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THE DYNAMOTOR AT THE RIGHT CONVERTS THE ELECTRIC POWER NECESSARY TO OPERATE THIS PORTABLE RADIO TRANSMITTER WHICH IS USED AS A FLEXIBLE LINK FOR TRANSMITTING SPORT AND NEWS EVENTS FROM REMOTE POINTS TO THE BROADCASTING STUDIO. (COURTESY COLUMBIA BROADCASTING SYSTEM)

Motor-Generators and Other Machine Converters

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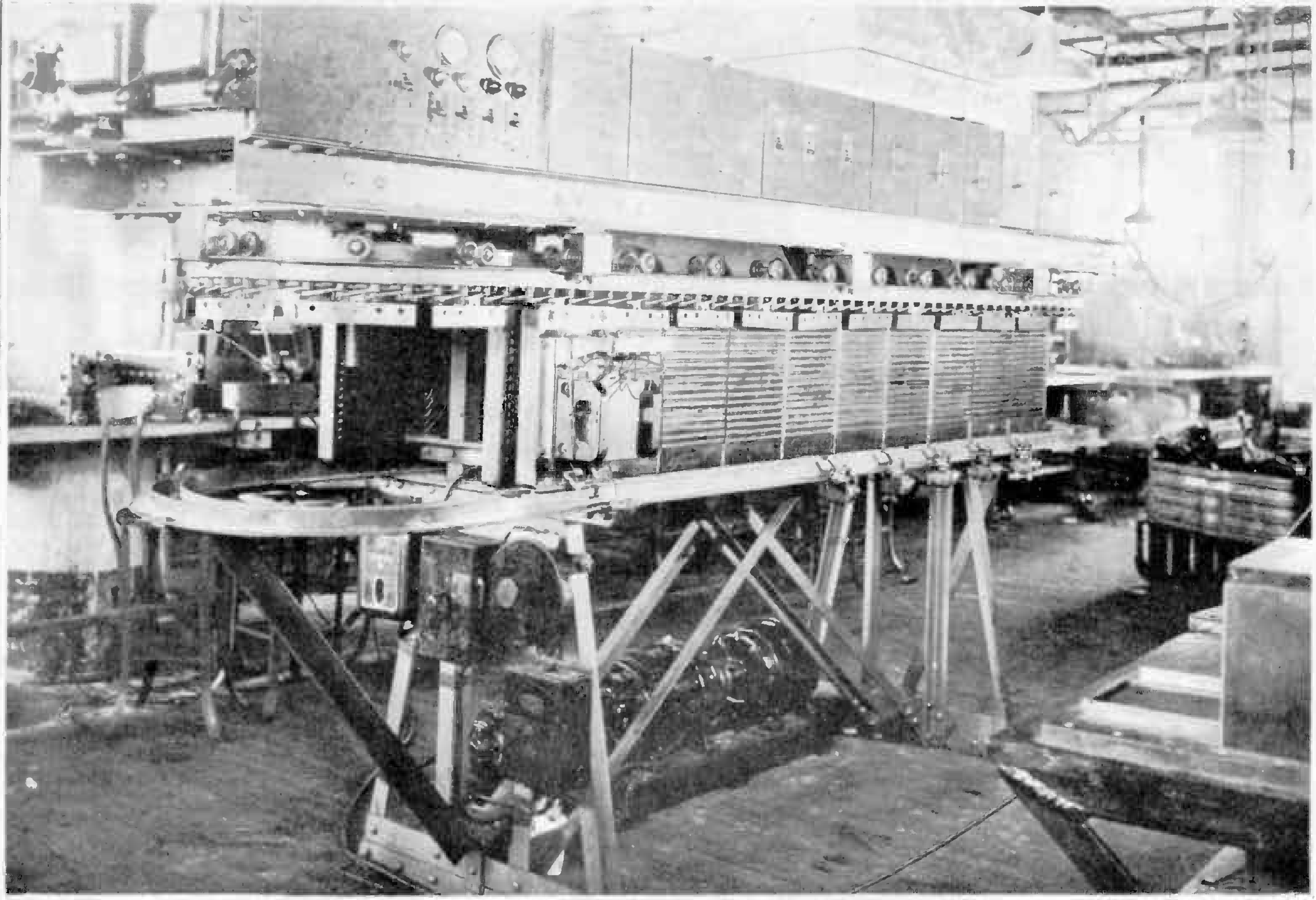

THE MOTOR-GENERATOR USED WITH THIS EQUIPMENT PROVIDES UNUSUAL VOLTAGES FOR TESTING THE POWER TRANSFORMERS CONVEYED ALONG THIS AUTOMATIC TESTING MACHINE

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MOTOR-GENERATORS AND OTHER MACHINE CONVERTERS

Along with the many varieties of electrical circuits which require either a-c or d-c for their operating power we frequently encounter different types of rotating machines used for the conversion of electrical energy from a-c or d-c sources into the a-c or d-c form at different voltages and frequencies according to requirements. In this lesson we deal with three principal types of converting machines which are named and defined as follows:

I. MOTOR-GENERATOR, consisting of a motor and one or more generators which have their shafts coupled together for a mechanical transfer of power, but which have no magnetic fields in common. This means that each machine is complete in itself as far as armatures, armature conductors, and field structures are concerned.

