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# A PROGRAMMABLE D-C HIGH-VOLTAGE RAMPED TEST SYSTEM FOR ELECTRICAL INSULATION

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16. ABSTRACT

A technique is presented that uses a programmable d-c high-voltage test set to automatically ramp the high voltage at a preselected rate while continuously recording the resultant rotating machinery stator insulation current. The principal advantage of the ramp testing technique over the conventional stepped method is the greatly improved sensitivity and accuracy of the test results. In addition, the ramp test requires only one person to run the test and provides that person with better control and sufficient lead time when a failure point is approached to avoid damaging the insulation. A full description of the test technique, interpretation of test results, and test set operation are included.

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by
U. Milano

October 1978

Electric Power Branch
Division of Research
Engineering and Research Center
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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## TABLE AND FIGURES

## INTRODUCTION TO RAMPED D-C TESTING

The nonlinear response of insulation leakage current with respect to applied potential is the main criterion by which generator stator insulation quality is judged. Unfortunately, large dielectric absorption currents mask the more pertinent leakage current nonlinearities. Consequently, elaborate techniques and tedious test schedules have been devised to linearize absorption current response with respect to applied voltage. [1][1] This allows one to assume that the observed insulation current nonlinearities are directly related to leakage current deviations. The ramped voltage test technique [2] automatically linearizes the dielectric absorption component of insulation current eliminating many of the problems encountered in direct-current, stepped voltage testing methods. Automatic compensation of absorption current eliminates the need for extensive absorption current calculations and complex volt-time testing schedules. Further improvements have been made through the use of state-of-the-art automatic testing equipment which has removed the uncertainty of the human factor in adjusting test voltages and in recording data. Direct-current testing controllability, sensitivity, and repeatability are significantly improved through the use of the new test method.

[1] Numbers in brackets refer to references at end of report.

The ramped technique of insulation testing uses a programmable d-c, high-voltage test set (fig. 1) and automatically ramps the high voltage at a preselected rate (usually 1 kV/min). Insulation current versus applied voltage is plotted on an X-Y recorder providing continuous observation and analysis of insulation current response as the test progresses. To evaluate an insulation, it is no longer necessary to hand plot insulation current

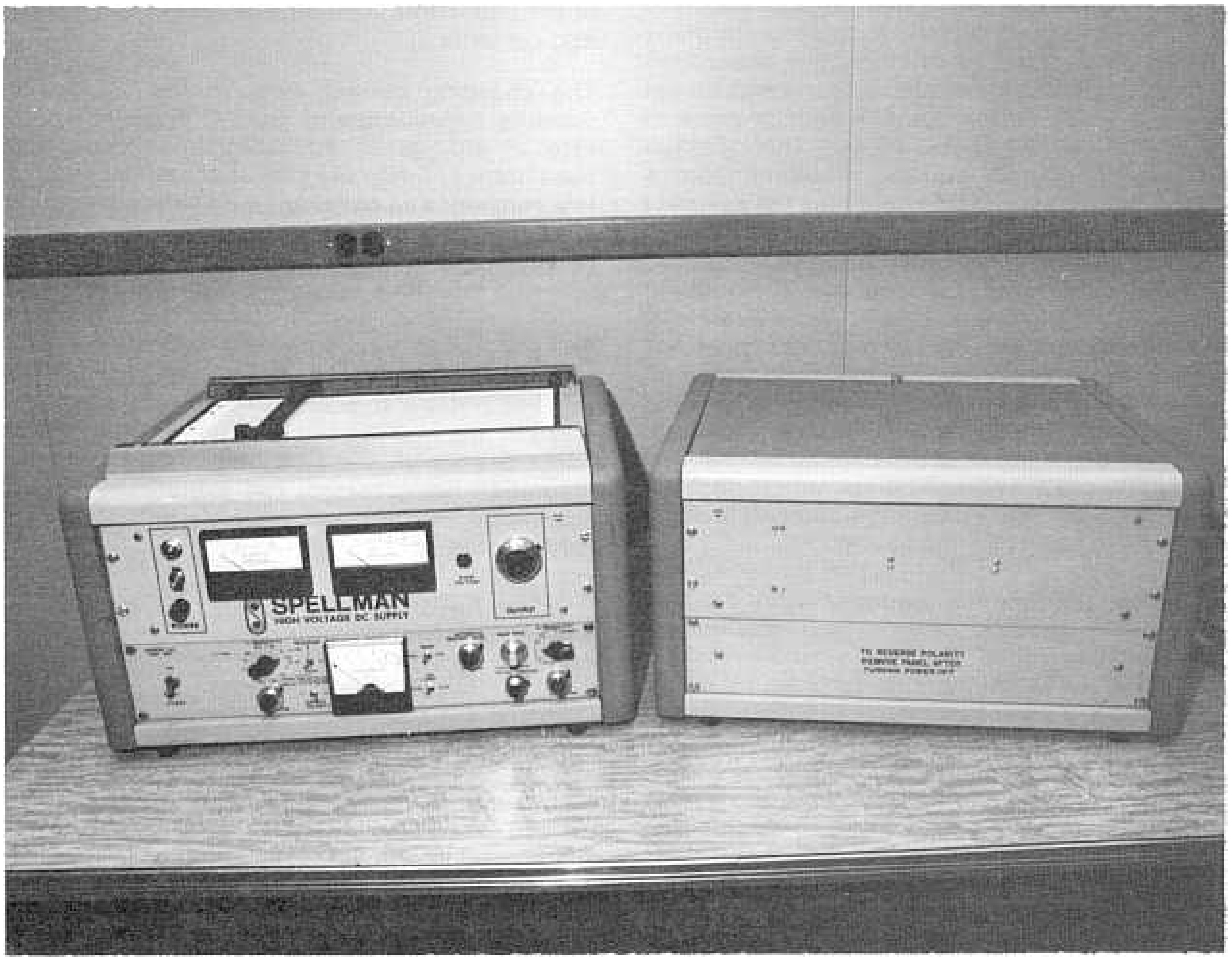



Figure 1.—Programmable d-c high-voltage test set. Photo P 801-D-78841

and resistance versus applied voltage. Insulation quality can be evaluated directly from the automatically recorded insulation current curves, since the observed insulation current non-linearities are directly proportional to leakage current variations.

The test technique was designed so automated test results are similar in nature to previous data obtained using the USBR's direct current step testing schedules [3].

## STATOR INSULATION CURRENT

The three components of stator insulation current are charging current, absorption current, and leakage current. The charging current is that component due to the winding capacitance to ground. Following an applied voltage step, the capacitive charging current decays exponentially to zero in a matter of seconds. The absorption current is similar to the charging current except that it normally takes about 1 hour or more to decay to a negligible value. The leakage component is that current resulting from a voltage being applied across a less than perfect insulation, that is, having a finite resistance.

As previously stated, the response of insulation leakage current with respect to applied potential is the main criterion by which insulation quality is judged. However, the leakage component of current is not readily discernible due to the long decay time of the larger absorption component. An enormous amount of time would be required waiting for the absorption component to decay in order to obtain the *V-I* (voltage-current) leakage curve for a particular insulation.

To shorten the time required to obtain *V-I* curves of stator insulations, complex volt-time schedules were developed. The idea behind these test schedules is to adjust the voltage, in steps, according to a predetermined time schedule such that the absorption component of the measured current is proportional to the applied voltage. In essence, the schedule linearizes the absorption current such that relative changes in the leakage current become readily discernible. Controlling test time intervals and voltage increments as well as visually averaging and reading a fluctuating insulation current meter often results in very poor test data accuracy. The faulty data appears as misleading dips, peaks, and false knees in the plotted insulation *V-I* curves.

