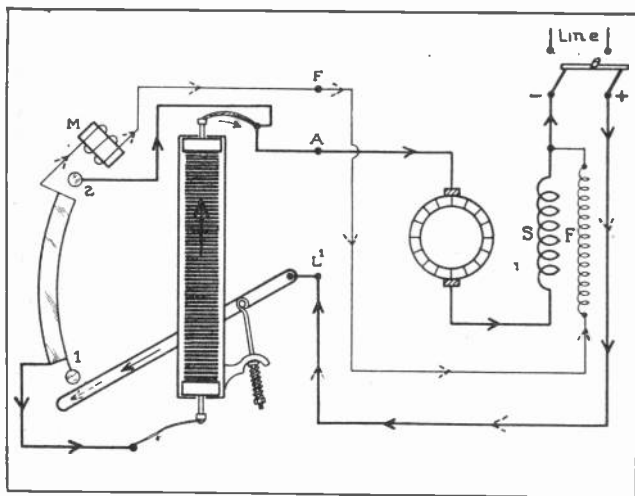


Fig. 11. Wiring diagram for a carbon-pile motor starter. Trace this circuit carefully.

control equipment. Elevator motors are usually located on the top floor of the building and are controlled by a switch in the car of the elevator which merely operates the circuits of the magnets or solenoids on controllers located near the motors.

Remote control devices can be used to improve the safety of operation of many types of machinery driven by electric motors. Push buttons for stopping and starting the motor which drives a machine can be located at several convenient places around the machine so that they are always within reach of the operator in case he should become caught in any part of the running machinery.

Automatic and remote types of controllers are, of course, more expensive to install, but they will usually save considerably more than the difference in their first cost, by increasing the life of the motor and control equipment, and by reducing repair bills which are caused by careless operation of manual starters.

## Direct Current

There are many types of automatic starters on the market and in use, but their general principles are very much the same; so you should have no difficulty in understanding or installing any of the common types, if you will make a thorough study of the principles covered in the following pages.

### 20. OPERATION OF AUTOMATIC CONTROLLERS

Fig. 12 shows a diagram of an automatic starter which uses a solenoid coil at "S" to draw up an iron core or plunger and at the same time raise the contact bar "B", which in this case takes the place of the lever arm used on the previously described controllers.

This controller is arranged for remote control by means of the stop and start push buttons shown at the upper right-hand corner. When the "start" button is closed, it completes a circuit through the solenoid coil, as shown by the small dotted arrows.

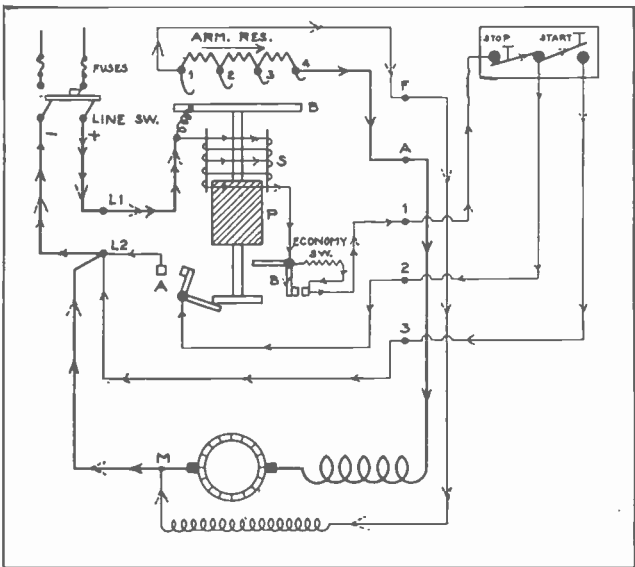


Fig. 12. This diagram shows the wiring for an automatic starter of the solenoid type. Trace each circuit until you thoroughly understand the operation of this controller.

Trace the circuit of this controller in Fig. 12 very carefully while reading the following explanation.

## Starters and Controllers

Assuming the line switch to be closed when the start button is pressed, current will flow as shown by the small dotted arrows from the positive line wire, through the solenoid coil and contacts "B", which are closed at this time; leaving the controller at terminal 1 and passing through the closed circuit stop switch, through the starting switch, and back to terminal 3.

From this point, it passes through a wire inside the controller to terminal L-2 and back to the negative line wire, thus completing the solenoid circuit. This energizes the solenoid coil and causes it to lift its plunger and raise the upper main contact bar "B"

This bar is prevented from rising too rapidly by a dash-pot attached to the solenoid plunger. The dash-pot consists of a cylinder in which are enclosed a piston and a quantity of oil. As the piston rises it presses the oil before it and retards the motion of the plunger, allowing it to move upward only as fast as the oil can escape around the edges of the piston, or through a by-pass tube which is sometimes arranged at the side of the cylinders.

As soon as the solenoid plunger starts to rise, it allows the spring contact "A" to close and complete the "holding" circuit through the solenoid, without the aid of a start button.

The start button then can be released and current will continue to flow through the solenoid, as shown by the small solid arrows, causing it to continue to draw up the plunger.

As the plunger moves up a little further, the copper contact bar "B" touches the contact finger or spring 1, which connects to the first step of the armature resistance. This allows current to flow as shown by the large solid arrows, from the positive line wire and line terminal "L-1", through the flexible connection to bar "B", contact spring No. 1, then through the full armature resistance to armature terminal "A", series field, motor armature, back to terminal "L-2", and the negative line wire.

A circuit can also be traced through the shunt field of the motor, as shown by the large dotted arrows.



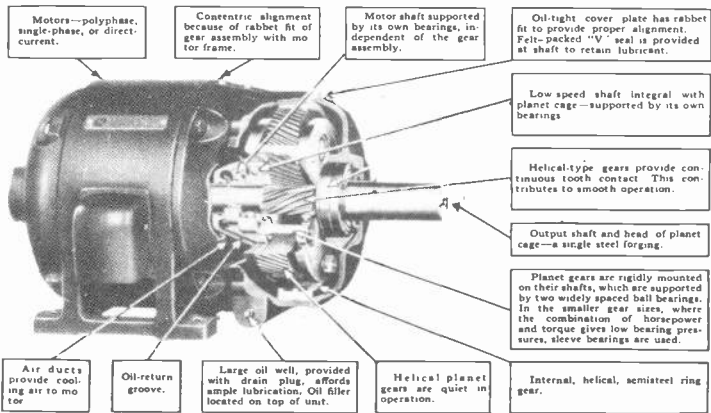
## Direct Current

As the solenoid continues to draw the plunger slowly upward, the bar "B" next makes contact with springs 2, 3, 4 in succession, thus short circuiting and cutting out the armature resistance one step at a time.

When the bar touches contact spring 4, the current will flow directly from the bar to terminal "A", and through the motor armature, without passing through any of the starter resistance.

### 21. ECONOMY COIL

The small auxiliary switch shown at "B" at the lower right of the solenoid in Fig. 12 is for the purpose of cutting a protective resistance in series with the solenoid coil, after the plunger has been raised to the top of its stroke. When the plunger reaches this point it will lift the arm of this switch, causing the contacts to open.



Cutaway view of G-E gear-motor, typical of "1000 Series," single-reduction units, output-shaft speeds 520 to 155 rpm.

The current required to hold the plunger in position once it is up is much less than the current required to start it and pull it up. This smaller holding current will flow through the economy resistance, instead of through the contacts at "B", as it did while starting.

Cutting in this economy resistance not only saves current but prevents the solenoid coil from becoming overheated when it holds the controller in operation for long periods. The economy resistance

## Starters and Controllers

will usually reduce the current flow through the solenoid coil to one-half or less than one-half its value during starting.

### 22. STOPPING THE MOTOR

To stop the motor with a controller of this type, it is only necessary to press the stop button. This breaks the holding circuit through the solenoid coil and allows the plunger to fall. The plunger is permitted to fall rapidly by means of a flap valve, which allows the oil to escape rapidly when the piston moves in a downward direction. When the plunger reaches the bottom of its stroke, it trips open the switch "A" in the holding circuit; so it will then be necessary to close the starting switch to energize the solenoid once more. The motor can also be stopped by opening the line switch.

Fig. 13 shows the front view of a solenoid-type starter very similar to the one just described. The spring contact-fingers which cut out the armature resistance are slightly different on this starter than on the bar and spring type illustrated in the dia-

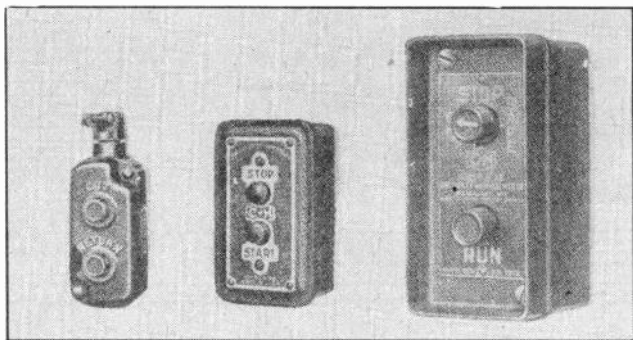


Fig. 14. Several types of push-button stations used with automatic remote controllers.

gram, but their electrical principle is identically the same.

### 23. DASH-POTS FOR TIME DELAY ON CONTROLLERS

Fig. 15 illustrates the principle of the dash-pot timing device used with many automatic starters. When the plunger rod "R" is drawn up by the sole-

## Direct Current

noid, the piston on the lower end of this rod lifts the oil by the suction of the piston and forces it

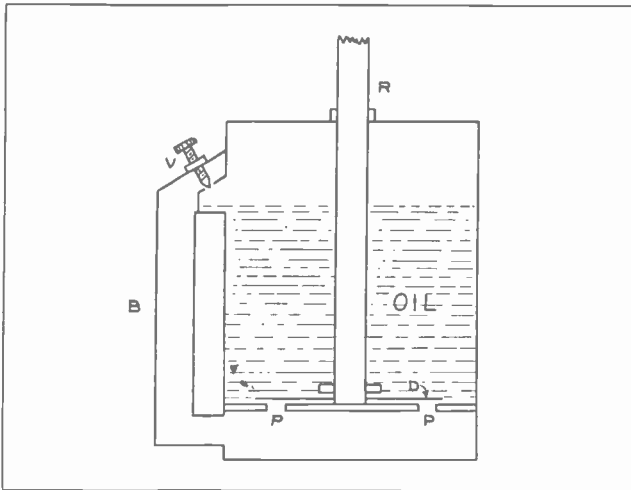


Fig. 15. The above sketch illustrates the principle of an oil dash-pot used as a time control on motor starters.

through the needle valve "V", and around into the lower part of the cylinder.

The speed with which the plunger will rise can, therefore, be adjusted by means of the screw of the needle valve, which will allow the oil to pass more or less rapidly through this opening.

During the period that the piston is lifting against the oil, the disk "D" holds tightly against the openings or ports at "P" in the piston. When the line switch is opened or the stop button is pressed, allowing the plunger to fall, the pressure on the under side of the piston forces the disk "D" to open the ports at "P," and allows the plunger to fall very rapidly.

This dash-pot time-delay device should be carefully adjusted, according to the load on the motor and the time required for the motor to accelerate this load to full speed.

## Starters and Controllers

### EXAMINATION QUESTIONS

1. Why are motor starters necessary on D. C. motors larger than  $\frac{1}{4}$  H. P.?
2. What is the average amount of time required to bring a medium sized motor up to full speed?
3. How many Watts power loss would there be in a field rheostat of 125 ohms, if the field current is 2 amperes?
4. Will the motor speed increase or decrease when the shunt field resistance is increased? Why?
5. Give three advantages of field resistance speed control over armature resistance speed control.
6. Why is the holding magnet coil as shown by Fig. 4 connected in series with the motor field?
7. Which type of starter would you select for use in cases where a motor must be started very slowly?
8. How are the switch arms operated on an automatic starter?
9. What advantage is there in using remote control starters?
10. What two advantages are there in using the economy coil resistance?

## MAGNETIC STARTERS

The term **magnetic starter** is commonly used to apply to starters on which the operation depends almost entirely on relays, although they may have either a solenoid or an electro-magnet for overload protection.

Controllers of this type have a number of separate contactors, each operated by its own electro-magnet. These contactors and their circuits are so arranged that they operate in succession, and thus gradually short out resistance from the motor armature circuit.

Controls of this type are used very extensively on large industrial motors, steel mill motors, elevator motors, etc.

On medium-sized motors, the controller mechanism and contactors are often assembled inside the metal box or cabinet. For very large motors the contactors and magnets are usually assembled on a panel similar to a switchboard, and the resistance grids or elements are generally located at the rear of this panel, either on the floor or in a special rack above.

Fig. 10 shows a diagram of a magnetic controller. This controller operates as follows:

After closing the line switch, either of the start buttons at the remote control stations can be pressed to close a circuit through the remote control relay "A," as shown by the small dotted arrows.

This relay magnet then attracts its double armature and closes contacts 1 and 2. Contactor 2 completes a holding circuit through relay "A" in series with the stop switches of the remote control stations. This circuit is shown by the small solid arrows.

The same contactor, No. 2, also completes a circuit through relay "B," as shown by the small curved arrows.

The current for this relay passes through the lower portion of the armature resistance and doesn't close contactor 4 immediately. Current for coil "B" is limited by the voltage drop in the armature resistance.

## Magnetic Starters

Contactor 1, which was operated by relay "A," closes a circuit through the overload release coil, "O. L.," to the motor terminal "M," as shown by the large dotted arrows. At this point the current divides and passes through both the armature and field circuits in parallel, and through the controller back to the negative line wire.

The armature current shown by the solid black

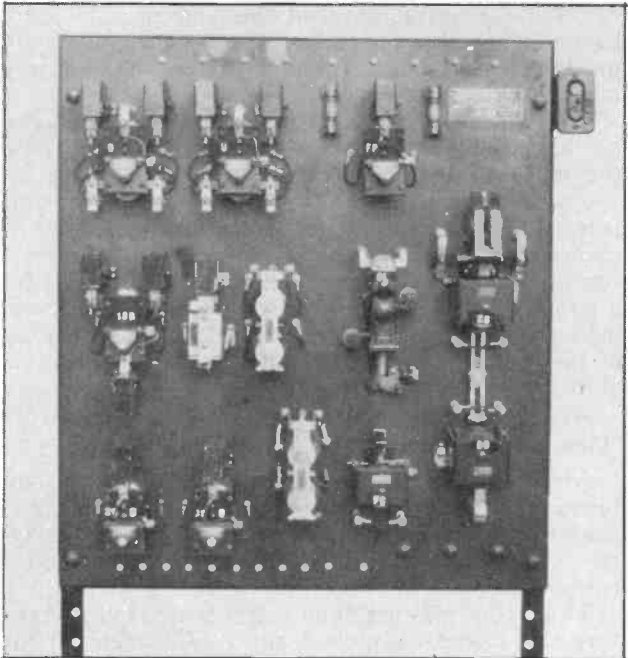
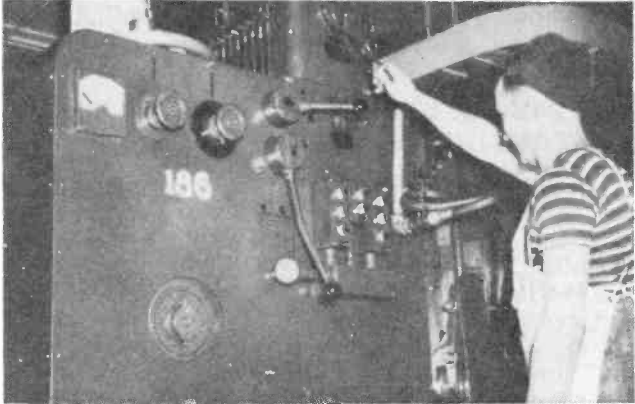


Fig. 1. This photo shows the manner in which the magnetic contactors of industrial controls of the larger type are often mounted on an open panel.

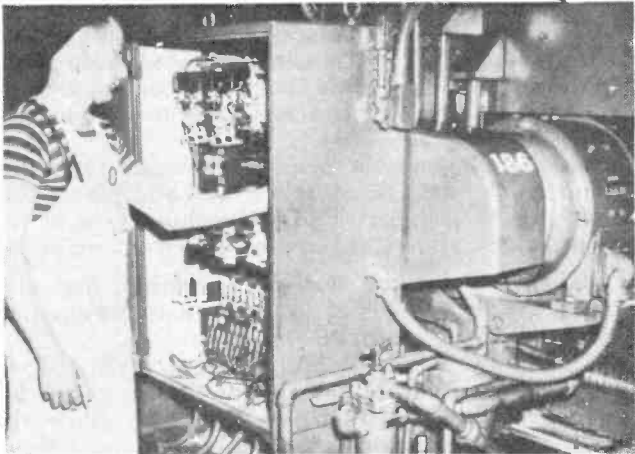
arrows returns through the terminal "A-1" on the controller, through the winding of relay "F" and armature starting resistance in parallel. This current divides through the relay winding and armature resistance in proportion to the resistance of each path. As the relay winding is of much higher resistance than the armature resistance unit, most of the current will pass through the armature resistance and back to the line. However, enough

## Direct Current

current flows through the winding of relay "F" to cause it to become energized and close contactor 3, which short circuits the field rheostat, "F R," cutting this resistance out of the shunt field circuit of the motor.



▲ The many motions on this traveling-head milling machine are controlled, from one position, by oil-proof push-button stations mounted on the machine within convenient reach of the operator. While the magnetic control is located at the back, in out-of-the-way space, it is nevertheless convenient for inspection and maintenance.



▼ The armature resistance used with this controller performs the same function as with any other type,

## Magnetic Starters

namely that of causing a voltage drop and reducing the current flow through the motor armature during starting.

When contactor 3 is closed, the shunt field of the motor is connected directly across full line voltage, thus allowing the shunt field to receive full strength current and produce the good torque necessary for starting.

### 1. TIME OF STARTING DEPENDS ON STARTING CURRENT

We recall that relay "B" didn't energize when the circuit through its coil was first closed because it is in series with about one-third of the armature resistance. Therefore, as long as the heavy starting current is flowing through this armature resistance and causing considerable voltage drop, part of that voltage drop being in series with the coil of relay "B," limits its current and prevents it from becoming strong enough to close its armature.

As the motor comes up to speed and develops counter-E. M. F., thereby reducing the starting current through the armature resistance, this will also reduce the voltage drop through that section of the resistance which is in series with coil "B." This allows the current through coil "B" to increase slightly and causes it to close contactor 4. When this contactor closes it places a short circuit on the coil of relay "F," which can be traced from X to X-1, and X-2 to X-3. This shorts the current around the coil of relay "F" and causes it to de-energize and release contactor 3.

When this contactor opens, it releases the short circuit on the field rheostat, "F. R." and places this resistance back in series with the shunt field of the motor. This allows the motor speed to make its final increase for the starting operation, and also allows the field rheostat to be used for regulating the speed of the motor.

Contactors 4 is adjustable and can be set to pull in on any desired voltage within the range of this controller. By adjusting the screws to allow the relay armature to normally rest farther away from the core, it will require a higher voltage to operate this contactor.



## Direct Current

This means that the motor will have to reach a little higher speed, develop more counter-E. M. F., and further reduce the starting current flowing

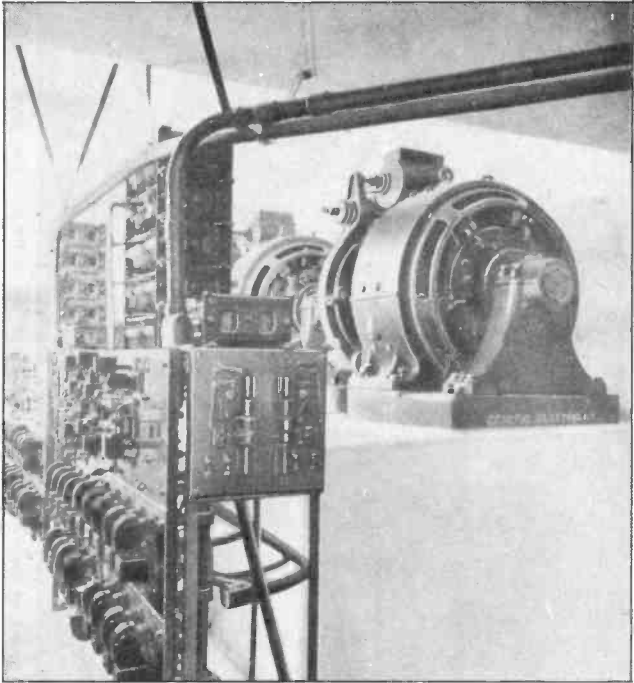


Fig. 2. Photo of the control panels for a group of elevator motors. Note the contactors on the face of the panel and the resistance grids located above.

through the armature resistance, and thereby reduce the voltage drop, allowing a higher voltage to be applied to the coil of relay "B" before it will operate.

When this relay does operate, it short-circuits the armature resistance completely out of the motor circuit by providing a path of copper around the resistance from X-1 to X-2. So we find that the time delay on this relay and controller depends upon the reduction of the starting current through the motor armature and the armature resistance of the controller.

Therefore, if the motor is more heavily loaded at one time of starting than at another and requires

## Magnetic Starters

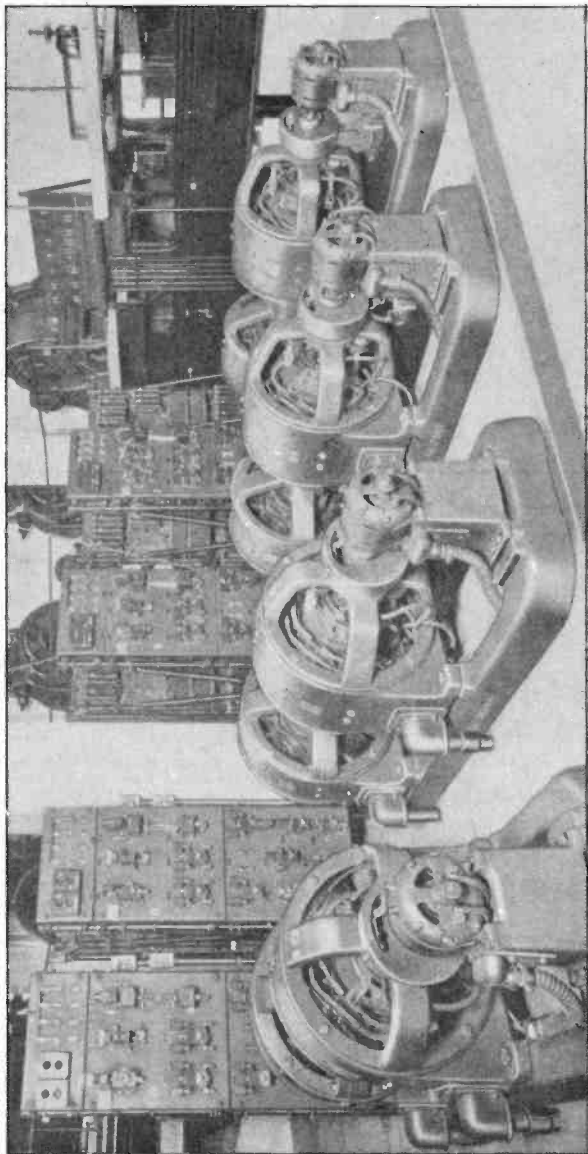


Fig. 3. This view shows the control panels for a group of modern elevator machines of the motor-generator type. The magnetic contactors on these panels are operated by remote control from the elevator car.