II. ROTARY CONVERTER, which is a single machine with one armature, one magnetic field, and only one set of armature conductors, which serve for both the driving and the generating functions of the machine.

III. DYNAMOTOR, which is a single machine with one armature and one magnetic field, but whose armature bears two sets of conductors, insulated from each other. One set acts with the common magnetic field to provide the driving action; the other set acts with the common field to generate the desired voltage.

The usual forms of conversion may be classed according to their purpose as follows:

A. Direct current to direct current of a different voltage.

B. Direct current to alternating current of a desired frequency and voltage.

C. Alternating current of an available frequency and voltage to a direct current of a desired voltage.

D. Alternating current of one frequency to alternating current of another frequency.

It is to be understood that alternating current at a certain voltage and frequency may be converted to a.c. at another voltage but of the same frequency by means of a machine, and such a conversion may be accomplished without rotating parts by employing a power transformer. The theory of power transformers is outside the scope of our present lesson, which will be limited to the three machine types listed above.

MOTOR-GENERATORS

When the shaft of a motor is coupled to the shaft of a generator, there is no difference in the fundamental design of either the motor or the generator. For purposes of mechanical rigidity they are mounted on a common base.

Fig. 1 shows a common form of motor-generator, the motor being at the left of the illustration. The method of coupling the two machines together is clearly shown, together with the housing for the bearings used to support the shafts of the motor and the generator. In this case the motor and generator have independent bearings.

In some machines the coupling plate used is a specially prepared disc of flexible material which will withstand the twisting strain of the motor shaft turning the generator armature. This allows for small irregularities in the alignment of the shafts. Where a solid mechanical connection is made the tightening of the bolts in the coupling device might easily throw the shaft out of alignment causing it to bind on one or more of the bearings. In Fig. 2 is illustrated the general outline of the motor-generator, all bearings and bearing housings being omitted for the sake of clearness.

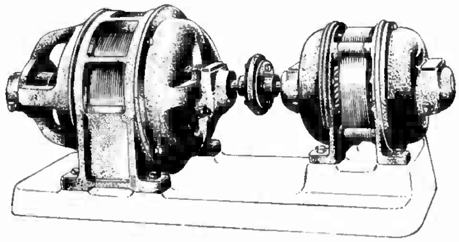


Fig. 1 - A MOTOR AND GENERATOR COUPLED TOGETHER

The general features of a machine employed for the conversion of direct current to alternating current can be grasped from the sketch in Fig. 2. Note the names and purpose of various parts which go to make up a machine of this kind as outlined in the legend given below

1. The switch controlling the direct-current supply.
2. The leads connecting the main line current supply with the motor armature.
3. The direct-current motor.
4. The armature of the motor.
5. The commutator of the motor.
6. The motor brushes.
7. The motor shaft.
8. The leads running from brushes supplying current to the motor field windings.
9. The motor field coils.
10. Motor coupling plate secured to motor shaft.
11. Flexible material used between metal coupling plates.
12. Leads from direct-current source supplying the field coils of the alternator.

13. Alternating-current generator.

14. A-C generator field coils.

15. A-C generator armature.

16. Generator coupling plate secured to generator shaft.

17. Collector rings of generator.

18. Generator shaft to which collector rings are secured.

19. Collector ring brushes which lead current from collector rings into external circuit.

20. Alternating-current leads to external circuit.

The motor shown is of the shunt wound type and receives its power from the available d-c power mains, usually at 110 volts. Note, at

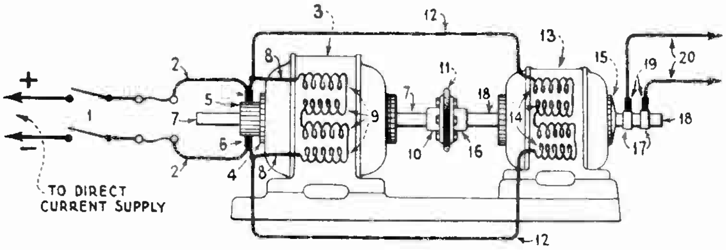


Fig. 2 - SHUNT-WOUND MOTOR COUPLED TO AN ALTERNATOR WITH ITS FIELD IN SHUNT TO THE D-C SUPPLY

this point, that the a-c generator field coils are connected with the same d-c supply which is driving the motor, direct current being necessary to excite the field coils of the alternator. In some installations, however, a small exciting generator is used which is driven from the motor shaft by a belt or directly coupled thereto. In practical work we find machines rated at different frequencies and voltages according to the design and purpose for which they are intended. The few examples which follow will serve to illustrate this point: Motors designed for 110-120 volt, 60 cycle a-c operation are extensively used; d-c generators which supply voltages from about 15 volts to 1000 volts are used to operate certain types of vacuum tube circuits; generators supplying 500 cycle a-c to power transformers have limited use in certain older types of radio telegraph (spark) transmitters; in certain sections of the country 25 cycles is the standard frequency used for industrial electrical equipment and so on. In sound picture practice the load on the alternator is practically constant and, therefore, the simple shunt-wound units in the above assembly will be satisfactory.