The application of a ramped voltage, instead of discrete voltage steps, automatically linearizes the absorption component of insulation current such that deviations in the leakage current are easily seen. The principal advantages of the ramp test over the conventional step method are that it requires only one person to perform the test and provides that person with better control and sufficient foresight of impending failure to avoid damage to the insulation. The elimination of the human factor from the time, voltage, and current parameters yields overall test results which are much more accurate and repeatable. In addition, the slow and continuous increase in applied voltage (17 volts per second) is less apt to damage insulation than the step method voltage increments (approximately 1 kilovolt per second).

A typical ramped voltage test response is shown in figure 2. This curve is a composite of the capacitive charging, absorption, and leakage currents.

The charging current through the equivalent winding capacitance to ground is equal to the rate of change of applied voltage times the capacitance. Since the rate of change of voltage is a constant and equal to 16.67 volts per second (1 kV/min ramp rate), the charging current is also constant and is equal to 16.67 x *C* microamperes, where *C* is expressed in microfarads.

The absorption current has been linearized by the ramped voltage and is a straight line above 2 to 4 kV. The voltage at which the current becomes a straight line and the slope of the line depends to some degree on the type and condition of the insulation being tested. The expression for the absorption current with respect to an applied voltage step is:

$$I_a = KVT^{-n}$$

where $I_a$ = absorption current
$K$ = constant
$V$ = applied voltage step
$n$ = the absorption exponent of the insulation ($\simeq 0.8$)
$T$ = time of the applied voltage step.

This equation was used to develop the previously mentioned volt-time stepped test schedules and the similar ramped-voltage test schedule. The ramp test can be considered a step test in which the voltage steps and time intervals are made very small. As the size of the voltage and time increments approaches zero, a voltage ramp is formed.

The charging and absorption current response is known to be linear above 2 to 4 kV. Therefore, any irregularities in the composite *V-I* curve are related to the leakage current. The leakage current response will vary somewhat depending on the quality of the insulation being tested. The leakage current of high quality insulation will be very small and linear in nature. As the insulation starts to age and weaken, the leakage current will increase, and at some voltage level, will become nonlinear in nature as evidenced by a positive increase in the slope of the *V-I* curve. The point at which the current starts to increase significantly is referred to as the knee. Further aging of the insulation will cause the knee to develop at progressively lower voltages.

The nonlinear, slowly increasing leakage current observed when testing very old insulation, consists of many small stepped current increases resulting from conduction through small contaminated fissures and delaminations throughout the insulation. Separately, these fissures merely cause a limited and inconsequential stepped increase in leakage current. However, a large crack or a series of small defects in the same area, could result in a large increase in leakage current. This sharp increase in current may or may not stabilize, but it always indicates a very localized weakness in the insulation.

## TEST SET BLOCK DIAGRAM DESCRIPTION

Please refer to figure 3. The ramp generator circuit produces a voltage signal that steadily decreases from zero at the rate of minus 0.25 volts per minute times the Ramp Rate dial setting. The Ramp Rate dial is a 10-turn potentiometer; therefore, if the dial is set to 4.0 turns clockwise, the ramp rate is 0.25 V/min x 4.0/10 = 0.1 V/min. This signal is fed to an inverting operational amplifier, the output of which starts at zero and increases (goes positive) at the preset ramp rate. An electronic comparator and switching circuit compares the ramped voltage to the initial condition voltage, selects the larger of

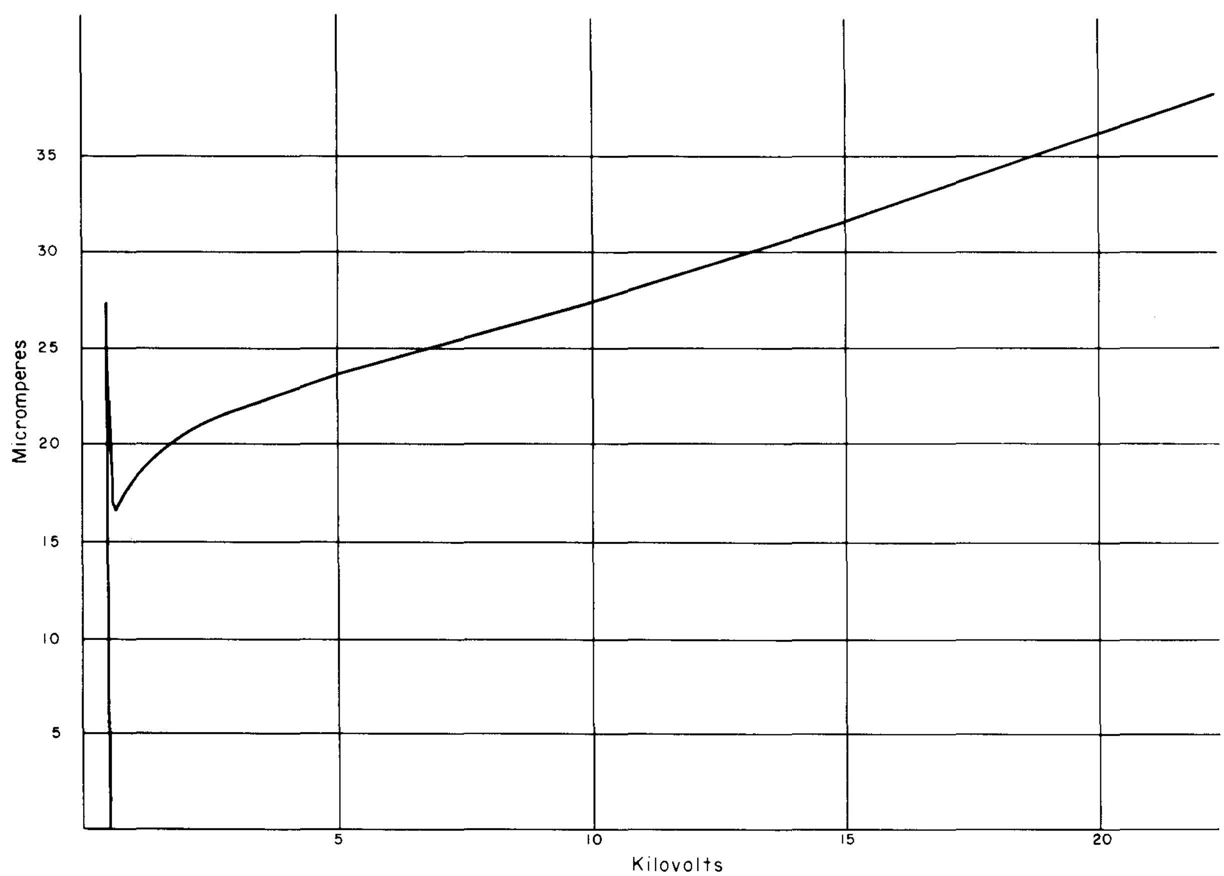



Figure 2.—Typical ramped voltage test response.