## Direct Current

longer to come up to full speed and develop the proper counter-voltage, this controller will automatically leave the armature resistance in series that much longer. For this reason it is a very practical and dependable type of control.

After the motor is up to full speed and the controller starting operation completed, the armature current will then be flowing through the circuits as shown by the square dots.



The full-voltage magnetic starter used on this metal saw is controlled from a push-button station located at the operator's hand. The complete metal enclosure protects the switch itself from metal chips, and the operator from live parts.

## 2. OVERLOAD PROTECTION

In tracing this circuit you will find that the ar-

## Magnetic Starters

mature current passes continuously through the coil of the overload relay "O. L." as long as the motor is in operation.

The purpose of this overload relay, which is included with many controllers of this type, is to protect the motor from overload, both during starting and while the motor is running at full speed.

The coil of this relay is in series with the motor armature and therefore consists of a very few turns of heavy conductor capable of carrying the full armature current for indefinite periods.

If an overload is placed on the motor, thereby increasing its armature current, the increased current will increase the strength of the coil of the overload-relay solenoid.

This will cause it to draw up the plunger "P" slowly against the action of the oil in the dash-pot "T." This dash-pot can be so adjusted that it will require more or less time for the plunger to complete its upward stroke, and so that an overload which only lasts for an instant does not raise the plunger far enough to stop the motor.

The dash-pot is often called an inverse time limit device, because the time required to draw up the plunger is inversely proportional to the current or amount of overload on the motor. A severe overload increases the strength of the coil to such an extent that the plunger will come up very quickly.

If the overload remains on the motor, the plunger will be drawn up completely until it strikes the overload-trip-contact, "O. L. T." This opens the circuit of the relay coil "A," allowing it to release both its armatures and contactors 1 and 2.

When contactor 1 is opened, it disconnects the motor from the line, and 2 breaks the holding circuit of coil "A," requiring it to be closed again, by means of the start buttons, after the overload on the motor is removed.

### 3. "BLOW-OUT" COIL

The magnetic blow-out coil, "B. O." is for the purpose of providing a strong magnetic flux for extinguishing the arc drawn at contactor 1 when the motor circuit is broken at this point.

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The action of this blow-out coil is purely magnetic. The few turns of which it consist are wound on a small iron core, which has its poles placed on either side of the contacts where the circuit will be broken. This provides a powerful magnetic field at the exact point where an arc would be formed when the circuit is broken by this contactor.

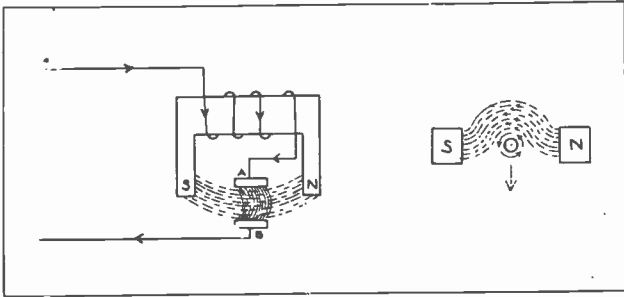


Fig. 4. The above sketch illustrates the principle by which the magnetic blow out coil extinguishes arcs on controller contacts.

As the arc is in itself a conductor of electrical current and has a magnetic field set up around it, this field will be reacted upon by the flux of the blow-out coil and cause the arc to become distorted or stretched so that it is quickly broken or extinguished. This prevents the arc from lasting long enough to overheat and burn the contacts to any great extent.

Regardless of the extent of the overload, the magnetic blow-out coil is very effective, because the entire load current of the motor flows through its turns and its strength is therefore proportional to the current to be interrupted at any time.

Fig. 4 illustrates the principle and action of this blow-out coil on an arc drawn between two contacts which are located between the poles of the magnet.

In the view at the left, the solid lines between the contacts "A" and "B" represent the arc and the current flowing through it, while the dotted lines between the magnet poles represent the strong flux which is set up by them.

In the view at the right, the circle and dot represent an end view of the arc, and the direction of the flux around the arc is shown by the three ar-

## Drum Controllers

rows. The dotted lines show the magnetic flux from the poles of the blow-out magnet.

By noting the direction of this flux and that around the arc, we find that the lines of force will tend to be distorted as shown, and will stretch the arc out of its normal path in the direction shown by the dotted arrow.

The circuit of a controller such as shown in Fig. 10 may at first seem rather complicated, but you will find after carefully tracing through each part of it several times, that its operation is exceedingly simple. It is by tracing such circuits as these, that you will be able to fully understand the operation of controls of this type and become competent in testing their circuits to locate any troubles which may develop in them.

This diagram and the explanation given in the accompanying paragraphs are, therefore, well worth thorough and careful study.

The controller shown in Fig. 10 uses a field rheostat for controlling the speed of the motor. This rheostat can be adjusted, or set at various points, by hand.

### 4. DRUM CONTROLLERS

Drum controllers are very extensively used in the operation of D.C. motors where it is required to be able to start, stop, reverse, and vary the speed of the motors. The name **Drum controller** comes from the shape of this device, and the manner in which the contacts or segments are mounted on a shaft or drum. This cylindrical arrangement of the contacts is made in order that they may be rotated part of a turn in either direction and brought into connection with one or more sets of stationary contacts.

Drum controllers are usually manually operated and can be provided with almost any number and desired arrangement of contacts. **Drum controls are extensively used for controlling the motors used on street cars and electric trains, cranes, hoists and machine-tool equipment, where it is necessary to be able to reverse and vary the speed of the motors.**

### 5. OPERATION OF SIMPLE DRUM CONTROL

Fig. 6 shows a very simple form of drum con-

## Direct Current

trol and illustrates the manner in which the movable drum contacts can be used to short out the armature resistance step by step from the motor cir-

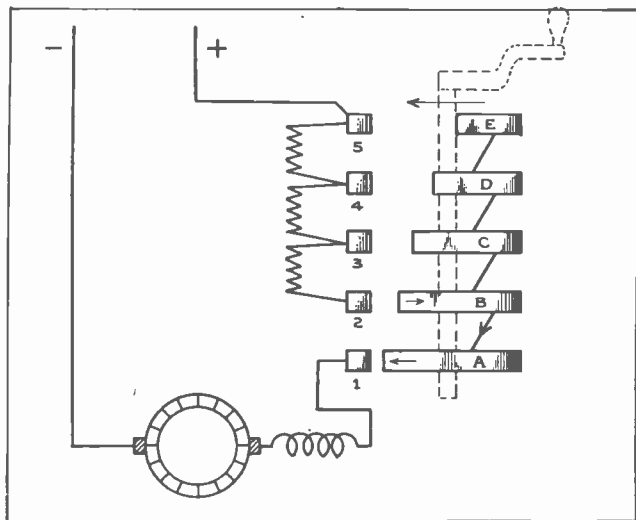


Fig. 6. Simple drum controller showing the method in which the contacts and segments cut out the armature resistance when starting the motor.

cuit. When the drum shown in this figure is rotated the first step and brings the movable segments, "A" and "B" into connection with the stationary contacts, current will start to flow through the entire set of resistance coils, through segments "B," and the jumper which connects it to "A," through segments "A" to contact 1; then through the motor armature and back to the negative side of the line.

When the drum is rotated another step to the left, segment "C" touches contact 3, and as "C" is connected to "B" by the jumper, this short circuits the resistance between contacts 3 and 2.

Rotating the drum two more steps will short out the remaining two sections of resistance in the same order. Thus a simple drum-control can be used to gradually cut out the resistance as the motor comes up to full speed.

By making the resistance elements large enough to carry the motor current continuously, and the drum contacts and segments of heavy copper so

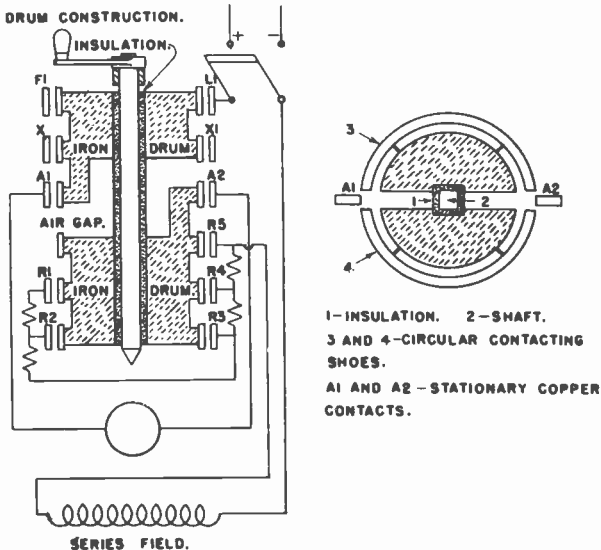
## Drum Controllers

they can stand the arcing and wear caused by opening and closing the motor armature circuit, this type of drum controller can be used for speed-regulating duty as well as for starting.

The motor used with this controller in Fig. 6 is a straight series motor similar to the type used on street cars and traction equipment.

### PRINCIPLES OF DRUM TYPE CONTROLLERS.

Drum controllers are extensively used to handle heavy loads such as, Street cars, hoist and crane operation. The name is derived from the fact that the movable contacts are mounted on a cylindrical metal drum as shown in sketch below. The movable part of the controller consists of an iron drum with copper contacts mounted the surface. These contacts complete a connection with stationary contacts when the drum is rotated. A fibre collar surrounding the shaft insulates the movable drum from the shaft and controller handle.



This type of controller, relatively simple and rugged in construction, may be designed to perform a variety of control functions not readily obtainable



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in motor controllers of other types; moreover, the durable and simple design lessens maintenance troubles.

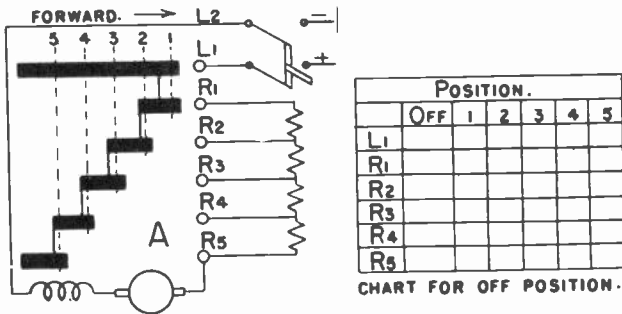
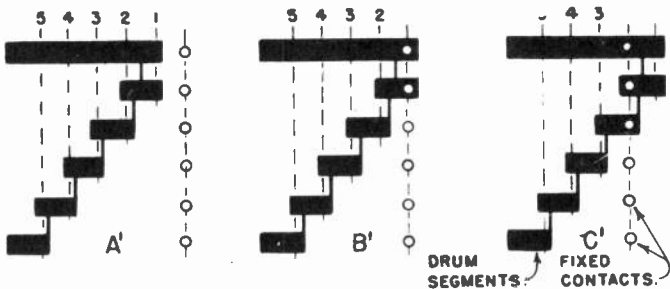


Figure A shows a drum type controller designed for starting a simple series type motor. As the drum segments, shown by the heavy black lines, move to the right, a connection is made from the line wire L<sub>1</sub>, through to R<sub>1</sub> and then through the starting resistor and motor to the other line wire L<sub>2</sub>. As the drum is revolved, positions number 2, 3, 4, and 5 are passed through, thereby cutting out the series resistance and connecting the motor directly across the line.

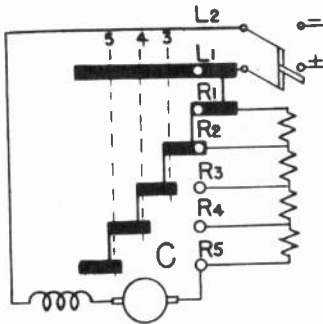


Analysis of the controller action may be made on one of two methods; either the contacts on the movable drum may be visualized as moving from left to right as the drum is moved forward; or the stationary contacts—shown by the small round circles—may be regarded as moving right to left. Either method of analysis may be used. Diagram A,



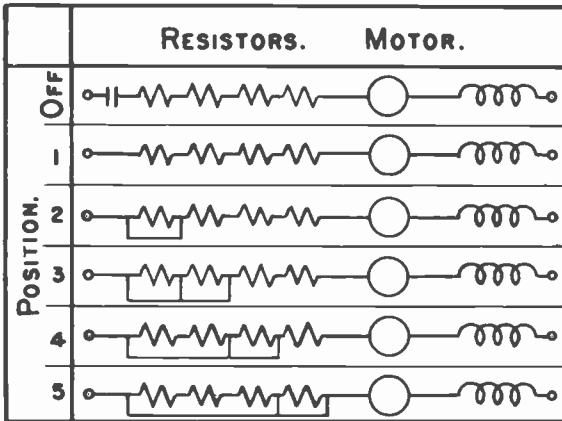
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The connection chart indicates the change in electrical connections as the controller is moved through the different positions. Note how the re-



		POSITION.					
		OFF	1	2	3	4	5
L1		●	●				
R1		●	●				
R2			●				
R3							
R4							
R5							

CHART FOR SECOND POSITION.



**CONNECTION CHART.**

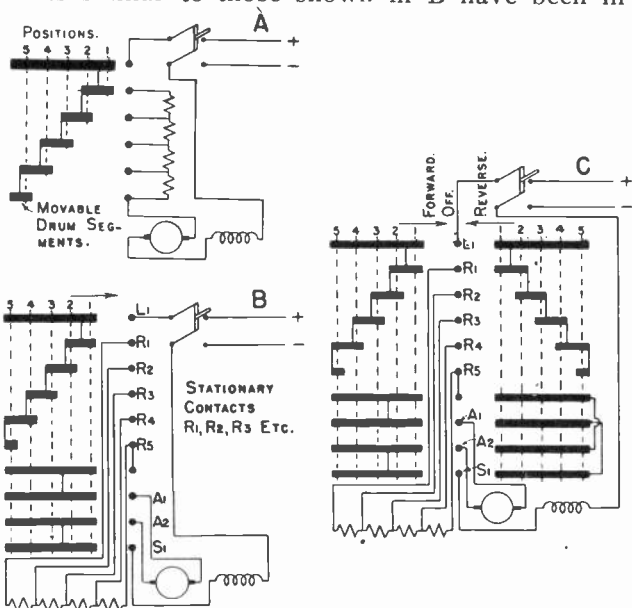
sistors are short-circuited or bridged as the controller is carried through the various positions.

The drum type controller designed for reversing duty is provided with the extra drum segments and stationary contacts necessary to reverse the armature connections. As the controller handle is moved from the OFF position, current is passed thru the armature in one direction; moving from OFF in the opposite direction reverses the armature current and the motor rotation.

Comparison of diagrams A, B, and C will show how the simple controller shown in A is converted to the reversible type shown in C.

## Drum Controllers

Figure A shows the simple controller. In B extra drum segments and stationary contacts have been added to permit reversal of the armature connections. Fig. C shows that an extra set of drum segments similar to those shown in B have been in-



stalled on the opposite side of the drum thereby producing a reversing type drum controller.

**CONTROL SEQUENCE TABLE.**

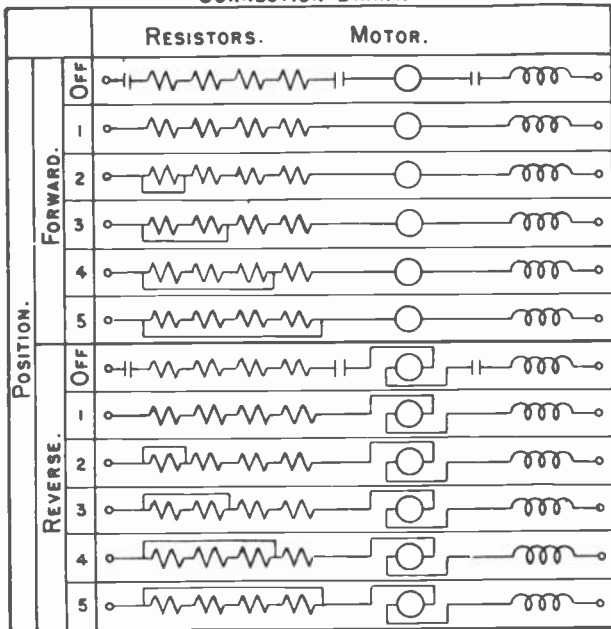
CON-TACTS.	FORWARD. →					OFF.	← REVERSE.				
	5	4	3	2	1		1	2	3	4	5
L1	●	●	●	●	●		●	●	●	●	●
R1				●	●		●	●			
R2			●	●			●	●			
R3		●	●					●	●		
R4	●	●							●	●	
R5	●	●	●	●	●		●	●	●	●	●
A1	●	●	●	●	●		●	●	●	●	●
A2	●	●	●	●	●		●	●	●	●	●
S1	●	●	●	●	●		●	●	●	●	●

The Control Sequence Table shows the order in which contact is established between the various drum segments and stationary contacts as the con-

## Direct Current

troller is moved through the different positions, while the chart below indicates the electrical connections made on each position.

**CONNECTION CHART.**



### 6. REVERSING ROTATION OF MOTORS

We have learned that, in order to reverse a D.C. motor, it is necessary to reverse either the field or the armature current, but not both. Some controllers are connected to reverse the field of a motor, while others reverse the armature. On ordinary shunt motors the field is usually reversed, but with compound motors it is necessary to reverse both the shunt and series field if this method of reversing the motor is used.

So, for motors of this type, it is common practice to reverse the armature and leave both the shunt and series fields remain the same polarity. To reverse the armature leads will require only half as many extra contacts on the controller as would be required to reverse both the series and shunt field leads.

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When the direction of rotation of a compound motor is changed by reversing the field, both the series and shunt field leads should always be reversed; because if only one of these fields were reversed the motor would be changed from cumulative to differential compound.

Fig. 7 shows the manner in which a simple double-pole, double-throw, knife switch can be used to reverse a shunt motor by reversing the connection between the field and the line.

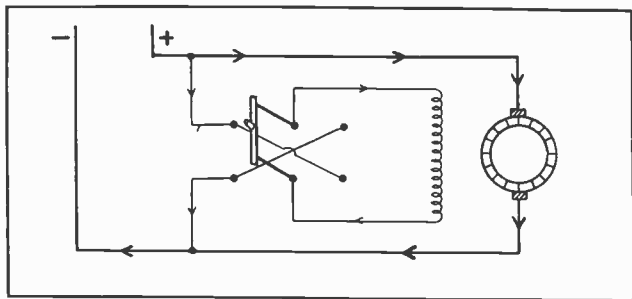


Fig. 7. The above sketch shows the manner in which a motor can be reversed by reversing its field with a double-pole, double-throw knife switch.

When switch blades are closed to the left, current will flow through the shunt field in the direction shown by the arrows. If the switch is thrown to the right, the current will flow through the field in the opposite direction, as can readily be seen by tracing the circuit through the crossed wires between the stationary clips. This same switching method can, of course, be used to reverse the connections of the armature to the line, if desired. This reversing switch effect can be built into a drum controller by the proper arrangement of its contacts.

### 7. REVERSING DRUM SWITCHES

Fig. 8 shows a simple reversing drum-control used for reversing the direction of current through the armature only. This diagram doesn't show the starting resistance or contacts, but merely illustrates the principle or method by which several of the contacts on a drum controller can be used for a reversing switch.

The drum control shown in Fig. 8 has one set of stationary contacts—A, B, C, and D, and two sets

## Direct Current

of moving segments or contacts, Nos. 1 to 8. These two sets of moving contacts are mounted on the same drum and both revolve at the same time, but in diagrams of this sort these parts are shown in a flat view in order to more easily trace the circuit.

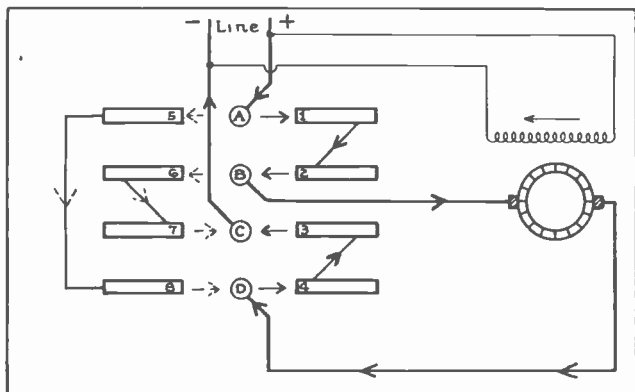


Fig. 8. Drum control with the contacts arranged to reverse the direction of current through the armature and thereby reverse the motor.

If the drum contacts are moved to the left, the movable contacts 1, 2, 3, and 4, will be brought into connection with the stationary contacts A, B, C, and D. The current flow through the armature can then be traced by the solid arrows, from the positive line wire to stationary contact "A," movable segment 1, through the jumper to movable segment 2, stationary contact "B," through the armature in a right-hand direction, then to stationary contact "D," movable segment 4, through the jumper to movable segment 3, stationary contact "C"; and back to the negative line wire.

If the drum contacts are moved to the right, the movable segments 5, 6, 7, and 8 will be brought into connection with the stationary contacts, and the armature current will then flow as shown by the dotted arrows. The field of the motor is left the same polarity and only the armature circuit is reversed. If the field and armature of a motor were both reversed at the same time, the direction of rotation would still remain the same.

### 8. REVERSING DRUM CONTROLLERS

Fig. 9 shows the circuit of a drum controller

## Drum Controllers

which is used for starting a D.C. motor, as well as for reversing duty. This controller has two sets of stationary contacts and two sets of movable segments. The diagram also shows the armature resistance used for starting the motor and while it is being brought up to speed. The contacts and parts of this drum are also laid out in a flat view in the diagram.

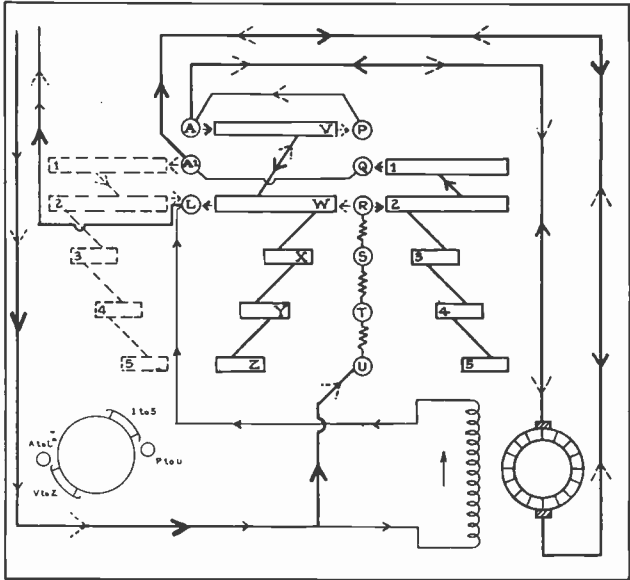


Fig. 9. Wiring diagram of a drum controller for starting and reversing shunt motors.

