ELECTRONIC GOVERNOR
(110-VOLT, 60-CYCLE SERVICE)

FORM 9161-A

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I. INTRODUCTION

The LINDE Electronic Governor is a precision device for controlling fractional horsepower (less than 1 hp) shunt-wound, direct-current motors. The governor monitors the motor speed, maintaining it constant at any selected value despite variations in load or in motor temperature. While designed primarily for controlling the special shunt motor used in certain LINDE equipments, it can be used with other suitable D.C. shunt-wound motors within its power capacity. Before using the governor with any motor which was not specifically supplied to work with governor, its suitability should be verified by the LINDE Development Laboratory.

The LINDE Electronic Governors, discussed herein are for use with a 110-120 volt, 60-cycle A.C. power supply only. (Direct current or other frequencies cannot be used.) When used with supplies of other A.C. voltages, a suitable step-up or step-down transformer must be used to furnish 115 volts to the governor. Governors designed for use with a 220-volt A.C. supply are discussed in Form 9256: "Instructions for the LINDE Electronic Governor for 220-Volt, 60-Cycle Service."

The material which follows concerning Design Features, Installation, Operation and Maintenance applies to the standard basic governor, as purchased separately for use with non-standard or customer-built apparatus. With minor exceptions it also applies to the slightly-modified governors which are used as integral components of standard LINDE apparatus. Any exceptions, special instructions and additional information (including applicable parts pictures and circuit diagrams) which pertain to your particular governor will be found in the Appendix at the back of the book.

* The discussion applies equally to governors built for use with other frequencies. The basic circuit will not change, although the ratings of certain components will be altered to accommodate the new power line frequency.

A. Design Features

1. SPEED RANGE

The governor provides control over a motor speed range of better than 100:1 ratio. (This is the ratio of maximum to minimum available motor speed. The actual usable speed range depends upon the application.) A simple control knob allows the operator to preset the speed before starting the motor, and to vary the speed quickly and accurately at any time during operation.

2. REGULATION

The speed/load regulation is very good. Normal changes in load or in motor temperature have negligible effect on the speed.

3. ACCURACY

An electrical meter provides accurate indication of speed. The meter readings are reliable, and the governor maintains its calibration for thousands of hours of operation, since the calibration of the meter is substantially linear.

4. REVERSIBLE OPERATION

A reversing switch permits operating the motor for both directions of rotation. The speed is substantially the same for either direction.

5. SIMPLICITY — EASY MAINTENANCE

The governor circuit is a simple one. It is composed of standard commercial parts, which have been installed on the chassis in locations which permit them to be easily and quickly replaced. A generous safety factor was used in the selection of components, to further reduce the likelihood of stoppages. Where external connections are used, the required terminals have been brought to a single terminal strip, so that these connections can be made easily, using a screwdriver.

![Fig. 1 - Self-Contained Electronic Governor](image1)

![Fig. 2 - Basic Electronic Governor (Without Controls)](image2)
6. FLEXIBILITY

To accommodate the widest variety of possible applications, the governor is made available in two standard models:

Type EG-101 (shown in Figure 1) is the basic self-contained governor (with integral controls). It is equipped with a motor reversing switch, a speed control, and a speed indicating meter.

Type EG-102 (shown in Figure 2) is the basic governor less controls. It is identical with Type EG-101, except that the controls listed above are not supplied.

Type EG-102 is used when the speed control, speed-indicating meter and reversing switch are to be located at a distance from the governor, in a position most convenient for the operator. When desirable, one or more of the controls can be mounted in the governor cabinet, and the remainder mounted in any convenient external location. The distance between governor and controls is unimportant. If the speed-indicating meter and/or reversing switch are unnecessary, they can be eliminated without difficulty.

Although the governor and its controls may be combined in various ways, the basic circuits and their operation will not be affected.

II. INSTALLATION

When purchased as an integral part of standard apparatus, the governor will in most cases be supplied already installed. To avoid damage during shipment, the thyatron tube is packed separately. This tube must be inserted in its socket inside the governor, before connecting the unit to any power source. (Tube locations are shown in the parts pictures in the Appendix.)

When purchased separately for use in non-standard or customer-built equipment, the governor can be mounted in a variety of ways to suit the convenience of the operator. A suitable mounting bracket can be fabricated, or the governor cabinet can be made self-supporting by drilling proper holes and attaching it directly to the apparatus or other support with standard hardware.

