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Preliminary Report on A Schering Bridge Method of Corona Detection In Cables

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Navy Department

Preliminary Report on

A Schering Bridge Method of Corona Detection in Cables

Naval Research Laboratory

Anacostia Station

Washington, D. C.

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1. ABSTRACT.

The following is a preliminary report on the Naval Research Laboratory method for the detection of corona in solid dielectric cables. It does not incorporate any information on the simplified method, still in the research stage, of testing cable. In short, it describes the method heretofore used at the Naval Research Laboratory for the measurement of type approval samples, but does not represent the laboratory's final word on the optimum equipment for corona detection.

2. INTRODUCTION.

The primary purpose of this equipment is the detection of corona in solid dielectric cable at power line frequency. It is desirable that the corona test be made in such a way that the cable manufacturers can readily perform the test under the supervision of Naval Inspectors. It is necessary, therefore, that the manner of preparing the specimen be such that no great skill or time is required for the operation, while at the same time none of the accuracy of the system in revealing the true corona point is sacrificed. Moreover, the gear should not be of a complicated design and should preferably be equipped with only those controls necessary for adjusting test voltage, together, of course, with means for observing the corona onset and an accurate measurement of the peak voltage at the onset point.

It is also desirable that interference from an outside source should not paralyze normal operation. Thus, it is of considerable advantage to use an oscilloscope as the means for indicating corona onset; any source of steady interference synchronized with the power frequency will then appear as a steady line or pulse on the trace, even with the high voltage removed from the cable. Since most interference encountered in these measurements is of a periodic nature, there should be no confusion of this with the irregular pulses due to corona.

3. METHOD.

1. Apparatus. The apparatus used in the corona test equipment consists in its essence of a device for measuring the current through the cable dielectric in excess of the displacement current arising from the a-c potential difference between inner and outer conductors. The means of obtaining this excess consists of connecting, in parallel with the series combination of the cable (CS Plate 3), and a measuring resistance (R_{22} Plate 3), another condenser-resistor combination (BC and R_{23} Plate 3). This second resistance is made equal to the resistance in series with the cable, while the auxiliary condenser is variable. This variable condenser is preferably so constructed that its corona point is higher than that of any cable to be tested by the set. If the capacitance of the variable condenser is set equal to that of the cable, it follows that the potential difference between the high ends of the two resistors is zero, provided that both cable and condenser have the same conductance loss. This condition obtains, in theory, whenever there is no corona in the cable; if, however, corona occurs, the current in the cable arm of the bridge formed by the two circuits increases, and the potential of

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the high end of the resistor in series with the variable condenser. It is not possible in practice to insure that the variable condenser has the same conductance loss as the cable; thus, when both capacitances and both resistances are made equal, a balance cannot in general be obtained. Usually, however, a satisfactory balance is available by adjustment of the series resistors in the bridge arms.

The effect of the ends of the cable remains to be considered. Normally, in ordinary preparation of a sample, there exist at the ends of the cable sharp ends of wire, inevitably produced by the preparing operation. In order that corona from these ends may not give erroneous readings on the testing equipment, guard rings are inserted under each end of the cable. These rings are thin sleeves of brass, one end of each of which is soldered into a brass disk of about 1½ inches diameter (See Plate 6). The rings are inserted between the braid and the dielectric, with a nominally good low voltage insulation between the braid and the ring. The sleeves themselves need be no more than about a half inch in length. The two guard rings are tied together and to the high side of the resistor in the <u>condenser</u> (not cable) arm of the bridge. Corona from the guard rings is then of opposite direction from corona in the cable and can easily be distinguished from it.

The output from the bridge circuit is fed into a balanced amplifier and thence into the input of a conventional oscilloscope. It is important that in the balanced amplifier a well regulated source of direct current be available so that the trace on the screen may be steady (See Plate 4). The oscilloscope should have ample gain available in its own amplifier; the DuMont type 208 is suitable and is in use at this laboratory.

2. <u>Preparation of the Specimen</u>. It is desirable that the sample of cable under test should not be of too great length, otherwise the amplitude of the cable corona spikes will suffer relatively to those produced by the guard rings. A satisfactory length is five feet. It is, of course, necessary that the transformer be of satisfactory design so that its current-carrying capacity is sufficient for both cable and balancing condenser.