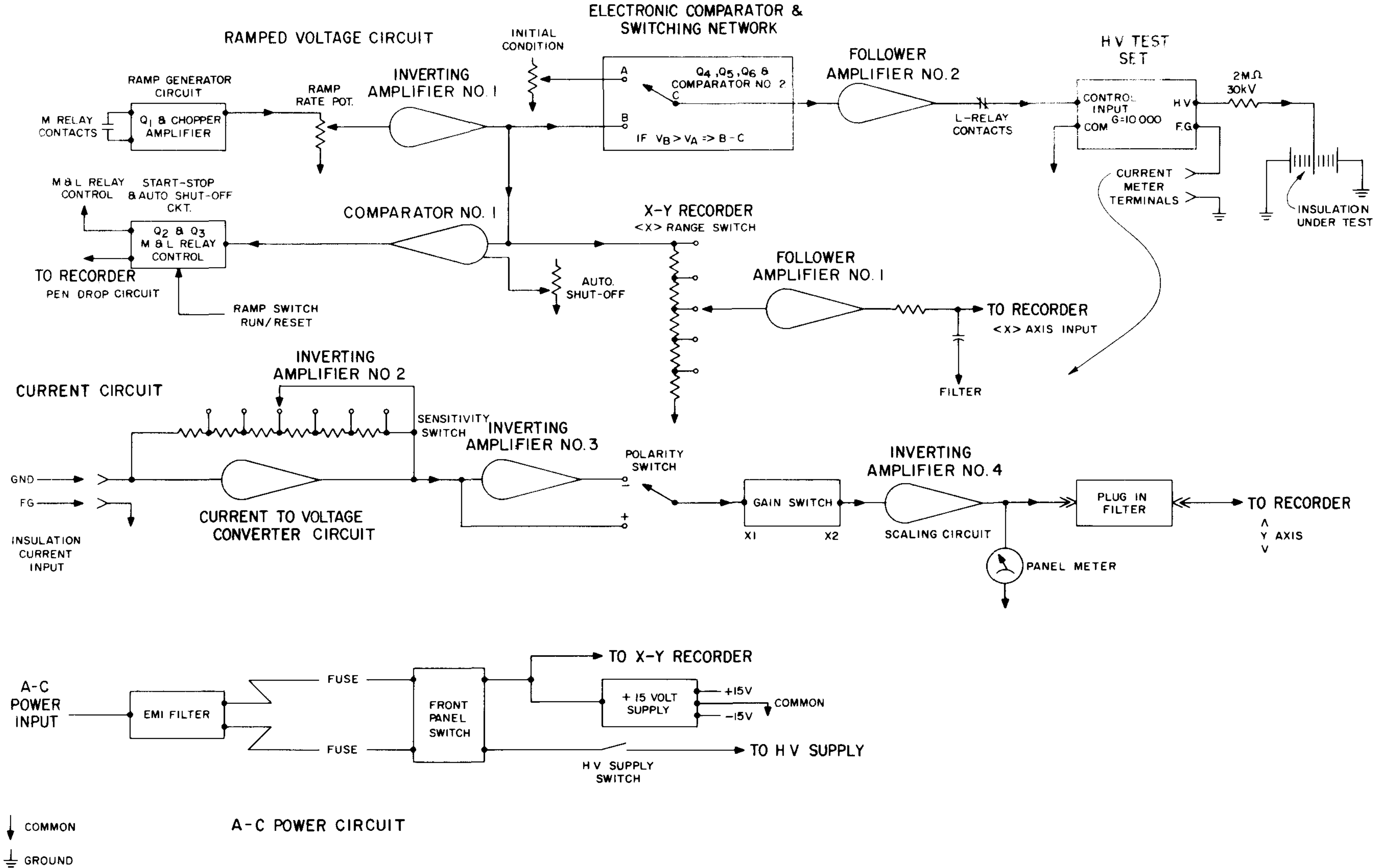



Figure 3.—Simplified block diagram.

the two signals, and routes it to the high-voltage test set control input. The initial condition reference signal is adjustable from 0.0 to 1.0 volt by means of another 10-turn potentiometer (0.1 V/turn). The programmable high-voltage test set has a transfer characteristic (gain) of 10,000. Using this figure for test set gain, the Ramp Rate and Initial Condition dials can be calibrated with respect to the high-voltage output. The calibrations are 0.25 (kV/min)/turn for the Ramp Rate dial and 1.0 kV/turn for the Initial Condition dial.

When the Initial condition dial is set to X kV and the Ramp Rate dial set at Y kV/min, the high-voltage output, at the start of the test, will immediately go to X kV and remain there for X/Y minutes. At the end of this period, the high-voltage output will start ramping up at Y kV/min as illustrated in figure 4.

The output signal from the inverting amplifier is also routed to the X-Y recorder X-axis input via the Sensitivity switch, follower amplifier, and filter. The switch permits selection of the recorder X-axis scale from 0.5 kV/cm to 4 kV/in in five discrete steps. It should be noted that the X-axis calibrations are expressed in kilovolts per unit length displacement and, therefore, remain constant regardless of the Ramp Rate dial setting. The follower amplifier prevents loading of the Range switch. The *R-C* network minimizes recording pen jitter by filtering out any extraneous noise. The recorder X-axis input circuit is independent of the initial condition circuit. The recorder will always start at zero and sweep across at the preselected rate.

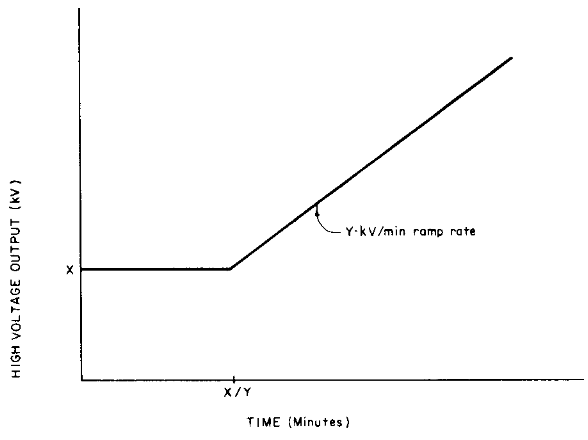



Figure 4.—High-voltage output response.

A comparator monitors the output of the inverting amplifier and compares it to the signal from the Automatic Shutoff potentiometer. As soon as the ramped signal becomes larger than the preset automatic shutoff signal, the comparator switches, activating and latching the *L* relay circuit. The *L* relay contacts open removing the input signal from the high-voltage test set. The ramp generator and recorder (X-axis) continue to sweep at their preset rates.

Part of the automatic shutoff circuit is the Ramp Run/Reset switch. This switch starts and stops the ramp generator via the M relay contacts. In the reset position, the *L* relay is energized, keeping the *L* relay contacts open for added security.

The high-voltage test set has an insulated high potential output and a current return input. The return terminal is referred to as the floating ground input and provides for insertion of a metering device between ground and the test set in order to record ground return current. The metering device used in this floating ground circuit must not have an input resistance greater than 10 kΩ. If an external metering device is not used, the floating ground terminal must be shorted to ground at the rear of the high voltage section.

**CAUTION: The floating ground input must always be connected to ground through no more than 10 kΩ.**

The current metering circuit is inserted between the floating ground and ground terminals. When the high-voltage output is negative with respect to the floating ground terminal, the direction of current is from the floating ground terminal through the current metering circuit into ground, and from ground to the high-voltage terminal of the test set through the insulation being tested (as shown in fig. 3).

The input stage of the current monitoring circuit consists of an inverting amplifier connected as a current to voltage converter. A range switch is connected in the feedback circuit and adjusts the circuit gain from 400 to 1 mV/μA in six steps. This switch is a 12-position rotary switch. With respect to the input circuit, positions 1 through 6 are electrically identical to positions 7 through 12. This switch has two other sections that are part of the scaling circuit which automatically provides for metric calibration in the first six positions and English calibration in the second six positions. This range switch is labeled Y-Sensitivity and is calibrated from 0.125 to 50 $\mu$A/cm (positions 1 through 6) and from 0.125 to 100 $\mu$A/in (positions 7 through 12).

A negative high-voltage output results in a negative voltage signal appearing at the output of the first amplifier stage. Positive current into the inverting amplifier produces a negative voltage at the output. This signal is applied to the unity gain inverting amplifier. A currrent Polarity switch allows the selection of the inverted or noninverted signal such that the X-Y recorder Y-axis response and the panel microampere meter deflection are always in a positive direction. The signal from the Polarity switch is applied to a 2-position Gain switch labeled X1 and X2. The voltage gain of the switch circuit is unity in the X1 position and 0.5 in the X2 position. This switch doubles the number of current ranges. The signal from the Gain switch is applied to a third inverting amplifier which provides English and metric scaling for the X-Y recorder Y input, and maintains proper calibration of the panel meter. The scaling circuit is switched from centimeter to inch calibration via the 12-position Y-Sensitivity switch previously described. The gain of the scaling circuit is unity on the metric ranges and 1.27 on the English ranges. The scaling circuit also maintains full scale meter deflection at 1 volt referenced to the input of the scaling circuit. As a result, full scale meter deflection is the same regardless of whether English or metric units are being employed. A plug-in filter is used to attenuate high-voltage power supply ripple and any extraneous noise. The filter reduces recorder pen jitter to an acceptable level.

