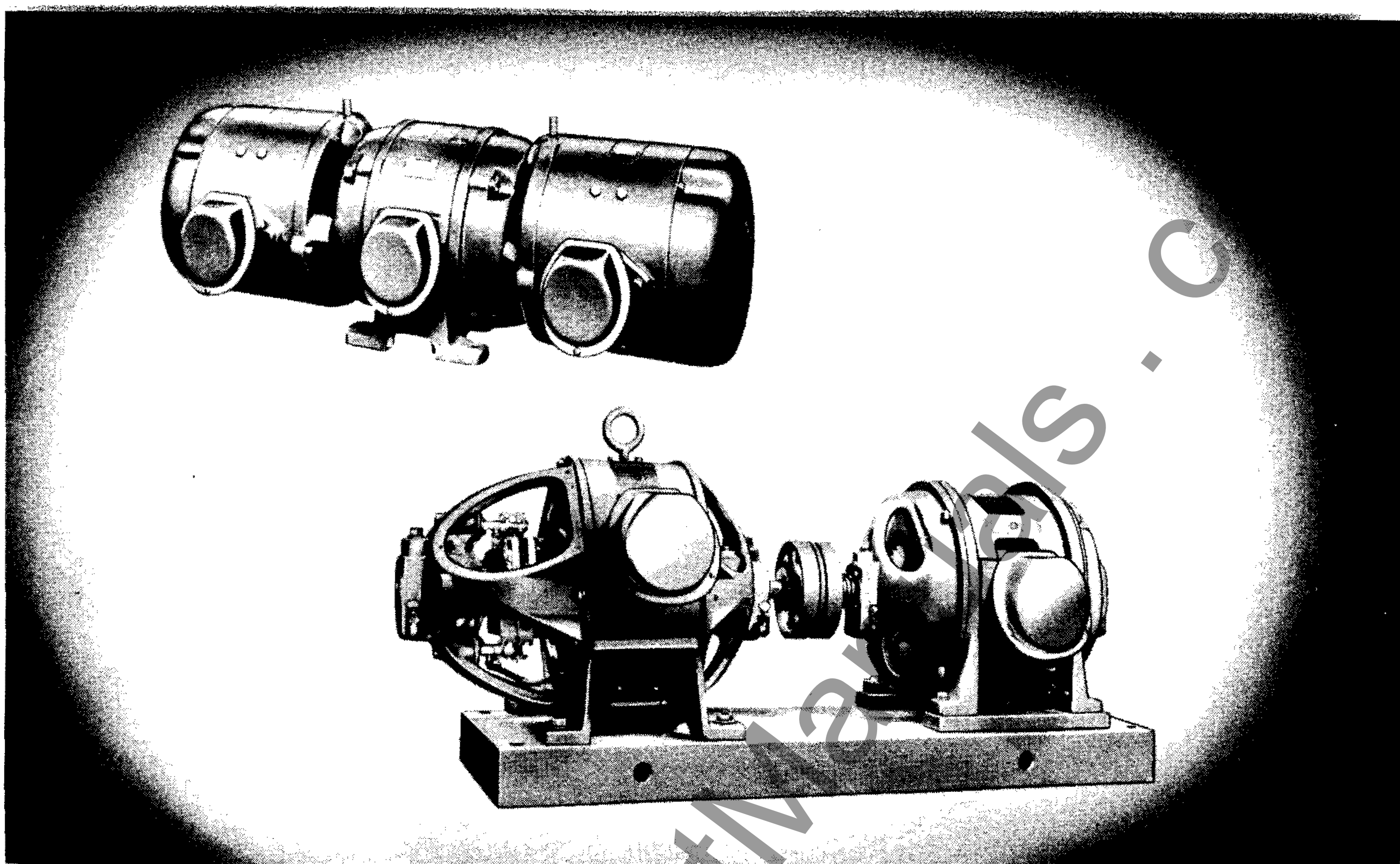


WESTINGHOUSE ROTOTROL

Rotating Regulator

Instructions for

ADJUSTMENT—OPERATION—MAINTENANCE

I.B. 9560-C-81

WESTINGHOUSE ELECTRIC CORPORATION

Buffalo, N. Y., U.S.A.

CONTENTS

Description Page

PRINCIPLES OF THE ROTOTROL

The Westinghouse Rototrol is a rotating regulator and amplifier. The name was coined from a contraction of the term "ROTating conTROL." The purpose of the following discussion is to describe the more fundamental characteristics and principles of the Rototrol.

Basically, the Rototrol is a direct current generator having special field windings. This explanation accordingly will be developed on the rather well known characteristics of a standard direct current generator.

Any direct current generator inherently provides amplification in that a relatively small change in the amount of field current can be used to exert a large effect on the armature voltage and current. The special features built into the Rototrol serve to increase this ratio of amplification, and to provide greater sensitivity and accuracy.

An examination of the magnetization curve of a standard direct current machine such as is shown in Figure 1, discloses that up to about three-quarters of normal armature voltage practically all of the field current is expended in forcing magnetic flux across the air gap. On this portion of the curve, the voltage output of the machine is directly proportional to the field current. Hence, this section is known as the straight "air-gap line." Above this portion of the curve, the iron in the magnetic circuit begins to require relatively more field ampere-turns for a corresponding increase in output voltage, and under these conditions the generator is said to become "saturated" as the amount of flux is increased to give the higher armature voltage. The entire curve given in Figure 1 is called the "no-load saturation curve."

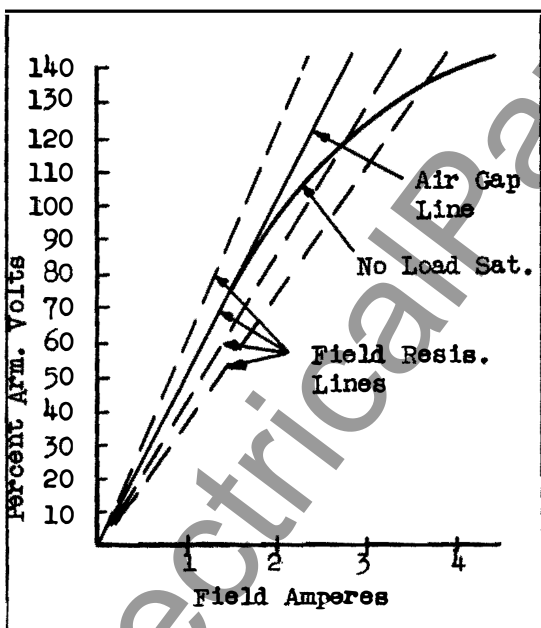
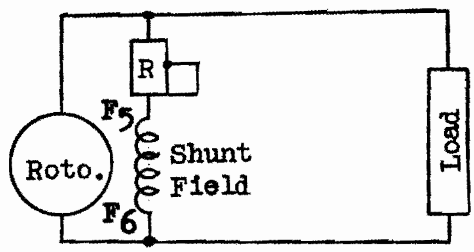


Figure 1

In a self-excited shunt machine, current forced through the constant-resistance field is directly proportional to the armature voltage, giving a straight "field resistance line." If an external field rheostat is connected in series with a shunt field as in Figure 2, the slope of the field resistance line can be altered by changing the amount of resistance R in the field rheostat. Changes in the field rheostat give the family of curves shown dotted in Figure 1. The steeper lines represent more total resistance - the less steep lines, less total resistance.

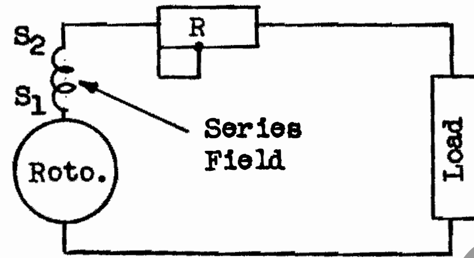
The voltage of a direct current generator with a self-excited shunt field will establish itself at that point where the no-load saturation and the field resistance lines cross each other. If the total resistance of the field circuit is increased sufficiently, the field resistance line will fall directly on the air-gap line. There is then no definite point of crossing and the voltage theoretically can balance at any point between zero and about 75% voltage. This results in what is known as "instability" in a self-excited direct current generator, and is a reason why the usual design of such machines cannot be operated at very much below rated voltage. This generally undesirable characteristic in regular shunt self-excited d-c generators has been explained in considerable detail, because it is an important part of the Rototrol principle.

Although the shunt wound generator was used for the foregoing illustration, identical reasoning applies to the development of a voltage in a series wound generator. In the series generator, the self-excited winding is connected in series with the load and both the load and the series winding comprise a shunt circuit across the armature(Figure 3). The series field current then is directly proportional to the armature voltage in the same manner as obtained for the self-excited shunt wound machine. This conception of the series wound generator is important because many Rototrol regulators make use of a series winding for the source of self excitation.



Shunt Self-energized Circuit

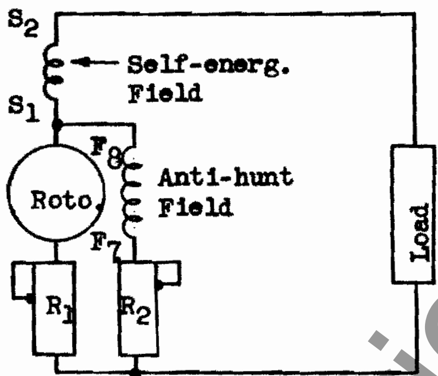
Figure 2



Series Self-energized Circuit

Figure 3

On many more recent Rototrols combinations of the series self-energizing field and the shunt connected anti-hunting field have been used. In circuits having high voltage (dynamic) amplification and in speed control circuits for high inertia loads a means to reduce overshooting was found to be necessary. The anti-hunt field, which is connected in the Rototrol self-energizing circuit differentially with respect to the series self-energizing field (Figure 4), responds to changes in the Rototrol armature voltage much faster than the load, which is usually the relatively large inductance of the field of another machine, thus the anti-hunt field is able to exert a stabilizing effort on the Rototrol. A net effect resistance line of the self-energizing field in combination with the anti-hunt field is adjusted to coincide with the Rototrol air-gap line, and the performance is the same as the shunt self-energized Rototrol and the series self-energized Rototrol.



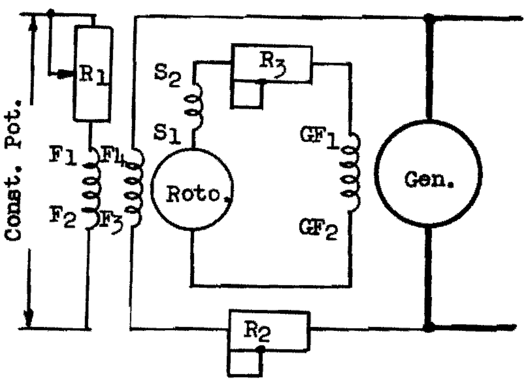
Series Self-energized Circuit
with Anti-hunt

Figure 4

The Rototrol is usually operated on the "straight" portion of its saturation curve. Stabilization is effected by additional field windings excited from other sources, and these auxiliary fields also serve as forcing, controlling, and regulating means. A significant fact is that under steady-state conditions, the self-energizing field furnishes all of the ampere-turns required to generate the output voltage, with the auxiliary or control fields having to supply only the stabilizing ampere-turns. The ampere-turns of the self-energizing circuit and of the regulating circuits are superimposed one on the other and the algebraic sum of the ampere-turns on all of the Rototrol fields determines the Rototrol voltage.

The separately excited or regulating fields are one or more in number, depending upon the requirements of the application. For simplicity, this explanation will use only two regulating fields. One regulating field is usually termed the "pattern" field and is excited from a constant potential. This is the reference source. The other is known as the "pilot" field, and measures the quantity to be controlled and regulated. The "pattern" and "pilot" fields normally are connected in opposition to each other so that any net difference between the two results in an amplified corrective action on the part of the Rototrol to bring the effects of these two fields again into balance.

A simple Rototrol voltage regulator circuit is shown schematically in Figure 5. The Rototrol armature is connected to the shunt field GF1-GF2 of the generator whose voltage output is being controlled. The tuning resistor R_3 in series with the self-excited series field, S1-S2, is adjusted to make the field resistance line coincide with the air-gap line. The pattern field F1-F2 is excited at a fixed strength from a constant potential. Any attempted variation in the voltage of the generator immediately is reflected



Rototrol Voltage Regulator Circuit

Figure 5

in a change in the strength of the voltage measuring or pilot field, F3-F4. Although this change in the voltage measuring field strength may be only a small fraction of an ampere, it alters the output voltage of the Rototrol and hence the current in the field of the generator until the pilot field F3-F4 again is in balance with the pattern field F1-F2. The adjusting rheostat R-1 in the circuit of the pattern field is used to change the value at which the generator voltage is to be held.