The requirements for a motor-generator used in radio telegraph communication are constant frequency and steady voltage under varying load conditions. The load on the generator is caused by the closing of the telegraph key which allows current to flow to the alternating-current transformer of the transmitting set. The load, therefore, is intermittent in character and when the key is closed the full amount of current is drawn from the generator immediately. There is no gradual increase of load; it is thrown on suddenly and discontinued just as abruptly.

Hence, it can be readily appreciated that some means must be provided to maintain a constant frequency output and constant voltage and, where possible, both conditions should be met. This calls for a self regulation which is secured by the manner in which the field coils of the motor generator are designed.

It now becomes necessary to divide the motor-generator equipment into three separate classes according to the field coil connections.

The first type, shown in Fig. 2, is a shunt wound motor coupled to an alternator with its field in shunt to the d-c supply; second, the same type of motor coupled to an alternator having compound field windings; third, the simple a-c generator of the first type driven by a motor having compound field windings. Let us consider these three divisions by studying the simple schematic drawings of Figs. 3, 4 and 5.

Before proceeding further, let us advise that if you are not already familiar with the electrical symbols, place the sheet bearing these symbols before you when studying the motor-generator diagrams.

Fig. 3 is the diagram of a simple shunt wound motor-generator set; it has the same field and generator connections as shown in Fig. 2. The parts are all clearly labeled. You will notice two field current regulating rheostats — one in the motor field circuit and one in the generator field circuit. We will explain the operation of these two rheostats.

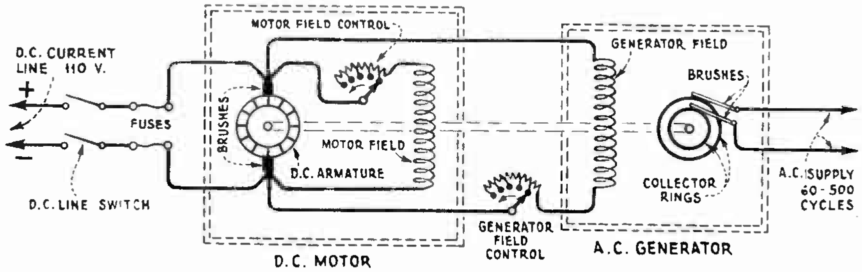


Fig. 3 - SIMPLE SHUNT WOUND MOTOR-GENERATOR SET

Beginning first with the motor field, if we turn the rheostat to the left as indicated by the arrow more resistance will be added to the field circuit, and this will reduce the current flowing in the motor field windings. This weakens the magnetic field which results in the motor speeding up, and since the generator is coupled to the motor the generator speed will also increase. It is very evident that the frequency output of the generator will be increased because its frequency depends upon its speed. By reversing this procedure, that is, decreasing the motor field resistance by turning the rheostat arm again to the right, the opposite effect is produced. In this case the motor and generator both slow down and, therefore, the frequency of the generator is reduced.

Now go through the same procedure with the generator field rheostat; turn it to the left as shown by the arrow thereby cutting in more resistance. Naturally, the result is a decrease in the current intensity in the generator field which reduces the generator output voltage. Reversing this process, that is, decreasing the generator field circuit resistance, will increase the field strength and consequently raise the output voltage.

Keep in mind the results just explained when introducing resistance in a generator field circuit and in a motor field circuit. Be sure that you fully comprehend the two actions and do not confuse them.

In Fig. 4 we have a shunt wound motor and compound wound generator; the motor and generator shunt fields have adjustable rheostats connected in their circuits enabling the speed of the motor to be regulated and the voltage of the generator to be controlled. When the desired speed of the motor is secured and the proper voltage output of the generator is obtained, these rheostats are left in that position.

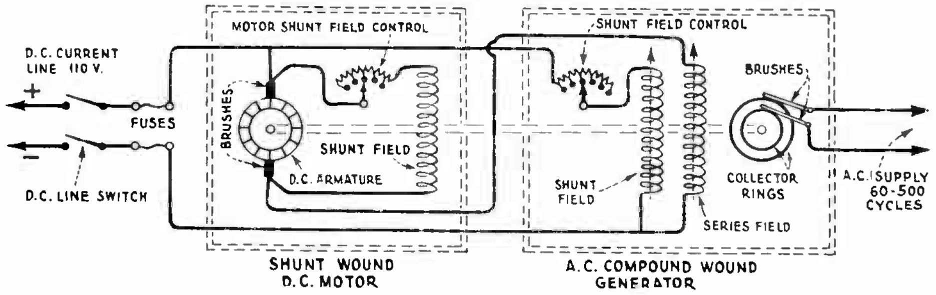


Fig. 4 - SHUNT WOUND MOTOR AND COMPOUND WOUND GENERATOR

The shunt and series field windings of the generator are connected in such manner that the field of the series winding and that of the shunt winding are in the same direction, i.e., of the same polarity. The motor-generator is subject to sudden loads when the telegraph key is closed and when this happens there is a tendency toward a decrease in speed. A decrease in speed causes an increase of current flow through the series winding, because the series winding is in series with the armature of the motor. This increased current flow through the series winding strengthens the field of the generator at once and it tends to restore the voltage to normal. Thus, in this type of motor-generator the speed of the motor and voltage output of the generator are maintained fairly constant under sudden variations of the load.