The two sets of movable segments are arranged on opposite sides of the drum, as are the stationary contacts. This is illustrated by the small sketch in the lower left-hand corner, which shows from a top view the position of the contacts at the time segments 1 to 5 are approaching the stationary contacts, "P" to "U."

Now, suppose we move the drum of this controller so it will shift both sets of movable segments to the left in the flat diagram. The first step of this movement will bring movable segments 1 and 2 into connection with stationary contacts "Q" and "R," and will also bring segments "V" and "W" into connection with stationary contacts "A" and



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“L.” A circuit can then be traced, as shown by the solid arrows, from the positive line wire to stationary contact “U,” through all of the armature resistance to stationary contact “R,” movable segment 2, through the jumper to movable segment 1, stationary contact Q to stationary contact A-1; then through the motor armature, back to stationary contact “A,” movable segments “V” and “W,” stationary contact “L,” and back to the negative side of the line.

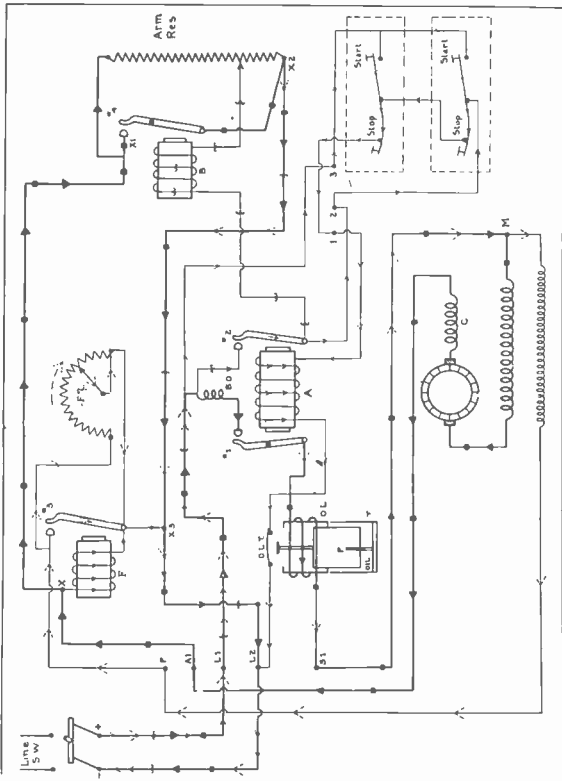


Fig. 10. This diagram shows the complete wiring of a modern magnetic type controller. You will find it very interesting and exceedingly well worthwhile to trace each circuit and obtain a thorough understanding of the operating principles of this starter.

NOTE: This diagram should be copied on a large sheet of paper and closely followed as the lesson is studied from pages 1 to 10. All circuits should be carefully traced and marked.

As we advance the controller still farther in this same direction, the successive steps will bring movable segments 3, 4 and 5 into connection with stationary contacts “S,” “T,” and “U,” thus gradually

## Drum Controllers

shorting out the armature resistance step by step.

When the controller has been moved as far as it will go in this direction and all armature resistance has been cut out, the circuit is from the positive line wire to stationary contact "U," movable segment 5, through the jumpers and segments to movable segment 1, stationary contact Q and on through the armature and back to the negative side of the line.

You will note that the movable segments 1 and 2, and "V" and "W" are all of sufficient length to remain in connection with the stationary contacts as they slide around and allow the step by step movement which brings the larger segments into connection with their stationary contacts

To reverse the motor, we will now move the controller in the opposite direction, which will bring the movable segments 1 to 5 clear around on the opposite side to the position shown by the dotted segments, 1 to 5; and the movable segments "V" to "Z" will be brought into connection with stationary contacts "P" to "U."

Before attempting to trace the circuit, get well in mind the position of these movable segments in this new location. Another reference to the circular sketch in the lower corner of the figure will help you to see the manner in which the movable segments are brought up on the opposite side of the stationary contacts as the drum is revolved in the opposite direction.

We now find that, on the first step of the drum movements, the movable segments "V" and "W" will be brought into connection with the stationary contacts "P" and "R," and the movable segments 1 and 2 (dotted) will be brought into connection with stationary contacts "A-1" and "L."

We can now trace a circuit through the armature, as shown by the dotted arrows, from the positive line to stationary contact "U," through the full armature resistance to stationary contact "R," the movable segments "W" and "V," stationary contacts "P" and "A"; then through the armature in the opposite direction to what it formerly flowed, and back to stationary contact A-1; then through movable segments 1 and 2 to negative line terminal "L."

## Direct Current

As the controller is advanced step by step in this direction, the movable segments "X," "Y," "Z" will cut out the armature resistance as the machine comes up to speed. In this position the movable segments 3, 4, and 5 will be idle.

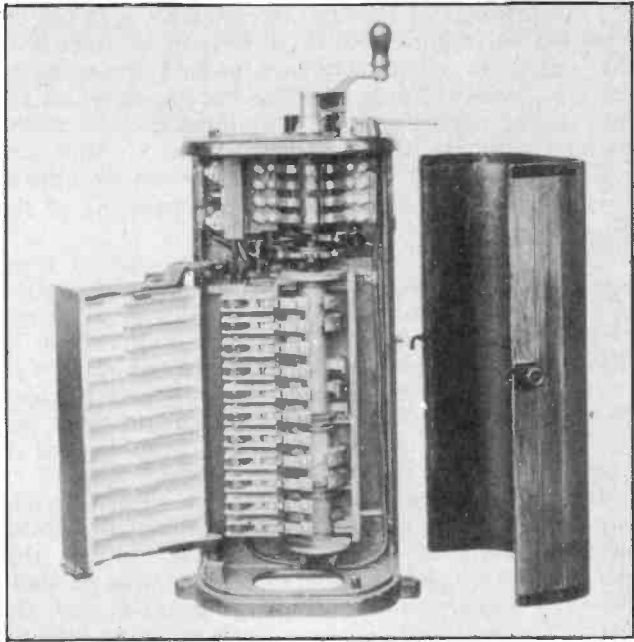


Fig. 11. The above photo shows the mechanical construction and arrangement of parts of a modern drum control. Note the flash barriers on the inner cover which is shown opened to the left.

The shunt field connections of this motor are left the same, so its polarity will remain the same at all times. Trace this diagram carefully until you are able to trace the circuit very readily in either direction or position of the control. A good knowledge of the principles and circuits of these controllers will be of great help to you in the selection of the proper controller for various applications in the field, and also in locating troubles which may occur in controllers of this type or the resistance attached to them.

## Drum Controllers

### 9. CONSTRUCTION OF DRUM CONTROLS

Fig. 11 shows a photo of a drum controller with the cover removed so that all of the parts can be quite clearly seen. The movable segments are made of copper and are attached to the shaft or drum, which is operated by the crank or handle.

The stationary contacts are in the form of fingers with flat springs to hold them in good contact with the segments when they are passed under these fingers. You will note that the copper shoes of the rotating segments and the individual fingers or stationary contacts are both removable, so they can easily be replaced when they are worn or burned by arcing which occurs during the operation of the controller.

These contacts should always be kept in good condition in order to assure the proper operation of the motor to which the controller is attached. At the left of the stationary contact fingers, can be seen a row of blow-out coils all of which are in series with their respective contacts and circuits. These blow-out coils, as previously mentioned, are for the purpose of extinguishing the arc drawn when the circuits are broken at the contacts.

The inner hinged cover, which is shown swung out to the left, is simply an assembly of boards or barriers made of fireproof material. When this group of barriers is swung into place, one of them comes between each stationary contact and the next. The purpose of these barriers is to prevent a flash-over or short-circuit between adjacent contacts.

This particular drum controller has a separate set of reversing contacts mounted in the top of the case and operated by a separate small handle, which is shown at the right of the main crank.

In addition to the function of starting, reversing, and varying the speed of motors, some controllers are also equipped with extra contacts for short circuiting the armature through a resistance, in order to provide what is known as **dynamic braking**.

This form of braking, which is frequently used to stop large motors, operates on the principle of a generator, using the counter-voltage generated in the armature to force a current load through the dynamic brake resistance. This method provides a

## Direct Current

very effective and smooth braking, and will be explained more fully in later paragraphs.

### 10. DRUM CONTROL FOR REVERSING AND SPEED REGULATING

Fig. 12 shows a diagram of a drum control which is arranged for starting, reversing, speed-regulating, and dynamic braking duty. This controller has two

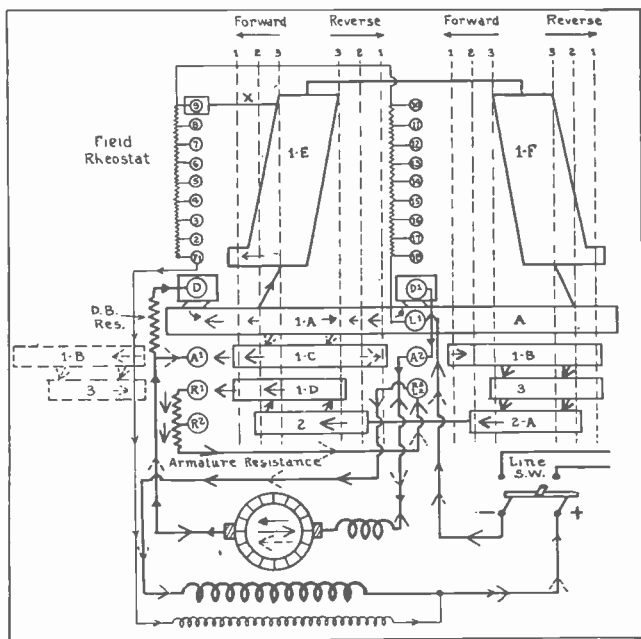


Fig. 12. This diagram shows the wiring for a drum controller used for starting, reversing, and varying the speed of a compound motor.

sets of heavy-duty segments and contacts for the armature circuit, and in the upper section are two sets of smaller contacts which are used in the shunt field circuit, and are short circuited by two large angular segments.

The shunt field resistance, or rheostat, is shown divided into two sections in the diagram; but you will note that the taps made to this resistance run consecutively from No. 1 to 18, and the resistance itself can be located all in one group and have the separate leads brought to the two rows of contacts

## Drum Controllers

as shown. One of the heavy-duty resistances is used for the armature during starting, and the other is used for the dynamic braking.

When this controller is operated in either direction, the first step will close the armature circuit through the armature resistance, and energize the field at the same time, thus starting the motor. As the controller is advanced step by step, the armature resistance will first be cut out and then resistance will be cut in to the shunt field circuit, causing the motor to speed up as much more as desired.

When the controller is in idle position, as shown in the diagram, the motor armature is short circuited by the small movable segments which are now resting on the contacts "D" and "D-1." These contacts are the ones used for the operation of the dynamic brake circuit.

### 11. FORWARD POSITION, STARTING

The long movable segment "1-A" is continuous around the drum and always makes contact with "L-1." When the controller is moved to the left one step, the movable segment "1-B" connects with the stationary terminal "A-2" in the center of the diagram, and the segments "C" and "D" connect with stationary contacts "A-1" and "R-1" at the left of the diagram.

This completes a circuit through the motor armature and full armature resistance, as shown by the larger solid arrows. In tracing this circuit, remember that this first step of movement of the controller will remove the short segments from contacts "D" and "D-1," thus breaking the short circuit on the armature.

The armature circuit which has just been closed can be traced from the positive line wire to "L-1," to the left through segment "1-A," through the jumpers to segment "1-C," then to terminal "A-1," and through the armature in a right-hand direction, on to terminal "A-2," segment "1-B," through the jumpers and segments 3 and 2-A of the right-hand group, through jumpers and segments 2 and 1-D of the left group, then to contact "R-1," through all of the armature resistance, to the contact which is marked "R-3" and "L-2"; then through the series

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field winding and back to the negative side of the line.

This first step or movement of the controller also causes the approaching tip of the large angular segment "1-E" to connect to contact "F-1" and close a circuit directly through the shunt field of the motor, without any resistance in series. This circuit can be traced from the positive side of the line to contact "L-1," segment "1-A," up through jumper to segment "1-E," contact "F-1," and then through the shunt field winding and back to the line.

When the controller is advanced another step, segment 2 of the left group connects with contact "R-2," and cuts out the upper section of the armature resistance. When the controller is moved still another step, segment 3 of the right-hand group connects with the contact which is marked "R-3" and "L-2," and cuts out the entire armature resistance.

By checking the circuit again with the controller in this position, you will find that a circuit can be traced from the line through the controller and the motor armature, back to the line, without passing through the armature resistance.

The dotted lines which run vertically through the controller and are numbered 1, 2, 3 at their top ends, show which segments make connection with the stationary contacts on the first, second, and third steps of either the forward or reverse rotation of the controller.

For example, the dotted lines No. 1 in both forward groups touch only the segments which will connect with the stationary contacts on the first joint of the controller. The dotted lines No. 2 run through the segments which will connect with the stationary contacts on the second step of the controller, etc. The dotted lines in the columns marked "reverse" show which segments make contact in order when the controller is moved in the reverse direction.

So far we have moved the controller only three steps to the left or in the forward direction, and we find that this has cut out all of the armature resistance and brought the motor up to approximately normal speed.

## Drum Controllers

### 12. SPEED CONTROL

During these three steps or movements, the large angular segment "1-E" has been moving across contacts 1 to 9 of the shunt field resistance. These contacts are all shorted together by the segment "1-E," but this makes no difference, because they are not in the field circuit after the first step of the controller.

When the controller is moved the fourth step to the left, the lower end of segment "1-E" will have passed clear across the stationary contacts, and its lower right edge will begin to leave these contacts in the order—1, 2, 3, etc. This begins to cut in resistance in series with the shunt field winding of the motor, thus increasing the speed of the machine as much as desired.

During the time that segment "1-E" has been breaking away from contacts 1 to 9, the segment "1-F" has been moving across contacts 10 to 18; and after the upper right-hand corner, or segment "1-E," has cut in the last step of the resistance from 1 to 9, the segment "1-F" starts to cut in the resistance in the steps from 10 to 18. This gives a wide range of speed variation by means of the shunt field controller. The shunt field circuit is traced with the small solid arrows through the controller for the first position only.

### 13. REVERSE POSITION

To reverse the motor, the controller will be returned to neutral or "off" position, and then advanced step by step in a right-hand direction. As the controller advances the first step in this direction, the right-hand ends of the movable segments will make connections with the groups of stationary contacts opposite to which they were connected before.

This means that segments "1-B" and 3 will have passed around the drum and will approach contacts "A-1" and "R-1" from the left, as shown by the dotted segments "1-B" and 3; and segments "1-C" and "1-D" will approach contacts "A-2" and "R-3" from the left.

With the controller in the first step of this reversed position, current can be traced through the



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armature by the dotted arrows, and we find it is in the reverse direction to what it formerly flowed through the motor armature.

This circuit is traced from the positive line wire to "L-1," segment "1-A," jumpers and segment "1-C" to contact "A-2," and then through the armature to the left, to contact "A-1," segments "1-B" and 3, contact "R-1," through the full armature starting resistance to contact "L-2"; then through the series field in the same direction as before and back to the negative line wire.

In tracing this circuit, we find that the direction of current through the armature has been reversed but that it remains the same through the series field winding. It is necessary to maintain the polarity of the series field the same in either direction of rotation, in order to keep the motor operating as a cumulative compound machine.

If the controller is advanced in the reverse direction, the additional steps will cut out the armature resistance and begin to insert resistance in the shunt field circuit, the same as it did in the former direction

### REVERSIBLE DRUM TYPE CONTROLLER (D.C.)

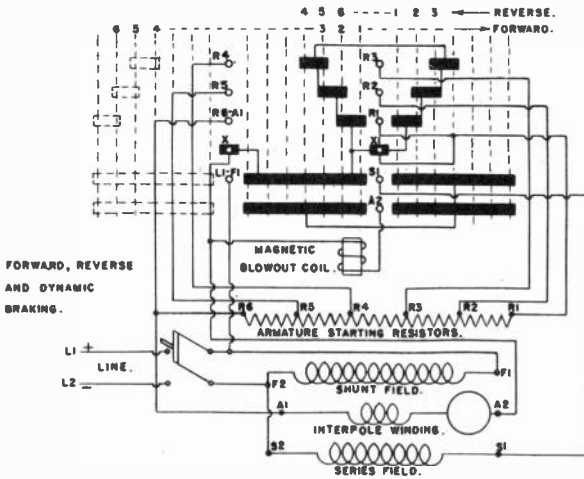
This controller is designed to provide forward or reverse operation, the rotation of the motor being determined by the movement of the controller handle. When the controller is moved to the OFF position, terminals X and X<sub>1</sub> complete the dynamic brake circuit. Notice that the armature starting resistors are in series with the armature when braking to protect the armature against excessive current.

The basic connections effected by the controller are shown in the connection chart below. The OFF section shows the circuit arrangement for dynamic braking, while the remaining sketches indicate how the connections for forward and reverse operation are obtained.

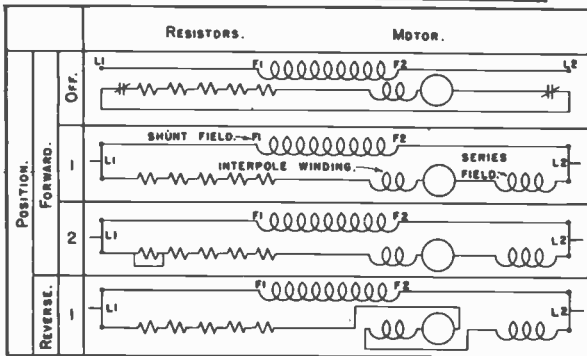
It is important to note that when the armature circuit is reversed for opposite rotation, that the armature and the interpole winding are treated as

# Drum Controllers

## REVERSIBLE DRUM TYPE CONTROLLER. (D.C.)



CON-TACTS.	FORWARD. →						OFF.	← REVERSE.					
	6	5	4	3	2	1		1	2	3	4	5	6
X							●						
X <sub>1</sub>							●						
L <sub>1</sub>													
S <sub>1</sub>													
A <sub>2</sub>													
R <sub>1</sub>													
R <sub>2</sub>													
R <sub>3</sub>													
R <sub>4</sub>													
R <sub>5</sub>													
R <sub>6</sub>													



one unit, the current through both being reversed at the same time. Check the step by step operation of this controller and fill in sequence chart.

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### DYNAMIC BRAKING

As the magnetic reactions between the armature poles and the field poles may be used to rotate the armature of a D.C. motor, it is evident that this same force might be used to stop the machine, provided a reversal of polarity of either the armature poles or the field poles can be brought about while the machine is operating. Such braking action is called dynamic braking.

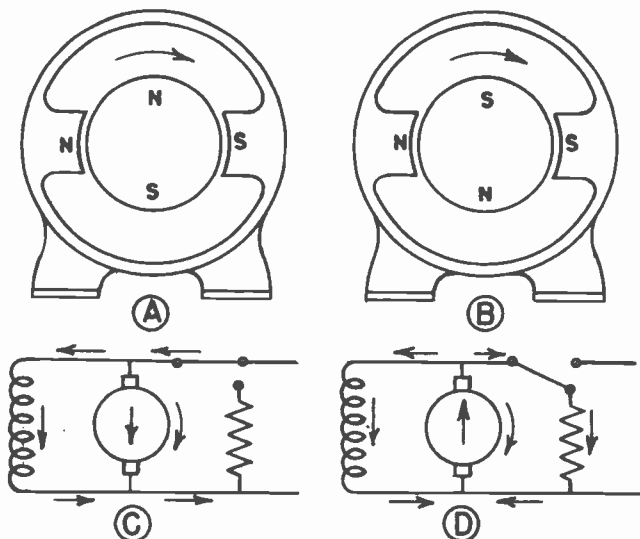


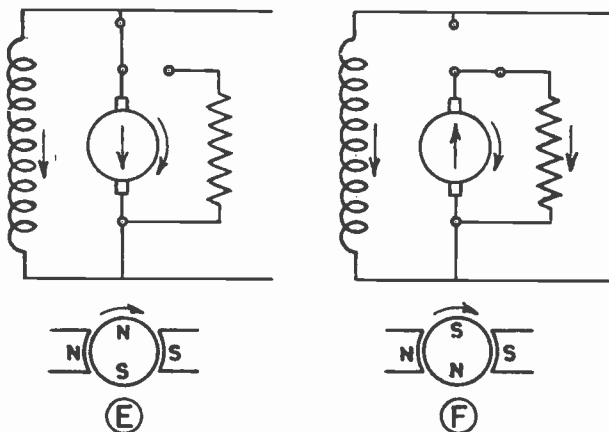
Fig. A shows the rotation and polarity of the motor when connected as in C. Fig. B indicates the operation when connected as shown in D. The machine is still turning clockwise due to its momentum, but the armature poles have reversed and the magnetic action opposes rotation.

Figure A shows polarity and connections on an ordinary shunt motor; note the polarity of the armature poles and the field poles is such as to produce clockwise rotation. Observe also the direction of current flow through armature and field as shown in the connection diagram. Current is flowing down through the armature and down through the field.

In Figure B the motor has been disconnected from the line and a resistance has been connected across the armature. As the armature, due to its

## Drum Controllers

momentum, continues to rotate, the voltage generated in it causes the armature current to reverse; this reverses the polarity of the armature poles as shown in B. This action opposes rotation and tends to bring the motor to a standstill. The armature voltage that produces this reversed armature current is the same voltage that is called a counter e.m.f. when the machine is operating as a motor. What actually happens is that when the switch is thrown down, the machine is changed from a motor to a generator and the energy of momentum in the rotating armature is changed to electrical energy that is dissipated in the external resistor.

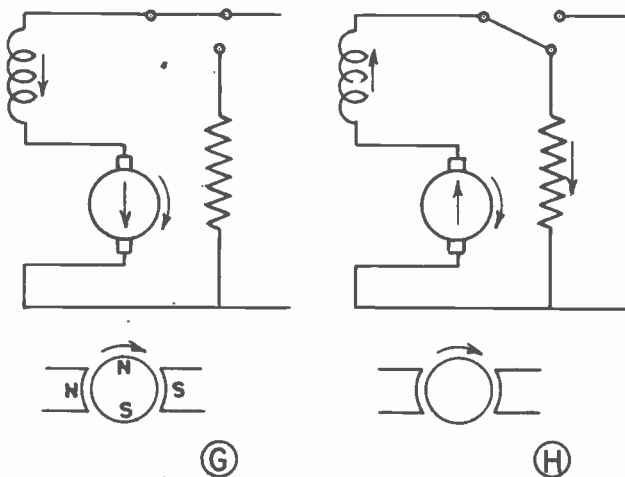


Figures E and F show the usual braking arrangement on a shunt motor. Full strength field is maintained at all times. Note the reversal of armature polarity shown on the right.