The governor should be installed in a position which provides sufficient clearance at its front to permit easy removal of the chassis for servicing. The front panel and chassis are removable as a unit. Withdrawing the four panel mounting screws permits the unit to be pulled forward out of the cabinet. The required clearance for this should be available, and the power cable which supplies the governor should have sufficient extra length to permit complete withdrawal of the unit. Do not install the governor in a position where it will be subjected to excessive heat or moisture. A space of at least one inch should be provided between the back of the cabinet and any vertical wall surface, to assure adequate ventilation.

The diagram in the Appendix shows the required connections of the controls, power line, motor, and ground to the terminal strip under the chassis. These connections are the same, regardless of whether the controls are mounted within the governor or at other external positions. When the controls are mounted externally, the connecting leads are brought into the governor cabinet through one or both of the strain-relief bushings provided in the back of the cabinet.

The governor requires a 110-120 volt 60-cycle A.C. power supply having good regulation. When operated directly from a factory power line, the line voltage fluctuations should not exceed ±5 volts; if fluctuations in excess of this value are encountered, the unit should be transferred to a steadier source, such as a lighting circuit.

IMPORTANT: Never attempt to operate the governor without first connecting the motor and controls to the proper terminals on the terminal strip.

III. OPERATION

The LINDE Governor is composed of four basic circuits. Each of these will be described individually below. The circuit diagram will be found in the Appendix. To clarify the explanations which follow, a schematic diagram of the governor is shown in Figure 3. This diagram has been laid out with emphasis on electrical relationships. It is not intended to show the actual physical layout of parts or wiring.

A. Thyatron Filament and Time Delay Circuit

1. FILAMENT CIRCUIT

(a) Function: To supply heating current to the Thyatron Tube.

(b) Principal Electrical Component: Filament Transformer TR101.
(c) Operation:

For proper operation, the filament of the thyatron tube T101 must be heated to the proper temperature. To do this, the filament terminals must be connected to a 2-1/2-volt source supplying 9 amperes. When this current flows through the tube filament it becomes hot, just as the metal ribbon in an electric toaster becomes heated by the passage of current.

The proper filament current is supplied by transformer TR101. The transformer primary is connected across the 115-volt A.C. supply line. The thyatron filament terminals are connected to the transformer secondary winding, which furnishes approximately 2-1/2 volts A.C.

2. TIME DELAY CIRCUIT

(a) Function: To protect the thyatron tube from damage due to premature conduction of current.

(b) Principal Electrical Component: Time Delay Relay TD101.

(c) Operation:

The thyatron filament reaches operating temperature approximately 30 seconds after the filament current is turned on. If current is permitted to flow in the motor armature circuit during this warm-up period, the thyatron will be damaged. Time delay relay TD101 has been incorporated in the governor to prevent this.

The relay tube contains a pair of contacts and a heating coil. One of the contacts is mounted on a fixed metal arm; the other contact is mounted on a flexible bi-metal strip. The heating coil is mounted close to this bi-metal strip. When the governor master switch SW101 is turned on, current is supplied to transformer TR101. The thyatron filament and the relay heating coil are both connected to the secondary of TR101; heating current is thus supplied to the filament and coil simultaneously. The heat generated in the relay coil causes the bi-metal strip (and its contact) to bend toward the fixed arm (and its contact). After approximately 30 seconds (during which time the thyatron filament heats up to operating temperature) the two contacts touch, completing the circuit in which their terminals are connected. This "unlocks" the thyatron, placing the governor in operating condition. Details on this "unlocking" process will be given under "Grid Control Circuit" on page 8.

Transformer TR101 and time delay relay TD101 are used only for filament heating and protection as explained above. They are independent of the other governor circuits, and play no direct part in the "governing" action.

B. Drive-Motor Field Rectifier Circuit

(SEE FIG. 4)

1. FUNCTION: To supply rectified current to the field of the Drive Motor.

2. PRINCIPAL ELECTRICAL COMPONENTS:
   - Voltage Adjusting Resistor R106
   - Selenium Rectifier SR101
   - Filter Condensers C104 and C105

3. OPERATION:

   The properties of selenium rectifier SR101 are such that current can flow through it in only one direction (this direction is indicated by the arrow which is part of the symbol). Whenever the voltage on the upper leg of the rectifier becomes positive with respect to that of the lower leg, current will flow down through the rectifier. When the polarity is reversed, however, no current can flow up through the rectifier. Since the rectifier is connected to the 60-cycle A.C. supply line, it will conduct during half of each A.C. cycle — the half during which the upper leg is positive. The current which flows through the rectifier circuit is therefore pulsating direct current. Condensers C104 and C105 filter out the pulsations, so that a substantially steady D.C. voltage is made available between points A and B. Direct current for energizing the drive-motor field is taken from these points. Variable resistor R106 provides an adjustment for controlling the D.C. voltage output. This is adjusted at the factory to 110 volts D.C.