## EQUIVALENT HIGH-VOLTAGE CIRCUIT

The high-voltage circuit under normal insulation testing conditions can be modeled as shown in figure 5. The 2-megohm, 30-kV resistor is used for filtering, overvoltage protection, and transient suppression. The 1-$\mu$F capacitor represents the stator winding capacitance to ground. The stator insulation voltage versus absorption and leakage current characteristic is shown as a black box. The open circuit inductor represents the stator winding inductance. The input to the current meter circuit is modeled as a 15.1-$\mu$F capacitor in parallel with a 4.0-k$\Omega$ resistor. The signals at the panel meter and X-Y recorder are proportional to the d-c current through the 4.0-k$\Omega$ resistor.

The maximum high-voltage power supply ripple is approximately 15 V rms (60 Hz). This ripple, if applied directly across the stator winding insulation (1-$\mu$F capacitance), would force 5.6 mA a.c. to flow in the high-voltage circuit. This a-c signal must be reduced to an acceptable value to avoid biasing or saturating the d-c panel meter, X-Y recorder, or associated circuits. The 2-megohm resistor and 15.1-$\mu$F capacitor reduce the a-c current through the 4.0-k$\Omega$ metering resistor to approximately 0.125 $\mu$A rms. On the most sensitive range of 0.25 $\mu$A/in, the voltages generated by this a-c ripple current are too small to disrupt the electronic circuits or panel meter; however, the signal can cause recording pen jitter. To eliminate the jitter, a filter is used in front of the recorder input to reduce the 60-Hz a-c signal by a factor of 40.

Should the winding insulation arc at point A (fig. 5) during a test, the winding to ground capacitor will discarge through the winding inductance to ground. This *L-C* discharge could produce large voltage transients. The 2-megohm resistor acts as an isolation resistor to protect the high-voltage test set from flashover induced voltage transients.

The high-voltage resistor and winding capacitance form an *R-C* filter that suppresses smaller voltage transients during normal test conditions. Should the test set fail and the output go into an overvoltage condition, the same *R-C* network will provide the operator with sufficient lead time (2 to 3 seconds) to shut off the high voltage test set before an overvoltage condition across the insulation can occur.

## GROUNDING

The powerplant ground mat is part of the high-voltage circuit. To minimize induced a-c voltages in this circuit, the test set grounds should be connected to plant ground as close to the stator core as possible. The discharge resistor and grounding stick should be tied to the ground mat in the same area where the test set grounds are attached. Do not ground these sticks at the test set ground terminals.

The winding should not be discharged with the grounding stick. Direct grounding of a charged winding will induce very high voltage transients across the insulation. The d-c voltage should be allowed to decay to 12 to 15 kV before attempting

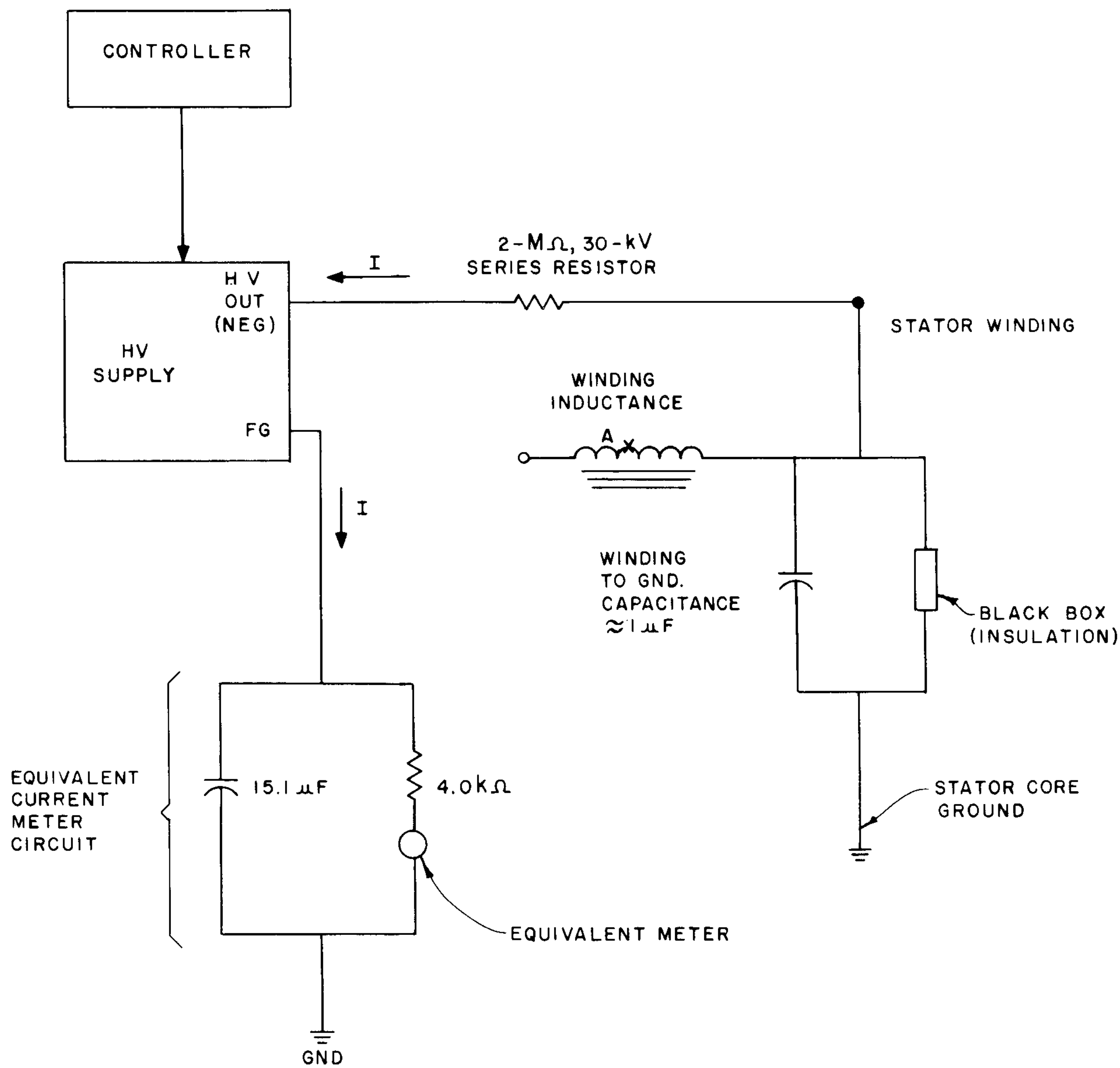



Figure 5.—Equivalent high-voltage circuit.

to bleed down the voltage with the discharge resistor. Below 3 to 5 kV d.c., the shorting stick may be used to completely discharge the winding.

Due to the nature of the insulation absorption current, the winding must remain grounded for 1.5 to 2 hours, or the voltage will recover by itself to a fraction of the original d-c test voltage. An a-c voltage shouldn't be applied until the winding has been thoroughly discharged (left grounded for 1.5 to 2 hours). Failure to properly discharge the winding constitutes a safety hazard and could also result in failure of the insulation upon application of an a-c voltage.

## HIGH-VOLTAGE CONNECTIONS AND CORONA SHIELDING

The high-voltage lead that comes with the test set is a polyethylene insulated coax cable (Belden No. 8870). The shield is connected to the floating ground terminal and serves as a guard electrode.

The cable is rated at 80 kV d.c., 24 kV rms, 60 Hz. This cable is only recommended in applications where the power source is limited so if cable failure occurs, there is no safety hazard.