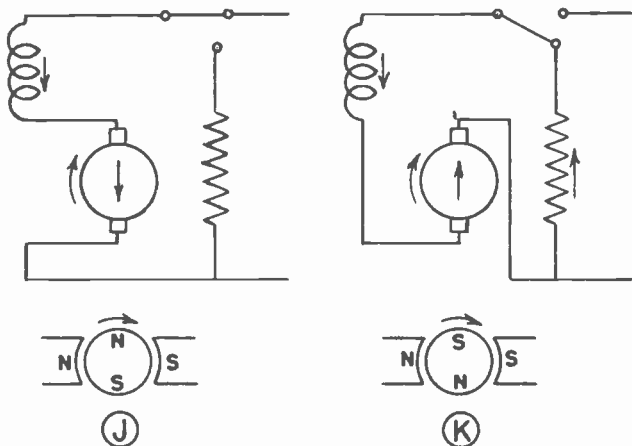
The disadvantage of the arrangement shown in Fig. C and D is that the field poles are weakened as the machine slows down; consequently the braking action diminishes as the speed falls. To overcome this defect, the connection scheme used at E and F is employed. In this case, the field remains permanently connected to the line but the armature is connected to a resistance as before; since the field is maintained at full strength, the dynamic braking action is considerably greater than with the previous arrangement. Note that in both connecting schemes, the direction of current flow through the

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armature is changed, but the direction of field current is unaltered.



Figures G and H show that connecting a resistor across a series motor will not produce dynamic braking. Reversal of armature current demagnetizes the field; result is no polarity and no braking action.

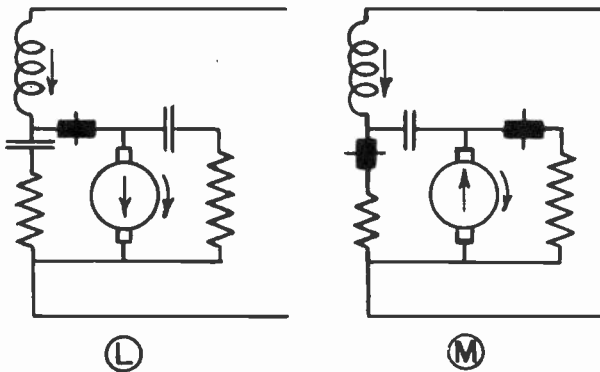


Figures J and K show the connections for dynamic braking on a series motor. Note that the armature connections have been reversed in K to

## Drum Controllers

produce the generator action essential to dynamic braking.

In the series motor dynamic braking cannot be obtained by merely connecting a resistor across the motor as shown in G and H. This is because reversal of the armature current results in a change in direction of the field current also; as a result, the armature current demagnetizes the field and the generator action responsible for the braking is not obtainable. To overcome this, arrangement is made to reverse the armature connections at the same time the braking resistor is connected across the motor as shown in J and K. Note in K that the field current is the same direction as shown in J, but that the direction of current flow through the armature has reversed; consequently the generator action is obtained and braking results. In some applications the same effect is produced by connecting the series field across the supply line (with a suitable resistor in series to limit the current to a safe value) and then connecting a resistance across the armature in the manner shown.



Figures L and M show an arrangement sometimes used on series motors to ensure full strength field during braking. In L the machine is operating as a motor; in M the series field has been connected across the line with a resistor in series and the armature connected to a resistor. This arrangement provides better braking action on series machines.

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When the controller shown in Fig. 12 is brought back to neutral or off position, we find that the short movable segments directly above the long segment "1-A" will be brought to rest on contacts "D" and "D-1," thus short-circuiting the motor armature through the dynamic braking resistance, contact "D," segment "1-A," contact "D-1," and the commutating field.

When the current is shut off from the motor armature by bringing the controller to the "off" position, if the motor is a large one or if the load attached to it has considerable momentum, the motor and machine or car which it is driving, will tend to keep on moving or coasting for some time before coming to a complete stop.

If we leave the shunt field excited during this period, the motor armature will continue to generate its counter-voltage as long as it is turning. Then, if we short circuit the armature through the dynamic brake resistance, this counter-voltage will force a heavy load of current to flow and the coasting motor armature will act as a generator.

We know that it requires power to drive a generator armature; so, when this short or load is placed on the motor armature, the energy of its momentum is quickly absorbed by the generator action, thus bringing the armature to a smooth, quick stop.

The field circuit is left complete when the controller is in the off position and as long as the line switch remains closed. This circuit can be traced from the positive line wire to contact "L-1," segment "1-A," segment "1-E," and the jumper at "X," segment "F D," contact 9 and through one-half of the shunt field resistance, then through the shunt field back to the negative line wire.

This half of the shunt field rheostat is left in series with the field for dynamic braking so that the motor armature will not generate too high a counter-voltage.

The effect of dynamic braking and the period of time in which the motor armature can be stopped

## Drum Controllers

by this method will depend upon the strength of field excitation which is left on the motor when the controller is placed in the off position, and upon the amount of resistance used for dynamic braking.

Fig. 14 shows a simplified connection diagram for a shunt motor equipped with dynamic braking. This diagram shows only the controlling contacts which would be used for dynamic braking alone. The solid arrows show the normal direction of current flow through the armature when it is operating from the line voltage, and with contacts "L-1" and "L-2" closed. During this time the contacts "D-1" and "D-2" are, of course, open.

When this motor is stopped, line contacts "L-1" and "L-2" are opened and contacts "D-1" and "D-2" are closed. The counter-voltage in the armature then sends current through it in the reverse direction, as shown by the dotted arrows.

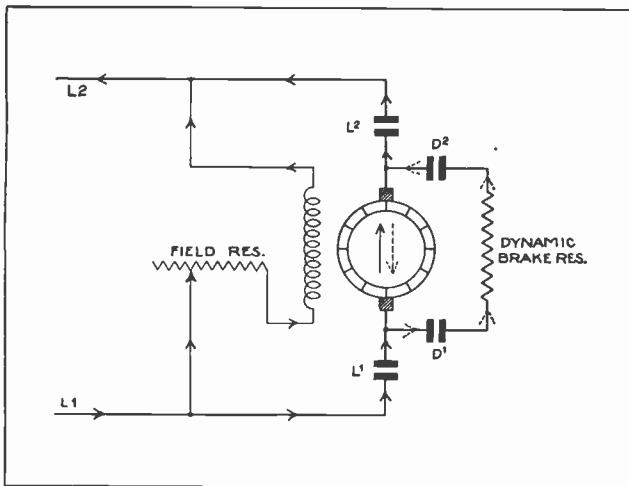


Fig. 14. Diagram showing connections and contacts used for switching a dynamic brake resistance across the armature of a D.C. motor when the line is disconnected.

The shunt field is connected across the line in series with its resistance and, as long as it remains excited, the current in the reverse direction will tend to reverse the rotation of the armature. As the motor armature slows down, the counter-voltage generated becomes less and less, and the



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effect of dynamic braking is reduced.

When the motor armature reaches a complete stop, the voltage on its conductors, of course, ceases to be generated. This results in a sort of cushioning effect and provides one of the smoothest forms of braking which can be used on D.C. motors.

### 15. REGENERATIVE BRAKING

If the armature of a D.C. motor connected to the power line be driven above its normal speed by the mechanical load attached to it, the c.e.m.f. of the motor armature will increase until it is greater than the applied voltage; when this occurs, the motor becomes a generator and feeds power back into the line. As soon as the armature starts to deliver power to the line, an opposition to rotation is set up, and this retarding action may be used to prevent the mechanical load from driving the motor at excessive speeds. This action is called regenerative braking.

This type of braking is frequently used on electric trains, street cars, and on electric cranes and hoists. When an electric car or train, for example, starts down a grade and attempts to rotate its armature rapidly, the motor armature will generate a higher counter-voltage than the applied line voltage.

This will actually force current back into the line, as though this machine were operating in parallel with the power-plant generators.

Regenerative braking effects great savings in power in this manner and in some cases may supply from 10 to 35 per cent of the energy required by all trains on the system.

Dynamic braking on electric railway applications also saves an enormous amount of wear on brake shoes and air-brake equipment, and a great amount of wear and tear in cases where it is used for cranes, hoists, etc.

Neither dynamic braking nor regenerative braking is effective when the machine is at a stop or practically stopped. Therefore, it is necessary to have either mechanical or magnetic brakes to hold the motor armature stationary if there is some load which tends to revolve it, such as the load on a

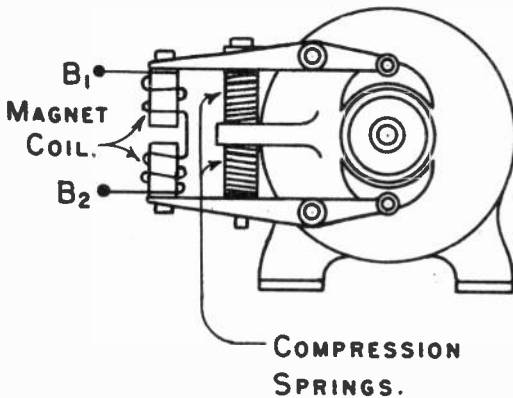
## Drum Controllers

crane or elevator motor, or the tendency of a train to run down a grade.

### HOIST CONTROL

Due to its ability to develop a high starting torque, the series motor is widely used for hoists and cranes. The relatively high torque per ampere which this motor can develop makes possible the lifting of heavy loads with a relatively small motor; moreover, the speed characteristic of the series types is such as to produce rapid acceleration on light load, and this is desirable in crane and hoist applications.

As the control requirements on a crane or hoist are somewhat different from those associated with ordinary power drives, the controlling equipment is a little different from that ordinarily encountered. Fig. A shows the connections made by a simple hoisting controller set in the first hoisting position.

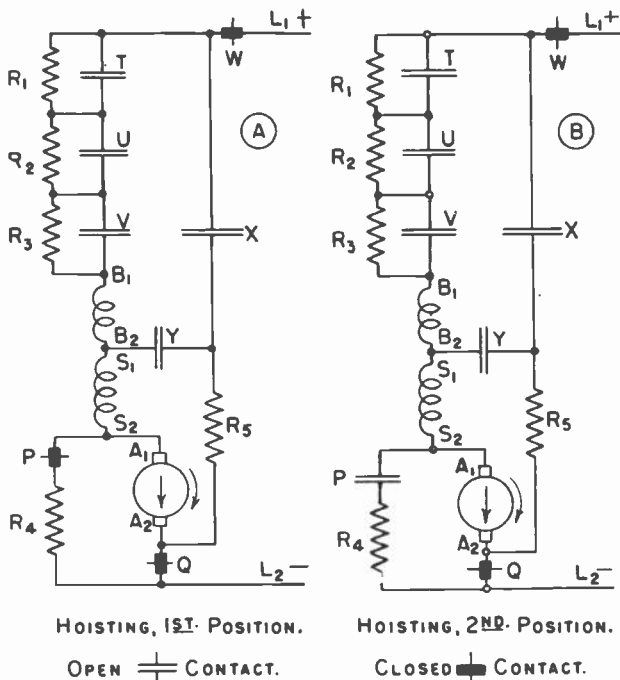


This shows the construction of a magnetically operated mechanical brake. When the magnet coil is energized, the magnet cores move together and release the brake. With the coil deenergized the compression springs set the brake.

Contacts W and Q and P are closed; all the others are open. Under these conditions current will flow from the positive line through closed contact W, through the series resistors R<sub>1</sub> and R<sub>2</sub> and R<sub>3</sub>, through the brake coil B<sub>1</sub>-B<sub>2</sub>, through the series field S<sub>1</sub>-S<sub>2</sub>, and through the armature A<sub>1</sub>-A<sub>2</sub>, and through contact Q back to the negative line. Note

## Direct Current

that resistor  $R_4$  is connected in parallel with the armature; this is done to produce a very low or creeping speed on the first controller position.

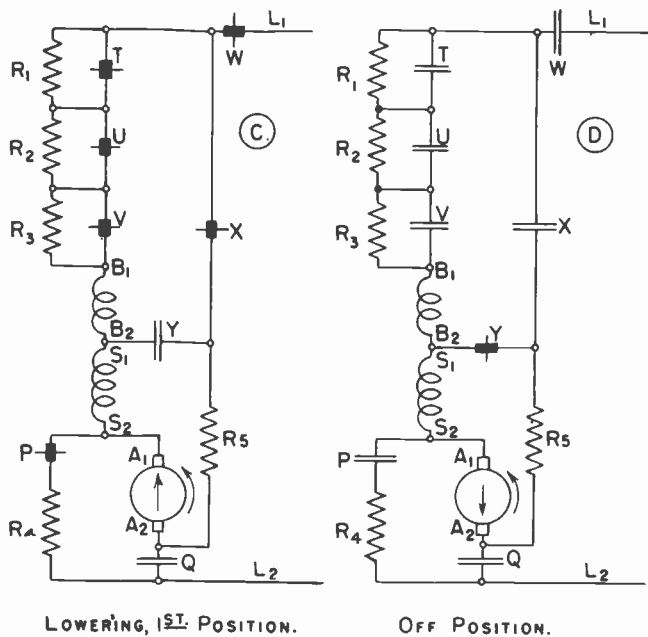


In the second hoisting position (Fig. B) the contactor P is opened and the armature shunting resistor  $R_4$  is taken out of the circuit. The next three steps on the controller short circuit  $R_1$  and  $R_2$  and  $R_3$  by closing contactors T and U and V in that order; the motor is then directly across the line, raising the load at maximum speed.

In the first lowering position, the contacts are closed as indicated in Fig. C. Note that current can now flow from the upper positive lines in two parallel paths; one of these is through contactors T and U and V, the brake coil, the series field, contactor P and resistor  $R_4$  to the negative line; the other is through contactor X, resistor  $R_5$ , the armature  $A_2 - A_1$ , and the resistor  $R_4$  to the negative line. Since

## Drum Controllers

with this connection the armature is in parallel with the field, the machine is now acting as a shunt motor.



Connecting the motor as shown in C has two principal advantages. In the first place, if the load on the crane is zero, the weight of the crane hook may be insufficient to overcome the friction and inertia of the hoisting equipment; consequently the motor has to be connected in a manner that will drive the hook down at a reasonable speed and the connections shown will accomplish this. Furthermore, if the load is heavy and tends to overhaul the motor—that is, rotate the motor armature above normal speed, the machine will act as a generator and deliver electrical power to the line. In this way, regenerative braking is obtained to prevent the load from running away. Speed in the downward direction can be increased by moving the controller and opening contactors T and U and V in order thereby inserting resistance in the field circuit.

## Direct Current

Figure D shows the connections made when the controller handle is moved to the OFF or STOP position. Contactor Y is closed and resistor  $R_5$  connected across the armature; this connection produces dynamic braking if the machine is in motion. Note that the brake coil  $B_1 - B_2$  is not energized which means that the magnetically-controlled mechanical brake is set. If the mechanical brake should fail, the load cannot run away because the connections are such as to then cause the motor to act as a generator with resistor  $R_5$  as a load. The opposition to rotation provided by this generator action acts as a brake and thus prevents excessive downward speeds in the case of failure of the mechanical brake.

Although there are many types of hoist control, the general principles involved will be found to be as above indicated. Some hoist motors may be provided with a shunt as well as a series field, for example, and some controllers may be designed for a wider speed range; nevertheless, the hoist motor is basically a series type, and the control functions are usually designed to include operation as a series motor when hoisting, operation as a shunt motor when lowering, dynamic and regenerative braking, and the use of a magnetically operated mechanical brake that sets automatically in case of power failure.

## Drum Controllers

### EXAMINATION QUESTIONS

1. Briefly describe a magnetic starter.
3. Briefly explain the operating principle of the "Blow-out coil."
3. Are "Drum Controllers" usually manually operated, or automatically operated?
4. Name three kinds of service for which Drum controlled motors are extensively used.
5. What connection changes are necessary in order to reverse the direction of rotation on a D.C. shunt motor?
6. Copy Fig. 7 and trace the circuits through which current will flow when the switch is closed in the right hand position.
7. How is "Dynamic Braking" accomplished on a D.C. motor?
8. Would you consider "Dynamic Braking" desirable or undesirable when smooth reasonably quick stopping is necessary?
9. Name two advantages of "Regenerative Braking."
10. Is Dynamic or Regenerative Braking effective when the motor is standing still? Why?

## Direct Current CARBON BRUSHES

The brushes play a very important part in the operation of any D. C. motor or generator, and are well worth a little special attention and study in this section.

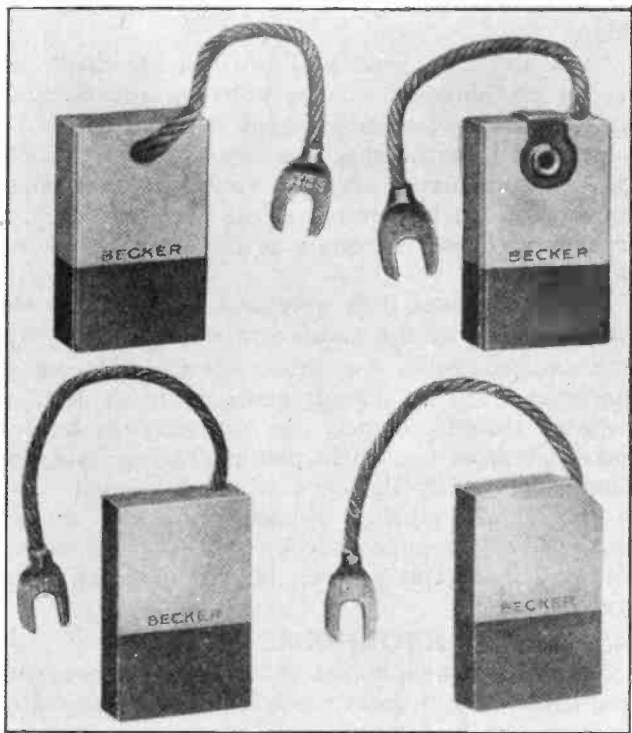


Fig. 144. Above are shown several carbon brushes of common types, such as used on D. C. motors and generators.

The purpose of the brushes, as we already know, is to provide a sliding contact with the commutator and to convey the current from a generator armature to the line, or from the line to a motor armature, as the case may be. We should also keep in mind that the type of brush used can have a great effect on the wear on commutators and in producing good or bad commutation.

## Carbon Brushes

It should not be assumed, just because any brush will carry current, that any piece of carbon or any type of brush will do for the replacement of worn brushes on a D. C. generator or motor. This is too often done by untrained maintenance men, and it frequently results in poor commutation and sometimes serious damage to commutators and machines.

Many different grades of brushes are made for use on machines of various voltages and commutator speeds and with different current loads.

In order to avoid sparking, heating, and possible damage to commutators, it is very important when replacing worn brushes to select the same type of brushes or brush materials as those which are removed.

In special cases it is necessary to use only the brushes made by the manufacturers of certain motors or generators for those particular types of machines. Or, in difficult cases of brush or commutator trouble, it may be necessary to have a specialist from a brush manufacturing company determine exactly the type of brush needed. But in the great majority of cases you can replace brushes very satisfactorily by applying the principles and instructions given in the following paragraphs.

### 185. BRUSH REQUIREMENTS

A good brush should be of low enough resistance lengthwise and of great enough cross-sectional area to carry the load current of the machine without excessive heating. The brush should also be of high enough resistance at the face or contact with the commutator to keep down excessive currents due to shorting the armature coils during commutation. In addition, the brush should have just enough abrasive property to keep the surface of the commutator bright and the mica worn down, but not enough to cut or wear the commutator surface unnecessarily fast.

Figs. 144 and 145 show several carbon brushes



## Direct Current

of different shapes, with the "pigtail" connections used for carrying the current to the brush-holder studs.

### 186. BRUSH MATERIALS

The most commonly used brushes are made of powdered carbon and graphite, mixed with tarry pitch for a binder, and molded under high pressure into the shapes desired. This material can be molded into brushes of a certain size, or into blocks of a standard size from which the brushes can be cut.

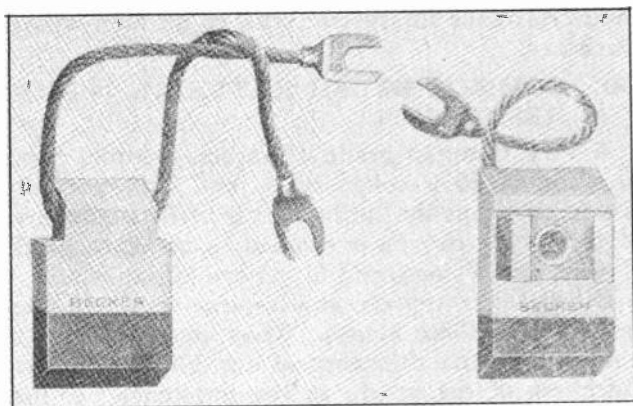


Fig. 145. Two carbon brushes of slightly different shapes, such as used with reaction type brush holders.

The molded material is then baked at high temperatures to give it the proper strength and hardness and to bake out the pitch and volatile matter.

Carbon is a very good brush material because it is of low enough resistance to carry the load currents without too great losses, and yet its resistance is high enough to limit the short circuit currents between commutator bars to a fairly low value. Carbon also possesses sufficient abrasiveness to keep commutator mica cut down as the commutator wears.

Graphite mixed with carbon in the brushes provides a sort of lubricant to reduce friction with the

## Carbon Brushes

commutator surface. It also provides a brush of lower contact resistance and lower general resistance, and one with greater current capacity.

Powdered copper is sometimes added or mixed with graphite to produce brushes of very high current capacity and very low resistance. These brushes are used on low-voltage machines such as automobile starting motors, electro-plating generators, etc. They often contain from 30 to 80 per cent of copper, and such brushes will carry from 75 to 200 amperes per sq. in.

Lamp-black is added to some brushes to increase their resistance for special brushes on high-voltage machines.

### 187. COMMON BRUSH MATERIAL. BRUSH RESISTANCE

A very common grade of carbon-graphite brush is made of 60% coke carbon and 40% graphite, and is known as the "utility grade". Brush material of this grade can be purchased in standard blocks 4" wide and 9" long, and in various thicknesses.

Brushes for repairs and replacement can then be cut from these blocks. They should always be cut so that the thickness of the block forms the thickness of the brush, as the resistance per inch through these blocks is higher from side to side than it is from end to end or edge to edge. This is due to the manner in which the brush material is molded and the way the molding pressure is applied, so that it forms a sort of layer effect or "grain" in the carbon particles.

This higher "cross resistance" or lateral resistance is a decided advantage if the brushes are properly cut to utilize it, as it helps to reduce short-circuit currents between commutator bars when they are shorted by the end of the brush.