C. Drive-Motor Armature Power Circuit

(SEE FIG. 5)

1. FUNCTION: To supply controlled, rectified current to the drive-motor armature.

2. PRINCIPAL ELECTRICAL COMPONENTS:
   - Thyatron Control Tube T101 (C3J)
   - Armature Reversing Switch SW102
   - Feedback Resistor R102 (function is explained under paragraph D on page 9)

3. OPERATION:

   To keep a motor running at constant speed, its output torque must be kept continually equal to the retarding torque of the load. If the load increases, the motor's torque must also be increased, otherwise it will slow down. Conversely, a decrease in load requires a corresponding decrease in motor torque to maintain constant speed.

   To increase or decrease the motor output torque, we must increase or decrease the power
FIG. 3 - ELECTRONIC GOVERNOR SCHEMATIC DIAGRAM (COMPLETE)

FIG. 4 - DRIVE-MOTOR FIELD RECTIFIER CIRCUIT

FIG. 5 - THYRATRON TUBE - BASIC SCHEMATIC DIAGRAM
supplied to the motor. This could be done by placing a rheostat in series with the motor armature, and adjusting this rheostat to increase or decrease the armature voltage as needed. This is a very inaccurate, inefficient method, however. Power is wasted in the rheostat, and it is impossible to adjust the voltage quickly and accurately enough to compensate for rapid load fluctuations.

Control of armature voltage can be effected very precisely and efficiently by using a thyratron tube in series with the motor armature. The thyratron uses a negligible amount of power in its grid circuit to control its relatively large output to the load circuit. Precise, instantaneous control of power supplied to the motor armature is possible merely by making slight alterations in a voltage which is applied to the thyratron control grid.

The Thyratron T101 is a gas-filled triode (three-electrode) tube. The standard symbol for this tube, and the designations of the electrodes, are shown in Figure 5. In practice, the tube is connected in series with a load as shown, across an alternating current supply (Va). In the case of the LINDE Governor, the load is the drive-motor armature, and the supply is the 115-volt A.C. power line. The filament terminals X-X' are connected to the heater-current supply as explained in paragraph A on page 3.

The thyratron will conduct current in only one direction. When the anode voltage is positive with respect to the (center-tap connection) filament voltage, current will flow from anode to filament and around the external circuit in the direction shown by the arrows. When the anode is negative with respect to the filament, however, no current will flow. This is an inherent property of the thyratron. It thus "rectifies" the current in the circuit, just as the selenium rectifier SR does. The current which flows in the load circuit is therefore direct current, as is required for operating the shunt-type drive-motor. When the tube is conducting current, the voltage drop across the tube is approximately 10 volts. The remainder of the supply voltage appears across the load. Due to this low voltage drop across the tube, very little power is consumed by the tube; this makes for high operating efficiency.

SW102 is a reversing switch. It reverses the direction of current flow through the motor armature, thus reversing the direction of rotation. Placing SW102 in its center position shuts the motor off by opening the load circuit.

D. Thyratron Grid Control Circuit

1. FUNCTION: To supply control voltage to the grid of thyratron tube T101, thus controlling the current passed by the tube.

2. PRINCIPAL ELECTRICAL COMPONENTS:

   A.C. Bias Transformer TR102
   Phase-Shifting Condenser C101
   Phase-Shifting Resistor R101
   D.C. Bias Battery (4-1/2 volts)
   Voltage Regulator Tube T102 (VR-105)
   Voltage Regulator Ballast Resistor R105
   Reference Voltage Potentiometer P101
   Feedback Filter Resistor R103
   Feedback Resistor R102
   Feedback Filter Condenser C103
   Grid Protecting Resistor R104
   Grid By-Pass Condenser C102

3. OPERATION:

   The grid of the thyratron can control the flow of current from anode to filament. This control is achieved by connecting a voltage source (Vg) between the grid and the filament center-tap, so as to make the grid negative with respect to the filament, as shown in Figure 5. How this negative voltage affects the anode-to-filament current flow will be seen as the explanation proceeds. It is important to remember that the anode-filament-load circuit and the grid-filament circuit in Figure 5 are two separate circuits. They have only a single point in common—the center-tap connection on the filament. All load current flow is confined to the anode-filament-load circuit. There is no appreciable current flow around the grid-filament circuit; the grid exercises control merely by introducing its negative potential between the anode and filament, within the tube.