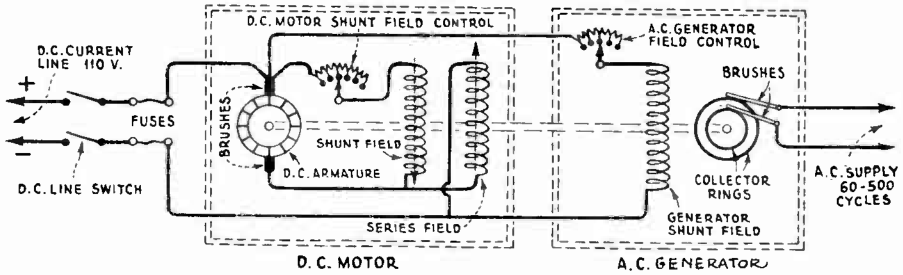


Fig. 5 - A DIFFERENTIALLY COMPOUND WOUND MOTOR COUPLED TO AN A-C GENERATOR

Now let us look at Fig. 5. The motor in this case is differentially compound wound. In other words, the magnetic field due to the shunt winding is opposed by the field due to the series winding, as determined by the relative directions of their turns about the field poles and the direction of current flow through the windings. Let us analyze the effect when the field of the series winding opposes the field of the shunt winding of this motor.

when a load is thrown on the generator in Fig. 5 the speed of the motor is reduced, thereby decreasing the counter e.m.f. As the shunt field winding is connected across the line, its current tends to remain normal, and the field flux due to the shunt winding, therefore, does not change. However, as the series winding is connected in series with the armature, the series winding will receive the increase in current caused by the lowered counter e.m.f. of the armature. The field flux due to the series winding will, therefore, increase. Since this flux opposes the main field flux which is due to the shunt winding, we find that the motor field as a whole will be weakened. This allows the motor to gain speed at once, building up the counter e.m.f. until a steady state has been reached with the motor running at its normal speed.

There is even a condition under which the generator will produce a higher frequency under load than when the load is removed. This occurs when the motor is "over-compounded". This term describes the effect of having the series winding wound with so many ampere-turns that the field flux created by it offers a considerable opposition

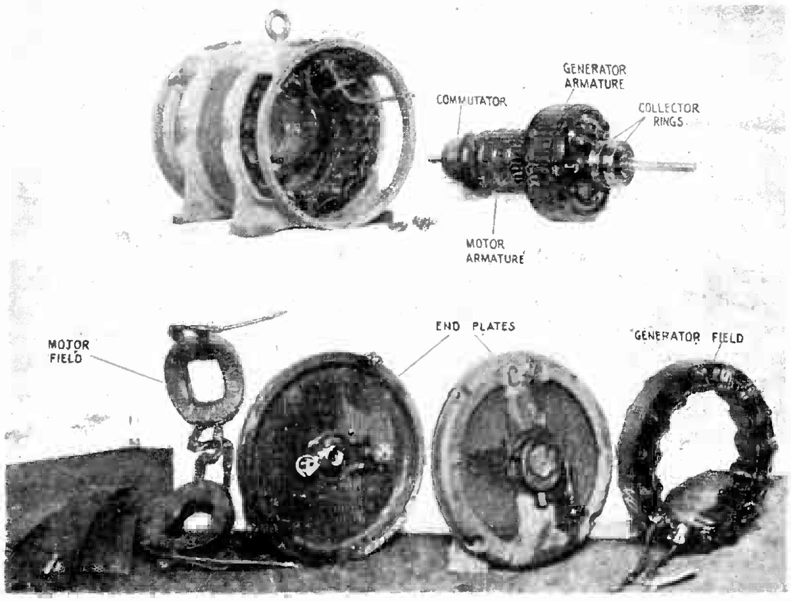


Fig. 6 - A DISASSEMBLED VIEW OF A CROCKER-WHEELER MOTOR-GENERATOR SET

to the field flux due to the shunt winding. Under this condition, when the load is applied, the motor field as a whole is so weakened that the machine comes up to a steady speed in excess of its no-load speed. This causes the generator frequency to increase as the load is applied; for a radio transmitter this is as objectionable as for the frequency to shift lower, under load.

In Fig. 6 is shown a disassembled d-c to a-c motor-generator of the 2 kw. Crocker-Wheeler type as used in some shipboard installations. It will be noted that the shaft is in one piece and carries both the motor armature and the generator armature. Their magnetic fields are effectively separated by suitable spacing along the shaft, which maintains the distinguishing quality of a motor-generator as compared to rotary converters and dynamotors. These latter have a common armature and common field structure for the motor and generator functions.

It is often difficult to tell the three types apart from a casual inspection of their exteriors.