The foregoing example gives only the elements of a typical Rototrol application. Actual cases frequently use additional control fields, as well as different arrangements and connections. The Rototrol armature and its fields are sometimes connected into a bridge circuit. The same Rototrol may be used for two or more purposes, for instance, control of motor speed together with limitation of maximum motor load. In applications following a definite load cycle, such as shovels and draglines, special characteristics may be built into the relatively small Rototrol, in order to give relations between torque and speed which formerly required a special design for the very much larger main generator. A close examination of any Rototrol circuit will nevertheless always reveal the presence of the basic elements given in the foregoing example; a self-energizing field, a pattern field energized by a constant potential, and a pilot field energized by the electrical quantity under regulation.

The Rototrol may be used to accurately control voltage, current, or speed over a wide range, as well as any other physical variables which may be translated into these electrical quantities. For example, if the field excitation of a d-c motor is held constant, d-c motor torque is proportional to armature current and regulation of the d-c motor current will regulate torque. Likewise, motor horsepower is a function of armature current if the motor supply voltage is held constant. Control of armature current or voltage may also be utilized to limit the rate of acceleration and deceleration on high inertia loads. The intelligence given the Rototrol is not always an exact measure of the quantity being regulated. For example a tension regulator will hold a constant current in order to regulate tension and some Rototrols regulate speed using a counter EMF as intelligence. The Rototrol may be used very readily in conjunction with other devices such as synchro-tie units and electronic tubes to meet the demands of the applications.

The wide application range of the Rototrol regulator is indicated by the following major types of applications:

1. Generator voltage regulation, such as turbo generators, high frequency generators, etc.
2. Wide range motor speed regulation; as for paper mill drives, steel mill and other processing drives.
3. Arc furnace power regulation.
4. Torque and tension control for various steel mill, paper mill, textile and rubber mill applications.
5. Control of accelerating and decelerating torques and speeds on definite load cycle applications; such as drives for hoists , shovels, draglines, and oil well drilling equipment.
6. Positioning control, such as ship steering gear, etc.

The operation and maintenance of a Rototrol regulator is relatively simple. The average electrician is familiar with the standard direct current generator, of which the Rototrol is merely an adaptation. Once placed in proper adjustment, Rototrol maintenance regarding brush replacement and settings, lubrication, etc., is exactly the same as that required for standard d-c machines.

ROTOTROL FIELD MARKING AND IDENTIFICATION

FIELD MARKING

Rototrol field markings are made to conform as closely as possible to NEMA standards. Field markings have been established as follows:

Field	Marking
Pattern and/or Control* (See Fig. 6a & 6b)	F1-F2
Voltage measuring (Fig. 6a)**	F3-F4
Shunt Self-energizing	F5-F6
Anti-hunt	F7-F8
Inertia Compensating or Other Special Potential**	F9-F10, etc.
Series Self-energizing	S1-S2
Current Measuring or IR Drop**	S3-S4
Current Limit**	S5-S6
Other Special Current**	S7-S8, etc.
Armature Terminals	A1-A2

On all Rototrols, field polarity rules apply, and the direction of rotation should be as indicated on the control diagram. The fields are marked so that for clockwise rotation (facing the commutator end) A2 is positive with plus excitation connected to the odd numbered terminal of any one field; and for counter-clockwise rotation, A2 is negative with plus excitation connected to the odd numbered terminal of any one field.

All differential connections of the fields are made external to the Rototrol.

If the need for wide range, parallel paths, a bridge connections, or time constants require that two fields be used for the same purpose, these fields are marked with the same function symbols plus an additional letter of identification as AS3, AS4, and BS3, BS4.

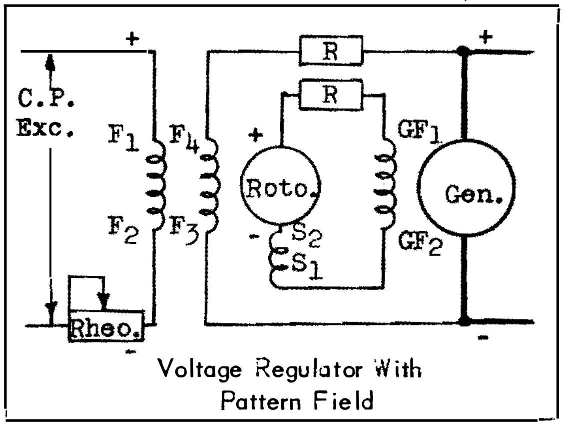
Rototrols manufactured prior to 1946 are not necessarily marked in accordance with the foregoing tabulation.

IDENTIFICATION OF ROTOTROL FIELDS

If the Rototrol field identification tags are lost or in a questionable condition, tests may be made which will positively identify each Rototrol field. The equipment required for the tests are: a d-c voltmeter,

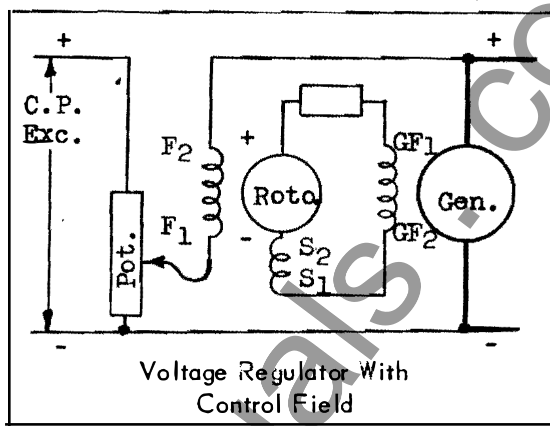
* The pattern field, see Figure 6a, is the field having fixed excitation or that field adjusted to set the pattern for the results to be obtained. The control field is the field which combines the pattern field with the voltage measuring and/or current measuring field, as shown by F1-F2, Figure 6b.

**Referred to as pilot fields.



Voltage Regulator With Pattern Field

Figure 6a



Voltage Regulator With Control Field

Figure 6b

15-150-300 volt range; a d-c ammeter, 0-1-5 ampere range, an ohmmeter, and a 6 volt battery. The field data for the machine also is required. Test procedure is as follows:

1. Disconnect all Rototrol leads from external circuits at the terminal box.

2. Using the ohmmeter locate the lead ends of each field and measure the field resistance. Correct the measured resistance values to 75°C. (temperature value of calculated field data). The fields may be identified, except for polarity, by agreement of approximately plus or minus 5% between the calculated and the measured values.

3. If two Rototrol fields have approximately the same resistance so that positive identification cannot be established by this means, additional tests may be made as follows: Connect the d-c voltmeter (50 or 100 volt range) to the Rototrol armature terminals; connect the ammeter (1 ampere range) in series with one of the fields and energize this field with the 6 volt battery. Start the Rototrol. With the Rototrol running, observe the Rototrol armature voltage and the field current. Repeat test on second field. Since the two fields in question have approximately the same resistance, each will pass approximately the same current value (as read on ammeter) during the test. The field having the greater number of turns will produce the higher Rototrol armature voltage.

4. To establish the field polarity marking, proceed as in Test #3, starting the Rototrol and observing the polarity of the excitation battery connected to the fields and the polarity of the voltage developed at the armature terminals. For clockwise rotation (facing the commutator end) A2 should be positive with plus excitation connected to the odd numbered terminals of any one field. For counter-clockwise rotation, A2 should be negative with positive polarity on the odd numbered terminal of any one field. This procedure may be followed for each field. Note that any differential connections of the fields are made external to the Rototrol.

TUNING THE ROTOTROL

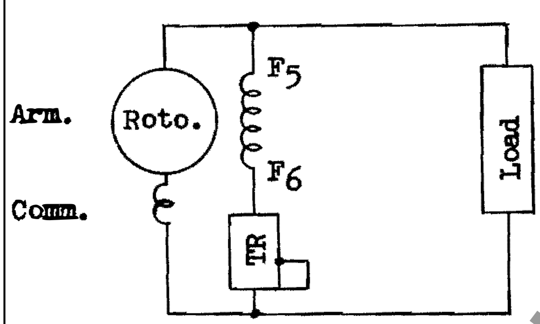
To tune the Rototrol is to adjust the armature circuit resistance line to coincide with the "straight" portion of the Rototrol saturation curve. Numerically, the slope of the air gap line is equal to the voltage at any point, divided by the field current at that point, or E/I. Since resistance, R = E/I, the proper adjustment of a resistor external to the self-energizing field will cause the resistance line of the Rototrol to have the same slope as the Rototrol air gap line.

In steady-state condition, tuning is not effected by any fields except the self-energizing field and the anti-hunt field, if used. Because the ampere turns of the separately excited or regulating fields are superimposed on the self-energizing field when the Rototrol is regulating, no consideration need be given to these regulating fields when "Tuning the Rototrol."

1. TUNING THE SHUNT SELF-ENERGIZED ROTOTROL

The shunt self-energized Rototrol circuit is not often used since problems of stability are more apt to be encountered in using this circuit. One application of this Rototrol circuit is the booster-type Rototrol used to hold constant current.

Figure 7



Shunt Self-energized Rototrol

CHECKING THE TUNING IN THE FIELD

The Rototrol should be run with all terminals open for a preliminary mechanical check. Before the circuits are closed and with the machine shut down the tuning should be checked. The checking procedure is as follows:

a. Check the resistance of the shunt self-energizing field circuit by opening this circuit at the control terminal block and measuring with an ohmmeter. Compare the measured resistance against the sum of the resistance values in the self-energizing loop using the values given in the field data table and control diagram (shunt self-energizing fields + permanent resistance + Rototrol armature resistance).

$$\frac{\text{Resistance of Winding at } T^{o}C.}{\text{Resistance of Winding at } t^{o}C.} = \frac{234.4 + T}{234.4 + t}$$

Example: Field F_5F_6 in foregoing example has a resistance of 222 ohms at 75°C. Convert this resistance to 25°C.

$$\frac{\text{Resistance of Winding at } 75^{o}C \text{ (222 ohms)}}{\text{Resistance of Winding at } 25^{o}C \text{ (R)}} = \frac{234.4 + 75}{234.4 + 25}$$

If, after temperature corrections are made for the field resistance, the self-energizing loop circuit resistance checks within about 10% of the calculated value, proceed with step b. But, if this resistance value is not within 10% of the calculated value, see step c.

b. If the resistance of the self-energizing loop is satisfactory, properly reconnect all wires, then proceed to check the tuning as follows:

1. Open all separately excited or regulating field circuits.

2. Connect voltmeter (300 volt range) across Rototrol armature.

3. Start Rototrol remaining near starter switch to be able to quickly stop Rototrol in case voltage build-up is too high as observed by bad commutation or by off scale voltmeter reading.

4. If the armature voltage builds up by itself due to residual magnetism then the Rototrol is OVERTUNED (see the following paragraph OVERTUNED for corrective action).

5. If the armature voltage does not build up, momentarily excite one of the high ohmic separately excited fields from an external source - exciter excitation may be used although a battery source of about 6 volts is preferred (even a 1.5 volt flashlight battery may be used). Observe the Rototrol armature voltage for conditions as follows:

TUNED

The Rototrol is properly TUNED if the voltage builds up when the excitation source is applied and then lazily falls to about 20 to 40 percent of the maximum straight line voltage when the excitation source is removed. The resistance line then lies very nearly on the air-gap line as represented by line B of Figure 8.

UNDERTUNED

The Rototrol is UNDERTUNED if the voltage builds up when the excitation source is applied and then rapidly falls to near zero volts when the excitation is removed. The resistance line then lies above the air-gap line as line A of Figure 8. The external resistance in the self-energizing circuit must be reduced in order to tune the Rototrol.