   If the grid were connected directly to the filament (that is, if the grid-to-filament voltage were made zero), the tube would act as an ordinary rectifier. It would conduct current during the entire time that the anode voltage remained positive. Since we are applying alternating current from the 115-volt supply line, this means that the tube would conduct during the entire positive half-cycle of the A.C. wave. During the negative half-cycle, when the anode is negative with respect to the filament, no current would flow. This is shown graphically in Figure 6. The shaded portions represent the relative amount of power which is consumed in the circuit; all but a negligible amount is consumed in the load itself. Our load in this case is the drive-motor armature, therefore, the shaded portions will indicate the relative amount of power being supplied to the armature. Since the motor output torque depends upon the amount of power supplied to the motor, these shaded portions will represent the relative output torque also.

   If the grid voltage is made slightly negative with respect to the filament, the tube will no longer conduct during the entire positive half-cycle. Conduction will not begin until the anode
voltage reaches a certain definite value. Once this value is reached, the tube "fires," and conducts current during the remainder of the positive half-cycle. Figure 7 shows the situation graphically. The value of anode voltage at which conduction begins is precisely determined by the value of the negative voltage on the control grid.

As the grid voltage is made more negative, the anode "firing" voltage becomes progressively higher; as shown by the diagrams, the tube thus "fires" progressively later in the cycle.

If the grid voltage is made sufficiently negative, the tube will not fire until the anode voltage reaches its peak. This condition is shown in Figure 8. If the grid voltage is made still more negative, the tube will not conduct at all, since the anode voltage never reaches the value needed to cause the tube to fire. The grid thus can cause the tube to conduct for any fraction of the positive half-cycle from 1/2 on up to 1. Comparison of Figures 6, 7, and 8 shows that by varying the voltage on the grid, we can vary the power input to the motor from half-power (Figure 8) to full power (Figure 6). The total variation of grid voltage required is less than 2 volts. To permit variation of power from zero to full power, it is necessary to add a small A.C. voltage to the negative grid voltage. This A.C. voltage must lag 90 degrees out of phase with the A.C. anode voltage, to be effective. Transformer TR102 supplies an A.C. voltage at its secondary winding of approximately 8 volts. This voltage, however, is in phase with the anode voltage, since the primary of TR102 is connected to the same supply line as the anode circuit. Resistor R101 and condenser C101 are connected as a phase-shifting network whose output to the grid circuit lags 90 degrees out of phase with the anode voltage, as is required for proper tube operation. This permits the grid to exercise control of tube current during the entire positive half-cycle, so that motor power can be varied at will from zero to maximum. The output of the phase-shift circuit is connected in series with the grid circuit, so that the phase-shifted voltage is added to the other voltages in the grid circuit.

To provide operator-control of the motor, an adjustable D.C. voltage is connected in series with the grid circuit. A D.C. voltage of 105 volts exists across potentiometer P101 and resistor R103 in series. As shown in Figure 9, P101 and R103 are in series with the thyratron grid circuit. When the movable arm of P101 is at the upper end of P101, therefore, 105 volts D.C. is connected in series with the grid circuit. As the movable arm is moved toward the lower end of P101, progressively less of this voltage appears in series with the grid circuit. As will be explained, the setting of potentiometer P101 establishes the operating speed of the motor.

The 105-volt supply voltage across P101 and R103 is furnished by the voltage-regulating tube T102 and its ballast resistor R105. This tube is a gas-filled diode (two-element) tube which has the ability to maintain a constant voltage of 105 volts D.C. across its terminals in spite of variations in line voltage or load. It does this by automatically and instantaneously increasing or decreasing the current which it draws through resistor R105. For example, suppose that the line voltage across the tube and resistor were 110 volts D.C.; the voltage across the tube would be 105 volts, and the voltage across the resistor would be 5 volts. If the line voltage were to suddenly increase to 120 volts, the tube would instantaneously draw more current through R105 so that the voltage drop across R105 would immediately increase to 15 volts. Thus the voltage drop across the tube would remain unchanged at 105 volts. This assures that the "reference" voltage supplied to P101 and R103 remains constant at 105 volts regardless of fluctuations in the power line voltage.
A bias battery is connected in series with the grid circuit, also. The battery provides a constant minimum D.C. bias of 4-1/2 volts (negative) on the control grid.

The grid-to-filament voltage is the sum of the various voltages in the grid circuit. (For the purposes of this analysis the A.C. phase-shifted voltage supplied by R101 and C101 can be ignored.) The grid voltage, therefore, can be any value from minus 4-1/2 volts to plus 100 volts (approximate values), depending upon the setting P101.

The governor grid circuit is connected as Figure 9 shows, with one important difference: the lower end of the grid circuit, instead of being connected directly to the filament as indicated in Figure 9, is connected below the load (the motor armature in this case) as shown in Figure 10. Examination of Figure 10 shows that the motor armature is now in series with the grid circuit, as well as with the anode circuit. This means that any voltage which appears across the armature terminals will be added to (or subtracted from, depending upon the polarity) the other voltages in the grid-to-filament circuit.