Fig. 146 shows how brush measurements should be taken and illustrates why it is an advantage to have the highest resistance through the thickness of the brush and in the circuit between the shorted commutator bars.

## Direct Current

The resistance of ordinary carbon-graphite brushes usually ranges .001 to .002 ohms per cubic inch, and these brushes can be allowed to carry from 30 to 50 amperes per sq. in. of brush contact area.

These brushes can be used on ordinary 110, 220, and 440-volt D.C. motors; and on small, medium, and large sized generators which have either flush or undercut mica, and commutator surface speeds of not over 4000 feet per min.

### 188. HARDER BRUSHES FOR SEVERE SERVICE

These utility grade carbon-graphite brushes can be obtained in a harder grade, produced by special

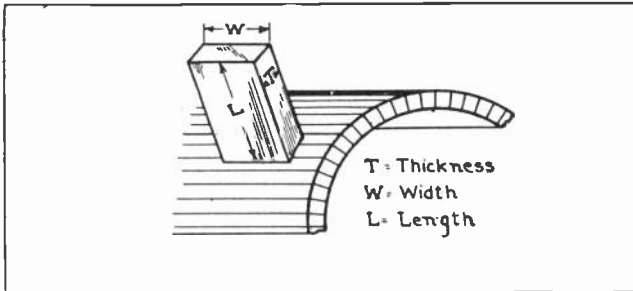


Fig. 146. This sketch illustrates the method of taking measurement for the length, width, and thickness of carbon brushes.

processing, and suitable for use on machines which get more severe service and require slightly more abrasiveness. These harder brushes are used for steel mill motors, crane motors, elevator motors, mine and mine locomotive motors, etc.

Brushes with a higher percentage of carbon can be used where necessary to cut down high mica, and on machines up to 500 volts and with commutator speeds not over 2500 feet per minute. This type of brush is usually not allowed to carry over 35 amperes per square inch, and is generally used on machines under 10 h. p. in size.

### 189. GRAPHITE USED TO INCREASE CURRENT CAPACITY

Brushes of higher graphite content are used

## Carbon Brushes

where high mica is not encountered, and for heavier current capacity. Such brushes are generally used only on machines which have the mica undercut; and are particularly adapted for use on older types of generators and motors, exhaust fans, vacuum cleaners, washing machines, and drill motors.

Brushes with the higher percentage of graphite do not wear or cut the commutators much, but they usually provide a highly-polished surface on both the commutator and brush face. After a period of operation with these brushes the surface of the commutator will usually take on a sort of brown or chocolate-colored glaze which is very desirable for long wear and good commutation.

### 190. SPECIAL BRUSHES

Some brushes are made of practically pure graphite and have very low contact resistance and high current-carrying capacity. Brushes of this nature will carry from 60 to 75 amperes per square inch and they can be used very satisfactorily on machines of 110 and 220 volts, or on high-speed slip rings with speeds even as high as 10,000 feet per minute.

The greater amount of graphite offers the necessary lubrication properties to keep down friction at this high speed.

Another type of brush consisting of graphite and lamp-black, and known as the electro-graphitic brush, is made for use with high-voltage machines which have very high commutator speeds. These brushes have very high contact resistance, which promotes good commutation. They can be used to carry up to 35 amperes per square inch and on commutators with surface speeds of 3000 to 5000 feet per minute.

These brushes are made in several grades, according to their hardness; the harder ones are well adapted for use on high-speed fan motors, vacuum cleaners, drill motors with soft mica, D. C. generators, industrial motors, and the D. C. side of rotary converters. They are also used for street railway

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motors and automobile generators, and those of a special grade are used for high-speed turbine-driven generators and high-speed converters.

### 191. BRUSH PRESSURE OR TENSION

It is very important to keep the springs of brush holders or brush hammers properly adjusted so they will apply an even amount of pressure on all brushes. If the pressure is higher on one brush than on another, the brush with the higher pressure makes the best contact to the commutator surface and will carry more than its share of the current. This will probably cause that brush to become overheated.

To remedy this, the spring tension should be increased on the brushes which are operating cool, until they carry their share of the load.

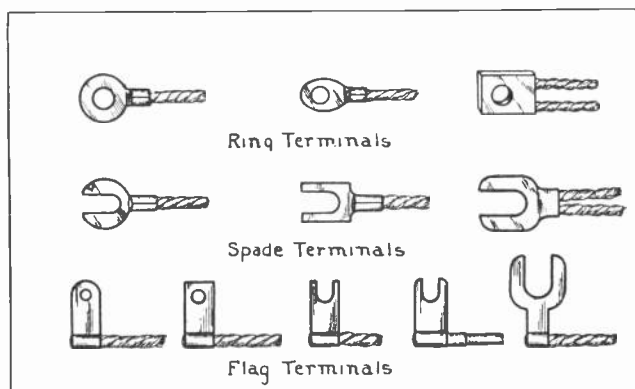


Fig. 147. Above are shown several types of terminals for brush shunts or leads.

Brush pressure should usually be from  $1\frac{1}{4}$  to 3 lbs. per square inch of brush contact surface. This brush tension can be tested and adjusted by the use of a small spring scale attached to the end of the brush spring or hammer, directly over the top of the brush. Then adjust the brush holder spring until it requires the right amount of pull on the scale to lift the spring or hammer from the head of the brush. One can usually tell merely by lifting

## Carbon Brushes

the brushes by hand, whether or not there are some brushes with very light tension and others with too heavy tension or pressure.

Motors used on street cars, trucks, and moving vehicles, or in places where they are subject to severe vibration, will usually require a higher brush-pressure to keep the brushes well seated. On such motors the pressure required may even range as high as 4 lbs. per square inch.

### 192. BRUSH LEADS OR SHUNTS

All brushes should be provided with flexible copper leads, which are often called "pigtails" or brush shunts. These leads should be securely connected to the brushes and also to the terminal screws or bolts on the brush holders, and their purpose is to provide a low-resistance path to carry the current from the brush to the holder studs.

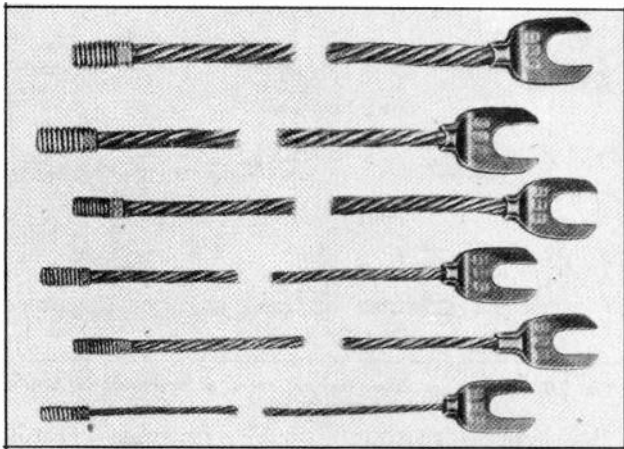


Fig. 148. Brush shunts can be obtained with threaded plugs on their ends for securely attaching them to the brushes.

If these brush shunts or leads become loose or broken, the current will then have to flow from the brush through the holder or brush hammers and springs. This will often cause arcing that will damage the brush and holder and, in many cases,

## Direct Current

will overheat the springs so that they become softened and weakened and don't apply the proper tension on the brushes.

The brushes shown in Figs. 144 and 145 are equipped with leads or brush shunts of this type and Fig. 147 shows a number of the types of copper terminals or clips that are used to attach these leads to the brush holders by means of terminal screws or bolts.

When new brushes are cut from standard blocks of brush material, the pigtails can be attached by drilling a hole in the brush and either screwing the end of the pigtail into threads in this hole or packing the strands of wire in the hole with a special contact cement.

Fig. 148 shows a number of brush shunts or leads with threaded plugs attached to them. These leads can be purchased in different sizes already equipped with threaded end plugs.

Fig. 148 illustrates the method of preparing a brush and inserting the threaded ends of the brush shunts. The top view shows a bar of brush stock from which the brushes may be cut, and in the center is shown the manner of drilling a hole in the corner of the brush.

Carbon graphite brushes are soft enough to be drilled easily with an ordinary metal drill, and they are then tapped with a hand tap, as shown in the left view in Fig. 148. The threaded plug on the end of the copper lead can then be screwed into this hole in the brush by means of pliers, as shown in the lower right-hand view of the same figure.

Brush leads of this type save considerable time in preparing new brushes, and insure a good low resistance connection to the brush. These leads can be unscrewed and removed from worn brushes, and used over a number of times.

### 193. CEMENT FOR ATTACHING LEADS TO BRUSHES

When brush leads with threaded tips are not available, a special compound or cement can be

## Carbon Brushes

made by mixing powdered bronze and mercury. The bronze powder should first be soaked in muriatic or hydrochloric acid, to thoroughly clean it.

The acid should then be washed from the powder with lukewarm water. The bronze powder can then be mixed with mercury to form a thick paste. This paste is tamped solidly around the copper strands of the brush lead in the hole in the carbon brush, and will very soon harden and make a secure connection of low resistance.

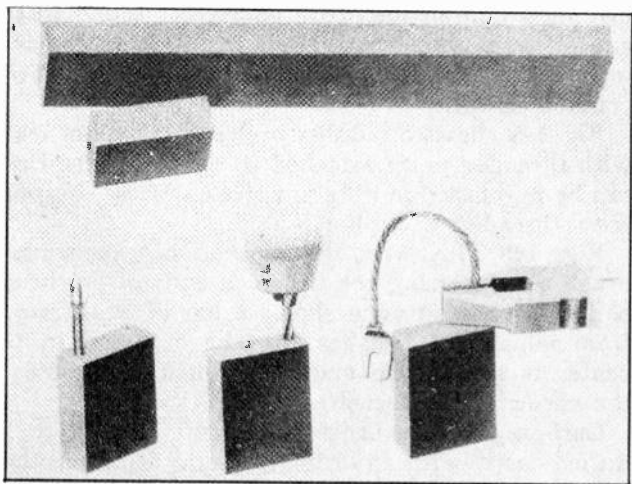


Fig. 148-A. These views illustrate the method of preparing a carbon brush to attach the threaded end of the brush lead or pigtail.

Care must be used not to make this cement too thick or it may harden before it can be tamped in place. It is usually advisable to mix only a very small quantity of the paste at one time, because it may require a little experimenting to get it just the right consistency.

### 194. DUPLICATING AND ORDERING BRUSHES

Worn or broken brushes should always be promptly replaced, before they cause severe sparking and damage to the commutator. Always re-



## Direct Current

place brushes with others of the same grade of material if possible. The new brushes should also be carefully cut to the same size, so they will span just the same width on the commutator bar and will not fit too tight or too loose in the holders.

If it is necessary in emergencies to replace one or more brushes with others of a slightly different grade, place all those of one grade in the positive brush holders, and those of the other grade in the negative holders. If brushes of different grades are placed in the same set of holders, the current will divide unequally through them and cause heating of certain ones, and it may also cause unequal wear on the commutator.

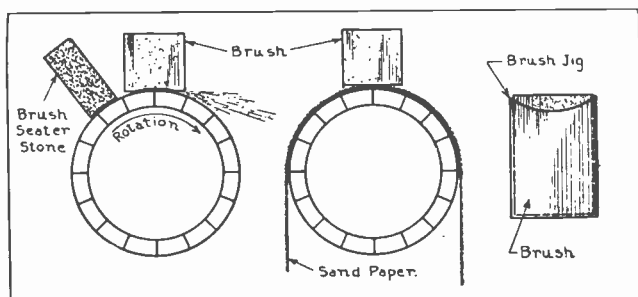


Fig. 149. The above sketches show several methods of cutting brush faces to fit the commutator surface. Each is explained in the accompanying paragraphs.

When ordering new brushes for any certain machine, careful measurements should be taken of the brush width, thickness, and length. The brush thickness is measured in the direction of travel of the commutator or slip rings; the width is measured parallel to the armature shaft or commutator bars; and the length is measured perpendicularly to the commutator or slip ring surface. These measurements are shown in Fig. 146. Any other special measurements should also be given, and in some cases it is well to send the old brush as a sample.

The length of brush leads or shunts should also be specified when ordering new brushes. They are usually provided in standard lengths of five inches,

## Carbon Brushes

but can be furnished shorter or longer where required.

The style of terminal or end-clip should also be given, along with the diameter of the slot or hole by which they are attached to the bolts on the brush-holder studs.

It is generally advisable to have on hand a few of the brushes most commonly required for re-

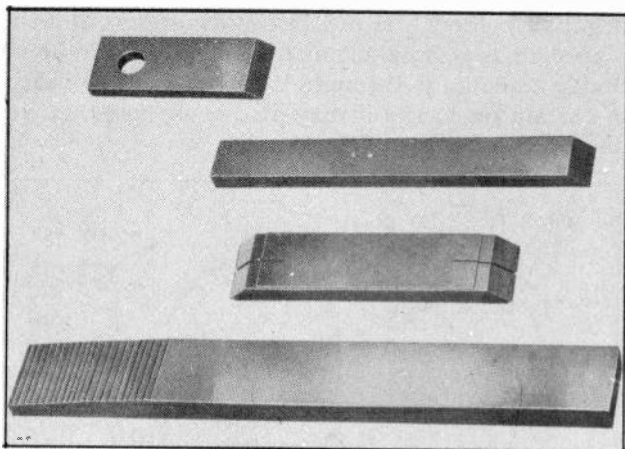


Fig. 150. Brushes made of copper strips or copper "leaf" construction are often used for low voltage machines which handle very heavy currents.

placement on any machines you may be maintaining. It is also well to have a catalogue of some reliable brush manufacturer, to simplify ordering by giving the number and exact specifications of the brushes required.

### 195. FITTING NEW BRUSHES TO THE COMMUTATOR

New brushes should always be carefully fitted to the surface or curvature of the commutator. This can be done by setting the brush in the holder with the spring tension applied, and then drawing a piece of sandpaper under the contact surface or face of the brush, as shown in the center view in Fig. 149. **Never use emery cloth for fitting brushes,**

## Direct Current

as the electrical conducting of the emery particles tends to short circuit the commutator bars.

The sandpaper should be laid on the commutator with the smooth side next to the bars and the rough or sanded side against the face of the brush. Then, with the brush held against the paper by the brush spring, draw the paper back and forth until the face of the brush is cut to the same shape as the commutator surface.

Be sure to hold the ends of the sandpaper down along the commutator surface so these ends will not cut the edges of the brush up away from the commutator bars.

On small machines where it is difficult to use sandpaper in the manner just described, a brush-seater stone can be used. These stones consist of fine sand pressed in block or stick form with a cement binder.

The brush seater is held against the surface of the commutator in front of the brush, as shown on the left in Fig. 149, and as the commutator revolves it wears off sharp particles of sand and carries them under the brush, thus cutting out the end of the brush until it fits the commutator.

When fitting a number of brushes, a brush jig such as shown on the right in Fig. 149 can be used to save considerable time. This jig can be made of either metal or wood, and in the form of a box into which the brush will fit. The open end of the box or jig has its sides cut to the same curve as the commutator surface.

A new brush can then be dropped in this box and its face cut out to the curve or edge of the box by means of a file. The bulk of the carbon can be cut out very quickly in this manner, and the brush can then be set in the holder and given a little final shaping with sandpaper as previously explained.

Graphite brushes should generally be used on iron slip rings on three-wire generators, and metal-graphite brushes on copper rings.

## Carbon Brushes

On certain very low voltage machines where heavy currents are handled, "copper leaf" brushes are used. These are made of a number of thin flat strips of hard drawn copper, with the end of the group beveled as shown in Fig. 150.

When brushes of too low resistance are used, they will generally cause long, yellow, trailing sparks at the commutator surface behind the brushes.

Brushes of too high resistance will cause blue sparks and will also cause the brushes to overheat.

If the commutator mica is not being cut down by the brushes and becomes too high, it will cause sparking and burned spaces to the rear of the mica segments, on the leading edges of the commutator bars.

The proper type of brushes and their proper fitting, well deserve thorough attention on the part of any electrical maintenance man or power plant operator; as a great many troubles in motors and generators can be prevented or cured by intelligent selection and care of brushes.

# MAINTENANCE OF D.C. MACHINES

Direct current motors and generators are so similar to each other in mechanical construction and electric operation that many of the same rules for care and maintenance apply to both.

With the many thousands of these machines in use in factories, mines, power plants, steel mills, stores, and office buildings, and on railways, the electrician who can intelligently and efficiently operate and maintain them is in great demand.

Most of the repairs and adjustments which have to be made on D.C. machines are usually on parts that are easily accessible and which can be easily handled with simple tools.

**In the majority of cases, the brushes, commutator, and bearings require closer attention and more frequent repair than other parts of the machines.** These should not, however, require an excessive amount of attention if the motors or generators are operating under favorable conditions and are given the proper care.

The windings of motors and generators very seldom give any trouble, unless the machines are frequently overloaded or if the windings are very old or are subjected to oil and dirt.

## 1. IMPORTANCE OF CLEANING

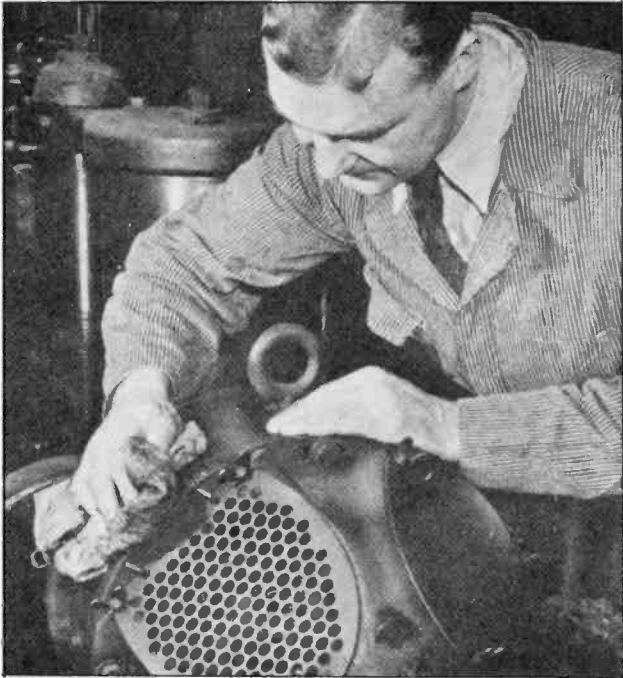
One of the most important rules for the maintenance of all electric machines is to **keep them clean and well lubricated.** If this simple rule is followed it will prevent a great many of the common troubles and interruptions to the operation of the equipment.

If dust and dirt are allowed to accumulate in the windings of motors or generators, they clog the ventilation spaces and shut off the air which is necessary for proper cooling of the machine. A layer of dust is also an excellent insulator of heat, and tends to confine the heat to the windings and prevent its escape to the surrounding air. Dust and

## Maintenance

dirt also absorb and accumulate oil and moisture.

For these reasons, the windings of all electric machines should be kept well cleaned by brushing them with a duster or cloth and occasionally blowing out the dust from the small crevices by means of a hand-bellows or low pressure compressed air. Never use compressed air of over 40 lbs. pressure per square inch, or air that contains particles of grit or metal or any moisture.



**Periodic Cleaning Prevents Dust and Dirt  
from Getting into the Motor Windings**

Sometimes it is necessary to wash off an accumulation of oily or greasy dirt from the windings of machines. This can be done with a cloth and gasoline. If the windings are well impregnated with insulating compound, the gasoline will not penetrate deeply into them, but if it is allowed to soak into the windings to any extent they should be thor-

## Direct Current

oughly dried before the machine is again connected to a line or operated.

A mixture of from  $\frac{1}{4}$  to  $\frac{1}{2}$  of carbon-tetra-chloride with gasoline reduces the danger of fire or explosion when using it as a cleaning solution.

### 2. EXCESSIVE OIL VERY DETRIMENTAL TO ELECTRIC MACHINES

Oil is very detrimental and damaging to the insulation of machine windings and should never be allowed to get on them. Once a winding becomes thoroughly oil-soaked, it will probably have to be rewound.

In some cases, if the oil has not penetrated too deeply, it may be possible to wash it out with gasoline and then thoroughly dry out the gasoline before the winding is put back in service.

When oiling the bearings of a motor or generator, extreme care should be used not to fill the oil-cups or wells too full and cause oil to run over on to the commutator or windings of the machine.

It is practically impossible to secure good commutation if the commutator of a motor or generator is covered with dirt and oil. This will cause the faces of the brushes to become glazed and packed with dirt and will in many cases cause considerable sparking.

Dirt and oil will form a high-resistance film on the surface of the commutator, which will tend to insulate the brushes and prevent them from making good contact.

Oil is also very damaging to the cement used in the mica segments of commutators.

If any oil accidentally gets on the surface of a commutator, it should be wiped off immediately with a cloth and a small amount of kerosene or gasoline and carbon-tetra-chloride. Gasoline should not be used around a running machine because of the danger of igniting it by a spark from the brushes.

## Maintenance

### *Faulty Bearings Cause Most Motor Failures*

All motors depend upon a mechanical assembly of some sort for the transformation of electrical energy into mechanical energy or work. The bearings are a very important link in this mechanical assembly. Bearing troubles probably cause more motor shut-downs, delay, and expense than any other cause. This is not surprising when it is remembered that bearings are often affected by poor foundations, misalignment, vibration, thrust from couplings, dirt, too much or too little lubrication, and wrong lubricant.

### *Proper Lubrication a Basic Requirement*

The first requirement of successful bearing operation is lubrication. This entails more than just an adequate supply of lubricant; the lubricant, the bearing design, and its condition must be correct.

The maximum safe temperature for bearings under normal operating conditions is considered to be 40 degrees C. (72 degrees F.) above the surrounding room air. At this temperature, a bearing feels comfortably warm to the hand. Assuming proper mechanical condition of the bearing, whether sleeve or ball, and the bearing assembly, and also assuming that proper lubricants are used, temperatures above a 40-degree C. rise call for immediate investigation.

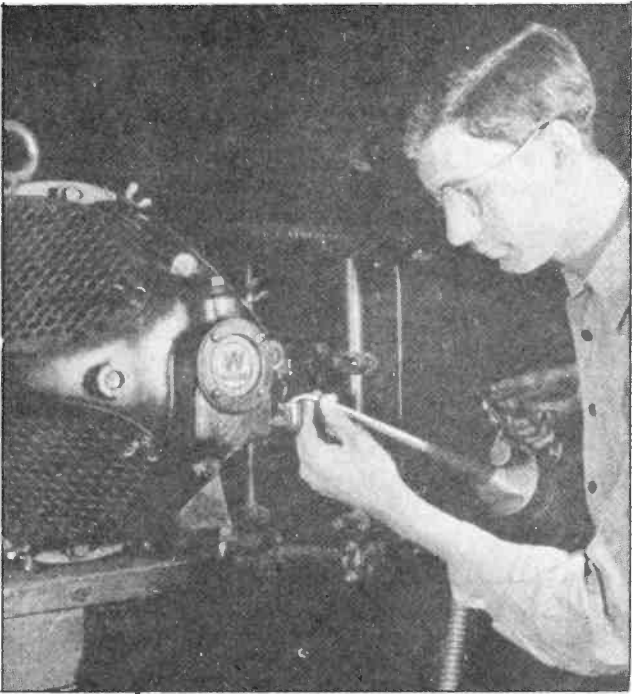
### *Lubrication of Sleeve Bearings*

In a sleeve bearing, the oil adheres to the shaft and is dragged along by the rotation of the shaft so as to form a wedge-shaped film between the shaft and the bearing. This film of oil carries the load and prevents metal-to-metal contact. So long as this film is established and maintained,



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there is no metal-to-metal contact in the bearing while the shaft is rotating, and, therefore, no perceptible bearing wear.