D-C TO D-C MOTOR-GENERATOR SETS

When a d-c generator is driven by a d-c motor the generator field may be supplied by the d-c power mains (as in the case of the alternator previously described) or the generator may be self-excited. When several generators are coupled to the same motor a further variation in practice may occur. One d-c generator of the group may provide the field excitation for another generator, whether the latter is d-c or a-c as to its output. The use of such a connection is dictated by common sense in the designing by the manufacturer.

This might occur especially in the case of a high-voltage d-c generator, whose field is designed for separate excitation at a much lower voltage as a measure of safety and economy in the use of wire and insulation. If the voltage of the supply mains is lower than the normal voltage required for that field, the latter may be excited by another d-c generator. This may have been added for that purpose alone, or it may have been required for some other electrical purpose concerned with the equipment.

An example of this practice is shown in Fig. 7, which shows the four-unit motor-generator set used with early sound-picture installations of the type PG-1 and PG-2. The 15 volt d-c generator is

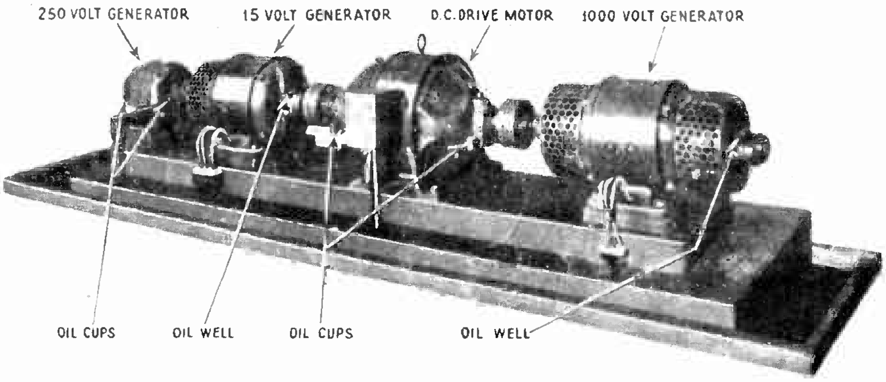


Fig. 7 - A FOUR-UNIT MOTOR-GENERATOR SET DESIGNED FOR SOUND PICTURE EQUIPMENT

required for filament voltages, the 1000 volt d-c generator supplies plate voltage for the last several stages of the amplifier, and the 250 volt d-c generator provides grid bias voltage for the output stage. This 250 volt machine is self-excited, and in addition provides the field excitation voltage for both the 15 volt and the 1000 volt generators.

One of the main reasons for having a d-c generator separately excited has to do with a difficulty encountered in getting a self-excited generator to build up its terminal voltage, starting out with only the residual field magnetism in its poles. If the normal load for which it is installed happens to be connected to the generator terminals when the motor-generator is started up, the terminal voltage might not build up. In the set described above, the current load on the 250 volt generator is small, and its terminal voltage easily rises to normal. However, the filament load on the 15 volt machine is very heavy, so its field is separately excited to insure operation, even with the load on, when starting up.

The 1000 volt generator has two commutators, one on each end of the armature, and each delivers 500 volts. These commutators are connected in series to give a total of 1000 volts. This construction not only reduces the insulation requirements and the sparking at

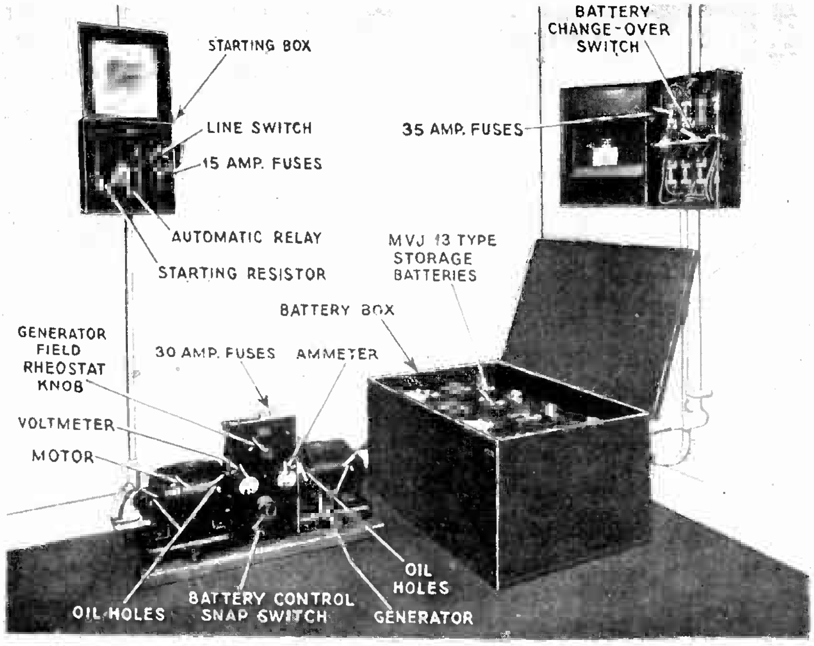


Fig. 8 - ARRANGEMENT OF BATTERY CHARGING EQUIPMENT USED WITH A SOUND-PICTURE INSTALLATION

the commutators, but provides economically the intermediate voltages of 500 and lower which would otherwise have to be secured through series resistances or voltage dividers applied to the total 1000 volts generated.