To illustrate the effect of the armature voltage on the control grid, assume that the "reference voltage" has been adjusted to 50 volts by means of P101. At the instant that the governor operating switch is turned on, the motor armature is, of course, not rotating. In this condition, its resistance to the passage of current is small. The voltage drop across it will also be small. The grid-to-filament voltage will then consist only of the "reference voltage" of 50 volts minus the battery voltage of 4-1/2 volts, or 45-1/2 volts. With this high positive voltage on its grid, the thyatron will begin conduction as soon as the anode becomes positive, and will conduct during the entire positive half-cycle of anode voltage, as shown previously in Figure 6. As the shaded portions of Figure 6 show, full power will be supplied to the motor armature when starting up.

When the armature begins to revolve, however, a voltage is induced in its coils. This voltage, known as the "counter-electromotive force" exhibits a polarity (across the armature terminals) as indicated in Figure 10. This counter-e.m.f. increases directly as the speed of rotation increases. As the armature speed increases, it eventually reaches a point where the induced armature voltage becomes equal to the reference voltage (50 volts). Since these two voltages are in series in the grid circuit, and are of opposite polarity, they cancel out, leaving only the bias battery voltage of 4-1/2 volts (negative) on the grid. Since, as explained earlier, a negative grid voltage of less than 2 volts is sufficient to completely prevent the thyatron from conducting, current will cease to flow in the anode circuit, thereby shutting

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FIG. 9 - THYATRON GRID CONTROL CIRCUIT - BASIC TYPE

FIG. 10 - THYATRON GRID CONTROL CIRCUIT AS USED IN "LINDE" ELECTRONIC GOVERNOR
off armature power. The armature naturally begins to slow down. The counter-e.m.f. being proportional to armature speed, decreases. Suppose, for example, that it decreases to 46 volts. It then no longer cancels out the "reference voltage" completely, but leaves a remainder of 4 volts (positive). The total grid-to-filament voltage then is 4 volts minus 4-1/2 volts, or 1/2 volt negative. This grid voltage permits the thyatron to conduct during a major portion of the positive half-cycle of anode voltage, as shown graphically in Figure 7. The shaded portions of Figure 7 show that about 3/4 full power is then being supplied to the armature. If the motor happens to be lightly loaded, this much power may be more than is needed. The armature would naturally tend to speed up again. But this will increase the counter-e.m.f. As just explained, this would result in a more negative grid voltage, and hence would decrease the power being supplied to the armature, thus slowing it down. A condition of balance is quickly reached where:

(a) The armature revolves steadily at a certain speed.

(b) This armature speed produces a certain steady value of counter-e.m.f.

(c) This value of counter-e.m.f. establishes a particular grid voltage.

(d) This particular grid voltage permits the thyatron to pass a particular quantity of current to the armature.

(e) This particular quantity of current provides just enough power to keep the armature running at the "certain speed" established in Step 1, thus completing the chain.

Although the above explanation seems lengthy, the condition of balance is actually reached almost instantaneously after turning on the motor.

It can be seen from the foregoing that the "reference voltage," as determined by the setting of P101, establishes the operating speed of the motor. P101 is a potentiometer, and is provided with a control knob. Mounted on the front panel of the governor (see Figure 2) or in some other convenient position, it provides the operator with a quick, simple means of adjusting or changing the drive motor operating speed.

Since the motor operating speed is proportional to the "reference voltage," this voltage can be used to provide visual indication of the speed of the motor, or of the apparatus which it propels. Accordingly, a voltmeter, in series with its dropping resistor, is connected across the reference voltage. When the meter dial is calibrated to the motor or apparatus in terms of revolutions-per-minute or inches-per-minute, it will serve as an accurate, dependable speed indicator. Since the "reference voltage" is on continually, even when the motor is not running, the motor operating speed can be preset by adjusting P101 until the meter indicates the desired speed.

A slight additional analysis will show how the governor maintains the motor speed constant in spite of variations in load. If the load on the motor momentarily increases for some reason, it would tend to cause the armature to slow down. This would decrease the counter-e.m.f. This, in turn, would instantly affect the voltage on the thyatron control grid, making it less negative. Instantly the tube would increase the power supplied to the armature. This power increase would balance the load increase, and the motor would continue to operate at substantially its original speed. A decrease in load would be counteracted in an analogous manner. The circuit would operate to decrease the armature power, thus counterbalancing the decrease in load.