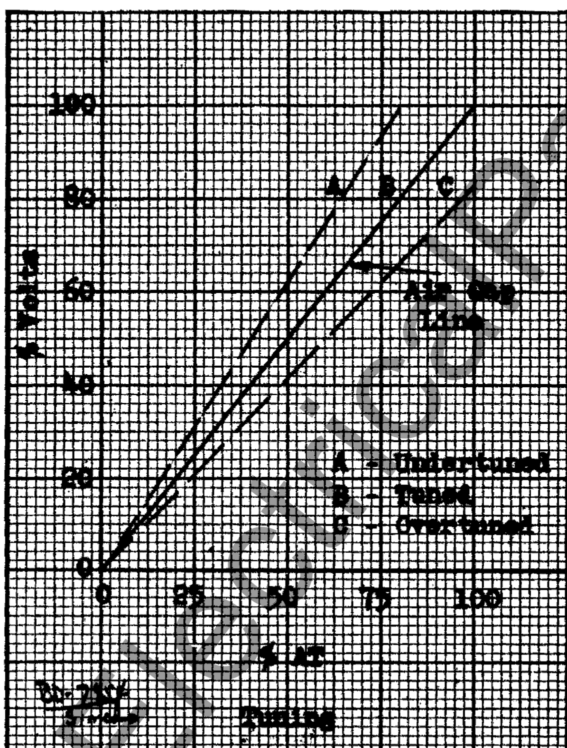


Figure 8

OVERTUNED

The Rototrol is OVERTUNED if the voltage builds up when the excitation source is applied and then falls a very small amount when the excitation source is removed. The resistance line then lies below the air-gap line as line C of Figure 8. The external resistance in the self-energizing circuit must be increased in order to tune the Rototrol.

c. If the circuit resistance fails to check within 10% of the calculated resistance after temperature correction for the field coils has been made, then the resistance of the shunt self-energizing field and the external resistance should be individually checked to locate the member at fault.

If the external resistance is improperly adjusted, correct this resistance, reconnect and repeat a.

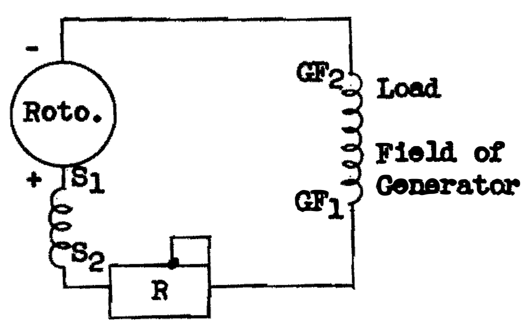
If the field resistance is not in accordance with the instruction book data after temperature allowances are made and 10% manufacturing tolerances are allowed, then check identification as outlined under "Identification of Rototrol Fields." If no logical explanation can be found, refer to the factory.

2. TUNING THE SERIES SELF-ENERGIZED ROTOTROL

The series self-energized Rototrol circuit is commonly used for voltage regulators, current regulators, and speed regulators of relatively low voltage amplification. Problems of stability are not usually encountered when this circuit is used.

CHECKING THE TUNING IN THE FIELD

The Rototrol should be run with all the terminals open for a preliminary mechanical check. Before the circuits are closed and with the machine shut down the tuning should be checked. The checking procedure is as follows:



Series Self-energized Rototrol

Figure 9

a. Check the resistance of the series self-energizing field loop circuit by opening this circuit at the control terminal block and measuring with an ohmmeter. Compare the measured resistance with the sum of the resistance values in the self-energizing loop using the values given in the field data table and control diagram (series self-energizing field + Rototrol armature resistance including commutating coil + permanent resistance + load resistance). The field data should be corrected to room temperature according to the following relation:

$$\frac{\text{Resistance of Winding at } T^{\circ}C.}{\text{Resistance of Winding at } t^{\circ}C.} = \frac{234.4 + T}{234.4 + t}$$

If, after temperature corrections are made for the field resistance, the self-energizing loop circuit resistance checks within about 10% of the calculated value, proceed with step b. But, if this resistance is not within 10% of the calculated value, see step c.

b. If the resistance of the self-energizing loop is satisfactory, properly reconnect all wires, then proceed to check the tuning as follows:

1. Open all separately excited or regulating fields.

2. Connect a voltmeter (300 volt range) across the Rototrol armature.

3. Start Rototrol, remaining near starter switch to be able to quickly stop the Rototrol in case the voltage is too high as observed by bad commutation or by off scale voltmeter reading.

4. If the armature voltage builds up by itself due to residual magnetism, then the Rototrol is OVERTUNED. (See the following paragraph OVERTUNED for corrective action.)

5. If the armature voltage does not build up, momentarily excite one of the high ohmic separately excited fields from an external source - exciter excitation may be used although a battery source of about 6 volts is preferred (even a 1.5 volt flashlight battery may be used). Observe the Rototrol armature voltage for conditions as follows:

TUNED

The Rototrol is TUNED if the voltage builds up when the excitation source is applied then lazily falls to about 20 - to 40 per cent of the maximum straight line voltage when the excitation source is removed. The resistance line lies very nearly on the air-gap line as represented by line B of Figure 10.

UNDERTUNED

The Rototrol is UNDERTUNED if the voltage builds up when the excitation source is applied and then rapidly falls to near zero volts. The resistance line lies above the air-gap line as line A of Figure 10. The external resistance in the self-energizing circuit must be reduced in order to tune the Rototrol.

OVERTUNED

The Rototrol is OVERTUNED if the voltage builds up when the excitation source is applied and then falls a very small amount when the excitation source is removed. The resistance line then lies below the air-gap line as line C of Figure 10. The external resistance in the self-energizing circuit must be increased in order to tune the Rototrol.

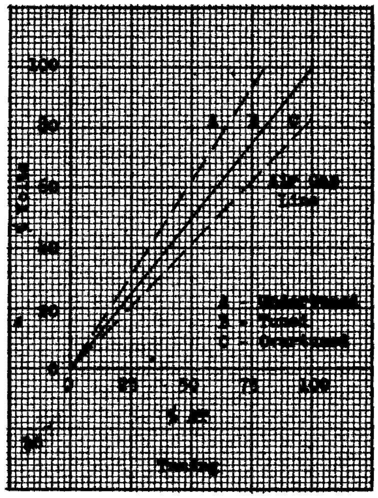


Figure 10

c. If the series self-energizing circuit resistance fails to check within 10% of the calculated resistance after temperature correction for field resistances has been made, then the resistance of the series self-energizing field, the load and the external resistor should be checked individually to locate the member at fault.

If the external resistance is improperly adjusted, correct this resistance, reconnect and repeat a.

If field resistance of the self field or the load is not in accordance with the instruction book data, after temperature allowances are made and 10% manufacturing tolerances are allowed, then check identification as outlined under "Identification of Rototrol Fields." If no logical explanation can be found, refer to the factory.

3. *TUNING ROTOTROLS HAVING SERIES SELF-ENERGIZED AND ANTI-HUNT FIELDS*

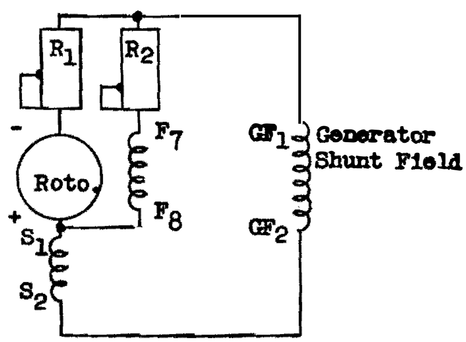
On many of the more recent Rototrols a combination of series self-energized field and shunt connected anti-hunt field have been used, because a reduction of overshooting was found to be necessary in circuits having high voltage (dynamic) amplification and in speed control circuits for high inertia loads. The anti-hunt field, which is connected in the Rototrol self-energizing circuit differentially with respect to the self-energizing field, responds to changes in the Rototrol armature voltage much faster than the load which is usually the relatively large inductance of the field of another machine; thus, as the ampere-turns in the anti-hunt field build up, the net result is a stabilizing effect on the Rototrol.

The strength of the anti-hunt field is determined by the Design Engineer based on calculations and experience with each application. For most applications an anti-hunt field strength of from 10 to 25% of the series self-energizing field has been found to be satisfactory.

Example: 125% series self-energizing field strength - 25% anti-hunt field strength = 100% tuned self-energizing effect.

CHECKING THE TUNING IN THE FIELD

The Rototrol should be run with all terminals open for a preliminary mechanical check. Before the circuits are closed and with the machine shut down, the tuning should be checked. The checking procedure is as follows:



Rototrol with Series Self-energized and Anti-hunt Fields

Figure 11

a. Check the resistance of the series self-energizing field loop circuit by opening this circuit at the control terminal block and measuring with an ohmmeter. Compare the measured resistance with the sum of the resistance values in the self-energizing loop using the values which are given in the field data table and control diagram, (series self field S_1S_2 + Rototrol armature resistance including commutator coil + permanent resistance + load resistance). The field data should be corrected to room temperature according to the following formula:

$$\frac{\text{Resistance of Winding at } T^{\circ}\text{C.}}{\text{Resistance of Winding at } t^{\circ}\text{C.}} = \frac{234.4 + T}{234.4 + t}$$

b. Check the resistance of the anti-hunt field circuit (anti-hunt field + external resistance) and compare it with the calculated resistance after making the temperature corrections.

If after temperature corrections are made for the field resistances, the self-energizing circuit resistance and the anti-hunt circuit resistance each check within 10% of the calculated value, proceed with step c. But if either of these resistance values is not within 10% of calculated value, see step d.

c. After checking the resistances as described above, properly reconnect all wires, then proceed to check the tuning as follows:

1. Open all separately excited or regulating field circuits.

2. Connect voltmeter (300 volt range) across the Rototrol armature terminals.

3. Start the Rototrol, remaining near starter switch to be able to quickly stop the Rototrol in case the voltage build-up is too high as observed by bad commutation or by off scale voltmeter reading.

4. If the armature voltage builds up by itself due to residual magnetism, then the Rototrol is OVERTUNED. (See the following paragraph OVERTUNED for corrective action.)

5. If the Rototrol armature voltage does not build up, momentarily excite one of the high ohmic separately excited fields from an external source - exciter excitation may be used although a battery source of about 6 volts is preferred (even a 1.5 volt flashlight battery may be used). Observe the action of the Rototrol armature voltage for conditions as follows:

<u>TUNED</u>

The Rototrol is TUNED if the voltage builds up when the excitation source is applied then lazily falls to about 20 to 40 per cent of maximum straight line voltage when the excitation source is removed. The effective resistance line lies very nearly on the air-gap line.

UNDERTUNED

The Rototrol is UNDERTUNED if the voltage builds up when the excitation source is applied and then rapidly falls to near zero volts when the excitation source is removed. The effective resistance line lies above the air-gap line.

To tune:

1. Increase the amount of external resistance in the anti-hunt field circuit. This should not be done to the extent of adding more than 25% additional resistance to the anti-hunt field circuit, but should be done first.

2. Reduce the amount of external resistance in the self-energizing field circuit. Use the anti-hunt field adjustment as a vernier.

OVERTUNED

The Rototrol is OVERTUNED if the voltage builds up when the excitation source is applied and then falls a very small amount when the excitation source is removed. The effective resistance line lies below the air-gap line.

To tune:

1. Reduce the external resistance in the anti-hunt field circuit. This should not be done to the extent of reducing the anti-hunt field circuit resistance more than 25% of the calculated value, but should be done first.

2. Increase the amount of external resistance in the self-energizing field circuit. Use the anti-hunt field adjustment as a vernier.

d. If the circuit resistance of either the series self-energizing field loop circuit or the anti-hunt field circuit fail to check within 10% of the calculated resistances after temperature corrections for the field coils have been made, then the resistance of each member of self circuit should be individually checked, to locate the member at fault. These members are the following:

   1. Self-energizing field loop circuit consisting of resistance of self-energizing field S_1S_2, load resistance, and external resistance.

   2. Anti-hunt field circuit consisting of the anti-hunt field F_7F_8 resistance and external resistance.

   If the external resistance is improperly adjusted, correct this resistance, reconnect and repeat a.

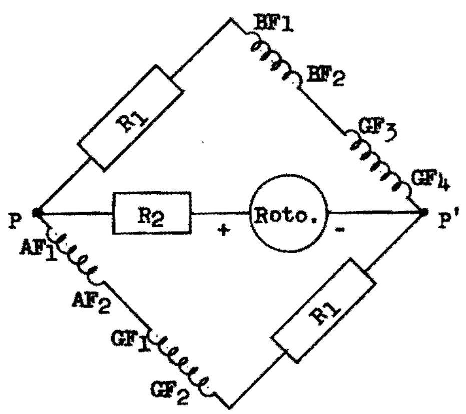
   If any one of the various field resistances are not in accordance with the instruction book data, after temperature corrections are made and 10% manufacturing tolerances are allowed, then check identification of the fields as outlined under "Identification of Rototrol Fields." If no logical explanation of resistance variation can be found refer to the factory.