Even when the power mains provide direct current for the charging of storage batteries, it is found more economical to reduce the vol-

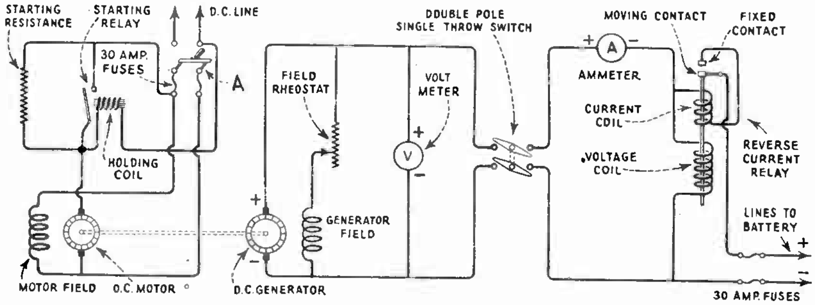


Fig. 9 - SCHEMATIC DIAGRAM OF A D-C MOTOR-GENERATOR CHARGING UNIT

tage by the motor-generator method than by the use of series resistance in the circuit. This is particularly true when the battery terminal voltage is small compared to the line voltage. This is demonstrated in the case of a battery-charging arrangement used for certain sound-picture installations, as illustrated in Fig. 8. A schematic drawing of the connections is shown in Fig. 9, including the starting equipment and a reverse current relay for the charging circuit, designed to prevent the battery from discharging into the generator circuit when the e.m.f. generated by the machine becomes less than the internal e.m.f. of the battery, due to slowing down or other causes.

A-C TO D-C MOTOR-GENERATOR SETS

It is easier to understand the many variations that come under the head of motor-generators if we bear in mind these fundamentals:

1. The electrical characteristics of the motor are determined by the available electric supply.

2. The power rating of the motor is determined by the shaft power required to drive the generator or generators under their normal loads.

3. The electrical characteristics of each generator coupled thereto are determined by a specific load requirement of the device or apparatus to be operated.

Manufacturing economy has long since dictated that standard parts be used for as many purposes as possible. This has resulted in identical frames being used for motors produced for a variety of voltages, and including both a-c and d-c types. Only the field and armature structures may differ. With the frame mounting holes and shaft heights identical for motors of widely different electrical characteristics, we see that the motor-generator becomes a very handy and convenient device for matching load requirements to an available electric power supply.

We find, therefore, that motor-generator sets for use with certain installations will vary in different localities mainly in the motor equipment and the necessary starting and control accessories. A further difference enters in the case of a-c mains, in that the generator fields will not be excited from the power mains.

The photograph on the back cover page shows a three-unit motor-generator set of which one generator develops 600 volts d.c. and the other 12 volts d.c. The field of the low-voltage machine is excited by the terminal voltage of the high-voltage machine. With such an arrangement, when the set is started up, the field rheostat of the 600 volt machine is always adjusted first for its normal voltage, because the voltage of the second generator will depend on its 600 volt field excitation. Then the field rheostat of this 12 volt machine is adjusted to its normal voltage as shown by the panel voltmeter. A novel construction enters here, in that the two field rheostats are mounted on the same center line, and a single control knob serves for both, being shifted in or out a short distance to engage the contact arm of the rheostat which is to be moved.

A-C TO A-C CONVERSION

The conversion of alternating current of one frequency into alternating current of another frequency is met with less often than the other forms of conversion. This change may be made with or without an accompanying change in the number of phases and the voltage. This might occur where the power mains were 25 cycle single-phase alternating current, and it is desired to operate standard radio transmitting equipment of the 60 cycle three-phase type.

THE ROTARY CONVERTER

Rotary converters have several uses. In commercial practice they are generally used to convert alternating current into direct current for use on traction lines, in the charging of storage batteries, and in electro-plating plants. In the communication fields, such a conversion is usually accomplished by electronic or gas discharge devices.

For a-c to d-c operation, the machine may be designed, as a motor, for single-phase, two-phase or three-phase alternating current. There are no new principles with which you are not familiar in the fundamentals of this machine other than its physical construction. Just remember when you think or hear of a rotary converter that it is simply two machines in one. There is one armature and on this is placed a simple winding which serves to revolve it and from which generated current is collected. This generated current is the result of what was, in the independent motor or generator, the counter

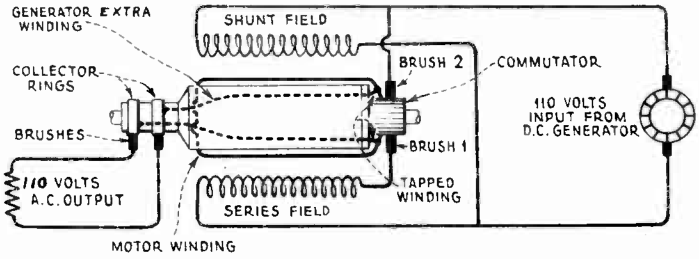


Fig. 10 – FUNDAMENTAL CIRCUIT OF A ROTARY CONVERTER

e.m.f. Furthermore, only one set of field windings is used to supply the magnetic field for both the motor and generator functions of the machine.