The cable itself, when cut to length as determined above, is prepared by first cutting back the armor (if any) and outer jacket a distance of some eight inches from the ends of the cable. The innermost braid is then rolled back over the outer jacket and any excess length over about two inches is cut away. The ends of the braid are then held down by a layer or two of friction tape; enough of the braid must be left exposed so that connection can be made to it, but there are no other requirements. To separate the braid underneath the outer jacket from the cable dielectric it is generally found helpful to employ a tool, consisting of a fairly thick sleeve (wall thickness about 1/16 inch) whose inner diameter is rather closely equal to the dielectric outer diameter of the cable, and so made that the outer diameter of the tool gradually diminishes to its inner diameter in a taper of about one-half inch. This should be eased, not forced, under the braid for a distance of about an inch. In

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some pulse cables, where the adhesion between braid and dielectric is exceedingly tight, a thick tool of this type cannot be used. Under these conditions guard rings with a smaller wall thickness must be employed.

The guard rings have already been described, as has their method of insertion under the cable ends.

The testing procedure consists in first applying a small amount of voltage to the cable in order to obtain an approximate balance. Then the voltage should be steadily increased until fairly strong cable corona appears on the scope trace. In general, guard ring corona will appear before cable corona does; the two coronas are, of course, in opposite direction on the trace. In order to be sure of which corona belongs to the guard rings and which to the cable, it is desirable on the first sample to tie the guard rings to the outer braid of the cable. The direction in which corona then shows on the trace will be that in which cable corona will appear when the guard rings are returned to the balancing condenser, the observer will note deflection in two directions on the trace. Deflection in the opposite direction to that noted when the guard rings were returned to the braid is due entirely to the guard rings and should be neglected.

After the voltage has been raised to a point at which the cable corona appears as a rather appreciable deflection on the trace, it should then be slowly lowered until the cable corona just persists. That point is rather well defined with respect to any given cable; if the voltage is reduced beyond this value, the corona will no longer be able to sustain itself and will drop out after a short time of observation. It is reasonable then to say that if the appearance of corona on the scope trace does not vanish after thirty seconds of observation, but that at any lower voltage the appearance does vanish after observation of this duration, then this particular voltage represents the corona point of the cable. Actually this criterion is far too rigorous, since for practically all cables the range between no corona in less than five seconds of observation and continuous corona is of the order of only about two hundred volts. This does not hold in all cases, however, and the operator of the equipment can easily tell when it will be necessary to observe the cable for the longer period; thus, when there is any question, the longer interval (thirty seconds) should be used.

3. Calibration. The measurement of all voltages involved in corona onset tests made at this laboratory is in terms of peak voltage applied to the cable. Since it is the peak voltage that gives rise to the corona, it is the opinion of those at this laboratory who have been conducting the cable tests that the use of r.m.s. voltage, by itself, is susceptible of error, while if the further stipulation is made that the applied voltage should be sinusoidal within two percent, the use of r.m.s. voltage is at best artificial. Surely it is an unnecessary requirement and one, moreover, not always easily met to specify that a given voltage shall be sinusoidal within two percent, when a measurement of the peak voltage is so easily made and is the quantity in which the engineer is primarily interested.

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The procedure followed at this laboratory is to use a meter which measures r.m.s. volts. By adjusting the scale on such a meter, (which may be put in the primary of the high-voltage transformer) so that it reads 2 times the actual r.m.s. applied voltage, an approximation to the true peak can be obtained, and this approximation is sufficiently exact for some purposes. In order, however, to be certain of the peak voltage, the observer should obtain or construct a small peak-reading slide-back voltmeter. A circuit of the calibration meter used by this laboratory is appended (Plate 5). The only part of the circuit which is at all critical is the voltmeter, V, which must, of course, have whatever accuracy is expected of the calibration. It is also necessary to know accurately the ratio of the resistors, R_1 and R_2. Actually the ratio is $(R_1 + R_2)/R_2$, but R_2 is so small compared with R_1, that R_1/R_2 is accurate within the range of the meter. R_1 should be made rather large in order that whatever additional load is produced by the voltmeter may be kept as small as possible. The set should be calibrated with a load consisting of a typical length of cable and the balancing condenser so that any distorting effect the load may have on the waveform is taken into account in the calibration. R_1 on the set at this laboratory is 125 megohms.

A question which occasionally arises relates to the sensitivity of the detecting device. This laboratory has used as great amplification as possible consistent with stability of operation, but the only reason for this extreme sensitivity is to aid the observer in seeing the first pulse of corona. That is, when the gain is increased above a certain amount, no advantage can be gained from the increase; if no corona is present, no possible increase in gain can indicate the existence of any. It is therefore sufficient to say that any oscilloscope which is the equivalent in sensitivity of the DuMont type 208 already mentioned is satisfactory for the measurement; this oscilloscope has actually more than adequate sensitivity, but the excess makes the first pulse of corona have quite sizable amplitude.