4. TUNING THE BRIDGE ROTOTROL

The bridge type Rototrol is different from the majority of Rototrols in that the functions of the self-energizing field and the pattern field are performed in one field. This field is broken into two parts, and placed in opposite legs of the bridge circuit. The self-energizing circuit may be considered entirely separate from the pattern field circuit and thus the task of tuning is no different than that of tuning the series self-energized Rototrol with separate self-energizing and pattern fields.

CHECKING THE TUNING IN THE FIELD

The Rototrol should be run with all terminals open for a preliminary mechanical check. Before the circuits are closed and with the machine shut down the tuning should be checked. The checking procedure is as follows:



Self-energized Circuit Bridge-type Rototrol

Figure 12

a. Check the resistance of the self-energizing field loop circuit by opening this circuit at the Rototrol armature and measuring with an ohmmeter. Compare the measured resistance with the sum of the resistance values in the self-energizing loop using the values given in the field data table and control diagram (two legs of bridge in parallel + Rototrol armature resistance + permanent resistance adjacent to Rototrol armature). The field data should be corrected to room temperature according to the following formula:

$$\frac{\text{Resistance of Winding at } T^{o}\text{C.}}{\text{Resistance of Winding at } t^{o}\text{C.}} = \frac{234.4 + T}{234.4 + t}$$

If after temperature corrections are made for the field resistances, the self-energizing loop circuit checks within 10% of the calculated value, proceed with step b. But if this resistance value is not within 10% of the calculated value, see step c of "Checking the Tuning in the Field" under "TUNING THE SERIES SELF-ENERGIZING ROTOTROL."

b. If the resistance of the self-energizing loop is satisfactory, properly reconnect all wires, then proceed to check the tuning as follows:

1. Open all separately excited Rototrol fields including the separate excitation source to the pattern self-energizing field.

2. Connect a voltmeter (300 volt range) across the Rototrol armature terminals.

3. Start Rototrol but remain near starter switch to be able to quickly stop the Rototrol in case the voltage build-up is too high as observed by bad commutation or by an off-scale voltmeter reading.

4. If the voltage builds up by itself due to residual magnetism, the Rototrol is OVERTUNED. (See the following paragraph OVERTUNED for corrective action.)

5. If the armature voltage does not build up, momentarily excite the voltage field from an external source - exciter excitation may be used although a battery source of about 6 volts is preferred. Observe the action of the Rototrol armature voltage for conditions as follows:

TUNED

The Rototrol is TUNED if the voltage builds up when the excitation source is applied then lazily falls to about 20-to 40 per cent of maximum straight line voltage when the excitation source is removed. The resistance line lies very nearly on the air-gap line.

UNDERTUNED

The Rototrol is UNDERTUNED if the voltage builds up when the excitation source is applied and then rapidly falls to near zero. The resistance line lies above air-gap line. The external resistance, adjacent to the Rototrol armature (not in the legs of the bridge) must be reduced in order to tune the Rototrol.

OVERTUNED

The Rototrol is OVERTUNED if the voltage builds up when the excitation source is applied and falls very little when the excitation source is removed. The resistance line lies below the air-gap line. The external resistance adjacent to the Rototrol armature (not in the legs of the bridge) must be increased in order to tune the Rototrol.

ADJUSTMENT OF THE SEPARATELY EXCITED OR REGULATING FIELDS OF THE ROTOTROL

Any field not receiving its excitation from the Rototrol armature is a separately excited or regulating field. The separately excited field circuits can be adjusted without consideration of the self-energizing field circuit. Therefore, after the self-energizing field circuit is adjusted, do not change its setting while adjusting the separately excited fields.

If the self-energizing circuit is TUNED, the algebraic sum of the ampere turns in the separately excited fields should be zero for any given steady-state condition. The maximum ampere turns in each of the separately excited fields is determined by the design engineer on a thermal basis. The heating of the Rototrol fields varies as the arithmetic sum of all of the ampere turns in the self-energizing and regulating fields. The maximum number of ampere turns that can be used is determined by the maximum amount of field heat that can be dissipated with the maximum mass of copper it is physically possible to install in a given Rototrol frame size. In making field adjustments of Rototrols, the maximum value of field current assigned to each field should not be exceeded without first checking with the design engineer.

During all such adjustments, the following principles should be observed.

1. The maximum ampere turns possible in each field are fixed by the design engineer.
2. No consideration should be made of the self-energizing field circuits when calculating the settings of the regulating fields.
3. The algebraic sum of the steady-state ampere turns in the separately excited fields will total zero when the Rototrol is TUNED.
4. In Rototrol systems having only one separately excited field (control field) the ampere turns in this field should be very nearly zero at any steady-state condition.

After an installation is made the following field checks on the separately excited fields should be made:

1. Range:

   Check that the Rototrol regulates over the designed range.

   Example: In a voltage regulating system having a 5 to 1 voltage range the regulation should be checked at top voltage (for example 250 volts) and at 1/5 voltage (50 volts).

2. Characteristic:

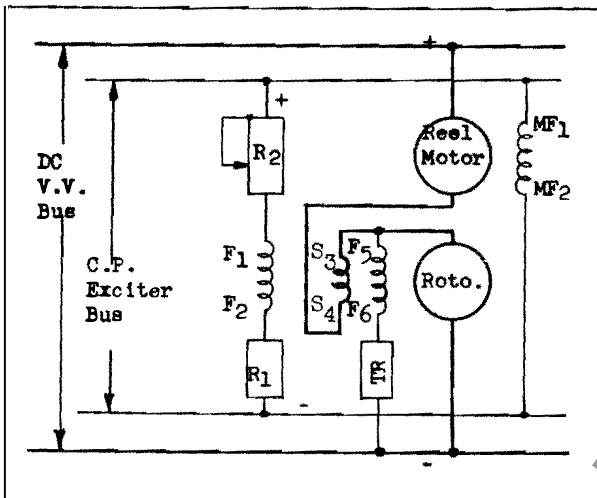
   Check that the Rototrol causes the regulated quantity to have a flat linear characteristic that is neither rising nor falling.

3. Stability:

Check that the Rototrol system is stable by application of load or by changing the pattern field setting.

1. ADJUSTMENT OF THE SEPARATELY EXCITED OR REGULATING FIELDS OF CURRENT REGULATOR

One application of the current regulator is to hold constant torque for a reel drive. A booster Rototrol is a simple example of a constant torque regulator.



Booster-Rototrol Constant-Torque Reel Drive

Figure 13

CHECKING THE ADJUSTMENT

1. Range:

Check that the apparatus regulates over the design range.

a. If the maximum current cannot be reached, decrease the ampere turns in the current field by shunting; or increase the ampere turns in the pattern field by decreasing the series resistance.

b. If the minimum current cannot be reached, increase the resistance in series with the pattern field.

2. Characteristic:

Check that the current regulation is flat. See "Rising Regulation" and "Falling Regulation" under "ROTOTROL PERFORMANCE ADJUSTMENTS."

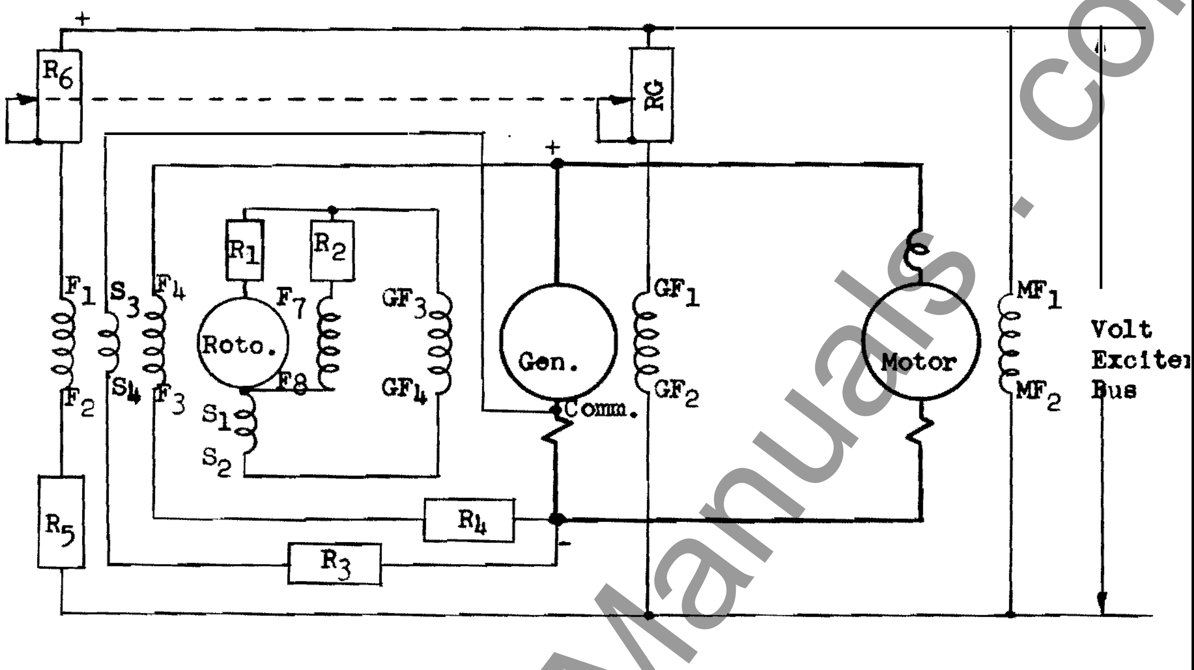
2. ADJUSTMENT OF THE SEPARATELY EXCITED OR REGULATING FIELDS OF A COUNTER EMF SPEED REGULATOR

The counter EMF speed regulator is a system requiring more than two regulating fields on the Rototrol. The calculation and adjustment of such a regulating system is a more complex problem than that of a one or two regulating field system. (See comments on Bridge-type Counter EMF speed regulator section C below.)

A. CHECKING THE ADJUSTMENT

1. Range:

Check that the apparatus covers the design speed range.



Rototrol Counter EMF Speed Regulator

Figure 14

a. If the maximum speed and maximum voltage cannot be reached increase the resistance in series with the differential voltage field.

b. If the maximum speed cannot be reached after the maximum rated voltage is reached, weaken the motor shunt field to increase the motor speed.

c. If the minimum speed cannot be reached, increase the resistance in series with the pattern field.

2. Characteristic:

Check that the speed regulation is flat.

a. If the speed rises with load, see section on "Rising Regulation" under "ROTOTROL PERFORMANCE ADJUSTMENTS."

b. If the speed falls with load, see section on "Falling Regulation" under "ROTOTROL PERFORMANCE ADJUSTMENTS."

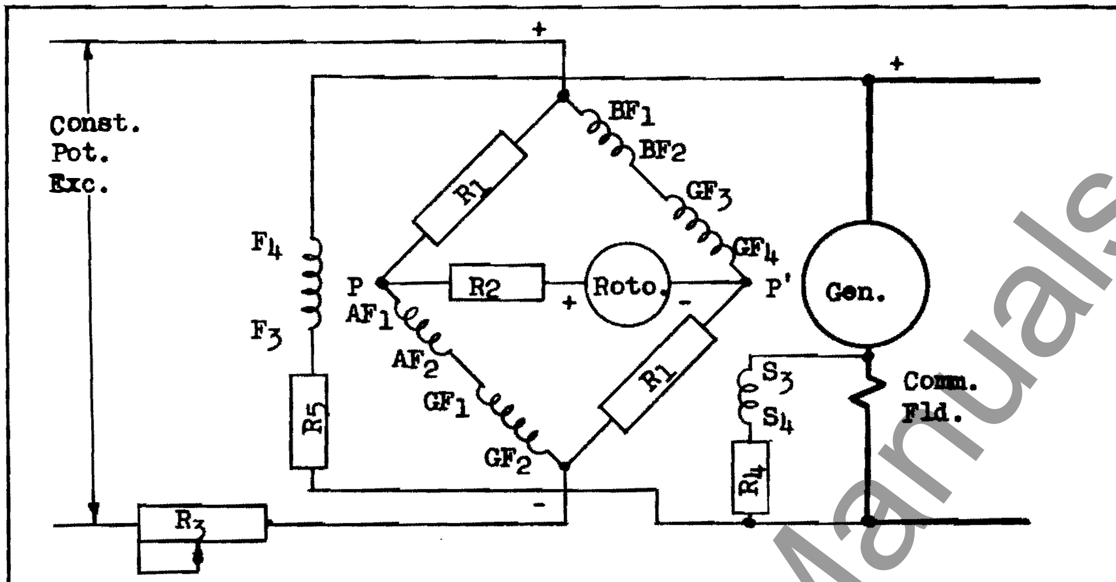
B. BRIDGE-TYPE COUNTER EMF SPEED REGULATOR

In considering the separately excited or regulating fields of the bridge type Rototrol, Figure 20:

1. The self-energizing circuit should not be considered in the calculations of the settings of the separately excited fields.