Oiling the Motor Regularly is Essential to Long Bearing and Shaft Life, but Too Much Oil May Get into the Motor Windings and Cause Deterioration of the Insulation

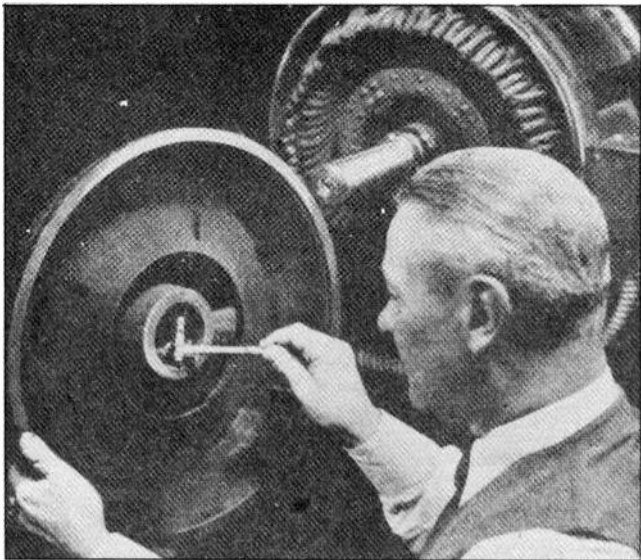
Two outstanding considerations govern the maintenance of sleeve bearings. The first is to insure the existence of the oil film, once rotation has begun. *Use the right oil.* The second is to minimize the destructive effects of metal-to-metal contact when the film is lost, either by accident or during the starting period. *Use the right babbitt.*

For sleeve bearings, proper maintenance keeps the oil well filled to the proper level and the oil-

## Maintenance

rings turning freely. New oil should be added only when the motor is at rest to prevent overfilling of the reservoir. Oiling of bearings is more often overdone than underdone. Sleeve bearings that require frequent refilling, so that oil leaks on the stator windings, should be replaced with sealed sleeve type brackets and bearings.

It is well known that oil-rings generally carry far more oil than is necessary for proper lubri-



After Eleven Years of Severe and Continuous Service, a Bearing Wear of Less than 0.0015 Inch—Thanks to Proper Lubrication and Intelligent Maintenance

cation of the bearing. When running, most of the oil is carried on the outside diameter of the rings by centrifugal force. This excess oil causes splashing and spray inside of the bearing housing. Air currents passing through the housing pick this spray up and deposit it on the motor windings. Sealing the bearing against the entry

## Direct Current

of air currents is, therefore, necessary, and is accomplished in all modern designs by close tolerances, felt seals, and air bypasses to offset the blower action of rotating parts.

The purpose of the felt washer in these seals, often misunderstood, is to keep out air and dirt. In itself, it has little value in preventing leakage of oil, once it becomes oil-soaked. Bearing wear, which results in radial movement of the shaft, spoils the effectiveness of the bearing seals. Replace all felt seals at the same time when sleeve bearings are being replaced. These felt seals should be ordered from the manufacturer of the motor. If it is necessary to make them in an emergency, use high-grade felt not less than 1/4 inch thick before compression. Make the inside diameter of the washer the same as that of the shaft or slightly less. Cut the felt true, with edges at right angles to its facing surfaces. Oil leakage is generally aggravated by high temperatures. Keep bearings as cool as is practicable, and use an oil that does not foam easily.

Recommended Maintenance Practice

Keep motor off line when not needed.	Saves unnecessary wear of brushes, commutator, and bearings; saves lubrication.
Do not leave field circuit excited unless motor has been especially designed for this type duty.	Check temperature of shunt fields with thermometer to see that temperature does not exceed 90 degrees C. When field must be excited, caution maintenance men to be sure field circuit is opened before working on the motor.
Keep motor clear of metal dust or cuttings that can be drawn into windings and pole pieces.	Magnetic attraction will draw metal parts into air gap and damage windings.
Reassembling of motor.	Be sure to retain proper air gaps in motor by checking bore of pole faces before dismantling. Reassemble, replacing poles and liners in their original position.
Note wearing parts and parts frequently replaced to determine anticipated repairs.	Carry in proper store-room stock of replacement parts. Make survey of standard repair parts to avoid duplication of parts to be carried.

### *Factors in Ball-Bearing Lubrication*

Ball bearings are being widely used in motors, particularly in the totally enclosed and fan-cooled types. In a sleeve bearing, as just explained, the shaft, when in motion, is separated from the bearing by the oil film. In a ball bearing, a series of steel balls act as the separating

## Maintenance

medium, both when the motor is stationary and when it is running.

To keep the steel balls uniformly distributed around the bearing, a cage or retainer is used, each ball having its own pocket. The balls have rolling contact with the raceway, but sliding contact with the surface of the retainer. This means that lubrication is necessary.

Most ball bearings used in horizontal motors are grease-lubricated, although some supplied

Maintenance Checking Chart for Alternating- and Direct-Current Motors

Trouble	Cause	What to Do
Hot Bearings	Bent or sprung shaft Excessive belt pull Pulley too far away Pulley diameter too small Misalignment	Straighten or replace shaft Decrease belt tension. Move pulley closer to bearing. Use larger pulleys. Correct by realignment of drive
Sleeve Bearings	Oil-grooving in bearing obstructed by dirt Bent or damaged oil-rings Oil too heavy Oil too light Insufficient oil  Too much end thrust  Badly worn bearing	Remove bracket or pedestal with bearing and clean oil-grooves and bearing housing; add new oil Repair or replace oil-rings. Use a recommended lighter oil. Use a recommended heavier oil. Fill reservoir to proper level in overflow plug with motor at rest Reduce thrust induced by driven machine or supply external means to carry thrust Replace bearing
Ball Bearings	Insufficient grease Deterioration of grease or lubricant contaminated Excess lubricant  Heat from hot motor or external source Overloaded bearing Broken ball or rough races	Maintain proper quantity of grease in bearing Remove old grease, wash bearing thoroughly in kerosene, and add new grease. Reduce quantity of grease. Bearing should not be more than half filled Protect bearing by reducing motor temperature  Check alignment, side thrust, and end thrust. Replace bearing; first clean housing thoroughly.
Oil Leakage from Overflow Plug	Stem of overflow plug not tight Cracked or broken overflow plug Plug cover not tight	Remove, re-cement threads, replace, and tighten. Replace the plug. Requires cork gasket, or if screw type, may be tightened.
Motor Dirty	Ventilation blocked, and windings filled with fine dust or lint  Rotor windings clogged  Beefing and brackets coated inside	Clean motor will run 10 to 30 degrees cooler. Dust may be cement, sawdust, rock dust, grain dust, coal dust, etc. Dismantle entire motor and clean all windings and parts.  Clean, grind, and under-cut commutator. Clean and treat windings with good insulating varnish. Dust and wash with cleaning solvent.
Motor Wet	Subject to dripping  Drenched condition  Submerged in flood waters	Wipe motor and dry by circulating heated air through motor. Install drip or canopy type covers over motor for protection. Motor should be covered to retain heat and the rotor position shifted frequently. Dismantle and clean parts. Bake windings in oven at 105 degrees C. for twenty-four hours or until resistance to ground is sufficient. First make sure commutator bushing is drained of water.

with vertical motors use oil. Follow the advice of the motor manufacturer in selecting a suitable grease. Soda-base soap greases are usually preferred on account of their high melting point and their stability. They mix readily with water,

## Direct Current

however, and blend to form an emulsion.

Carelessness in allowing containers to remain open often causes trouble from abrasive dirt. Ball bearings that are not in good condition can usually be detected by undue heating or by unusual noise. Broken or nicked balls cause rapid destruction of the bearing. They can be detected by the "clicks."

If the conventional 40-degree C. rise above the surrounding air is exceeded, look for an overfilled bearing, since the first result of overgreasing is heating, caused by churning of the grease. The general rule is that the housing should not be over half full. Clean the old grease from the bearing and from the housing once a year and replace it with new grease. Average service is assumed.

After it is dismantled, the bearing should be carefully wrapped in clean cloth or paper to protect it from outside dirt. Remove all old grease from the housing, and clean the housing and the bearing either in Stoddard solvent or in carbon tetrachloride. This is not an easy operation because particles of grit are insoluble and are removed with difficulty. Remove any final residue of the cleaning medium with a light oil before filling with new grease. The container with fresh grease must be carefully protected from dirt. Keep the cover on tight. Use a clean, non-metallic paddle for applying the fresh grease.

### *Check Air Gap with Four Readings*

The correct air gap between the stator and the rotor in a motor is dependent, first, on proper maintenance of the bearings, and second, on proper alignment of the brackets or pedestals with the frame. Alternating-current motors operate with less air gap than direct-current motors, and are, therefore, more critical. Check the air gap with a feeler gage at the established

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schedule period. Make these checks at the pulley end, taking four readings on each motor 90 degrees apart. For motors below 10 H.P., a minimum gap of 0.005 inch should be maintained; for those above 10 H.P., the minimum gap should be 0.010 inch.

Trouble Correction Chart for Direct-Current Motors

Trouble	Cause	What to Do
Fails to Start	Circuit not complete Brushes not down on commutator; held up by brush springs Brushes stuck in holders Armature locked by frozen bearings in motor or main drive Power off	Check to see if switch is open or leads broken. Brushes worn out: need replacement.  Remove and sand, clean up brush boxes. Remove brackets and replace bearings or recondition old bearings if inspection makes possible. Check line connections to starter with light. Check contacts in starter.
Motor Starts, Then Stops and Reverses Direction of Rotation	Reverse polarity of generator that supplies power Shunt and series fields backing each other	Check generating unit for cause of changing polarity. Reconnect either the shunt or series field so as to correct the polarity. Then connect armature leads for desired direction of rotation. The fields can be tried separately to determine the direction of rotation individually, and connected so both give same rotation.
Motor Does Not Come up to Rated Speed	Overload  Starting resistance not all out  Voltage low  Short circuit in armature windings or between bars  Starting heavy load with very weak field  Motor on neutral  Motor cold	Check bearings to see if in first-class condition with correct lubrication. Check driven load for excessive load or friction. Check starting to see if mechanically and electrically in correct condition. Measure voltage with meter and check with motor nameplate. Inspect commutator for blackened bars and burned adjacent bars. Inspect windings for burned coils or wedges. Check full-field relay and possibilities of full-field setting of the field rheostat. Check for factory setting of brush rigging or test motor for true neutral setting. Increase load on motor so as to increase its temperature, or add field rheostat to set speed.
Motor Runs Too Fast	Voltage above rated  Load too light  Shunt field coil shorted Shunt field coil reversed Series coil reversed Series field coil shorted Neutral setting shifted off neutral  Too much resistance in field circuit. Part of shunt field rheostat may be cut in Motor ventilation restricted, causing hot shunt field	Correct voltage or set recommended change in air gap from manufacturer. Increase load or install fixed resistance in armature circuit. Install new coil. Reconnect coil leads in reverse. Reconnect coil leads in reverse. Install new or repaired coil. Reset to neutral by checking factory setting mark or testing for neutral. Measure voltage across field and check with nameplate rating.  Hot field is high in resistance. Check causes for hot field, in order to restore normal shunt field current.
Motor Gaining Speed Steadily, and Increasing Load Does Not Slow It Down	Unstable speed load regulation  Reversed field coil shunt or series Too strong a commutating pole or commutating pole air gap too small	Inspect motor to see if off neutral. Check series field to determine shorted turns. See if series field has a shunt around the series circuit that can be removed. Test with compass and reconnect coil. Check with factory for recommended change in coils or air gap
Motor Runs Too Slow Continuously	Voltage below rated  Overload  Motor operates cold  Neutral setting shifted  Armature has shorted coils or commutator bars	Measure voltage and try to correct to value on motor nameplate. Check bearings of motors and the drive to see if in first-class condition. Check for excessive friction in drive. Motor may run 20 per cent slow due to light load. Install smaller motor, increase load, or install partial covers to increase heating. Check for factory setting of brush rigging or test for true neutral setting. Remove armature to repair shop and put in first-class condition.

# Direct Current

Trouble Correction Chart for Direct-Current Motors—(Continued)

Trouble	Cause	What to Do
<p><b>Motor Overheats or Runs Hot</b></p>	<p>Overloaded and draws 25 per cent to 50 per cent more current than rated Voltage above rated</p> <p>Inadequately ventilated</p> <p>Draws excessive current due to shorted coil</p> <p>Grounds in armature, such as two grounds which constitute a short</p> <p>Armature rubs pole faces due to off-center rotor, causing friction and excessive current</p>	<p>Reduce load by reducing speed of gearing in the drive or load on the drive.</p> <p>Motor runs drive above rated speed, requiring excessive horsepower. Reduce voltage to nameplate rating.</p> <p>Location of motor should be changed, or restricting surroundings removed. Covers used for protection are too restricting of ventilating air and should be modified or removed. Open motors cannot be totally enclosed for continuous operation.</p> <p>Repair armature coils or install new coil</p> <p>Locate grounds and repair or rewind with new set of coils.</p> <p>Check brackets or pedestals to center rotor and determine condition of bearing wear for bearing replacement</p>
<p><b>Hot Armature</b></p>	<p>Core hot in one spot, indicating shorted punchings and high iron loss</p> <p>Punchings uninsulated</p> <p>Punchings have been turned or band grooves machined in the core.</p> <p>Machined slots</p>	<p>Sometimes full slot metal wedges have been used for balancing. These should be removed and other means of balancing investigated.</p> <p>No-load running of motor will show hot core and high no-load armature current. Replace core and rewind armature. If necessary to add band grooves, grind into core. Check temperature on core with thermometer, not to exceed 90 degrees C.</p>
<p><b>Hot Commutator</b></p>	<p>Brush tension too high, causing overload</p> <p>Brushes off neutral</p> <p>Brush grade too abrasive</p> <p>Shorted bars</p> <p>Hot core and coils that transmit heat to commutator</p> <p>Inadequate ventilation</p>	<p>Limit pressure to 2 to 2 1/2 lbs. per sq. in. Check brush density and limit to density recommended by the brush manufacturer.</p> <p>Reset neutral.</p> <p>Get recommendation from manufacturer.</p> <p>Investigate commutator mica and under-cutting and repair.</p> <p>Check temperature of commutator with thermometer to see that total temperature does not exceed ambient plus 55 degrees C. rise, total not to exceed 105 degrees C.</p> <p>Check as for hot motor.</p>
<p><b>Hot Fields</b></p>	<p>Voltage too high</p> <p>Shorted turns or grounded turns</p> <p>Resistance of each coil not the same</p> <p>Inadequate ventilation</p> <p>Coil not large enough to radiate its loss wattage</p> <p>Overheating deteriorates insulation and shortens life of the motor</p>	<p>Check with meter and thermometer and correct voltage to nameplate value.</p> <p>Repair or replace with new coil.</p> <p>Check each individual coil for equal resistance to be within 10 per cent, and if one coil is too low, replace coil.</p> <p>Check as for hot motor.</p> <p>Replace all coils if room is available in motor.</p>
<p><b>Motor Vibrates and Indicates Unbalance</b></p>	<p>Armature out of balance</p> <p>Misalignment</p> <p>Loose or eccentric pulley</p> <p>Belt or chain whip</p> <p>Mismatching of gear and pinion</p> <p>Unbalance in coupling</p> <p>Bent shaft</p> <p>Foundation inadequate</p> <p>Motor loosely mounted</p> <p>Motor feet uneven</p>	<p>Remove and statically balance or balance in dynamic balancing machine.</p> <p>Realign.</p> <p>Tighten pulley on shaft or correct eccentric pulley</p> <p>Adjust belt tension.</p> <p>Recut, realign, or replace parts.</p> <p>Rebalance coupling.</p> <p>Replace or straighten shaft</p> <p>Stiffen mounting members</p> <p>Tighten holding down bolts.</p> <p>Add shims under foot pads to mount each foot tight.</p>
<p><b>Motor Sparks at Brushes or Does Not Commutate</b></p>	<p>Neutral setting not true neutral</p> <p>Commutator rough</p> <p>Commutator eccentric</p> <p>Mica high, not under-cut</p> <p>Commutating pole strength too great, causing over compensation, or strength too weak, causing under compensation</p> <p>Shorted commutating pole turns</p> <p>Shorted armature coils on commutator bars</p> <p>Open circuited coils</p> <p>Poor soldered connections to commutator bars</p> <p>High bar or loose bar in commutator at high speeds</p> <p>Brush grade wrong type</p> <p>Brush pressure too light</p> <p>Current density excessive</p> <p>Brushes stuck in holders</p> <p>Brushes shunt loose</p> <p>Brushes chatter due to dirty film on commutator</p> <p>Vibration</p>	<p>Check and set on factory setting or test for true neutral.</p> <p>Grind and roll edge of each bar.</p> <p>Turn and grind commutator.</p> <p>Under-cut mica.</p> <p>Check with manufacturer for correct change in air gap or new coils for the commutating coils.</p> <p>Repair coils or install new coils.</p> <p>Repair armature by putting into first-class condition</p> <p>Same as above.</p> <p>Resolder with proper alloy of tin solder.</p> <p>Inspect commutator nut or bolts and retighten; re-turn and grind commutator face.</p> <p>See section on Maintenance of Brushes in article.</p> <p>Resurface commutator face and check for change in brushes.</p> <p>Eliminate cause of vibration by checking mounting and balance of rotor.</p>

## Maintenance

### 3. KEEP BEARINGS WELL LUBRICATED

The bearings of all motors and generators should be kept well oiled but not flooded with oil. The oil in the bearings should be examined frequently to make sure that it is clean and free from dirt and grit, and should be changed whenever necessary.

If the oil in a bearing has become exceptionally dirty or mixed with any abrasive dirt, the oil should be drained and the bearing and oil-cup washed out with kerosene or gasoline. The bearing and cup should then be refilled with clean fresh oil and when the machine is started it should be revolved slowly at first, to be sure that all the kerosene or gasoline on the bearing surfaces has been replaced by oil before the machine is running at full speed.

Bearings should not be filled from the top when regular oil openings or vents are provided on the side.

Bearings which are equipped with oil rings should be inspected frequently to make sure that the rings are turning and supplying oil to the shaft. Check the temperature of bearings frequently either by means of a thermometer, or by feeling of them with the hand to make sure that they are not operating much above normal temperature.

A great amount of work and trouble and costly shut-downs of electrical machinery can be prevented by proper attention to lubrication of bearings.

### 4. WINDING TEMPERATURES

The temperature of machine windings should be frequently checked to see that they are not operating too hot, that is at temperatures higher than 40° C. above that of the surrounding air.

Convenient thermometers can be obtained for this use and placed in crevices in the winding or against the side of the winding with a small wad of putty pressed around the thermometer bulb and against the winding.

All terminals and connections on electric machines should be frequently inspected and kept se-



## Direct Current

curely tightened. This includes those at the line, at the controller or starting switches, and at the brushes and field coils.

### 5. PROTECT MACHINES FROM WATER

Moisture or water is always a menace to the insulation and operation of electrical machinery, and machines should be thoroughly protected to keep all water away from their windings and commutators. If a motor or generator is located where water from above may drip upon the commutator, it is very likely to cause flash-overs and damage to the brushes and commutator.

If the windings of a machine become water-soaked or damp, they must be thoroughly dried, either by baking in an oven or by passing low-voltage direct current through the machine to dry them out.

Where a machine is too large to put in an oven or where no oven is available, the armature can be locked to prevent its rotation and then, by the use of a rheostat, low-voltage direct current can be applied in just the right amount to dry out the winding.

Water should be carefully excluded from oil wells and bearings, as it is not a good lubricant and it may cause serious damage if it mixes with the oil.

Motors that operate pumps may often have to be enclosed in a special box or shielding to prevent any drip or spray from coming in contact with them.

### 6. BRUSH ADJUSTMENT AND MICA UNDERCUTTING

Brushes should be frequently inspected to see that they are seated properly on the commutator and have the proper spring tension. If the commutator mica becomes high it should be corrected, either by using brushes of a type that will keep the mica cut down, or by undercutting the mica with a tool for this purpose.

Commutator mica on small machines can be undercut by hand with a piece of hack-saw blade equipped with a handle, as shown in Fig. 1. The

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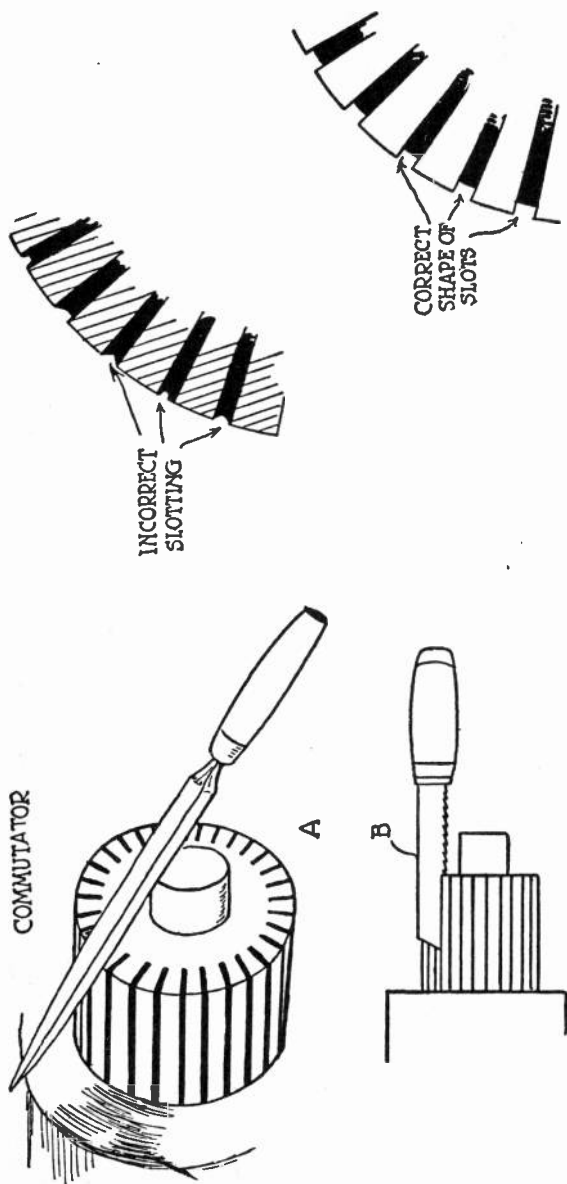


Fig. 1. The above sketch shows methods of undercutting mica segments on the commutator. Mica must be kept down even with, or below the surface of the commutator bars, or it will cause the brushes to make poor contact and cause severe sparking.