The thyatron control grid is extremely sensitive to the most minute changes in the motor's counter-e.m.f. The corrective action is so instantaneous that there is no appreciable change in motor speed, though the load be varied rapidly and within wide limits.

Resistor R102 is a "feedback" resistor. It is connected so that it is in series with both the armature circuit and the "reference voltage" circuit. Connected in this way, it feeds back a small compensating voltage from the armature circuit to the "reference voltage" circuit, helping to maintain the motor speed constant under varying load conditions.

Condenser C103 filters out the individual pulsations in the voltage across R102 so that only an average value is fed back to the "reference voltage" circuit.

Resistor R104 has been inserted in the grid circuit to protect the thyatron tube from damage in the event of a flow of current in the grid circuit. It plays no direct part in the operations of the grid control circuit.

Condenser C102 by-passes transient voltages, preventing them from affecting the normal grid voltage.

The contacts of time-delay relay TD101 are in series with the "reference voltage" circuit, as shown in Figure 3. While these contacts are open, no voltage appears across P101 and R103. This leaves only the bias battery voltage of 4-1/2 volts negative on the thyatron grid. This value of voltage being sufficient to completely prevent the thyatron from conducting, no anode current can flow, regardless of whether the operating switch SW102 is on or not. After the 30 second delay period the contacts of TD101 close, completing the circuit and thus supplying a reference voltage to the grid circuit. Normal operation can then occur.
IV. MAINTENANCE

A. General Information

If a spare governor is available, it is advisable to exchange units and perform maintenance on the replaced unit at the test bench rather than at the production line.

The governor circuit is relatively simple. Rather than provide a list of possible malfunctions with suggested remedies, a logical test procedure is given below. This will enable you to quickly check the entire governor and isolate the source of trouble.

The type of test meter used in checking the governor will influence the results obtained. Voltage readings given below are based on the use of a 1000 ohms-per-volt voltmeter, such as the Weston 697 Analyzer. This particular meter has in addition a built-in ohmmeter which can be used for testing resistors and condensers, and A.C. scales for checking line and transformer voltages. However, any other suitable meter with 1000 ohms-per-volt scales can be used.

It is important that the D.C. meter scales be used in measuring D.C. voltages, and A.C. scales be used in measuring A.C. voltages. If this is not done, the meter readings obtained will be valueless.

B. Test Procedure

1. MECHANICAL STOPPAGES

Before checking for electrical failure, make certain that the drive-motor and governor are not being overloaded. Loads beyond their ratings may:

(a) Blow fuses F101 and F102.
(b) Overheat the motor, or damage gears.
(c) Cause motor speed to vary erratically, or to be out of calibration with the speed indicator.

In the event of such occurrences, examine the mechanism operated by the motor for conditions which might be causing an overload. These include tight bearings, misalignment, excessive roll pressure, jamming, foreign material on rails or gear trains, etc.

The armature current of the motor is roughly proportional to the torque delivered by the motor. Armature current can therefore be used as an indication of motor load. When the normal current values to be expected are available, a quick check of the motor load can be made by inserting an ammeter in series with the armature. When normal current values have not been provided, they can be obtained by operating the equipment under average conditions and recording the current readings registered on an ammeter in series with the armature.

These readings should then be inscribed on a label or plate and mounted on the apparatus in a convenient location.

Because of the wave form of the armature current, a D.C. D'Arsonval type of ammeter should be used to measure the armature current. Other meter types will not give correct readings.

The ammeter can be inserted in series with the armature circuit at any convenient point. A suggested location is at the terminal strip in the governor. Disconnect the reversing-switch wire from terminal 1, and connect the ammeter between the switch wire and the terminal. The positive side of the ammeter connects to the terminal, the negative side of the meter to the switch wire.

2. ELECTRICAL STOPPAGES

When the governor is not functioning properly, and you have determined that the trouble is not mechanical, proceed with the following step-by-step tests. Complete each step before going to the next. Do not skip any tests.

In describing these tests, it is assumed that the power line, controls and drive-motor are connected to the governor. The terminal strip referred to is located on the bottom side of the governor chassis. To reach this terminal strip you must remove the chassis from the cabinet, and remove the bottom plate from the chassis.

(a) Control and Power Circuit Tests

(i) Line voltage

Check the line voltage between terminals 9 and 10 on the terminal strip. This should be 110 to 120 volts A.C., (60 cycles).

(ii) Master switch

Turn on the master switch SW101. The pilot light PL101 should light immediately. If it fails to light, check fuses F101 and F102. If the fuses are good, a faulty master switch or pilot light is indicated.