2. The pattern field is in a balanced bridge and the total current in the pattern field rheostat is twice that in the pattern field.

3. The differential voltage field and the current (IR drop) field are the same as for any other counter EMF speed regulator.



Bridge-type Counter EMF Speed Regulator

Figure 15

ROTOTROL PERFORMANCE ADJUSTMENTS

Although Rototrol construction is similar to that of standard d-c machinery, its performance is dependent on certain adjustments peculiar to the Rototrol. These adjustments have been explained in preceding chapters. The purpose of this section is to describe those adjustments which may be made to achieve optimum Rototrol performance.

1. TUNING

A Rototrol is TUNED when the resistance line of its self-energizing field circuit coincides with the air-gap portion of its saturation curve.

Tuning may be affected by any one of the following:

1. Variation of the field resistance due to temperature.

2. Variation of the resistance of the load or self-energizing field from the calculated value.

3. Discrepancy between the test saturation curve and the calculated curve.

   (Deviation of calculated no-load saturation curve from the actual test curve of as much as $\pm$ 5% is allowable due to manufacturing tolerances encountered in building the machines.)

4. Variation of the number of turns in the self-energizing (or anti-hunt) field coils or short circuited turns in the field coils. (Rarely encountered.)

The following considerations should be made when Rototrol performance indicates poor tuning:

a. If the Rototrol is UNDERTUNED after all external resistance has been cut out of the self-energizing field circuit, the following can be done:

1. Operate the Rototrol UNDERTUNED with the consequent Falling Regulation.

2. With the Design Engineer's approval, further reduce the self-energizing field resistance by:

   (a) Paralleling the load in the case of the series self-energizing field circuit.

   (b) Parallel the self-energizing field in the case of the shunt self-energizing circuit.

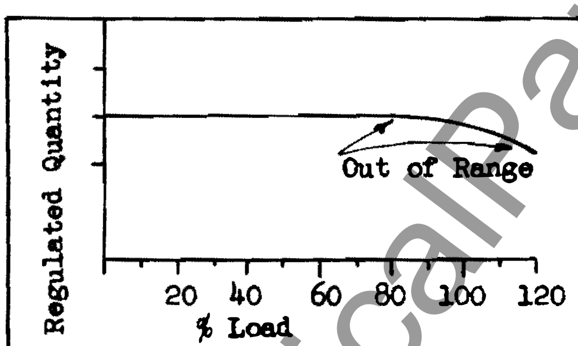
3. Refer to Design Engineer for new Rototrol field coils.

b. If the Rototrol is OVERTUNED after all external resistance is inserted in the self-energizing field circuit, the following can be done:

1. Add more external resistance in the self-energizing circuit. (Do not permit the Rototrol to run out of range.)

2. Operate the Rototrol OVERTUNED with the consequent Rising Regulation and increased probability of hunting.

2. RUNNING OUT OF RANGE



Running Out of Range

Figure 16

A Rototrol is within range when it is operating on the straight portion (air-gap line) of its saturation curve and the continuous heating capacity of the Rototrol or the load is not exceeded. During transients Rototrol saturation is permissible.

The Rototrol can be suspected of Running Out Of Range if the quantity (current, voltage, speed) being regulated departs from the desired value when the Rototrol output voltage is maximum. This can be checked by comparing the measured Rototrol terminal voltage with the saturation curve to be sure that the operation is confined to the straight line portion of the Rototrol saturation curve.

Adjustments can be made in the Rototrol circuits to bring the regulation within range provided the equipment has adequate design margin.

a. Bridge-type Speed Regulator can be brought into range by adjustment of the differential voltage field.

1. Decreasing the resistance in series with the differential voltage field will bring the Rototrol within range if it runs out of range when the Rototrol output is adding to the generator excitation supplied from the exciter.

2. Increasing the resistance in series with the differential voltage field will bring the Rototrol within range if it runs out of range when the Rototrol output is subtracting from the generator excitation supplied from the exciter.

b. Rototrol Speed Regulator Working on Auxiliary Generator Field can be brought into range by adjustment of external resistance in series with the main generator field.

1. If the Rototrol runs out of range when the generator auxiliary field is adding to the generator main field, then the external resistance in series with the main field should be decreased.

2. If the Rototrol runs out of range when the generator auxiliary field is subtracting from the generator main field, then the external resistance in series with the main field should be increased.

c. Rototrol Supplying Entire Excitation of Motor or Generator can be brought into range.

1. By decreasing external resistance in series with self-energizing field and decreasing the resistance in series with the anti-hunt field if the Rototrol is provided with an anti-hunt field.

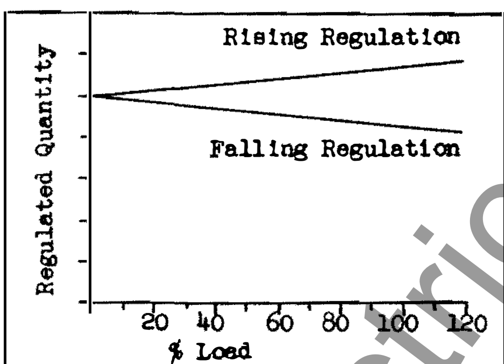
2. By paralleling (with the Design Engineer's approval) the field that the Rototrol is exciting (i.e. the load) and retuning.

3. By redesign of the Rototrol.

3. *RISING REGULATION*

The Rototrol has a Rising Regulation if the quantity (current, voltage, speed) being regulated rises from the desired value as the voltage is increased on a current regulator, or as the load is increased on a voltage or speed regulator.

Rising Regulation is usually caused by OVERTUNING. It can be corrected generally by retuning. On a counter EMF speed regulator the rising regulation can be caused by too strong a current (IR drop) field and can be corrected by increasing the resistance in series with this field.



Rototrol Regulation

Figure 17

4. *FALLING REGULATION*

The Rototrol has a Falling Regulation if the quantity (current, voltage, speed) being regulated falls from the desired value, as the voltage is increased on a current regulator, or as the load is increased on a voltage or speed regulator.

Causes and corrections for Falling Regulation are as follows:

a. Falling Regulation is usually caused by UNDERTUNING, and can be corrected by retuning.

b. On a counter EMF speed regulator, the Falling Regulation can be caused by too weak a current (IR drop) field and can be corrected by decreasing the resistance in series with the current field.

c. Falling Regulation may be caused by the pattern and pilot fields being too weak to regulate accurately (low dynamic or voltage amplification). This condition can be corrected by increasing the strengths of the pattern and pilot fields.

d. A non-linear Falling Regulation may be caused by non-linearity of the Rototrol air-gap line. If this condition cannot be tolerated by the customer, refer to the Design Engineer.

5. *EFFECTS OF TEMPERATURE CHANGES*

The operation of Rototrols may be affected by field resistance changes due to temperature changes. The changes are not usually a serious matter except on certain speed and voltage regulators which are required to maintain the regulated quantities constant over long periods of time.

a. Resistance changes in the separately excited or regulating fields affect performance because variations in the pattern or pilot field ampere-turns will cause a variation in the regulated quantity. By proper design, however, the same variation can be caused to occur in both the pattern and the pilot fields simultaneously. Thus, temperature compensation can be obtained. Schemes of temperature compensation usually are explained in detail in the instruction book for the drive.

If objectionable performance due to temperature changes is encountered, refer to the control engineer.

b. Rototrol tuning may be affected by resistance changes in the self-energizing field circuit, either in the Rototrol fields or in the field of the machine being regulated.

1. If the Rototrol is tuned when hot, it may have a Rising Regulation when cold.

2. If the Rototrol is tuned when cold, it may have a Falling Regulation when hot.

The best results usually are obtained if the final adjustment of the Rototrol tuning is made after the Rototrol has been operating for two hours or more at the average output.

6. *HUNTING*

In a Rototrol system, if a periodic variation of the regulated quantity about its desired value occurs, the system is said to be Hunting. A hunting condition in a Rototrol system depends on the relations of the time constants of the various members of the system (including the inertia of the load as well as the time delays of the fields) and the system amplification.

Hunting may be classified into three principal categories as follows:

a. Rototrol systems having Sustained or Increasing Magnitude oscillations of the regulated quantity usually cannot be put into operation unless the period of oscillation is long or the magnitude of oscillations is small. Corrective measures must be taken for this condition.

b. Damped oscillations sometimes occur after a disturbance (adjustment of Rototrol pattern field load change or Rototrol speed change, etc.) In some drives highly damped oscillations can be tolerated. No correction need be made if the oscillations are of a small magnitude, damps itself out in a very few cycles and is not otherwise objectionable.

c. Overshooting may occur on starting, adjusting to a new regulated value or sudden application of load. An overshoot is a half-oscillation. If the overshoot is not of objectionable magnitude, no correction need be made.

The following corrective measures can be taken to improve stability or decrease over-shooting. These measures should be tried in the order given and one at a time. If a change is made and found to be ineffective try the succeeding corrective measures before returning to the original setting.

a. In a system having an anti-hunt field, increase the strength of the anti-hunt field by reducing the series resistance. Retune by reducing the external resistance in series with the series self-energizing field. For detailed calculations and setting of tuning see "TUNING ROTOTROLS HAVING SERIES SELF-ENERGIZED AND ANTI-HUNT FIELDS." DO NOT OVERTUNE!

b. In a system without anti-hunt field, check the tuning to be sure that the Rototrol is NOT OVER-TUNED. For detailed information on the tuning see "TUNING THE SHUNT SELF-ENERGIZED ROTOTROL" or "TUNING THE SERIES SELF-ENERGIZED ROTOTROL."

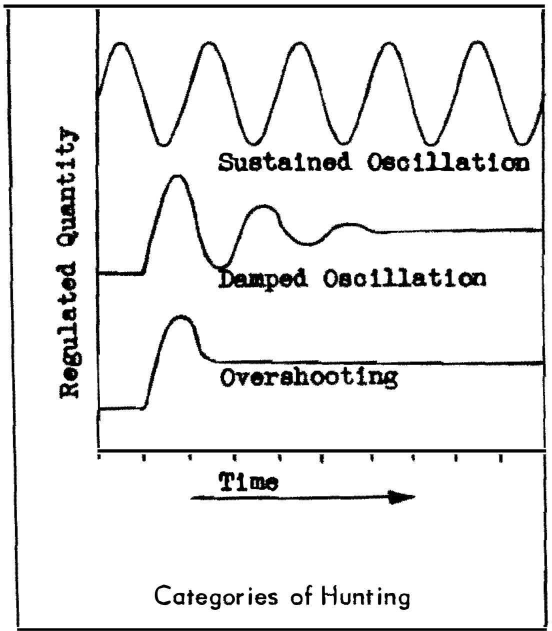


Figure 18

c. Reduce the ampere-turns in each of the separately excited fields, by increasing the resistance in series with each separately excited field. If enough resistance is added to the pattern field circuit to reduce the ampere turns in the field to 50% of its original value, then enough resistance should be added to each of the other separately excited fields to reduce their respective ampere turns to 50% of their original value.

As a first trial, reduce the ampere turns to approximately 50% of their original value. If the system then becomes dead-beat (no overshoot) gradually increase the ampere turns until objectionable hunting is approached.

If the system continues to oscillate after the ampere turns have been reduced to 50% of their original value, further reduce the ampere turns. Note: Response and accuracy of regulation will be sacrificed with reduction of ampere turns in the separately excited fields.

d. Undertune causing a usually undesirable Falling Regulation. This can be accomplished by increasing the resistance in series with the self-energizing field or when there is an anti-hunt field by decreasing the resistance in series with the anti-hunt field.

e. If no acceptable improvement can be made in the stability refer to the Design Engineer.

THE CURRENT LIMIT ROTOTROL

For many applications where the rotation of a motor in a variable voltage system must be reversed frequently it is important that the speed change be completed as quickly as possible, without dangerous overloading of the equipment. Typical applications of this type are mine hoists, reversing blooming mills, balancing machines, and car dumpers.