A tube containing the 2-MΩ, 30-kV d-c series resistor is attached to the end of the high-voltage cable. This resistor is fragile and could break if dropped or hit hard. The resistor should be checked occasionally with an ohmmeter to make sure it has not been damaged.

Stator insulation is tested one phase at a time while the other two phases are grounded. This test configuration also tests phase to phase insulation. The phase being tested should be isolated at one end and connected only to the high-voltage test lead at the other end. Surge capacitors, phase bus leads, potential transformers, and the like must be disconnected from the phase being tested. Both ends of the winding should be fully covered with 2 to 3 layers of sheet plastic (75 to 150 μm thick) and sealed with electrical tape. This will confine corona activity to the air space inside the plastic covering and eliminate corona induced leakage currents that could obscure the stator insulation leakage current. Duct seal can be used in place of the plastic coverings to eliminate corona discharges.

## DISCHARGING THE WINDING

The highly capacitive and inductive properties of stator windings make it essential that they be discharged slowly. When the capacitively stored energy in the winding is suddenly discharged through the winding inductance, dangerously high voltage transients are generated across the insulation.

After a test, the Ramp switch should be reset and the winding voltage allowed to bleed down by itself to approximately 15 kV. The discharge stick (100-MΩ, 15-kV resistor) can then be used to bleed the winding down to 3 to 5 kV before shorting with the grounding stick. Then the HV supply can be turned off and the winding grounded with safety grounds for 1.5 to 2 hours before reenergizing with a.c. A winding that has not been thoroughly discharged could fail when energized with a.c.

## SCALING

The recorder X-axis calibration can be read directly from the X-axis Sensitivity switch. The ranges are:

| **Metric** | **English** |
|---|---|
| 0.5 kV/cm | 2.0 kV/in |
| 1.0 kV/cm | 4.0 kV/in |
| 2.0 kV/cm | |

The Y-axis recorder sensitivity is the product of the Y sensitivity switch times the Gain switch factor. The panel meter full scale deflection is equal to the Y-axis recorder sensitivity times the meter constant. The meter constant is 20 cm in the metric system and 10 inches in the English system. Table 1 lists the recorder Y axis and panel meter scales.

## INITIAL TEST SET CHECKOUT AND OPERATION

**CAUTION: This equipment operates at very high voltages that are dangerous and may be fatal. Extreme caution must be used when working with this equipment. Make certain all loads are discharged and grounded before handling.**

### Initial Setup Instructions

Set up the test equipment as described below:

1. Ground the high-voltage chassis and control section to powerplant ground.

2. Connect the discharge and grounding sticks to powerplant ground.

3. Wire the high-voltage section for negative output polarity.

4. Insert the high-voltage coax cable into the high-voltage output jack.

5. Remove the jumper on the rear of the high-voltage test set that is required for normal front panel control (jumper connecting terminals 3 and 4).

6. Adjust the high-voltage test set power limiting resistor (never adjust this circuit with the test set power on).

Table 1.—*Current ranges*

| Y Sensitivity | Recorder Sensitivity | | Current Meter Full Scale Deflection ( $\mu$A) | |
|---|---|---|---|---|
| Switch Position $\mu$A/in | Gain Factor = X1 $\mu$A/in | Gain Factor = X2 | Gain Factor = X1 Meter Factor = 10 inches | Gain Factor = X2 |
| 100 | 100 | 200 | 1000 | 2000 |
| 25 | 25 | 50 | 250 | 500 |
| 10 | 10 | 20 | 100 | 200 |
| 2.5 | 2.5 | 5 | 25 | 50 |
| 1 | 1 | 2 | 10 | 20 |
| 0.25 | 0.25 | 0.5 | 2.5 | 5 |
| $\mu$A/cm | $\mu$A/cm | | Meter Factor = 20 cm | |
| 50 | 50 | 100 | 1000 | 2000 |
| 12.5 | 12.5 | 25 | 250 | 500 |
| 5 | 5 | 10 | 100 | 200 |
| 1.25 | 1.25 | 2.5 | 25 | 50 |
| 0.5 | 0.5 | 1 | 10 | 20 |
| 0.125 | 0.125 | 0.25 | 2.5 | 5 |

7. Connect the main control cable between the two sections.

8. Interconnect the FG (floating ground) terminals on the back of both sections with the coax cable provided.

9.Interconnect the ramped voltage terminals on the back of both sections with the coax cable provided.

10. Insulate the high-voltage test lead from ground by suspending it in the air.

11. Turn off both a-c power switches before connecting the power cord.

12. Put inch by inch paper on the X-Y recorder table.

13. Establish initial dial settings.

### Initial Dial Settings

| | |
|---|---|
| Main a-c power switch | Off |
| HV supply a-c power switch | Off |
| HV supply output voltage adjust | Zero (fully ccw) |
| HV supply overvoltage limit adjust | 25 kV (fully ccw) |
| Ramp switch | Reset |
| HV limit switch | 30 kV |
| Automatic shutoff dial | 10 kV (1 turn cw) |
| Ramp rate dial | 0 kV/min (fully ccw) |
| Initial condition dial | 0 kV (fully ccw) |
| X-sensitivity switch | 2 kV/in |
| Current polarity switch | Negative |
| Gain switch | X2 |
| Y-sensitivity switch | 10 $\mu$A/in |

**CAUTION: Never leave the HV (high-voltage) supply unattended when it is energized. The operator should stand by ready to immediately shut off the HV power supply switch (not the main power switch) in the event of equipment malfunction or insulation failure.**

### Initial Checkout

Turn the main a-c power switch on. This will apply power to the control section, X-Y recorder, and high-voltage supply a-c power switch. Position the recording pen with the X and Y controls 9 seconds to the left of the selected origin. The high voltage ramps up from zero volt 9 seconds after the X-Y recorder starts. Turn the high-voltage supply switch on. The high-voltage supply is energized only when both a-c power switches are on. Set the ramp switch to the run position and slowly turn the high-voltage supply output voltage adjust dial clockwise to the 10-kV position.

As the dial is turned up, the kilovolt meter should continue to read zero. A meter reading other than approximately zero indicates a malfunction and the equipment should be repaired before proceeding. High voltages exist in the supply and in case of a malfunction, extreme caution should be used so as not to create a safety hazard, further damage the test set, or apply high voltage to the insulation. In the voltage programming mode, the high-voltage supply output voltage adjust dial limits the maximum output voltage to a value slightly above the dial setting. For proper operation, the dial should be set slightly higher than the maximum test voltage.

Make the following adjustments on the control panel:

| | |
|---|---|
| Ramp switch: | Reset |
| Initial Condition: | 2.0 kV (2 turns cw) |
| Ramp Rate dial: | 2.0 kV/min (8 turns cw) |

Flip the Ramp switch to the run position. The high-voltage output will immediately jump to 2 kV. At the end of 1 minute, the voltage will increase at 2.0 kilovolts per minute up to 10 kV and then automatically return to zero. The X-Y recorder pen will sweep across at 1 inch per minute, (1 in/2 kV × 2 kV/min = 1 in/min) until the Ramp switch is reset. The pen will lift up when the high-voltage output is reset to zero.

Reset the Ramp switch and discharge the high-voltage cable with the discharge and grounding sticks. Leave the ground stick on the high-voltage cable and shut off the high-voltage supply.

### Normal Operation

Attach a 100-MΩ, 15-kV resistor from the high-voltage output to ground and then remove the grounding stick. Turn on the high-voltage supply and set the Ramp switch to run. The kilovolt meter and X axis of the recorder will respond as previously described. The current in the high-voltage circuit will increase to 20 $\mu$A (2 kV ÷ 100 MΩ). After 1 minute, it will increase at the rate of 20 $\mu$A/min until the high-voltage supply is automatically shut off at the preset 10-kV limit. The Y-axis current scale is 20 $\mu$A/in. The panel meter full scale deflection is 200 $\mu$A. At the end of the test, reset the Ramp switch. Discharge and ground the high-voltage output. Turn off the high-voltage supply and attach the safety ground. Keep the ground stick attached until the safety grounds are secured.