4. CONCLUSIONS.

With the method described it has been found possible to obtain with considerable accuracy the corona points of polyethylene cables; pulse cables have been tested, with corona voltages above 30 kv. p., by the same method except that the ends of the cable were immersed in oil instead of being prepared by the guard ring method. The oil immersion technique requires more time than the guard rings. but the latter technique is difficult to employ with conducting rubber cables. Comparisons between guard ring and corona suppression techniques, e.g., oil immersion, aquadag preparation, etc., indicate that when the suppression method is perfectly used, the corona points agree within calibration accuracy. A poorly prepared sample with the suppression technique employed shows a lower corona point than when prepared with guard rings.

The final report, for which this is the preliminary, will show a circuit which will be relatively simply constructed and which can be built by an outside manufacturer, for use in factories in which cables are being made. The equipment described in this paper is of high inherent accuracy and has great resolving power; it is proposed, however, to simplify further the bridge balance method so that a relatively

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inexperienced person can make a complete cable test, including preparation of sample and obtaining corona point, in about ten minutes.

Since it has been tentatively decided that the 60-cycle corona point is a criterion for the performance of cable at higher frequencies, specifications have been set up for 60-cycle corona point. As more data is obtained with regard to corona point at higher frequency, it is hoped that it will be found possible to correlate data so that the 60-cycle point will still furnish all the information required for knowing accurately the voltage capacity of any cable. Thus, the use of a rapid and accurate method for 60-cycle corona testing is a requisite, and it is believed that the equipment described in this and the supplementary report fills the requirement.

5. APPENDIX.

1. Calibration of Metering Circuits. The purpose of this calibration is to establish the shunts used in the current metering circuit so that when the unit is used in a field application, these resistors can be used as standards for periodic calibration checks.

In order to obtain proper values for the shunts in the metering circuits it is first necessary to calibrate the circuits with a precision standard. Reference to Plate 2 shows the current and voltage metering circuits. In order to calibrate the former the apparatus should be turned on and allowed to warm up thoroughly; the high voltage primary should not be energized. The input to the current metering circuit should be connected to a source of low voltage alternating current (60 c.p.s.). Switch SW-6 should be set to position 0, and RL-1 shorted out by setting R-3 to zero resistance. To provide a current standard some form of precision meter for reading low values of alternating current should be connected in series with the input to the apparatus. This standard should be capable of reading accurately alternating currents of the order of 100 microamperes r.m.s. The contact of R-1 should be disconnected so that the internal calibrating system is not in the circuit. Points 0 and c2 of SW-6-1 should be tied together. Set R-12 so that M-1 has zero reading and set SW-7 to the 1 milliampere position. Now adjust the calibrating current source so that the precision meter in the input circuit reads 1 ma r.m.s. Then adjust R-7 so that M-1 reads one milliampere on the 0-1 ma scale. Next set SW-7 to the 0.5-ma position, and adjust the calibrating current source to 0.5 ma as measured on the standard current meter. Then adjust R-6 so that M-1 reads 0.5 ma on the 0.5 ma scale. Then set SW-7 to the 0.1 ma position and the calibrating current to 0.1 ma. Adjust R-5 so that M-1 reads 0.1 ma on the 0.1 ma scale. Return SW-7 to the 1 ma position and reset the calibrating current to 1 ma. Set SW-6 to position c1 and adjust R-8 so that M-1 reads 1 ma on the 1 ma scale. The current shunts are now set and should not be changed; it is preferable that these shunts be wire wound resistors of the variable or semi-variable type, so that after they are set by the described procedure they may be fixed in position by cementing them or otherwise fastening them so that they cannot be changed in value.

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In order to calibrate the voltage measuring circuits a precision peak vacuum tube voltmeter is required. Such a meter is shown on Plate 5. Voltmeter V is a precision instrument, reading 0-10 volts d.c. A more sensitive meter may be desired for calibration of the low voltage ranges. With potentiometer P contact returned to point A, so that no voltage is read on V, a certain current is read on meter M with no high voltage applied. If now the high voltage is connected, the reading of the meter M is changed. Potentiometer P is then adjusted so that M again reads its initial value. The voltage read on V is then the peak voltage across R-2, and the peak high voltage is, within limits of accuracy, the reading of V multiplied by R-1/R-2. It is assumed that circuit input capacitive reactance is very large compared with R-2. This is true for measurements up to the voltages involved in this equipment if R-1 is not made too large. R-1 in this gear is an IRC type MVO resistor with a nominal resistance of 135 megohms. This value is not sufficiently accurate to be used as a standard, although the resistor holds its calibration quite accurately. In order to be certain of the initial resistance of the unit, it should be checked against a high resistance standard, such as the Weston 15 megohm precision multiplier, or a similarly accurate standard. R-2 should be measured on a Wheatstone bridge.