A standard Rototrol, in combination with a current-limit Rototrol, is ideally suited for these applications.

The construction of a current-limit Rototrol is similar to a normal four-pole d-c generator and a standard Rototrol except for specially designed main poles and magnetic shunts between the poles. Also, like the normal Rototrol, it has a pattern field, a voltage field, and a current field. However, the current-limit machine is not self-energizing. The coils are wound on both the pole and shunt, and are connected in series so that the same current passes through all coils. The current coils are either connected in parallel with the commutating field of the regulated generator or motor, or across a series resistor. Thus, the coil current provides a measure of the generator or motor armature current.

With this unusual arrangement of iron, the machine has two types of air gaps. One is between the main poles and armature and the other between the main poles and magnetic shunts. The number of turns in the coils and the different air gap dimensions are selected so that when the current of the coils indicates near normal generator or motor armature current the total main pole flux will pass through the magnetic shunt and its air gap. No flux will pass across the armature gaps so long as the magnetic shunt remains unsaturated. For this condition the Rototrol voltage, therefore, will be zero. With increasing field current the shunt becomes saturated. Thus abnormal motor or generator currents produce a flux in the armature air gaps and a voltage at the Rototrol armature terminals.

The current-limit machine is customarily used in conjunction with a counter emf speed regulating Rototrol, or a voltage regulating Rototrol. With this scheme the output of the current-limit Rototrol is used to excite the current field of the main regulating Rototrol. When the motor or generator armature current exceeds a set limit the current-limit Rototrol armature voltage builds up and energizes the current-limit field of the main Rototrol. This field neutralizes the net ampere-turns of the pattern field of the main Rototrol thereby decreasing the generator voltage and preventing further current rise.

One purpose of the pattern field and voltage field of the current limit machine is to limit the accelerating current to the same value regardless of the motor speed. Assume that the master switch or controller is suddenly moved to the full "On" position while the drive is at rest. In order to keep the motor armature current from exceeding the limiting value, the generator excitation must produce only enough voltage to circulate this current through the motor at the speed at which it is running at that instant. Roughly speaking, this is almost zero voltage at standstill, 40 percent voltage at 40 percent speed and about 100 percent voltage at full speed. The master switch, however, is fully advanced and the pattern field is at its maximum strength. The main Rototrol is therefore, trying to regulate for 100 percent speed, or voltage. In order to limit current, the current-limit field on the main Rototrol must neutralize the effect of the pattern field to the point where it can be balanced by the voltage, or speed measuring fields at the particular speed at which the motor is running.

The current limit Rototrol magnetic shunt is saturated when the motor armature current reaches the limiting value. The voltage fields, or speed measuring fields, will initially have no excitation, but the pattern fields full excitation. This full pattern field excitation will produce sufficient current-limit Rototrol armature voltage, now that the magnetic shunt has been saturated, to excite the current-limit field of the main Rototrol to the proper value to neutralize almost all the effect of the main Rototrol pattern field. The resulting main generator voltage is sufficient to circulate only the limit current at the particular motor speed.

Assume that the motor has accelerated to forty percent of full speed and that the master switch is still in the full "On" position. The current limit Rototrol magnetic shunt is still saturated. However, the voltage fields are now at forty percent normal strength. The pattern field excitation is still sixty percent above the actual motor speed. This sixty percent must be neutralized by the action of the current-limit Rototrol. Its output voltage is dependent upon the net excitation provided by the pattern field at 100 percent excitation and the voltage field at forty percent excitation. This difference is sixty percent, and since the magnetic shunt is saturated, the current-limit Rototrol voltage has dropped to sixty percent of its initial value, providing sixty percent of the initial ampere turns in the current-limit field of the main Rototrol. This sixty percent current-limit field strength bucking the pattern field excitation leaves a net excitation of approximately forty percent. This will in turn produce the Rototrol voltage necessary to obtain the value of generator voltage that will circulate limit current at forty percent motor speed.

The main generator voltage will continue to rise as the motor speed increases but never to the place where it will circulate more than the limit current. When the motor reaches the speed corresponding to the master switch setting at that time, the voltage ceases to rise and is regulated at that value since the pattern and voltage, or speed matching, fields balance each other. For normal loads, the current is not sufficient to saturate the magnetic shunt which causes the current-limit Rototrol output to drop to zero. This condition prevails until the master switch position is changed.

The pattern and voltage fields on the current limit Rototrol also make it possible to hold the same magnitude of limit current for plugging operations and for overhauling load as is obtained for normal acceleration.

With proper circuit adjustments the current limit-current should be independent of speed. With caution this may be checked easily by stalling the drive and then advancing the master controller. The motor current at stall should be the same on the first point of control as on the last.

Caution:- Do not leave the motor stalled more than a few seconds with this high circulating current. The localized commutator heating may raise the particular commutator bars that are under the brushes. Let the motor turn slightly between trials in order to use different commutator segments each time.

If the current limit point is higher on the first control point than on the last, increase the resistance in the circuit containing the main Rototrol current-limit field and the current-limit Rototrol armature. Conversely, if the current limit point is low on the first control point, and becomes larger on the last points, reduce the resistance in the current limit field circuit.

The magnitude of the limit-current is controlled by another independent adjustment. It may be raised by inserting more resistance in the current field of the current-limit Rototrol, or decreased by reducing this field circuit resistance.

The manner of operation of the current-limit Rototrol results in an unusual saturation curve. Basically it is the saturation curve of a normal d-c generator displaced laterally. The Rototrol voltage remains near zero until some appreciable value of field current is reached--the value at which the shunt saturates. Then it builds up rapidly following the straight line portion of the curve with increasing field current until it tapers off upon reaching the knee of the curve.

For some applications it may be desirable to produce a slight voltage rise with increasing current even before the magnetic shunt is saturated. This can be obtained by a slight increase in the gaps between the main poles and armature. If these air gaps are decreased the result will be a negative Rototrol voltage until the magnetic shunt is saturated.

GENERAL INSTRUCTIONS

FOR

ROTOTROL M-G SETS

GENERAL

To obtain long satisfactory service from rotating electrical equipment, it is necessary to properly install, operate and maintain such equipment. The following gives the simple precautions and instructions for such care. Properly maintained equipment will require very little care other than periodic inspections and lubrication. The most important factor is to keep the apparatus clean and free of oil, water and other foreign particles.

INSTALLATION

UNPACKING

When unpacking, be sure and protect any exposed windings from damage. Coil insulation is very easily damaged. Never pry against a winding nor strike it a blow with a hammer. Do not allow sharp instruments to come in contact with the coils. Avoid damage to the shaft. Keep it free from bumping which will cause burrs and interfere with the coupling or pulley fit. Do not bend shaft as it will cause misalignment.

INSPECTION

As soon as the apparatus is unpacked give it a thorough inspection. Look especially for any loose field connections, bolts, covers, broken brushes or brushholders and any noticeable damage to coil insulation. Repair immediately any damage found. If machine has been in storage some time or has been exposed to dampness, the insulation resistance should be checked. See instructions under "Maintenance" - Insulation. See that name plate reading agrees with the voltage and frequency provided for the motor.

HANDLING

Electrical equipment is easily damaged when dismantled. If the machine is dismantled and the windings are exposed, care is necessary to properly protect these windings from damage. In handling the armature, do not allow the commutator or coil ends to be bumped as this will damage them. Support the rotor or armature by rope slings about the shaft or steel punchings. Use a spreader to keep the ropes from pressing against the coil ends or commutator. Never support it by pressure on the coil ends or on the commutator, either when using a rope sling or when resting on blocks. Never use any sharp instruments on any coils as the insulation can be easily punctured.

CONNECTIONS

Connect the apparatus in accordance with the diagrams supplied with the apparatus and switchboard equipment.

OPERATION

BEFORE STARTING

Check to see that all connections are made and all joints are tight. Examine the brushes and brushholders. The brushes should be free to slide in the holders and should be bearing against the surface of the commutator or slip ring. If any broken brushes are found they should be replaced. (See instructions under "Maintenance" - Brushes). The holders should be providing approximately two pounds per square inch pressure and should be located 1/16 to 1/8 inch from commutator surface. If brush rig has been disturbed during installation it should be returned to the correct position as set at the factory and which is marked by means of a dowel bolt. Always keep the rig in this position. Examine air gaps and remove any foreign material found therein. See that rotating members turn freely.

ON D-C GENERATORS

Keep field rheostat turned to the "all in" position (position of minimum voltage) and all line switches should be open.

STARTING MOTOR-GENERATOR SETS

On initial starting proceed slowly and note especially for any evidence of rubbing. Check for heating in the bearings.

After load is applied to d-c generators look for evidence of sparking at the commutator. The generator should carry rated load with little sparking. If severe sparking occurs, see comments under "Maintenance."

STOPPING MOTOR-GENERATOR SETS

When stopping, gradually reduce load on generator as much as possible before tripping circuit breaker. Turn rheostat to minimum voltage and stop prime mover.

MAINTENANCE

INSULATION

Keep machine free of dirt, oil and water at all times. The greatest enemy to coil insulation is dirt, and if the equipment is kept clean little trouble will result. The best way to check for excessive dampness in the windings is to make an insulation resistance measurement. This can be done directly by a "megger". If a megger is not available, the measurement can be made using a 100 to 500 volt direct current (the higher voltage available the more accurate the results) and a direct current voltmeter, of which the resistance in ohms is known (generally marked on lable inside the instrument cover).

The method of making a resistance measurement with the voltmeter is to first read the voltage of the line, then connect the resistance to be measured in series with the voltmeter and take a second reading.

The measured resistance is calculated from the formula:

$$R = \frac{r\,(V-v)}{v} \text{ or } \frac{r}{v}(V-v)$$

V = First voltage reading.
v = Second voltage reading.
R = Resistance of insulation in ohms.
r = Resistance of voltmeter in ohms.

If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the machine. The voltmeter should be connected between the windings and the other side of the circuit.

The insulation resistance with the machine cold (at room temperature) should not be less than one megohm (1,000,000 ohms). When the windings are hot it should not be less than:

$$\frac{3\ (\text{rated voltage})}{KW + 1000} \quad \text{(In megohms)}$$

If the resistance is low, the generator should be dried out before it is started into regular service. It can be done by, (1) using a separate heater (such as a lamp bulb) inside the generator (do not place too near the coils and in general the machine should be enclosed for best results), (2) circulating current through the windings, or (3) dismantling and removing the armature and coils and baking them in an oven (at not over 105°C). This should be done in extreme cases.

If the second method is used, run the generator with a low voltage output, adjusting the load to a current value which will raise the temperature to approximately 70°C. This temperature should be maintained during the drying process by raising or lowering the current as required.

Careful attention should be given to the machine during this drying-out process. There is always danger of overheating the windings when drying them with current. The inner parts which cannot quickly dissipate the heat generated in them may get dangerously hot, while the exposed and more easily cooled portions are still at a comparatively moderate temperature. Therefore, the temperature of the hottest part accessible should always be observed during the drying-out process, and should not be allowed to exceed 80°C total temperature.

If it is found that the generator is in a very damp condition, it may require several hours or even days to dry it out because the insulation is more easily injured when damp than when it is comparatively dry. In such extreme cases, it will be better to bring up the temperature slowly at first, not allowing the maximum temperature to be reached until part of the dampness is expelled.

BRUSH POSITION

The correct brush position has been located at the factory and the rocker ring is locked to the magnet frame to prevent any movement. The brushholder should be adjusted to be approximately 1/16 inch from the face of the commutator.

BRUSHES

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing face. This can best be accomplished after the brushholders have been adjusted and the brushes inserted. Lift a set of brushes sufficiently to permit a sheet of sandpaper to be inserted. Draw the sandpaper in the direction of rotation under the brushes releasing the pressure as the paper is drawn back. Be careful to keep the ends of the paper as close to the commutator surface as possible as this will avoid rounding the edges of the brushes. It will be found that by this means a satisfactory contact is quickly secured. Use sandpaper grade 1-1/2 for the roughing out and grade 0 for the final fit.

Make frequent inspection to see that:

1. Brushes are not sticking in holders.
2. Shunts are properly attached to brushes and holders.
3. Tension is changed as brush wears. Maintain approximately two pounds per square inch.
4. Worn out brushes are replaced before they reach their limit of travel and break contact with the commutator.
5. Remove the free copper picked up by the face of the brush.