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views on the right in this figure show the correct and incorrect methods of undercutting mica.

Mica should be cut squarely with smooth, easy



To Assure Proper Maintenance and Prevent Sparking, This Tool Under-cuts the Mica 1/16 Inch below the Surface of the Faster Wearing Copper Commutator Bars on a Direct-current Motor

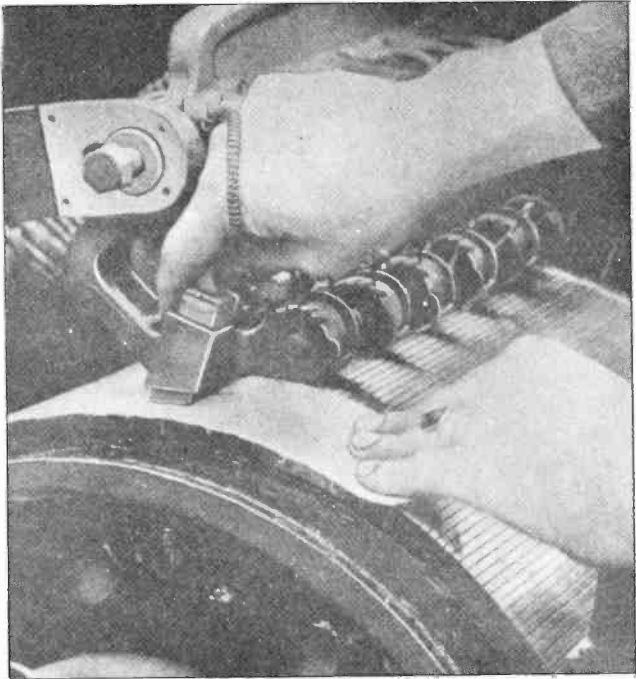
strokes of the hack-saw blade held in a vertical position. The mica should not be cut away too deeply, or the grooves will tend to accumulate dust and dirt, and cause short circuits between the commutator bars.

On small and medium-sized machines, the undercutting need not to be deeper than from 1/64 to 1/32 of an inch. Care should be taken not to scratch or scar the commutator bars while undercutting mica, and one should also be careful not to leave on the edges or corners of the bars any burrs which might

## Maintenance

cause a short circuit between them.

A small, three-cornered file can be used for cleaning the ends or corners of the mica segments, as shown in the left view in Fig 1, but a file or three-cornered object should not be used for undercutting mica, as the top of the mica segments must be cut squarely, as shown in the right-hand view in the figure.



**Proper Method of Cleaning and Surfacing Brushes is to Place Sandpaper under Brush, Flat against the Commutator Surface. Several Passes of Sandpaper should be Enough, Depending on Brush Condition**

For undercutting the mica on large machines, a regular motor-driven mica cutter can be used. These machines consist of a small rotary saw, driven by a motor with a flexible shaft and equipped with handles for guiding the saw blade in the mica slots.

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### 7. RESURFACING AND TRUING OF COMMUTATORS

If the surface of the commutator becomes rough and pitted it can be cleaned with sandpaper. Small spots of dirt or very lightly burned spots may be removed by holding sandpaper against the commutator while the machine is running.

If the commutator requires much sand-papering it should be done with a block, with a curved surface to fit the commutator, to hold the sandpaper in a manner that will tend to smooth out hollow spots or high spots on the bars, and bring the commutator back to a true round shape.

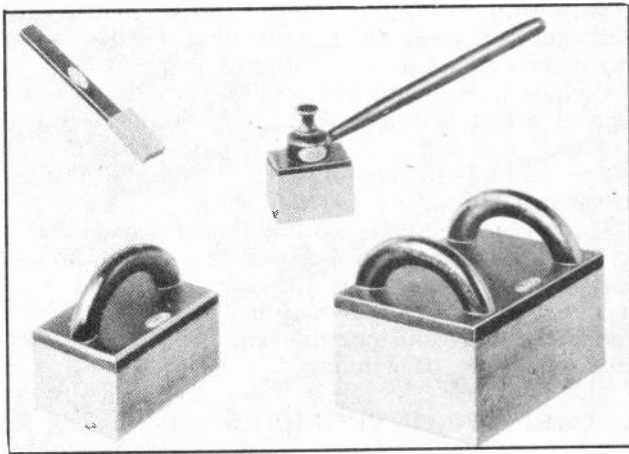


Fig. 2. Commutator stones of the above types are used for dressing or grinding down the burned and rough spots on commutator surfaces.

Several strips of sandpaper can be folded over the curved end of a block of this type and fastened in place with clamps or tacks. As each strip becomes worn it can be removed, exposing the next strip, etc.

Special commutator stones can be obtained for dressing or re-surfacing commutators. These stones consist of a block of grinding or abrasive material equipped with handles for convenient application to the commutator surface. Several stones of this

## Maintenance

type are shown in Fig. 2. These can be obtained in different sizes and degrees of hardness for use with machines having commutators of different diameters and surface speeds.

If a commutator has become badly pitted or burned or out of round, it may be necessary to remove the armature from the machine and turn the commutator down in a lathe, as shown in Fig. 4. When truing a commutator in a lathe one should never remove any more copper than is absolutely necessary, because even a very light cut with a lathe tool will remove more copper from the bars than several years of ordinary wear would destroy.

The armature should be carefully centered to run true in the lathe, and the tool set to remove only a very thin coating of copper, no thicker than a thin piece of paper. If this first cutting doesn't remove the flat spots, another cut can be made.

Commutators should never be turned down except as a last resort or when they are badly out of round.

Special tools for turning large commutators right in the machine are available.

Motors and generators should always have secure and firm foundations and should be anchored so that they don't vibrate while running. If the machine is allowed to vibrate, it may cause serious damage to the bearings and possibly also damage the commutator, shaft, or windings.

## 8. CARE OF CONTROLLERS

All switches, circuit breakers and controllers used in connection with motors and generators should be kept in good condition, because if they are allowed to become defective, they may cause damage to the machines by frequent interruptions in the current supply, or by causing voltage drop and lower voltage than the machine is supposed to operate on, or by failure to protect the motor in case of overload.

All contact shoes or fingers on starting and control equipment should be kept in good condition and securely tightened. Bolts, nuts, screws, and terminals should also be kept tight and clean.

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Sliding contacts or make-and-break contacts of controllers should be kept properly lubricated to prevent excessive wear. A good grade of vaseline serves very well for this purpose, as it will remain where applied on the contacts and will not run or spread over the equipment.

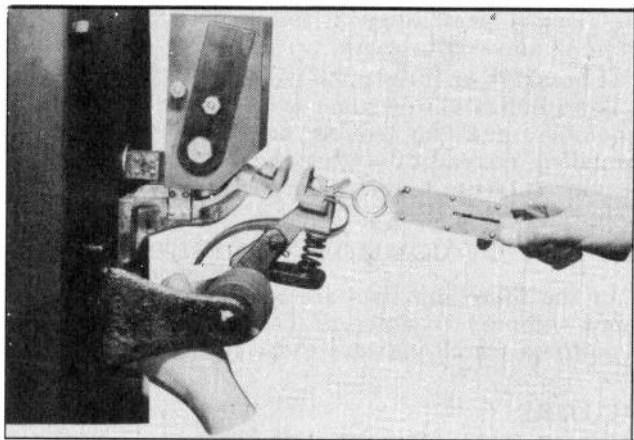


Fig. 3.—The above photo illustrates the method of testing the contact pressure or tension of controller contacts. The scale can be used in the same manner for adjusting tension on brushes.

Resistance elements of starting and control equipment should be kept in good condition. In case of open circuits in resistance units, it may be necessary to temporarily bridge this open section of the resistance with a shunt or jumper, in order to keep the machine in operation; but the defective resistance unit should be replaced with a new one as quickly as possible to prevent overloading the machine when starting, due to having insufficient resistance in the armature circuit.

Dash pots and time element devices should be kept properly adjusted to allow the proper time for starting of motors.

### 9. CARE OF OVERLOAD PROTECTIVE DEVICES

Fuses and overload devices on control equipment or anywhere in the circuit to electrical machines should be kept in good condition, and should be of

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the proper size and adjustment to protect the machines from current overloads. Fuses should never be replaced with others of larger current ratings than the machines are supposed to carry.

Overload trip coils on circuit breakers should be kept properly adjusted to trip at any current above the normal percentage of overload which the machine is allowed to carry.

If breakers or fuses open frequently in the circuit, it is an indication of some overload or fault on the machines, and the trouble should be located and remedied, instead of setting the circuit breakers for heavier currents or using larger fuses.

### 10. LIST OF COMMON TROUBLES

In the following lists are given a number of the more common troubles of D.C. machines and the symptoms which indicate these troubles:

#### MOTORS

##### MOTOR FAILS TO START

1. Fuse out, causing an open circuit
2. Brushes not making proper contact
3. Line switch open
4. Bearings "seized" due to lack of oil
5. Motor overloaded. This will usually blow the fuse
6. Open field circuit at the terminal block or in the starting box  
    "No voltage" release magnet burned out
7. Open armature or line connections, either at the motor or controller
8. Grounded winding, frequently blows the fuse
9. Brushes not set on neutral point
10. Armature wedged. Remove the wooden wedges from air gap of new machines
11. Dirty commutator or brush faces
12. High mica insulation on commutator preventing brush contact
13. Field coils short-circuited or grounded. Will usually cause excessive armature currents and blow the fuses



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14. Reversed field connections. Test for polarity with a pocket compass
15. Low voltage
16. Pulley, gear, or coupling, may be tight against the bearing
17. Bent shaft, causing armature to stick on pole faces
18. Badly worn bearings, allowing armature to rub
19. Burned out armature.

### 11. MOTOR STARTS TOO QUICKLY

1. Starting box resistance too low for the motor
2. Starting box resistance short-circuited
3. Insufficient time allowed for starting
4. Line voltage too high
5. Series motor without enough load for the starting resistance used with it
6. Too much resistance in field circuit.

### 12. MOTOR ROTATION REVERSED

1. Reversed field connections
2. Brush connections reversed or brushes in wrong position
3. Compound motor connected differential and starts in reverse direction from the series field. Speed will be high and torque very low
4. No field. Residual magnetism may start the motor in reverse direction on very light loads only. Motor will not start under heavy load
5. Wrong field connection in starting box. Armature resistance may be in series with the field.

### 13. SLOW STARTING OF MOTORS AND WEAK POWER

1. Low voltage
2. Resistance of starting box too high
3. Brushes off neutral, and will cause bad sparking
4. Motor overloaded
5. Heavy flywheel on driven machines
6. Weak field due to resistance in its circuit

## Maintenance

7. Dirty or loose connections
8. Dirty or loose brushes
9. Brushes improperly spaced on commutator
10. Armature defects, shorts, grounds or opens
11. Wet armature or commutator.

### 14. MOTOR BUCKING OR JERKING

1. Overloaded motor
2. Reversed interpole polarity
3. Loose field connections which alternately open and close the field circuit and cause the motor to run jerkily
4. Wet or shorted field coils
5. Defects or loose connections in starting box.

### 15. MOTOR OVERSPEEDS

1. Open field circuit, may cause dangerously high speed
2. Shorted or grounded field coils
3. Load suddenly reduced on compound motor using field control
4. Brushes off neutral
5. Shorted or grounded armature conductors
6. Line voltage too high
7. Series motor overspeeds on light loads or no load.

### 16. SPARKING AT BRUSHES

1. Brushes or commutator dirty
2. Rough or burned commutator
3. High or low bars in commutator
4. Commutator out of round
5. Commutator segments shorted by carbon or copper dust in the mica slots, or by solder bridged across the bars.
6. High mica
7. Brushes off neutral
8. Wrong type of brushes
9. Brushes poorly fitted
10. Brushes stuck in holders
11. Poor or unequal brush tension

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12. Weak field, due to short circuits or grounds in the coils
13. Reversed field coils
14. Opens or shorts in armature winding. Opens usually cause long blue sparks and shorts are generally indicated by yellow or reddish sparks. The location of the defective coils will usually be indicated by burned bars to which they are connected
15. Oil grease or water on the commutator
16. Unequal air gaps due to worn bearings
17. Unbalanced armature winding
18. Bent shaft which causes brushes to chatter
19. Poor foundation, permitting vibration of the machine.

## 17. OVERHEATING OF MACHINES

1. Overloading will cause heat on both motors and generators due to excessive current passing through their windings and brushes
2. Excessive brush friction and brush tension too great
3. Brushes too high resistance
4. Brushes off neutral
5. Damp windings
6. Excessive sparking at commutator, which may cause enough heat to melt the solder and loosen the armature connections
7. Opens or shorts in armature winding
8. Hot field coils caused by high voltage or short circuits in the coils
9. Field shunts loose or disconnected
10. Windings shorted by oil-soaked insulation
11. Hot field poles may be due to poor design causing eddy currents in the pole shoes. Unequal air gaps may cause field poles closest to the armature to heat
12. Hot bearings due to poor lubrication. May be caused by poor oil, stuck oil rings, or clogged oil wicks. Also caused by poor shaft alignment or excessive belt tension
13. Armature out of center with field poles, due

## Maintenance

to worn bearings. Causes excessive currents in parts of the armature winding and eddy currents in the field poles. Bearings should be repaired immediately

14. Clogged ventilating ducts
15. Loose connections between armature coils and commutator bars
16. Weak field, not allowing sufficient counter-E.M.F. to be generated to keep the armature current normal
- 17 Heat transfer through direct shaft connections from air compressors, steam engines or other machinery.

Normal operating temperatures of D.C. motors should not exceed  $40^{\circ}$  C. above the surrounding room temperature when operated at full load, or  $55^{\circ}$  C. at 25% overload for two-hour periods. If the machines are operated at temperatures above these values for any length of time, the insulation of the windings will become damaged and eventually destroyed. (Safe operating temperature about 140 to 150 degrees F.)

### 18. UNUSUAL NOISES

1. Belt slapping due to a loose, waving belt
2. Belt squealing due to belt slipping on the pulley, caused by loose belt or overloads
3. Brush squealing due to excessive spring tension, hard brushes, or dry commutator surface. Application of a good commutator compound will usually stop the squealing due to a dry unlubricated commutator
4. Knocking or clanking may be caused by a loose pulley, excessive end play in the shaft, a loose key on the armature spider, or a loose bearing cap
5. Chattering vibration, caused by poor brush adjustment and loose brushes, hard brushes, or commutator out of round
6. Heavy vibration due to unbalanced armatures, bent shaft, or loose foundations.

### 19. GENERATOR TROUBLES.

#### FAILURE TO BUILD UP VOLTAGE

1. Residual field lost or neutralized
2. Reversed field

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3. Poor brush contact or dirty commutator
4. Open field circuit due to loose connections or broken wires
5. Field rheostat open or of too high resistance
6. Series field reversed so it opposes the shunt field
7. Shunts disconnected or improperly connected
8. Wet or shorted field coils
9. Too heavy load on a shunt generator
10. Residual magnetism reversed by flux from nearby generators.

### 20. POOR VOLTAGE REGULATION

1. Loose field shunts or connections
2. Poor regulation of engine speed
3. Belt slipping (if generator is belt driven)
4. Brushes off neutral
5. Improper resistance of field rheostat, or loose connections at this rheostat
6. Series field shunts not properly adjusted
7. Overheated field coils
8. Loose or grounded field wires between generator and switchboard
9. Armature out of center
10. Brushes improperly spaced
11. Weak field caused by short circuits or grounds in the field windings
12. Shorts, opens, or grounds in the armature coils
13. Excessive and frequent variations in load
14. Improper compounding.

### 21. GENERATORS WILL NOT OPERATE IN PARALLEL

1. Poor speed regulation on prime mover, caused by improper governor adjustment
2. Open equalizer connections
3. Incorrect field shunts, open or loose field connections, or weak fields
4. Defective field rheostat
5. Wet field coils
6. Improper adjustment of series fields for compounding effects

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7. Extreme difference in size, causing the smaller machine to be more responsive to load changes than the larger machine
8. Belt slipping, on belt-driven generators
9. Variations in steam pressure, on generators driven by steam engines
10. Defective voltmeter, causing operator to make wrong adjustment.

## 22. SYSTEMATIC TESTING

The preceding lists of common troubles and their symptoms are given to serve as a general guide or reminder of the possible causes of trouble in D.C. machines. They do not cover every possible trouble or defect, but intelligent application of the principles covered throughout these sections on D.C. equipment and careful systematic testing, should enable you to locate any of the troubles listed or any others.

Keep well in mind the advice previously given to the effect that **even the troubles most difficult to locate can always be found by methodically and systematically testing circuits and equipment.**

Let us remind you once more that any defect or trouble in electrical equipment or circuits **can be found, and that someone is going to find it.** It will be to your credit to be able to locate any and all troubles, and the best way to gain experience and confidence is to undertake willingly every trouble-shooting problem you can find. Go about it coolly and intelligently, use your knowledge of the principles of electricity and electrical equipment and circuits, and in this manner you will save a great deal of time and many mistakes.

You will also be surprised to find out how very simple some of the apparently baffling electrical troubles are, to the trained man who knows how to test and locate them.

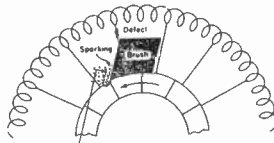
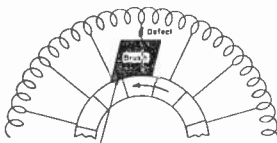
## 23. TEST EQUIPMENT FOR LOCATING FAULTS

Some of the more common devices used for trouble shooting and testing are as follows: -

## Direct Current

1. Test lamp and leads
2. Magneto tester
3. Battery and buzzer tester
4. Voltmeter (portable type)
5. Ammeter (portable type)
6. Thermometer
7. Speed indicator ,
8. Wheatstone bridge

TROUBLE	CAUSE	REMEDY
Motor stops after running short time	Motor is not getting power.	Check voltage at the motor terminals; also fuses, clips, and overload relay.
Motor attempts to start but overload relays operate	Motor is started with weak or no field.  Motor torque insufficient to drive load.	If adjustable-speed motor, check rheostat for correct setting. If correct, check condition of rheostat. Check field coils for open winding. Check wiring for loose or broken connection. Check line voltage with nameplate rating. Use larger motor or one with suitable characteristic to match load.
Motor runs too slow under load	Line voltage too low.  Brushes ahead of neutral. Overload.	Check and remove any excess resistance in supply line, connections or control. Set brushes on neutral. Check to see that load does not exceed allowable load on motor.
Motor runs too fast under load	Weak field.  Line voltage too high. Brushes back of neutral.	Check for resistance in shunt-field circuits. Check for grounds. Correct high-voltage condition. Set brushes on neutral.
<b>BRUSHES</b> Sparkling at brushes	Commutator in bad condition. Eccentric or rough commutator. Excessive vibration.  Broken or sluggish acting brush-holder spring. Brushes too short. Machine overloaded. Short circuit in armature.	Clean and reset brushes.  Grind and true commutator, also undercut mica.  Balance armature. Check brushes to make sure they ride freely in the holders. Replace spring, and adjust pressure to manufacturer's recommendations. Replace brushes. Reduce load, or install larger motor. Check commutator, and remove any metallic particles between segments. Check for short between adjacent commutator bars. Test for internal shorts in armature and repair.
Brush chatter or hissing noise	Excessive clearance of brush holders. Incorrect angle of brushes. Incorrect brushes for the service. High mica. Incorrect brush-spring pressure	Adjust holders.  Adjust to the correct angle. Get manufacturer's recommendations  Undercut mica. Adjust to correct value.



Burning of the next commutator bar ahead of the brushes usually indicates the presence of a loose or high-resistance connection between the armature coil and the commutator.

### 9. Megger.

Every maintenance electrician's kit should include a test lamp and a battery and buzzer test-outfit. These are very inexpensive and can easily be made up in a few minutes' time. It is a good idea to use two sockets and bulbs in series, for a test lamp which can be used either on 220 or 110-

## Maintenance

volt circuits. The two lamps will burn at full brilliancy when connected at 220 volts, and at one-half brilliancy on 110-volt circuits

### 24. USE OF TEST LAMPS, BUZZERS AND MAGNETS

Test lamps of this type can be used for locating open circuits, short circuits, and grounds on the machines themselves or the wires leading to them. They are also very convenient for testing to locate blown fuses and to determine whether or not there is any voltage or the proper voltage supplied to the terminals of the machines.

The battery and buzzer test-outfit can be made of one or two dry cells taped together, with the

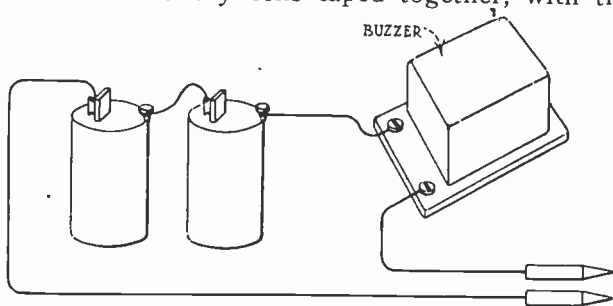


Fig. 5. A simple test set consisting of dry cells and buzzer is a very effective device for trouble shooting and locating of faults in electric circuits and machines.

buzzer taped securely to them. This unit should then be supplied with flexible test leads several feet long. The dry cells and buzzer can be located in a portable box if desired.

A simple test outfit of this kind can be used for locating grounds, opens, and short circuits on machines or circuits that are not alive.

The magneto test-outfit is very effective for locating high-resistance short circuits or grounds. These hand-driven magnetos generate voltage sufficiently high to break down the resistance at the point of the fault or defect, while a battery test set or test lamp used with ordinary line voltage might not show the fault.



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When installing any new circuits to generators, motors, or controllers, the wiring should be thoroughly tested for grounds, shorts, and opens before connecting the machines.

An ordinary A.C. test magneto will ring through 20,000 to 40,000 ohms resistance. The use of magnetos above 50,000 ohms is not advised because they will ring through the insulation of conductors on long circuits.

In some cases an A.C. magneto will cause its bell to ring when the terminals are attached to the windings of very large machines, due to capacity or condenser effect between the windings and the frame of the machine. In such cases the ringing of the magneto doesn't necessarily indicate defective insulation.

### 25. USE OF PORTABLE VOLTMETERS AND AMMETERS

Voltmeters are very essential in plants having a great number of electrical machines and circuits. Voltmeters should be used for measuring line voltages or voltage drop on various circuits, to determine whether or not the proper voltage is supplied to the equipment.