In order to calibrate the voltmeter of the corona detecting equipment, a load of a normal cable sample and the balancing condenser should be connected across the transformer (i.e., across half of the transformer, from one high-voltage connection to ground). The primary voltage should be increased until the slide-back voltmeter reads 10 kv peak from secondary to ground withSW-8 (Plate 2) set to the 20 kv position and R-16 set so that M-2 reads full scale. Now with the primary voltage off set R-17 so that M-2 reads zero. Reset the primary voltage to give 10 kv on the standard voltmeter and readjust R-16 for full-scale reading on M-2. Next set SW-8 to the 50 kv position, bring the secondary voltage to 25 kv on the slide-back meter, and adjust R-15 to give full scale reading on M-2. Repeat the procedure for R-14 and R-13 for 100 and 150 kv respectively. The meter now reads the voltage across the entire transformer so that cables can be tested for breakdown, in which case the voltage across half the transformer is not sufficient. When the voltage for the corona measuring set is required, it is obtained by simply dividing the indicated voltage by two.

For setting the overload relay, as well as for checking the calibration of the equipment against the standard resistors in the current metering circuit, an internal calibrating circuit is incorporated in the measuring circuit. Such a recalibration is occasionally necessary to take account of changes in tube characteristics, etc. The following procedure is then employed. With no high voltage applied to the primary of the transformer, set calibrating switch SW-6 in the 0 position; also set R-12 so that M-1 gives zero reading. SW-6 is then set to position c1 and R-1 adjusted so that M-1 has 1 ma reading. SW-6 is then set to position c2 and R-9 set so that M-1 again has zero reading. Now R-3, the overload relay adjustment, should be set so that the overload relay, RL-1, opens when M-1 has 1 ma reading. The current may be varied by setting R-1, and the operation of the relay checked from the operation of the red pilot light. The setting of R-3 is somewhat critical and should

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be checked several times to insure its proper functioning. After the final adjustment of R-3 SW-6 should again be set to position c1 and R-1 adjusted to give 1 ma reading on M-1. SW-6 should then be set to C2 and R-9 readjusted, if necessary, to give 1 ma reading on M-1. SW-6 may now be returned to the operate position.

2. Adjustment of the Bridge Balance Circuit (Plate 3). Since the bias voltage produced by the combined plate currents of V-8 and V-9 through R-24 is sufficient to cut off V-8, it is necessary to provide a positive bias on the grid of the latter. With the circuit in operation R-26 is adjusted until V-8 has the proper bias for class A operation (approximately -5 volts). This value of bias is not critical.

The purpose of R-24 is to provide a certain amount of voltage loss in the grid circuit of V-8 to make up for the loss in the cathode follower V-9. In order to adjust R-24 the points on Plate 3 marked "to cable specimen" and "to balance condenser" should be tied together and to a source of two or three volts a.c., applied between them and ground. R-24 should then be adjusted to give minimum voltage at the oscilloscope terminals.

For measurement of corona initiation point the cable specimen and balancing condenser are connected to their respective circuits and the balancing condenser adjusted (high voltage being applied) until the output of the balanced amplifier is a minimum. It is frequently a matter of some inconvenience to adjust the balancing condenser since it is in the cage housing the transformer and other high voltage equipment. Under these conditions the balancing condenser may be pre-adjusted to have a capacity equal to that of the average sample of cable, and an approximate bridge balance obtained by shunting a variable resistor across either R_{22} or R_{23}, as the case requires. It is desirable to cut all samples of cable tested in order that they may present approximately the same capacitance to the system.

3. Guard Rings. Plate 6 shows a guard ring such as is used in testing samples of RG 17/U cable. One of these guard rings is required at each end of the sample under test. Since the purpose of the guard ring is to prevent end corona currents from flowing in the braid, it is necessary that the guard rings adequately cover the ends of the braid. As shown in the sketch, the guard rings are made so that they extend under the sheath, between braid and dielectric, as well as extending over the outside of the braid for a short distance. The only critical dimension is therefore the inner diameter of the inside tube. This dimension should be such that the guard ring just slides over the dielectric; the diameter is thus determined by the D.O.D. of the cable under test.

The guard rings and braid must be insulated from each other by some low voltage insulating material since they are in different circuits as regards the measuring part of the equipment.