COMMUTATOR

The commutator is perhaps the most important part of the whole machine because it is most sensitive to abuse. Under normal conditions, it should require very little attention beyond frequent inspection. The surface should always be kept smooth. If, through extreme carelessness, neglect or accident, it becomes badly roughened, the armature should be removed and the commutator turned down in an engine lathe.

Sometimes a little sandpapering is all that is necessary. Emery cloth or paper should never be used for this purpose because of the continued abrasive action of the emery which becomes embedded in the copper bars and brushes. Even when sandpaper is used the brushes should be raised and the commutator wiped clean with a piece of canvas. Cotton waste should never be used.

All commutators are thoroughly baked and tightened before leaving the factory, but if a bar should work loose it should be attended to promptly. The same may be said of flat spots or "flats" which will sometimes occur, due to a loose bar, unusually soft copper or even too severe flash or short circuit.

Under normal conditions the commutator should become dark and highly polished after a few weeks' operation, and so remain unchanged for years; there should never be any lubricant used on the commutator.

Trouble is sometimes experienced from the burning out of mica insulation between segments. This is most commonly caused by allowing the mica to become oil-soaked or by the bars loosening between them. It is rarely, if ever, definitely traced to excessive voltage between bars. When this burning does occur, it may be effectively stopped by scraping out the burned mica and filling the space with a solution of sodium silicate (water glass) or other suitable insulating cement.

Even with the most careful workmanship, high mica will sometimes develop and start sparking, which burns away the copper and aggravates the difficulty. By prompt action, serious damage can be prevented by cutting away the mica to a depth of one-sixteenth of an inch below the adjacent copper.

SPARKING AT THE BRUSHES

Sparking at the brushes may be due to any of the following causes:

(a) Machines may be overloaded.
(b) The brush may not be set exactly on neutral.
(c) The brushes may be wedged in the holders or have reached the end of their travel.
(d) The brushes may not be fitted to the circumference of the commutator.
(e) The brushes may not bear on the commutator with sufficient pressure.
(f) The brushes may be burned on the ends.
(g) A commutator may be rough; if so, it should be smoothed off.
(h) A commutator bar may be loose, or may project above the others.
(i) The commutator may be dirty, oily or worn out.
(j) The carbon brushes may be of an unsuitable grade.
(k) The brushes may not be equally spaced around the periphery of the commutator.
(l) Some brushes may have extra pressure and may be taking more than their share of the current.
(m) High mica.
(n) Vibration of the brushes.
(o) Incorrect brush angle.

There are more causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken it will draw a bright spark as the break passes the brush position. This trouble can readily be located, as the bars adjacent to the disconnected bar will be more or less pitted.

FLASHOVER

A flashover happens when arcing occurs between adjacent brushholder brackets. In general, it is caused by excessive voltage, or by abnormally low surface resistance on the commutator between brushholders of opposite polarity. Any condition tending to produce poor commutation increases the danger of flashover. Among other causes are the following:

1. Rough or dirty commutator.
2. A drop of water on the commutator from leaky steam pipes or other source.
3. Short circuits on the line producing excessive overload.

BEARINGS, SLEEVE

When machines are installed, put a good grade of light dynamo oil in each bearing housing. Use oil of a viscosity of from 185 to 212 seconds at 40°C. This oil is satisfactory for normal temperature down to 0°C or 32°F. For oils suitable for lower temperature, secure special engineering recommendations.

The correct level of the oil is one-eighth inch below top of combination over gauge and filling device. Close down cover when through oiling.

When machines are first started, feel bearing housings occasionally to see that bearings are not overheating.

The frequency of bearing inspection depends on the conditions surrounding your application. Do not add oil unless the oil level has dropped more than one-eighth inch below the top of the combination overflow gauge and filling device.

Do not flood with oil. Do not spill oil over the housing or bracket and the Sealed Sleeve Bearing will not spill oil over the windings.

"Sealed Sleeve Bearings work best when left alone."

BEARINGS, BALL

Quietness and life of ball bearings depend largely on cleanliness and proper lubrication.

Never open the bearing housing under conditions which will permit entrance of dirt.

External inspection of the machine at the time of the first greasing, soon after it is put into operation, will determine whether the bearings are operating quietly and without undue heating. Further inspection will not be necessary except at infrequent intervals, probably at greasing periods.

When shipped from the factory, grease-lubricated ball and roller bearing machines have sufficient grease of the right grade to last for a limited period. However, a charge of grease should be added soon after the motor is put in operation, and thereafter at suitable intervals, as determined by experience. The ideal condition is that the bearing housing be from one-third to one-half full of grease.

The grease to be used for ball bearings should be compounded from a pure mineral oil and a sodium base soap. It should have minimum free oil separation in storage. It should be free from dirt and fillings such as powdered mica, flake graphite, etc. It should be free from acid or alkali or from ingredients which will form these compounds. It should have maximum resistance to drying, gumming or oxidation. The melting point or dropping temperature should be about 300°F. In general, use a grease of a reliable grease manufacturer especially recommended for ball bearings.

CAUSES OF INSUFFICIENT VOLTAGE (GENERATORS)

The following causes may prevent generators from developing their normal voltage:

a. The speed of the generator may be below normal.
b. The switchboard instruments may be incorrect and the voltage may be different from that indicated, or the current may be different from that shown by the readings.
c. Part of the shunt field may be reversed or short circuited.
d. The brushes may be incorrectly set.
e. A part of the field rheostat or other unnecessary resistance may be in the field circuit.

HEATING OF FIELD COILS

Heating of field coils may develop from any of the following causes:

a. Operating at too low a speed, requiring more than normal field current.
b. Too high voltage.
c. Partial short circuit of one coil.
d. Overload.

HEATING OF ARMATURE OR ROTOR

Heating of the armature may develop from any of the following causes:

a. Too great a load.
b. A partial short circuit of two coils with heating of the two particular coils affected.
c. Short circuits or grounds on armature or commutator.

HEATING OF COMMUTATOR

Heating of commutator may develop from any of the following causes:

a. Overload.
b. Sparking at the brushes.
c. Too high brush pressure.
d. Lack of inherent lubrication of brushes.

CLEANLINESS

Particular care should be exercised towards keeping all parts of the machine reasonably clean. High rotative speed draws air into the armatures and the other parts with a velocity sufficient to carry with it particles of dirt or oil vapor that may be in the air. The rotating part must be cleaned periodically or the machines will ultimately short circuit between commutator necks or break down to ground over insulation surfaces. Stationary windings should be well cleaned for the same reason.

In extreme cases clean machine using carbon-tetrachloride on a rag. Use sparingly and in a well ventilated place as the fumes are nauseating. Do not scrape coils with any instrument.

After several years of operation it is good practice to coat all coils with a good coat of insulating varnish. If possible, a baking varnish is much superior to any air-drying varnish.

DISASSEMBLING OF MACHINES ON BEDPLATE

If, for any reason, a machine must be removed from a bedplate, the following procedure should be followed:

1. Remove coupling bolts to disengage shaft from other units.

2. Remove dowel in feet of machine to be removed from bedplate by tightening nut on dowel pin until entire dowel can be removed. There should be two dowels per frame located diagonally opposite each other.

3. Remove holding-down bolts in feet, being careful to observe and maintain correct shims under each foot for reassembly.

REASSEMBLY OF MACHINES ON BEDPLATE

After a machine has been removed from a bedplate, reassemble as follows:

1. Place machine on bedplate with same shims under each foot as when disassembled.
2. Start holding-down bolts, but do not tighten.
3. Install dowel bolts, and drive down as far as possible.
4. Tighten holding-down bolts, and drive dowels all the way in.
5. Install coupling discs and bolts. Machine is ready to run.
6. Observe the rules for starting as given under "Operation."

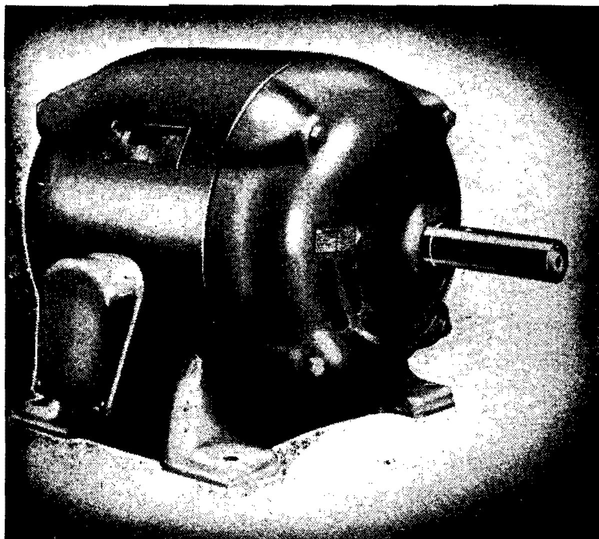
INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

SQUIRREL-CAGE *Life-Line* MOTORS

DRIP-PROOF, TYPE CSP, 1 TO 20 HP

(Frames 203 Through 326 with Prelubricated Ball Bearings)



LIFE-LINE DRIP-PROOF Type CSP Motors in NEMA frame sizes 203 through 326 are squirrel-cage induction motors designed for a wide variety of constant speed applications. The stator core is completely encased in a rolled steel frame. Steel end brackets protect the windings from falling chips and dripping liquids, and offer special support to the prelubricated ball bearings.

Warranty. The Corporation in connection with apparatus sold agrees to correct any defect or defects in workmanship or material which may develop under proper or normal use during the period of one year from the date of shipment, by repair or by replacement f.o.b. factory of the defective part or parts, and such correction shall constitute a fulfillment of all the Corporation's liabilities in respect to said apparatus, unless otherwise stated in the quotation.

Any defects that may develop should be referred to the nearest Westinghouse Sales Office for complete servicing information.

RECEIVING

Unpack the motor and make certain that it was not damaged during shipment. Turn the shaft by hand to see that it turns freely.

Check to see that the nameplate data agrees with the voltage and frequency of the power supply provided for the motor.

Shaft extension is coated with a slushing compound to prevent rusting during shipment and storage. This slushing compound may be removed by wiping with any petroleum solvent, such as benzine, gasoline, turpentine, Stoddard solvent, etc. See precautions under "Maintenance" for use of these solvents.

INSTALLATION

Mounting. Locate the motor in a place that is clean, dry and well-ventilated. If protecting shields or guards are used, they must not obstruct the free flow of air around the motor. The external air temperature should not exceed 40°C or 104°F.

Fasten to a rigid foundation using bolts or screws of the largest size permitted by the drilling in the mounting feet. The motor must rest evenly on all mounting pads.

For wall or ceiling horizontal mounting, the motor end brackets may be rotated 90° or 180° to offer greater protection from falling objects or dripping liquids.

Method of Drive. Any of the following drive methods may be used depending on the particular motor application:

1. Flat Belt Drive. Mount the motor on the slide rails or bedplate, which allows for adjusting the belt tension.

Mount the motor pulley so that the inner face of the pulley is in line with the shoulder on the shaft extension.

Use a belt wide enough to carry the load without excessive tension. Wide, single ply belts are preferable to double ply belts due to the lower bearing pressures that result.

The smallest pulley should not be less in diameter than that recommended by the belt manufacturer for the belt used, and in no case less in diameter than indicated in Table 1.

Align the pulleys so that the belt runs true, and tighten the belt just enough to prevent slippage.

EFFECTIVE FEBRUARY, 1949

Where the pulleys are not of approximately the same diameter, the distance between shaft centers should be greater than twice the diameter of the larger pulley. For short center distances, an idler pulley or a V-belt drive should be employed.

Table No. 1

PULLEY SIZE FOR FLAT BELT DRIVES

MOTOR FRAME	PULLEY DIMENSIONS	
	MIN. DIAM. (Inches)	MAX. WIDTH (Inches)
203-204	2½	3
224	2½	3½
225	3	3½
254	3½	4½
284	4	5½
324	5	6¾
326 (above 2000 RPM)	5	6¾
326 (2000 RPM and below)	6	7¾

2. **V-Belt Drive.** Mount the motor on the slide rails or bedplate, which allows for adjusting the belt tension.

Mount the motor sheave close to the bearing housing allowing sufficient clearance for rotor end play.

The smallest sheave should not be less in diameter than that recommended by the belt manufacturer for the belt used, and in no case less in diameter than indicated in Table 2.

Sheaves should be carefully aligned. Belt tension should be just sufficient to eliminate excessive sag in the slack of the belt. V-belts do not require as much tension as flat belts.