After all test preparations have been made and immediately prior to the actual testing, the high-voltage lead should be isolated and the test set checked for proper operation. After the test, the winding should be discharged slowly to prevent damaging the insulation or test equipment.

## RAMPED D-C TEST SCHEDULE

A ramp rate of 1 kV/min is normally used to test stator winding insulation. This rate produces a current response similar to the stepped test and is somewhat of a compromise between maximum sensitivity and minimum test duration.

The maximum voltage limit is the same as in the stepped test. However, the increased sensitivity and continuous current monitoring features of the ramped test provides more information even when the test is terminated approximately 85 percent of the maximum voltage limit. A reduced voltage test can be used to evaluate very old, weak, or problem insulation characterized by extensive corona damage, excessive abrasion, loose blocking, etc. Under no circumstances should a reduced voltage test be used for acceptance testing. Regardless of the insulation quality, a reduced voltage limit is not recommended when the d-c test is also to serve as a proof test. In any event, to avoid an insulation failure, testing should be terminated whenever leakage current starts to become excessive.

Following are some guidelines to help determine when insulation testing should be terminated because of high leakage current:

- D-c step testing should be halted whenever the insulation resistance drops below 33 percent of the initial resistance value.

- The ramp test should be terminated when a 1 to 2 $\mu$A or larger, sharp increase in insulation current is observed. If the increase is only a fraction of a microampere, testing can continue. However, if the current is unstable or there are more stepped type of increases directly following the first sharp increase, testing should be halted.

- An insulation having a gradually increasing leakage current response can tolerate much higher leakage current than an insulation having abrupt current increases in the *V-I* response curve. A test on an insulation having a slowly increasing leakage current response should be stopped when the total insulation current becomes three to six times larger than the capacitive charging component of current.

## RAMPED VOLTAGE TEST RESULTS

Figures 6 through 9 are typical stator insulation ramped voltage test results. Actual record size is 25 x 38 cm (10 x 15 in).

The curve shown in figure 6 is the response of new epoxy mica insulation when d-c ramp tested. Above 5 kV, the curve is very linear indicating excellent insulation quality.

The curve in figure 7 is typical of new asphalt mica insulation. This curve is also linear above 4 to 5 kV indicating high quality insulation.

Figure 8 shows a very sharp increase in leakage current suggesting the insulation of one coil or portion of a coil is very questionable. The test was terminated early to avoid the possibility of damaging the insulation.

The nonlinear response shown in figure 9 is due to many minute discontinuities similar to the one shown in figure 8. The curve shows a very gradual increase in leakage current and infers that a general deterioration of the insulation has taken place. As the test voltage increases, the slope of the leakage current will continue to increase in a nonlinear manner. Breakdown will occur as the current asymptotically approaches the vertical. Testing should be halted well before this point is reached.

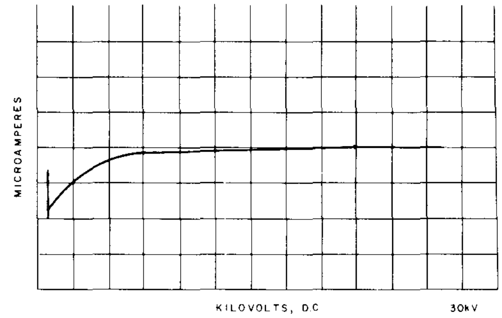



Figure 6.—New epoxy mica insulation.

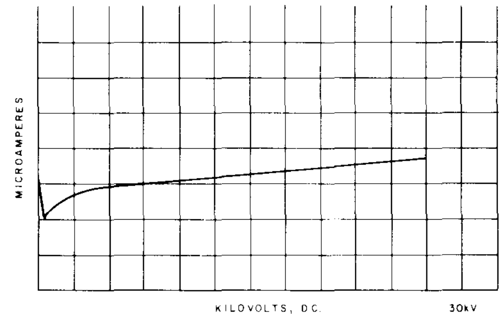



Figure 7.—New asphalt mica insulation.

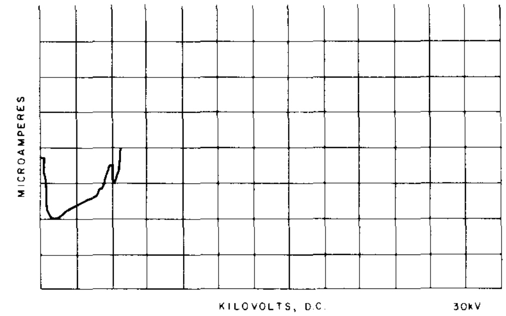



Figure 8.—Asphalt mica insulation with a localized weak spot.

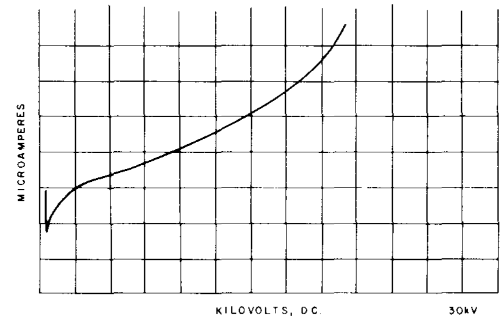



Figure 9.—Very old asphalt mica insulation.

## CIRCUIT DESCRIPTIONS

### Ramped Voltage Control Circuit

Please refer to figure 10. The FET (field effect transistor), *Q1* is connected as a 2.2 mA constant current source. This current produces plus 0.73 volt across the 332-ohm resistor.

The 35.7-k$\Omega$ resistor reduces this voltage to 10 millivolts across trimpot $T_1$. The trimmer is adjusted for proper calibration of the Ramp Rate dial. The output voltage from the trimmer (approx. +4.2 mV) is integrated by a chopper stabilized amplifier connected as a unity gain inverting integrator. The output voltage from the integrator linearly decreases with a constant rate of change of voltage of minus 4.2 millivolts per second (- 0.25 V/min). The *M* relay contacts in the feedback circuit are used to automatically reset the integrator to zero by discharging the 10-$\mu$F integrating capacitor through the 0.5-k$\Omega$ resistor. A 10-turn potentiometer (Ramp Rate dial) is used to adjust the ramped voltage rate from zero to minus 0.25 V/min.

Amplifier 1 is connected in a unity gain, inverting configuration. This amplifier isolates the Ramp Rate potentiometer to maintain dial linearity and inverts the signal to provide a positive ramped voltage signal. This ramped signal is applied to a switchable resistor divider network (Y-Sensitivity switch) to provide different ranges for the X input of the X-Y recorder. The output of the resistor network is buffered with a high input impedance, unity gain, noninverting amplifier (follower No. 1). The output signal is overvoltage limited to plus or minus 2.4 volts by the two diode strings and filtered by an *R-C* network before being applied to the X input of the recorder.

Comparator No. 2 compares a reference voltage from the 10-turn Initial Condition potentiometer to the ramped voltage signal. If the initial condition signal is larger than the ramped signal, the output of the comparator will go to plus 13 volts. The positive output voltage from the comparator turns on FET switch *Q5* and transistor *Q6*. When *Q6* turns on, its collector becomes negative and turns off FET switch *Q4*. The initial condition signal is applied to the input of follower amplifier No. 2 through the "on" FET switch, *Q5*. The ramping signal is blocked by the "off" FET switch, *Q4*. The output of the noninverting unity gain follower is applied to the high-voltage test set control input via the *L* relay contacts and the Ramp Run/Reset switch contacts. Both sets of contacts are closed only when testing. The four series diodes or the parallel zener diode limit the control voltage signal to a maximum of 3.2 or 6.4 volts depending on the position of the Limit switch.