(iii) Fuses

Normally, 2-ampere Littlefuse, Inc. "Slow-Blow" fuses are used in the governor. For certain specific applications the instruction manual for that application may call for a different size fuse. Under no circumstances should a larger fuse, or a fuse of a different type than that specified, be used.

Fuses can be tested by inspection, or by means of an ohmmeter. Do not use a
buzzer. The buzzer current may exceed the fuse rating and blow it.

(iv) Drive-motor field voltage

Test the field voltage between terminals 6 and 7 on the terminal strip. This should be approximately 110 volts D.C.

Resistor R106 has been adjusted at the factory to provide the proper field voltage. It should not be necessary to readjust R106, except possibly when certain parts such as rectifier SR101, condensers C104 and C105, or the drive-motor are replaced.

Resistor R106 has a total resistance of 25 ohms. To function properly, R106 should never be reduced below 10 ohms. If the correct field voltage cannot be obtained without making R106 less than 10 ohms, it is probable that one of the following conditions exists:

a.) The line voltage is below 110 volts A.C.

b.) The resistance of the motor field is below normal. This could be due to partial or complete shorts in the field winding.

c.) Rectifier SR101 is defective. (Refer to paragraph (d) on page 12 for testing.)

d.) Condensers C104 and C105 are defective. (Refer to paragraph (c) on page 12 for testing.)

(v) Reference voltage

Within 30 to 45 seconds after the master switch SW101 is closed, the contacts of time delay relay TD101 close. This places a D.C. voltage across potentiometer P101. Since the speed indicator meter is connected across P101 and resistor R103, the meter will give a reading as soon as the relay contacts close. This serves as a test to indicate the presence of reference voltage.

When no speed indicator meter is used, a D.C. voltmeter connected to terminals 2 and 5 should indicate 105 volts when the contacts of TD101 close.

(vi) Speed adjustment

As soon as the reference voltage is applied to speed-adjusting potentiometer P101 it delivers to the grid of the thyratron a voltage proportional to the desired speed. To check whether P101 is operating properly:

Rotate P101 from minimum to maximum settings. The speed indicator meter reading should vary smoothly from nearly zero to slightly above top scale. If the governor is not equipped with a speed indicator, a D.C. voltmeter connected between terminals 3 and 4 should vary smoothly from zero to approximately 100 volts D.C. as P101 is rotated from minimum to maximum settings.

(vii) Time delay relay

The contacts of time delay relay TD101 should close 30 to 45 seconds after the master switch SW101 is closed. Failure to do so could be caused by one of the following:

a.) Defective relay. Substituting another relay is the quickest way to test for this.

b.) The voltage on the heating coil of the relay may be abnormally low. The voltage between pins 2 and 3 on the relay mounting socket should be between 2.35 and 2.5 volts A.C. Voltages lower than this may indicate that the line voltage is abnormally low, or that transformer TR101 is defective.

c.) A break in the primary or secondary circuits of transformer TR101.

In some cases the contacts of the relay may fuse and remain closed all of the time. This would cause reference voltage to be applied to the thyratron grid as soon as the master switch SW101 is closed. The relay should be replaced immediately to avoid damaging the thyratron.

(viii) Bias battery

The bias battery should be tested with the master switch SW101 open. The battery should give a reading between 4.3 and 4.6 volts D.C. Any battery which gives a reading below 4.3 volts should be replaced. Although the life of this battery is in excess of one year, we recommend that it be replaced every six months as a routine service measure to eliminate the possibility of trouble.

The battery is wrapped in a fiber paper jacket to prevent it being cut by the battery mounting clip. When installing a battery replacement, transfer this jacket to the new battery. Be sure, also, that the red wire lead is connected to the positive terminal of the battery, and that the black-and-white wire lead is connected to the negative battery terminal.

If by any chance the battery remains in the circuit far beyond its normal life the battery cells may corrode and leak
fluid. Should this occur, carefully clean all fluid from the chassis, and install both a new battery and a new fiber jacket.

(ix) Voltage regulator circuit

The voltage regulator tube T102 shows a characteristic purplish glow in normal operation. Absence of this glow indicates that the tube itself or resistor R105 may be defective. To check the tube, substitute one known to be good. Absence of glow may also indicate that the input voltage is too low. The input voltage (measured between terminals 6 and 7 on the terminal strip) should be approximately 110 volts D.C.

Output voltage of the regulator tube, measured between terminals 5 and 9 on the terminal strip, is 105 volts D.C.

(b) Resistor Tests

When testing resistors, be sure that the governor is disconnected from the power line.

All resistors except R106 and R107 are located on the underside of the chassis. They can be identified from Figure 11. Resistor R106 is on the top side of the chassis, and R107 is attached to the speed indicator meter.