Table No. 2

SHEAVE SIZE FOR V-BELT DRIVES

MOTOR FRAME	SHEAVE DIMENSIONS	
	MIN. PITCH DIAM. (Inches)	MAX. WIDTH (inches)
203-204	2¼	3
224	2¼	3½
225	2½	3½
254	2¾	4½
284	3	5½
324	3¾	6¾
326	4½	7¾

3. **Chain Drive.** Mount the motor on the slide rails or bedplate, which allows for adjusting the chain tension.

Mount the motor sprocket close to the bearing housing, allowing sufficient clearance for rotor end play, and align the sprockets accurately.

4. **Gear Drive.** Mount the motor and driven unit so as to maintain accurate alignment. The gears must mesh accurately to prevent vibration.

Mount the motor gear close to the bearing housing to minimize the overhang, allowing sufficient clearance for rotor end play.

Dowel the motor to the base.

5. **Direct Drive.** The motor shaft and driven shaft must be carefully aligned.

Dowel the motor to the base.

Note: Pulleys, pinions or coupling halves should have a close sliding fit on the shaft extension and must be securely locked to avoid hammering out in operation. If it is necessary to drive the part into position, it is important, on ball bearing motors, that the end of the shaft opposite the extension be backed up so that the force of the blow is not taken in the bearing. Use a pinion puller for removing tight pulleys.

Electrical Connections. Be sure the motor is connected as shown on the nameplate diagram, and that the power supply (Voltage, Frequency and Number of Phases) corresponds with the nameplate data.

Connect to the power supply through a suitable switch and overload protection.

Install all wiring and fusing in accordance with the National Electric Code and local requirements.

To change the direction of rotation on three-phase motors, interchange any two line leads.

To change the direction of rotation on two-phase motors, interchange the line leads of either phase.

Conduit Box. If the conduit box is desired on the opposite side of the motor, remove the brackets and rotor, reverse the frame, and reassemble.

The conduit box on the side of the motor is designed with three conduit knock-outs to suit various mounting conditions. Where it is desired to extend conduit from above, remove the two mounting screws, and turn the conduit box 180° so that the knock-out will be at the top. Recommended method of connecting conduit for overhead entry is shown in Fig. 1. When conditions warrant it, the same method may be applied to the side knock-outs.

When the motor is mounted on a bedplate, or on slide rails for belt adjustment, flexible metallic conduit should be used to protect the leads to the motor. In making this connection a squeeze connector should be used for attaching the flexible conduit to the conduit box. Squeeze connectors may be straight, 45° or 90°.

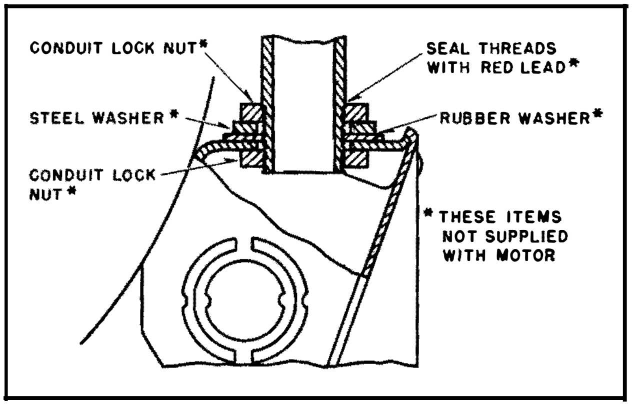


FIG. 1. Method of Connecting Conduit to Keep Out Liquids When Leads Enter Top of Conduit Box

OPERATION

Run the motor without load to check the connections and direction of rotation.

The motor will operate satisfactorily with a 10% variation in voltage, a 5% variation in frequency, or a combined voltage and frequency variation of 10%, but not necessarily in accordance with the standards of performance established for operation at normal rating.

MAINTENANCE

Inspection. Although Life-Line motors require a minimum of attention in service, they should be inspected at regular intervals to guard against excessive (1) dirt, (2) moisture, (3) friction and (4) vibration, which account for 90% of all motor failures.

1. Guard Against Dirt. Keep the insulation and mechanical parts of the motor clean. Dust that is free from oil or grease may be removed by wiping with a clean, dry cloth, or preferably, by suction. Dust may be blown from inaccessible parts with clean, dry air, using not more than 30 to 50 pounds pressure. Use care to prevent personal injury from the air hose; use goggles to avoid eye injury from flying particles.

When grease or oil is present, wipe with a cloth moistened (but not dripping) with a petroleum solvent of a "safety type" such as Stoddard solvent or similar materials available under various trade names. When a material is difficult to remove, carbon tetrachloride is more effective than petroleum solvents. Wear neoprene gloves to prevent skin

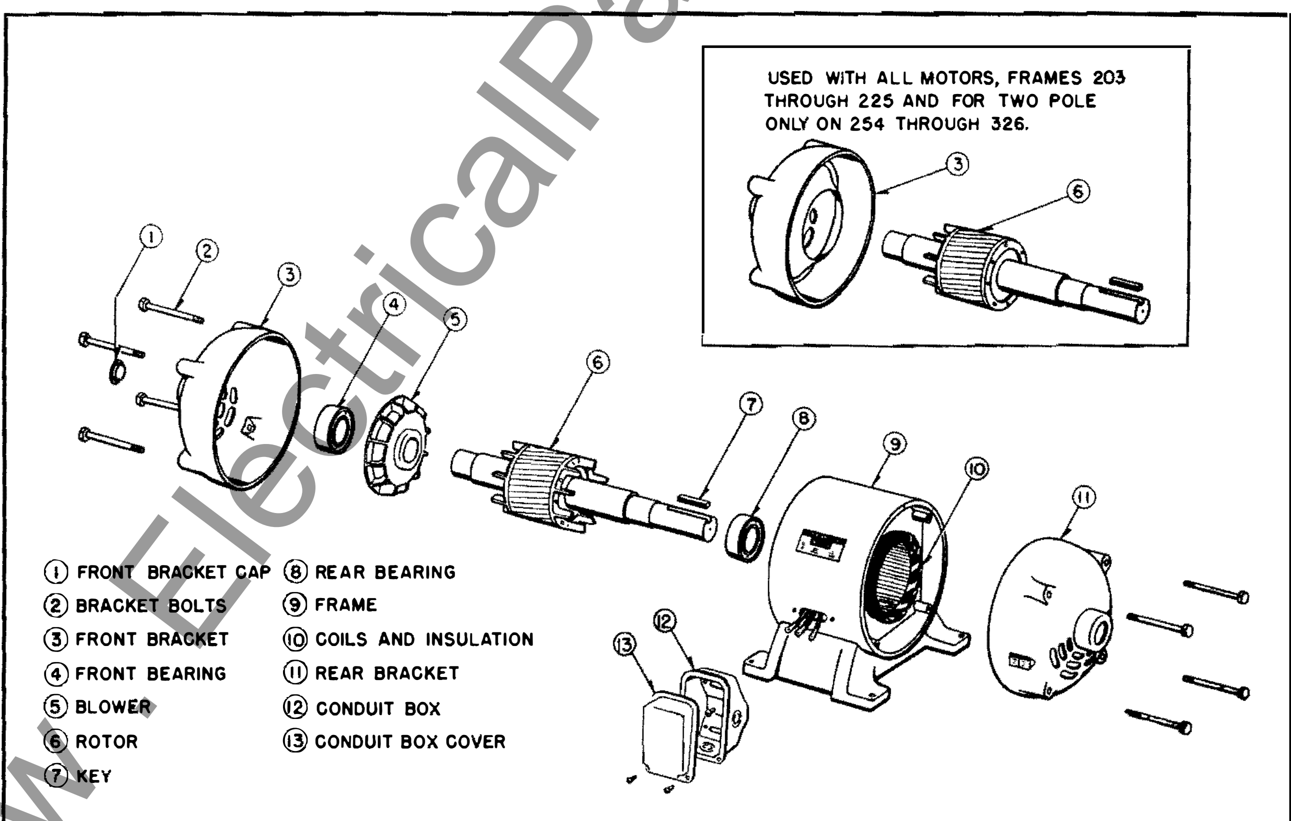


FIG. 2. Arrangement of Parts—*Drip-Proof Type CSP Motor (Frames 203-326)

* Parts arrangement for Totally Enclosed Non-Ventilated motors is similar to that for Drip-Proof except: bearings (items 4, 8) are factory packed with a silicone base grease; brackets (items 3, 11) have no ventilating openings; gaskets are supplied between conduit box and frame and between box and cover.

In addition, to afford extra protection against entrance of moisture into the motor interior, the fits between brackets and frame of Totally Enclosed Non-Ventilated motors are sealed with water-repellant grease and the bearing housings in brackets are packed with water-repellant grease.

irritation when using either petroleum sovents or carbon tetrachloride.

Petroleum solvents are flammable and comparatively nontoxic.

Carbon tetrachloride is nonflammable, but is highly toxic. Suitable ventilation should be provided to avoid breathing vapors. When ventilation is not sufficient to prevent a distinct odor of carbon tetrachloride, a chemical cartridge respirator or gas mask must be used.

2. Guard Against Moisture. Drip-proof motors should always be guarded against the accidental intrusion of water from splatter or splashing.

Stand-by motors should be run at least once a week to guard against moisture condensation.

Before motor windings are blown out with air, make sure that water has not condensed in the air line.

3. Guard Against Friction. Excessive friction or overheating of bearings is usually traced to one of the following causes:

a. Excessive belt tension.

b. Poor alignment causing excessive vibration or binding.

c. Bent shaft.

d. Excessive end or side thrust due to gearing, flexible coupling, etc.

4. Guard Against Vibration. To avoid failures due to vibration, a few simple checks should be made regularly.

Check for misalignment such as may be caused by foundation settling or heavy floor loading. These may be causing vibration through misalignment.

Check to see if vibration from the driven machine is being transmitted to the motor.

Check for excessive belt or chain tension or the push-apart effect inherent in spur gears.

Check the motor mounting bolts and bracket bolts to be sure they are tight.

Coils. Revarnishing the windings when motors are overhauled will lengthen their life. Suitable varnish may be obtained from the nearest Westinghouse Sales Office.

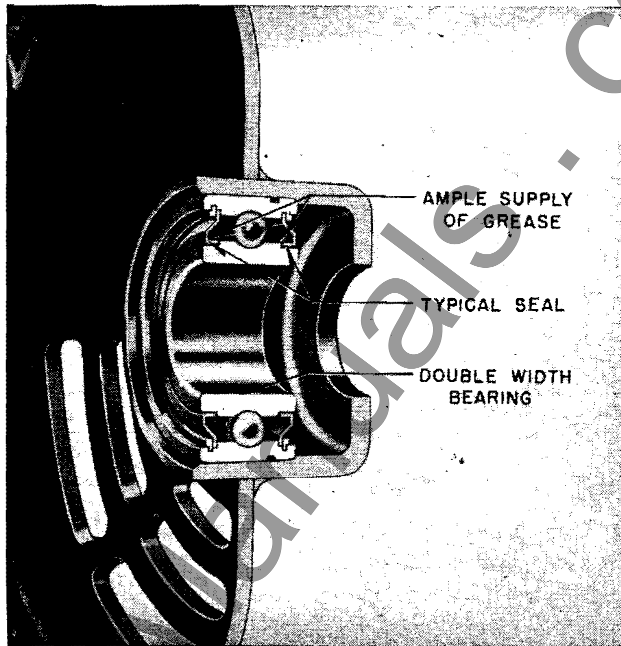


FIG. 3. Sectional View—Prelubricated Ball Bearing

Bearings. (See Fig. 3.) The bearings used in Life-Line motors are packed at the factory with the proper amount of lubricant; no further lubrication is needed for the normal life of the bearings.

A grease having a high degree of stability is permanently sealed in the bearings. This grease has been proven by tests both in the laboratory and field for long service.

Bearings from several suppliers are used in Life-Line motors; for a given size motor, the bearings of all suppliers are interchangeable. The details of the seal construction vary somewhat depending upon the bearing manufacturer, but each type of seal is equally effective in keeping out foreign material and retaining the lubricant. A typical seal construction is shown in Fig. 3.

RENEWAL PARTS

Renewal Parts information may be obtained from the nearest Westinghouse Sales Office. Be sure to name the part or parts required (See Fig. 2) and give the complete nameplate reading on the motor for positive identification.

WESTINGHOUSE ELECTRIC CORPORATION

BUFFALO PLANT • MOTOR DIVISION • BUFFALO 5, N.Y.

(Rep. 11-49) Printed in U.S.A.