When the ramped voltage becomes larger than the initial condition voltage, the comparator output switches to minus 13 volts. This voltage turns off FET switch *Q5* and transistor *Q6*. As *Q6* turns off, the positive collector voltage turns on FET switch *Q4*. Now, the ramped voltage signal is applied to follower amplifier 2 via the "on" FET switch *Q4*. The initial condition signal is blocked by the "off" FET switch *Q5*.

Comparator 1 compares the ramped voltage signal from amplifier No. 1 to a d-c reference voltage from the Automatic Shutoff potentiometer. When the ramped signal becomes larger than the reference voltage, the comparator output switches from minus 13 volts to plus 13 volts. The positive voltage signal turns on transitor *Q2* which then supplies emitter base current to transitor *Q3*. Transistor *Q3* turns on and energizes the *L* relay. The *L* relay contacts open removing the ramped voltage signal from the high voltage test set control input. A second set of *L* relay contacts open causing the recorder pen to lift up. Transistor *Q3* also applies a positive feedback voltage signal to the base of *Q2* causing the circuit to latch.

If the Ramp Run/Reset switch is inadvertently in the run position during power up, the initial charging current through the 4.7-$\mu$F capacitor will initiate circuit latch up preventing accidental energization of the high-voltage output.

### Current Monitoring Curcuit

Please refer to figure 11. The insulation current path is from ground into the current metering circuit. The 15-$\mu$F capacitor and the stator winding capacitance to ground form an a-c voltage divider circuit. The divider reduces the a-c ripple current in the metering circuit by greatly decreasing the ripple voltage across the 4.0-k$\Omega$ input resistor. Two back-to-back diodes are used to protect the input amplifier from incoming voltage transients. Since the input signal is generated by a current source, the amplifier operates as a current-to-voltage converter. The current-to-voltage conversion factor, or gain, is determined by the value of the amplifier feedback

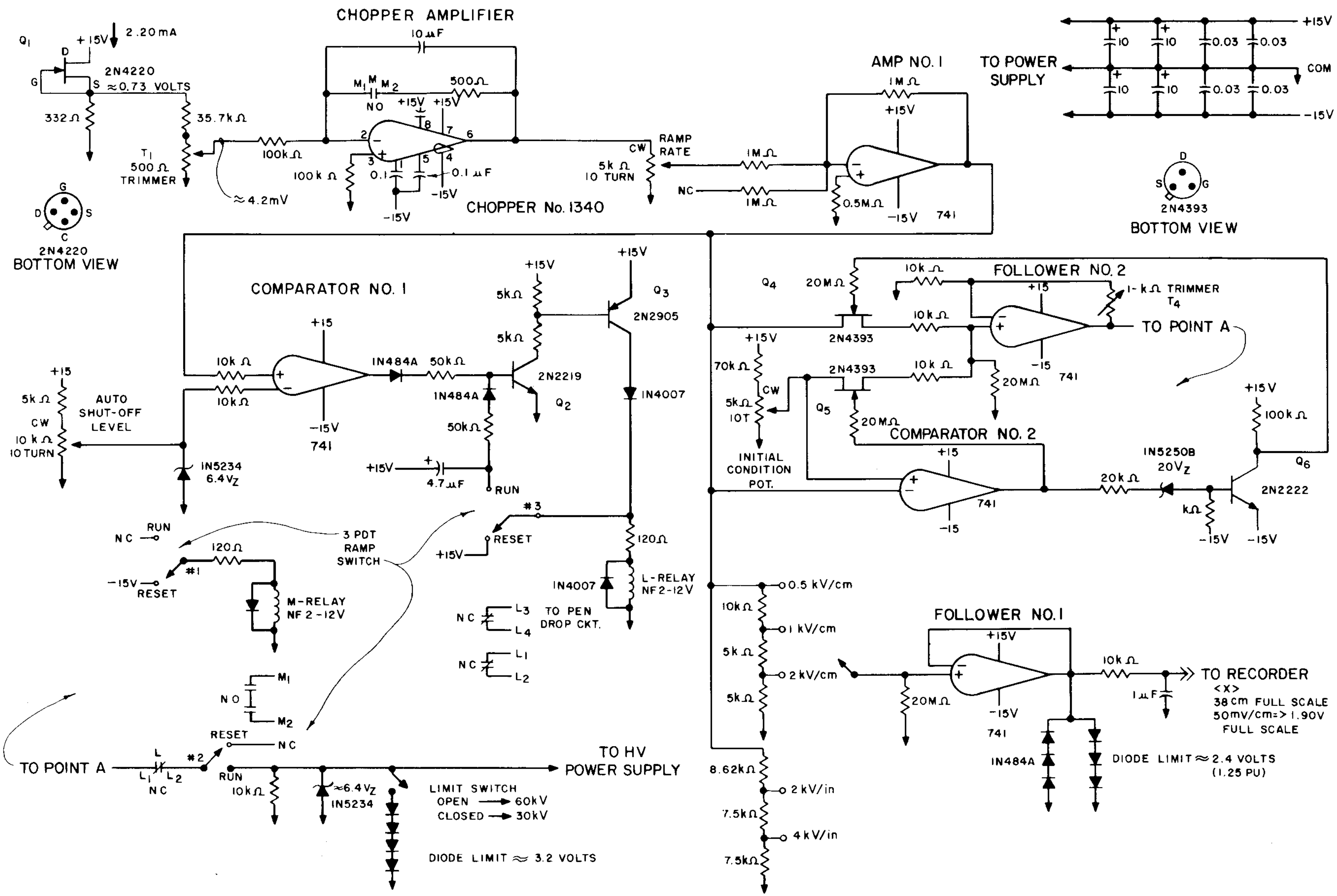
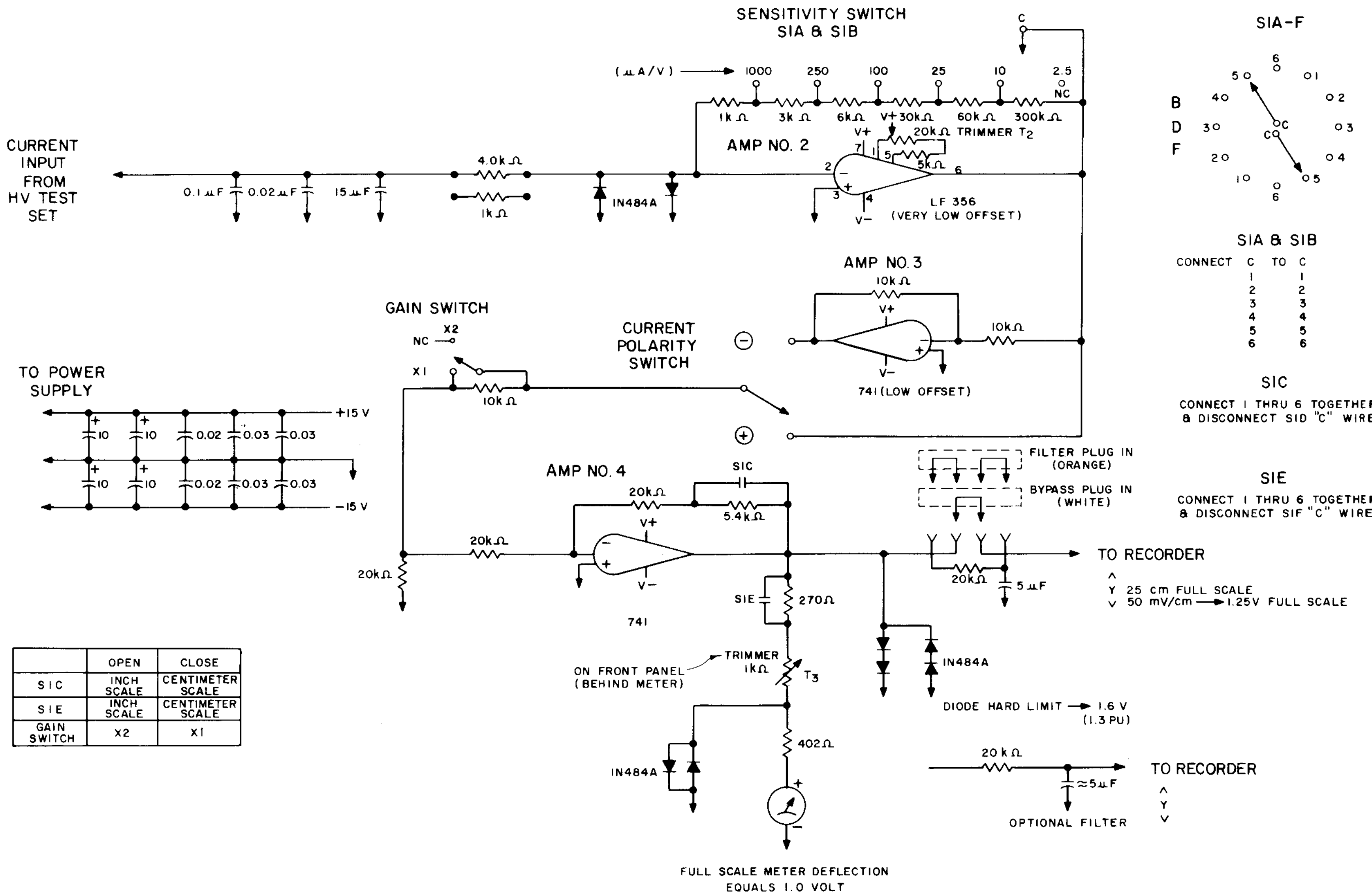