The nominal resistance values are given in the circuit diagram. With the exception of R107, the values are not critical, and may vary up to ±20% from the nominal value, although a tolerance of ±10% is preferable. R107 determines the calibration of the speed indicator meter; it should be within ±5% tolerance. When measuring its resistance, one side of R107 must be disconnected, to avoid the shunting effect of P101.

(c) Condenser Tests

When testing condensers, be sure that the governor is disconnected from the power line.

Condensers C101 and C102 are paper condensers which are used so conservatively that it is very unlikely that they will require replacement unless they are mechanically damaged. A fairly reliable check of C101 and C102 can be made by connecting an ohmmeter across the condenser terminals, without disconnecting the condenser from its circuit. If the condenser is good, the meter will read the resistance in parallel with the condenser. For C101 this resistance will be approximately 56,000 ohms. For C102 this resistance will be approximately 1,000,000 ohms. If the condenser in either case is shorted, the reading will be much lower than that indicated.

Condensers C103, C104, and C105 are electrolytic condensers. The three are contained in a single metal case. If one of them is damaged, all three must be replaced.

These electrolytic condensers are used conservatively. They should give years of service before requiring replacement. The end of their useful life is usually indicated when it is no longer possible to obtain 110 volts D.C. across the motor field (measured between terminals 6 and 7 on the terminal strip), even when R106 is reduced to as little as 10 ohms. When the field voltage is measured, be sure that the power line is delivering at least 110 volts A.C., and that the selenium rectifier SR101 is in good condition.

Occasionally an electrolytic condenser may fail by short-circuiting. This can be detected by disconnecting the motor field from terminals 6 and 7 on the terminal strip, then connecting an ohmmeter across these terminals. When the ohmmeter needle comes to rest, it should indicate a resistance of at least 20,000 ohms. Reverse the ohmmeter leads and take a second reading. The highest reading of the two is the significant one. When the higher reading is a few hundred ohms or less, it indicates a shorted condenser.

Because of its position in the circuit, it is difficult to test C103 without first disconnecting it. However, since it is very lightly loaded, its life will usually be much greater than that of C104 or C105.

If C104 or C105 should short-circuit, this may damage SR101 or R106 by overloading them. If C104 or C105 are found to be shorted, therefore, SR101 and R106 should also be checked.

(d) Selenium Rectifier Test

Selenium rectifier SR101 is used conservatively. It should give many thousands of hours of service.

The end of the rectifier's useful life is indicated when it is no longer possible to obtain 110 volts D.C. across the motor field (measured across terminals 6 and 7 on the terminal strip) even when R106 is reduced to as little as 10 ohms. When measuring the field voltage, be sure that the power line is delivering at least 110 volts A.C. and that condensers C104 and C105 are in good condition.

(e) Transformer Tests

A transformer can be tested by measuring the secondary voltage under normal load, while the proper voltage is applied to the
primary winding. The primary voltage in the case of the governor will be the line voltage. The circuit diagram shows the voltage of the secondary as marked by the manufacturer. As noted below, that actual voltage as measured is not exactly this value.

(i) Transformer TR101. With a line voltage of 115 volts A.C., the secondary voltage (with the thyratron tube inserted in its socket) is approximately 2.45 volts A.C. when the transformer is cold and 2.35 volts A.C. when the transformer is hot. This voltage can be measured under load by removing the time delay relay TD101 from its socket and placing the voltmeter leads on pins 2 and 3 of the socket.

(ii) Transformer TR102. With a line voltage of 115 volts A.C., the secondary voltage is 8 volts A.C. This voltage can best be measured at the terminal plate under the chassis where the transformer leads connect to C101 and R101.

(f) Thyratron Tube Test

The thyratron tube T101(C3J) should give more than 10,000 hours of service before requiring replacement. If all previous tests show that the circuits are in good order, and that the tube may be causing trouble, the quickest way to check the tube is to substitute one known to be good. When substituting a tube, be sure to turn the governor master switch off for a few minutes to permit the time delay relay to open its contacts.

(g) Motor Tests

When the standard LINDE shunt motor (Part No. 57V23) is used with the governor, the following information may help in detecting a defective motor:

(i) The resistance of the field winding when cold is approximately 350 ohms.

(ii) The resistance of the field winding when hot is approximately 440 ohms.

(iii) The resistance of the armature when cold is approximately 6.5 ohms.

(iv) Since the field is fully energized at all times, the motor will normally run at a fairly high temperature. This is particularly true when it is operated at low speeds, or is stopped for long periods of time without turning the master switch off.

Under no circumstances should an OXWELD standard series-wound drive-motor be substituted for the special shunt motor required by this unit.

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