It is very important that D.C. motors be operated at their proper rated voltage and not at voltages 10% or more below this, which sometimes results from overloaded line circuits and excessive voltage drop.

Low reading voltmeters are very satisfactory test devices for locating faults in armatures and field coils, as well as commutator defects. They can also be used for testing voltage drop in controller coils and resistors and to locate defective coils in this manner.

Ammeters can be used to measure the current through any circuit or machine and to determine whether wires or machine windings are properly loaded or overloaded.

One or more ammeters should always be available in plants where numerous electrical machines are to be operated and maintained.

### 26. THERMOMETERS

Thermometers should be used to determine the temperature at which various machines are oper-

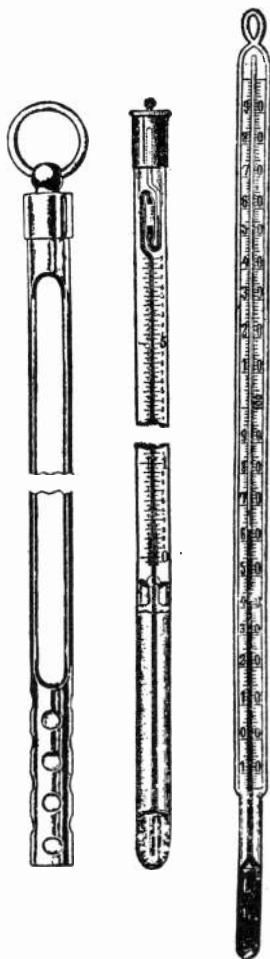


Fig. 6. Convenient thermometers of the above type are used for determining the temperature of the machine windings, by attaching the bulb to the windings with a small amount of putty.

ated, and especially if a machine is known to be operating somewhat overloaded. On machines that are not overloaded, if the temperatures rise above the rated temperature increase for a normal load, the cause should be determined and remedied at once.

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By checking the temperatures at different points on a machine or its windings, the exact location of the fault or trouble can frequently be found by noting the points of higher temperature. Some thermometers for this use are marked with the centigrade scale, while others are marked with the Fahrenheit scale.

A convenient rule for converting the temperature in either scale to the other is as follows:

$$\text{Temperature C.} = 5/9 \times (\text{Temperature F.} - 32)$$

$$\text{Temperature F.} = (9/5 \times \text{Temperature C.}) + 32$$

### 27. SPEED INDICATORS

Speed indicators or revolution counters are commonly used to determine the speed of various machines. If machines are overloaded or thought to be operating at low voltage, it is often necessary to test their speed.

In other cases, checking the speed of machines may assist in locating certain faults within the machine or its own windings. In many industrial plants and factories it is very important that the motors driving production machines be kept operating at their proper rated speed, in order not to delay the production of the article being manufactured.

With the ordinary low-priced revolution counters or speed indicators, a watch with a second-hand can be used to check the time during which the revolutions are counted, and to get the speed in R.P.M.

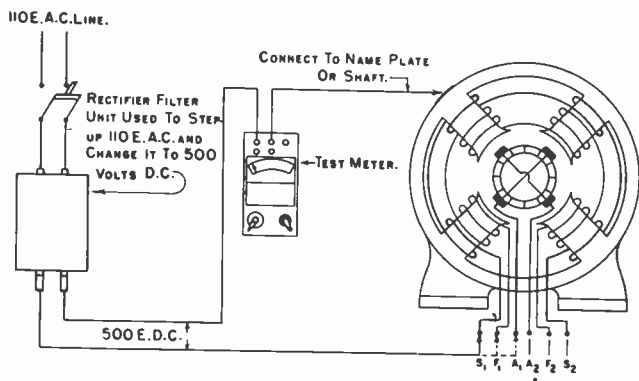
Where a large number of machines are to be tested frequently, a higher-priced speed indicator known as a "tachometer" may be used. This device when placed against the shaft of any revolving machine indicates the speed in R.P.M. instantly.

### 28. IMPORTANCE OF RESISTANCE TESTS ON INSULATION

Since the quality of the insulating materials used on any electrical machine deteriorates with age, due to the action of moisture, dirt, oil, acids, etc.,

## Maintenance

it is necessary to periodically test the electrical resistance of the insulation so that weaknesses may be detected and corrected before they result in complete failure.



The above sketch shows how an insulation resistance test may be made by using a rectifier and filter combination for obtaining the D.C. voltage needed for this type of check. Note that the connections are such as to read the current leakage through or over the insulation from the conductor to the frame of the machine.

Insulation resistance tests are usually made by applying 500 volts D.C. between the winding of the machine and the frame; the current which this pressure forces through or over the insulation to the frame is measured by a sensitive instrument, the scale of which is usually calibrated to read in megohms. The 500 volts D.C. may be developed by a hand-operated generator as in the megger, or it may be supplied from an A.C. source by a rectifier-filter combination as shown above.

The readings obtained on any given machine will vary greatly with the temperature of the insulation, a 10 degree Centigrade rise in temperature reducing the insulation resistance as much as 50%. The dampness of the location, and the amount of oil, dust, or dirt on the winding, will also materially affect the readings. Wherever possible, the test should be made when the insulation is at the maximum operating temperature, 167 degrees F., (75 degrees C.). The minimum safe insulation resistance at maximum operating temperature should not be

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lower than one megohm for equipment having a voltage rating below 1000 volts.

To make the test, connect the rectifier unit to 110 volts A.C., set the control switch on the meter to the one mil position, set switch in D.C. position, make the connections shown above, and read the insulation resistance on the top scale of the dial. Usually a general test is made between one lead of the machine and the frame, and if this proves to be too low, the windings are tested individually. So after the general test, test the armature, shunt field, series field, and brush holders separately. To do this, take the brushes from the holders, disconnect the windings from each other, and test the insulation resistance of each. In this manner, the faulty element can quickly be found. This same procedure is used on A.C. equipment also. If such readings are taken at regular intervals and the values recorded, a close check may be kept on the condition of the insulation resistance of all electrical equipment, and apparatus may be removed from service and reconditioned before breakdown occurs. If a megger is employed, the 500 volt potential is obtained by cranking the generator inside the instrument, the method of testing is the same as given above.

In medium-sized and larger plants, instruments of this type will very soon save much more than their original cost.

Electric instruments are usually furnished by the employers or plant owners, although in some cases the maintenance man and electrician can well afford to own one or more low-priced portable instruments for the great convenience and aid they give in his work.

Whether these instruments are supplied by the employer or owned by the electrician, they should always be handled with proper care and intelligence.

Most meters are delicate devices and they should not be carelessly handled or banged around. Extreme caution should always be used not to connect ammeters across a line or in circuits with greater loads than the ammeter is designed for. The same warning applies to connecting voltmeters and watt-

## Maintenance

meters, which should never be connected to circuits of higher voltage than the instrument is made for.

### 29. COMMON TOOLS FOR MAINTENANCE WORK

A few of the more common tools used by the electrical maintenance man are as follows:

1. Knife
2. Pliers (side cutting)
3. Gas pliers
4. Screw drivers
5. Adjustable wrenches
6. Pipe wrenches
7. Machinists hammer
8. Center punch
9. Cold chisels
10. Soldering iron
11. Blow torch
12. Tin snips
13. Bearing scrapers
14. Speed indicator
15. Air-gap gauge
16. Files; flat, round, and three-cornered
17. Hack saw
18. Breast drill.

This list covers the more essential tools for ordinary jobs. Various other tools can be added for certain things, according to the class of work and equipment to be handled. A few good pointers in the selection and use of these tools are given in the following paragraphs.

An electrician's knife should be a good substantial one, with one sharp blade that can be used for the removal of insulation from conductors, and one general utility blade for miscellaneous cutting, scraping, etc.

The most common and handy size of pliers is the 7-inch length, and if only one pair is used this should be the size. If one wishes to carry or to have on hand two or more sizes, the 6-inch and 8-inch sizes should also be included.

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Cheap pliers never save any money, and only good pliers with strong jaws and good cutting blades should be purchased. Pliers larger than 9-inches are seldom used, except for the handling of very heavy wires, and cables. Good pliers are made of the best grade of tempered steel and should never be held in the flame of a torch or allowed to become overheated in any way. Pliers should not be used to cut hard steel bolts or spikes.

The gas pliers are very convenient for holding cable lugs when heating them to melt solder and apply to cable ends, and for other general uses such as gripping bolts, nuts, and small parts. An 8 or 10-inch size is usually most convenient.

You should have at least three or four sizes of screw drivers and sometimes more. It is well to have one short and one long screw driver, both with points to fit a No. 7 wood screw; one short and one long driver to fit a No. 10 wood screw; and at least one large screw driver for No. 14 to No. 16 screws.

Never use a screw driver for a crow bar or chisel, as such abuse will only bend their bits or split the handles and render them unfit for the purpose for which they were intended.

If screw drivers become dull they can be careful reground on the flat side of an emery wheel. Never grind them to a sharp point, as it tends to make them slip out of the slots in screws.

Adjustable wrenches should be of the 6-inch, 8-inch and 10-inch sizes, and these will handle all except the very heavy work. These tools are used for tightening bolts and nuts on motors, controllers, and all kinds of electrical equipment; and both for taking apart and reassembling motors and machines to be repaired.

When using an adjustable wrench, always tighten the jaws securely on the nut before applying any pull on the handle, as this will avoid slipping and injury to the operator as well as "rounding" of the corners on nuts or bolt heads.

Never use a wrench upside down or backward, and don't hammer the handles, as it will only spring

## Maintenance

the jaws and spoil the wrench. Wrenches are made with handles long enough to apply by a steady pull all the pressure their jaws will stand.

Pipe wrenches should be used for loosening stubborn or worn nuts on which the adjustable wrench slips, and also for making BX or conduit connections. One 10-inch and one 12-inch pipe wrench will usually be sufficient for ordinary repair work.

A good hack saw is indispensable for cutting bolts, BX, conduit, and heavy cable. Either an adjustable or a rigid frame may be used, and several good sharp blades should always be on hand for this saw.

When using a hack saw, the object to be cut should be securely held in a vise or clamp. If the object is allowed to wobble or twist it will crack the teeth out of the saw blade.

A machinists hammer of one lb., one and a half lbs., or two lbs. weight will usually be found most convenient.

Center punches are very handy for marking places for drilling holes in metal, or for marking the endplates of motors or machines before they are removed, so you can be sure of getting them replaced properly.

A small breast drill or Yankee drill with a dozen or more short drills will be found very convenient in making many time-saving repairs.

Several sizes of cold chisels are needed for cutting bolts, screws, metal strips, etc., on which the hack saw cannot be conveniently used.

Tin snips are very convenient for cutting strips of hard insulation, such as fibre, or for cutting shims of thin metal for lining up bearings or machine bases. They can also be used for cutting shims to place under field poles when adjusting air gaps on the poles of motors or generators.

A set of bearing scrapers, such as used on automotive work are usually very convenient. These are to be used for scraping sleeve-bearings to fit the shafts of motors or generators.

An air-gap gauge consist of a group of thin



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metal feeler gauges that can be used for determining the air gap between the armature core and various field-pole faces.

It is quite important to keep the armature centered in the machine, in order to secure best operation, and when bearings become worn and allow the armature to drop below the center, an air-gap gauge can be used to re-center the armature or determine which poles it is closest to.

One or more pieces of hack saw blade can be easily fitted with file handles and used for undercutting mica on small and medium-sized machines, as was explained in a previous article.

Flat files are very convenient for resurfacing and dressing the faces of contacts on controllers, and hundreds of other uses which are not necessary to mention, as most everyone knows the common uses for a file.

Where most of the work to be done is within reach of electrical circuits of the proper voltage, an electric soldering-iron is generally most convenient. Where electric supply of the proper voltage is not available or where very heavy soldering is to be done, a blow torch is essential. One or more soldering coppers can then be used, by heating them in the flame of the blow torch.

### 30. OPERATION AND CARE OF BLOW TORCHES

At this point it will be well to give a few general hints on the use of gasoline blow-torches.

A torch of one quart size is usually most convenient for ordinary work. To fill the torch, unscrew the cap in the bottom and pour the gasoline in the opening with a funnel. If any gasoline is spilled on the bottom of the torch it can be run inside by gently rocking the torch back and forth until most of it runs into the opening.

After filling, replace the cap, making sure that the composition washer is in place, to seal the

## Maintenance

torch air-tight and prevent leakage of gasoline. Tighten the screw cap securely and pump a small amount of air into the tank. Six to ten strokes of the pump is sufficient for starting a torch. Then hold the hand or some object over the torch nozzle, tipping the torch back slightly, and open the needle valve a small amount. The gasoline which is allowed to escape will then drain into the small vessel or cup under the torch. The cup should be nearly full before the valve is closed.

This gasoline should then be carefully ignited with a match and allowed to burn away almost completely before opening the valve again.

This flame heats the torch nozzle and gas generator so the liquid gasoline will be turned into vapor as it escape. This is necessary for proper operation and to secure the full heat of the flame.

When the torch is well-heated, open the needle valve and adjust it until the flame is a sort of blue color with a slight pink tinge.

If the torch is operated in a breeze or wind, turn the torch so the flame points against the breeze. This will tend to confine the heat of the flame where it will do the most good and keep the torch hot enough to operate.

When through using the blow torch, it should be extinguished by closing the needle valve; never by blowing or smothering the flame. After extinguishing the torch, let it stand a few minutes; then open the needle valve until a hissing sound is heard. This relieves the pressure in the tank and the needle valve can then be closed gently and the torch put away until it is to be used again.

Never use a pliers on the needle valve or you may damage the soft metal seat of the valve. **Never use one blow torch to heat another, or it may result in an explosion and dangerous burns.**

These few general hints on the types of tools and the methods of their use are intended simply to aid those who have never used tools of this kind to become properly acquainted with them.

Thoughtfulness, pride, and care in your work, and the application of a little mechanical ability

## Direct Current

along with practice, are all that are required to make most anyone proficient in the use of these tools and in ordinary electric maintenance work.

Always do all repair work neatly and thoroughly. You will find that in the long run it saves time and trouble. Take a reasonable pride in all electrical machinery and equipment which you may be operating or maintaining, and also in your knowledge of the proper operation and care of this equipment.

Conscientious and intelligent application of the knowledge you can gain from this lesson and preceding lessons and experiments should enable you to qualify in the operation or maintenance of practically any Direct Current equipment.

### MAINTENANCE SCHEDULE

Getting the most out of motors depends on careful selection and proper installation as well as on-schedule inspections, lubrication and cleaning.

Work stoppages caused by motor failures at critical moments can be forestalled to a large degree by proper preventive measures.

Although not actually maintenance, the correct selection and application of a motor involve a great many factors affecting the installation, operation, and subsequent servicing of the motor. Here are some general rules on selection:

1. Check motor rating against load requirements.

The motor should be the proper type as well as size. Overloading causes overheating and overheating means shortened motor life. Underloading wastes current, lowers power factor—an item in many rate schedules.

2. Be sure voltage and frequency are correct for circuit.

Variations in voltage of more than 10% plus or minus and frequency variations of more than 5% above or below nameplate rating should be avoided. Voltages below normal are particularly objectionable.

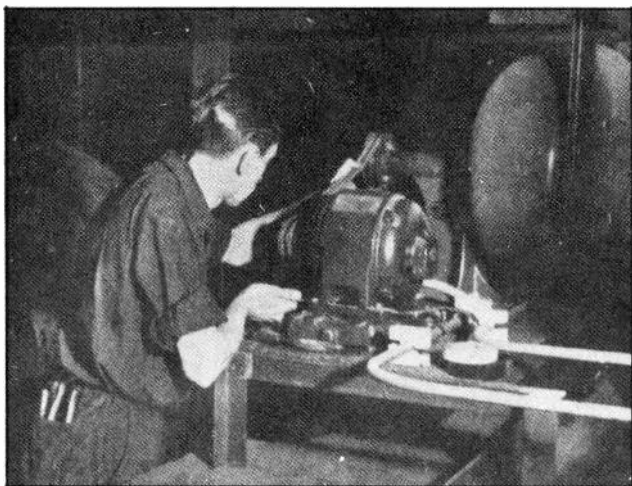
3. Select a high-speed motor—if possible.

Where application permits, a high speed motor means smaller size with less cost and higher operating efficiency.

## Maintenance

More specific instructions for matching the motor to the power supply and the driven machine may be obtained from any motor manufacturer.

After the correct motor has been selected, it must be properly installed in order to deliver the maximum efficiency and require the minimum of servicing. The following installation pointers will get the motor off to a good start:



**Install the motor so that it is accessible for inspections and repairs.  
Align it properly with the driven load.**

1. Mount in a dry, clean, accessible place.

Motors must be protected from dirt, moisture, dripping oil, fumes—either by proper location or by using an enclosed type. Good ventilation and accessibility are essential.

2. Match control to motor rating and load.

Control equipment in correct size and type will protect the motor against overloads in starting, stopping, and acceleration.

3. Check Connections.

Terminal lugs should be tightly soldered or bolted to prevent loosening from vibration. Try the motor for correct rotation—then tape leads with rubber and friction tape.

## Direct Current

### 4. Make certain of proper alignment.

Align motor with shaft of machine to be driven and fasten securely to a rigid base or foundation. Sprung shafts, overload, burned-out bearings are some consequences of misalignment.

Inspection, lubrication and servicing of each motor should be systematic. Frequency and degree of thoroughness will depend on the amount of operation, nature of service, and environment under which the motor operates. The following schedule covering both a-c and d-c motors is based on average conditions insofar as duty and dirt are concerned:



Keep motors free from dust and dirt by frequent wiping.

### Every Week

1. Check oil level in bearings and see that oil rings are moving freely.
2. Examine fuses and control equipment. Wipe off control housings.
3. Check commutator and brushes for possible adjustment.
4. Start motor and see that it is brought up to speed in normal time.

## Maintenance

### Every 6 Months

1. Blow dirt out of motor with dry compressed air at not over 50 lb pressure.  
Wipe commutator and brushes.
2. Check grease in anti-friction bearings.  
Avoid excessive grease pressure as it causes overheating.

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3. Examine brushes and brush holders.  
Replace brushes more than half worn.  
Clean holders and check brush pressure and position.
4. Check operating speed and listen for signs of bearing wear.
5. Inspect condition of control apparatus.  
Dress or renew pitted contactor tips and see that fuses are in order so that motor will not single phase. Tighten connections.
6. Examine commutator and commutator clamping ring. Clean with cloth dampened with carbon tetrachloride.
7. Check motor foot bolts, end-shield bolts, pulley, coupling gear, and journal set screws.
8. See that all motor covers and guards are in place and securely fastened.

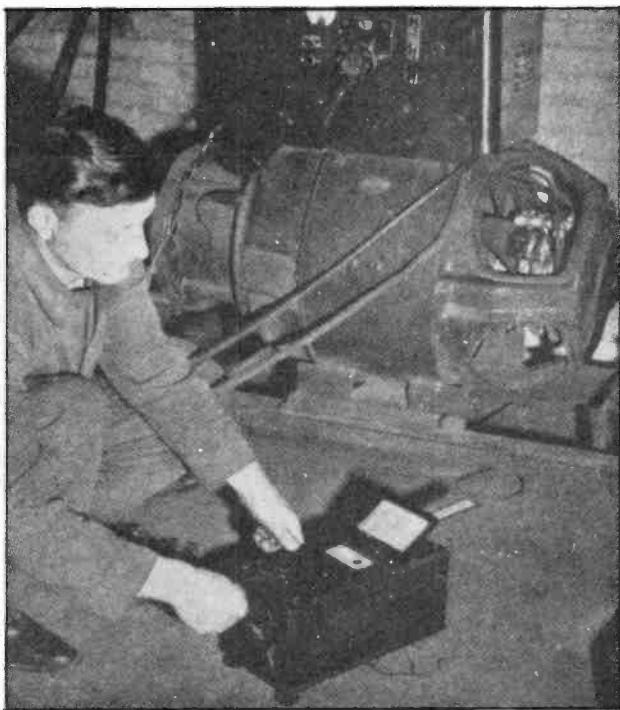
### Once a Year

1. Clean out and renew grease in bearing housings. Clean sleeve bearing housings and renew oil.
2. Test insulation with an insulation resistance tester. If reading is less than 1 megohm per 1000 volts; winding should be baked out until reading is satisfactory.
3. Clean out undercut slots in commutator. If commutator is spot worn have it trued up in a lathe. Undercut high mica separators.
4. Check current input and compare with normal to prevent underload or overload.
5. Inspect armature bands and connection of armature coils and commutator.
6. Check rotor clearance at each end with a

## Direct Current

feeler gage. Keep record of clearance as a check on bearing wear. For less than 10 HP the minimum gap permissible is .005 inch. For more than 10 HP gap should not be less than .010 inch.

7. Clean out magnetic dirt that may be hanging on poles.



Insulation resistance tester being used to determine condition of motor-generator insulation by indicating insulation's resistance to leakage currents.

### Every 2 Years

1. Dismantle the motor and clean.
2. See that windings are tight.
3. Replace loose wedges and loose bands.
4. Dry out motor in an oven at  $115^{\circ}$  C. maximum temperature. Dip in varnish and bake, 2 to 4 times depending on operating conditions.
5. Remove bracket and wash out bearing housing, using hot kerosene oil and compressed air, if available.

## Maintenance

An up-to-date record card should be kept for each motor showing periodic test values of clearance and insulation, all repair work and its cost. A visual record should also be maintained to show the schedule of lubricating, cleaning and inspection. Misapplications, poor drive engineering and excessive operating costs will be quickly disclosed with accurate records. Several excellent record systems have been developed and printed, so that it is not necessary to devise and prepare individual systems.

An adequate stock of spare motor parts and spare motors should be maintained for emergency repairs and replacements. Bearings of different sizes, spare armatures for d-c motors, brushes and other parts should be on hand in different sizes and properly classified for easy identification. Auxiliary motors in racks and large motors on skids should be ready for immediate installation at any point in the plant.

The importance of an adequate motor maintenance program cannot be over-emphasized. Such a program will do much toward maintaining peak operating efficiency in any plant.



## Direct Current

### EXAMINATION QUESTIONS

1. Which part of a D.C. motor or generator usually requires more attention than any other part of the machine?
2. Give one of the most important rules to follow in the maintenance of electric machines.
3. Is excessive oil detrimental to any part of a D. C. motor or generator? If so which parts?
4. How may the winding of a machine be dried out when there is no oven available or when the machine is too large for the oven?
5. If the mica between commutator segments becomes high, how may it be corrected?
6. Name at least five troubles which may cause excessive sparking at the brushes?
7. Name at least three troubles which may cause a D.C. motor to overspeed?
8. Give at least three reasons why a D.C. generator may fail to build up voltage?
9. What would be the temperature Fahrenheit when a centigrade thermometer registers thirty?
10. What instruments are recommended for use in measuring insulation resistance?

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