Figure 10.—Ramp generator circuit.




| | OPEN | CLOSE |
|---|---|---|
| SIC | INCH SCALE | CENTIMETER SCALE |
| SIE | INCH SCALE | CENTIMETER SCALE |
| GAIN SWITCH | X2 | X1 |

Figure 11.—Current metering circuit.

resistance. To obtain different conversion factors, the feedback resistance is changed by means of the Y-Sensitivity switch.

Amplifier No. 3 is a unity gain inverting amplifier. A switch selects the main signal from amplifier No. 2 or the inverted signal from amplifier No. 3 so the meter and recorder deflections are always positive regardless of input current polarity.

The signal from the Current Polarity switch is attenuated by 2 when the Gain switch is open. The 10-kΩ resistor and both 20-kΩ resistors (consider the two 20-kΩ resistors in parallel) form a voltage divider network. When the Gain switch is closed, the 10-kΩ resistor is shorted. This is the unity gain switch position and applies full voltage to the 20-kΩ resistors.

Amplifier No. 4 is an inverter with a gain of 1.00 when S1C is closed and 1.27 when opened. The amplifier prevents loading of the previous stage and via S1C allows the X-Y recorder displacement to be expressed in metric or English units (μA/cm or μA/in).

The S1E switch adjusts the microammeter circuit resistance so 1 volt referred to the input of amplifier No. 4 always results in full scale deflection regardless of the gain of the amplifier. the series 402 Ω resistor and parallel back-to-back diodes across the meter provide meter overcurrent protection. The trimmer is adjusted for proper full scale meter deflection with 1 volt applied to the input of amplifier No. 3. The four diodes limit the circuit output voltage to plus or minus 1.6 volts. The plug-in filter eliminates ripple and noise from the current signal before it is applied to the Y input of the recorder.

## ALINEMENT

### Ramp Generator Alinement

The ramp circuit is calibrated without the high-voltage test set. Connect a DVM (digital voltmeter) from circuit common to the output of amplifier No. 1. Set trimmer $T_1$ approximately 8 turns clockwise. Set the ramp rate dial to 2.5 kV/min. This corresonds to 0.25 volt/min at the ramped voltage terminal. Turn the ramp switch to the run position. At the end of 2 minutes, the DVM should read 0.500 volt. Reset the ramp switch; increase or decrease the trimmer setting as necessary for a corresponding change in the ramp rate and repeat this procedure until the DVM reads 0.500 volt at the end of 2 minutes. As a final alinement or check, repeat the procedure, adjusting the trimmer to obtain 2.500 volts at the end of 20 minutes. For best results, final adjustment(s) should be made at the ramp rate dial setting and test schedule time interval most often used. The ramped voltage output is proportional to the integral of the trimmer output voltage. Any attempt to accurately adjust the trimmer during a timing interval is almost impossible.

The ramp generator circuit may also be calibrated using the X-Y recorder instead of a DVM. Set the ramp rate dial to 2.5 kV/min and the X sensitivity dial to 1 kV/cm. Turn the ramp switch to the run position. At the end of 2 minutes, the recorder pen should have moved 5.0 cm in the X-axis direction. Reset the Ramp switch, increase or decrease the trimmer setting as necessary for a corresponding change in the ramp rate, and repeat this procedure until the recorder pen is displaced 5.00 cm at the end of 2 minutes. As a final check, repeat the procedure, adjusting the trimmer to obtain a 25-cm displacement at the end of 10 minutes. For best results, final adjustment(s) should be made at the dial settings and test schedule time interval most often used. Any attempt to adjust the trimmer during a timing interval is almost impossible since recorder pen X-axis displacement is proportional to the integral of the trimmer output voltage.

The test set output must be calibrated so that the high-voltage rate of rise corresponds to the ramp rate dial setting. Set the ramp dial to 2.5 kV/min. Turn the ramp switch to run. After 9 seconds, the high-voltage output will start ramping up. For any given time, t, from the start of the test, the high-voltage output should equal the ramp rate dial setting times (t - 9 seconds). Adjust trimmer $T_4$ until this relationship is met. Adjustments may be made any time during the ramping interval. For best accuracy, the final adjustment should be made between 25 and 30 kV. The output voltage can be determined to within 3 to 4 percent using the front panel high-voltage meter. For better accuracy, a DVM and high-voltage probe should be used.

Since the recorder and ramp generator have already been calibrated with respect to time, the high-voltage ramp rate can also be calibrated with respect to recorder X-axis pen displacement. Set the recorder X-axis sensitivity to 1 kV/cm, turn the ramp switch to run, and adjust $T_4$ until the output voltage (in kilovolts) equals the recorder pen X-axis displacement (in centimeters) minus 0.15 cm. The 0.15-cm adjustment is used to compensate for the 9-second delay at the start of the test. The final adjustment should be made between 25 and 30 kV.

### Current Monitor Circuit Alinement

The current circuit is calibrated without the high-voltage test set. Disconnect any leads that may be connected to the input of the current monitor circuit. Set the Y-Sensitivity switch to 0.25 $\mu$A/in and the gain switch to times 1. Connect a DVM (use the 1-volt d-c scale) from circuit common to the output of amplifier No. 4. Adjust the voltage offset trimpot, $T_2$, such that the DVM reads zero plus or minus several millivolts.

Set the front panel controls as follows:

| | |
|---|---|
| Y-Sensitivity Switch | 10 $\mu$A/in |
| Gain Switch | X1 |
| Polarity Switch | Negative |
| Automatic Shutoff Dial | Fully clockwise |

Jumper the ramped voltage output to the current monitoring input. Connect the DVM (1-volt d-c scale) from circuit common to the output of amplifier No. 3. Set the ramp switch to run and adjust the Initial Condition dial for 0.900 volt on the DVM. Adjust the trimmer on the back of the front panel to obtain 90 percent of full scale deflection on the microampere meter.

## REPLACEMENT PARTS

### High-Voltage Supply

Some of the components in the Spellman High Voltage Electronics Corporation's high-voltage supply were specially selected. To order replacement parts or for information regarding alinement please refer to the manufacturer's instruction manual.

### Ramp Generator and Current Monitor Circuit

Many of the components have been specially selected in order to reduce circuit complexity and alinement procedures. Operational amplifiers were screened for low offset voltages (1 to 2 millivolts). Resistors used in critical scaling and gain circuits were required to be within 0.2 percent of their stated values.

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## ABSTRACT

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