The use of a commutator, properly connected to the individual sections of the armature winding, makes available the counter e.m.f. developed in these sections, as a direct current.

If arrangements are made to revolve the armature by mechanical means, such as a gasoline motor, both alternating and direct current will be delivered. In this case the field windings of the machine would, of course, be excited from the d-c brushes of the commutator end.

By applying direct current to the windings and field from an external source, alternating current can be obtained from the collector rings. When used in this way, the machine is referred to as an inverted rotary converter and sometimes more briefly as a rotary inverter.

The distinguishing feature, as just stated, is the use of a single armature for both alternating and direct current. There are only two bearings needed, and it requires less space for installation. Therefore, the construction and installation of the machine as a whole is simplified.

There is the disadvantage, however, of not obtaining full control of voltage. For this reason it is often better to use the motor-generator than the rotary converter, even though the cost of the motor-generator is higher. When 110 volts is used as the supply, the alternating voltage delivered (which is really the counter e.m.f. of the armature) will reach a maximum of approximately 78 volts. When higher voltages are desired a step-up transformer may be used on the a-c side. It is possible to secure a greater voltage output than that stated, by means of an auxiliary winding. This is used especially when it is desired to have about the same a-c voltage as the d-c voltage supply.

This is shown by the fundamental circuit of Fig. 10. The current flows from the power mains, indicated as a 110 volt d-c generator, through the series field winding into the armature at brush 1, through the armature coils and out at brush 2. The shunt field is connected across the line as in any compound wound machine. As current is applied to the armature coils rotation results, and a counter e.m.f. is generated. If single-phase alternating current is desired, two

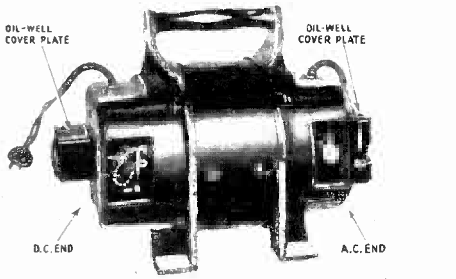


Fig. 11 - A D-C TO A-C ROTARY CONVERTER, RATED AT 3/4 KVA, USING THE AUXILIARY WINDING PRINCIPLE

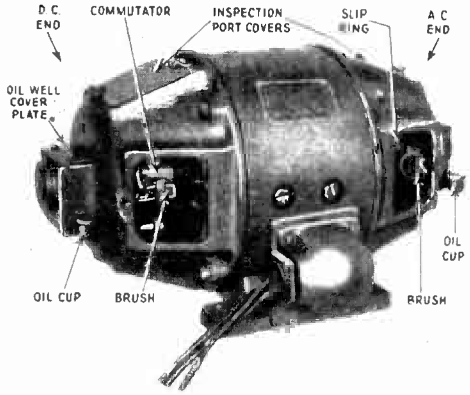


Fig. 12 - THIS MACHINE IS DESIGNED TO FURNISH TWICE THE POWER OF THE ONE SHOWN IN FIG. 11

taps are taken from the armature windings at points 180 degrees different in phase. These taps are connected to the slip rings through additional turns of wire on the armature which are not in the direct current circuit.

The extra conductors are so placed on the armature that the voltage generated in them adds to the voltage secured from the taps on the main armature winding. By proper selection of the number of turns in the extra winding, the desired voltage output can be secured. This construction is used on machines operating from 110-120 volt d-c mains to supply 60 cycle alternating current at 110-120 volts for radio sets of the latter kind. It might be considered that the combination of armature windings on this machine makes it a cross between a rotary converter and a dynamotor. The principles of the latter type of machine are described on the following page.

In Figs. 11 and 12 are shown two rotary converters using the auxiliary winding principle. The chief difference in the two machines is that one is designed for twice the power of the other. Otherwise there are no important differences.

THE DYNAMOTOR

The circuit of the dynamotor is shown in Fig. 13. The armature carries two separate windings wound in separate slots on the core, one to revolve the armature as a motor and the other for the production of e.m.f.

In the sketch shown the direct current used to drive the armature is obtained from a 30 volt storage battery outfit. (Commercial machines can be run on 110 v. d.c.and other voltages.) Voltages ranging from 350 to 2000 volts d.c.may be secured from the generator end, depending upon the design and type of dynamotor. The field is compound wound and is used as both the motor and generator field windings. The speed of this type of machine is 2000 r.p.m. and, to reduce vibration, the entire unit is suspended in a spring suspension saddle shown in Fig. 14.

The dynamotor is practically free from trouble due to armature reaction, and has an appreciably higher efficiency than the motor-generator. It suffers under the same handicap as the rotary converter, i.e., the output voltage can be controlled only by changing the input voltage to the motor side.

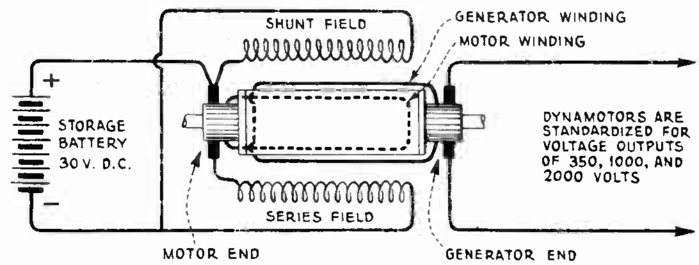


Fig. 13 - FUNDAMENTAL CIRCUIT OF A DYNAMOTOR

This type of converting machine is particularly useful in securing high d-c voltages for operation of airplane transmitters and receivers, when only a storage battery is available as a main power supply; the same holds good for automobile radio receivers when dry batteries for plate supply are to be avoided. Another important use is in sound picture work, where a 110 volt d-c supply is converted to a lower voltage for supplying exciter lamps, field supplies, and filaments of vacuum tubes, through a filter circuit designed to eliminate the commutation ripple.

In such uses, it will be seen that the dynamotor performs the same voltage step-up or step-down function for direct current that is performed for alternating current by a power transformer. In fact, we can truthfully carry this comparison still further. When a direct current is applied to the dynamotor armature and it rotates, the individual motor coils of the armature receive a current which continually changes direction, that is, it alternates, due to the commutator action. The motor coils, therefore, serve as the primary winding of a transformer whose iron core is the armature structure itself. The generator winding acts as the secondary of this transformer action, having induced in it an alternating e.m.f., the voltage of which depends on the relative number of turns in the primary and secondary windings (the motor and generator armature conductors). The second commutator then serves to rectify the alternating current, producing a direct current output at the generator terminals.

In the electrical entertainment industries, a dynamotor is used for a particular function, but we must remember that the principles of its operation are such that its function can be reversed in direction. By that is meant the conversion of voltages can be made in the

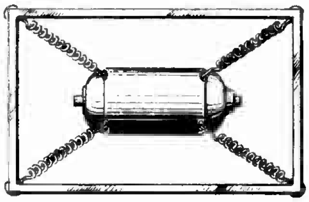
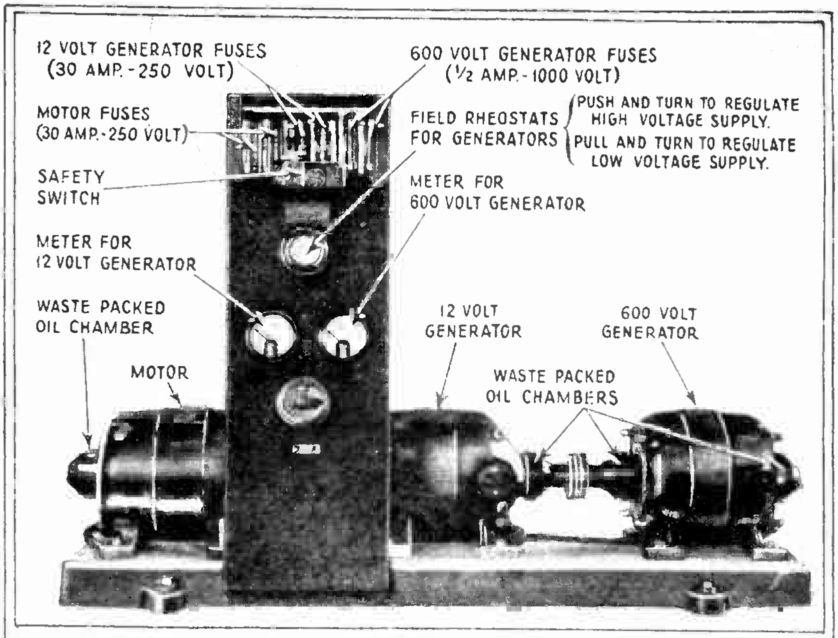


Fig.14 - DYNAMOTOR MOUNTED IN A SPRING SUSPENSION SADDLE TO REDUCE VIBRATION

opposite direction. If the input voltage to the motor side is 30 volts, with an output of 350 volts at the generator side, it would be possible to have the same machine supplied from an outside source with a potential of 350 volts or greater applied to what was the generator side of the first case. Then we would secure a voltage of about 30 generated by what was previously the motor side of the machine. In the technical subjects we are studying there is very seldom an occasion for doing this.

EXAMINATION QUESTIONS

1. What is a motor-generator?
2. What are the electrical requirements of a motor-generator set?
3. Draw a diagram of a shunt wound motor generator.
4. What are the three types of motor generators?
5. Draw a diagram of a compound wound generator set.
6. How would you regulate the speed of a shunt wound motor-generator?
7. Explain how the voltage output of the generator is controlled in a motor-generator set.
8. What is a dynamotor? Explain fully.
9. What is a rotary converter? Explain fully.
10. What advantage has the motor-generator over the rotary converter and the dynamotor?



PANEL BOARD AND MOTOR-GENERATOR SET USED WITH CERTAIN SOUND-PICTURE EQUIPMENTS. THE MOTOR IS A-C OPERATED AND THE GENERATORS SUPPLY D.C.

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