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Parts List

Control Circuit

Part No.	Description
*R_1	50 ohms, 200 watt
*R_2	"
*R_3	"
*R_4	"
*R_5	175 ohms, 500 watt
R_6	30 K, 10 watt
R_7	"
R_8	IRC, Type MVO, 2259, 135 mdg.
R_9	"
SW_1	DPST Power Switch
SW_2	SPST micro-switch, normal closed
SW_3	"
SW_4	SPST micro-switch, normal open
SW_5	SPST, part of voltage control switch SW_8
SW_8	Section of voltage control switch SW_8
RL_1	2500 ohm overload relay, SPST, normal closed
RL_2	A.C. relay, SPST, normal open
P_1	110 v. pilot light, green
P_2	110 v. pilot light, red
F_1	5 amp. fuse
T_1	High voltage transformer, 50 kv peak to ground
T_2	1-1 isolating transformer

*R_1 to R_5 inclusive are designed for use with a transformer drawing not over 1 amp. primary current.

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Parts List (Cont'd)

Metering Circuits

Part No.	Description
R_1	25 ohm, 10 watt potentiometer
R_2	100 K, 1/2 watt
R_3	5 K, 3 watt potentiometer
R_4	5 K, 10 watt
**R_5	52 K, 1/2 watt (100 ua shunt)
**R_6	10.4 K, 1/2 watt (500 ua shunt)
**R_7	5.2 K, 1/2 watt (1 ma shunt)
**R_8	3.9 K, 1 watt
R_9	100 K, 1 watt potentiometer
R_{10}	150 ohm, 10 watt
R_{11}	50 K, 3 watt potentiometer
R_{12}	10 K, 25 watt tapped resistor
**R_{13}	470 ohm, 1/2 watt (75 kv shunt)
**R_{14}	680 ohm, 1/2 watt (50 kv shunt)
**R_{15}	1800 ohm, 1/2 watt(25 kv shunt)
**R_{16}	10 K, 1/2 watt (10 kv shunt)
R_{17}	3 K, 3 watt potentiometer
C_1	0.001 ufd mica
C_2	50 ufd, 50 volt electrolytic
C_3	4 ufd, 450 volt paper
SW_6	5 pole, 3 position gang switch
SW_7	1 pole, 3 position switch (current range)
SW_8	Section of 3 pole 4 position switch (voltage range)
RL_1	Overload relay
M_1	D.C. milliameter similar to Weston 643 with 1.5 ma movement. Scale worked to give 0-1.5 ma full scale, 0-0.75 ma full scale, and 0-0.15 ma full scale.
M_2	0-40 ua D.C. meter - Triplett Type 726 Scale marked for full scale, 20 kv. p; 55 kv. p; 100 kv. p; 150 kv. p.
V_1	6X5GT/G Tube
V_2	6AG7 Tube
V_3	6H6 Tube

**See - "Calibration of Metering Circuits"

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Parts List (cont'd)

Power Supply Circuit

Part No.	Description
R_{18}	560 K, 1/2 watt
R_{19}	150 K, 1/2 watt
R_{20}	560 K, 1/2 watt
R_{21}	220 K, 1/2 watt
C_4	16 ufd, 450 volt electrolytic
C_5	10 ufd, "
C_6	10 ufd, "
C_7	4 ufd, "
C_8	1 ufd, 400 volt paper
L_1	10 henry, 75 ma choke
L_2	10 henry, 40 ma choke
L_3	10 henry, 40 ma choke
T_3	Plate and filament transformer 385 v. to C.T. @ 180 ma. 5 v. @ 4 amp., 63 v. C.T. @ 5 amp, 6.3 v. @ 2 amp.
V_4	5U4G Tube
V_5	6V6 GT/G Tube
V_6	6SJ7 Tube
V_7	1/4 watt neon bulb, bayonet base

Parts List (Cont'd)

Bridge Balance Circuit

Part No.	Description
R22	5.6 K, 1/2 watt
R23	5.6 K, 1/2 watt
R24	200 K, 1 watt potentiometer
R25	220 K, 1/2 watt
R26	10 K, 10 watt
R27	50 K, 1 watt
R28	50 K, 1 watt
R29	3.3 K, 1 watt
C7	0.1 ufd, 400 volt paper
C8	0.1 ufd, 400 volt paper
C9	0.02 ufd, 600 volt paper
V8	6J5 Tube
V9	6L6 Tube
CS	Cable Specimen
***BC	Balancing Condenser
***GR	Guard Rings.

*** See Sketch on Balancing Condenser and Guard Rings.

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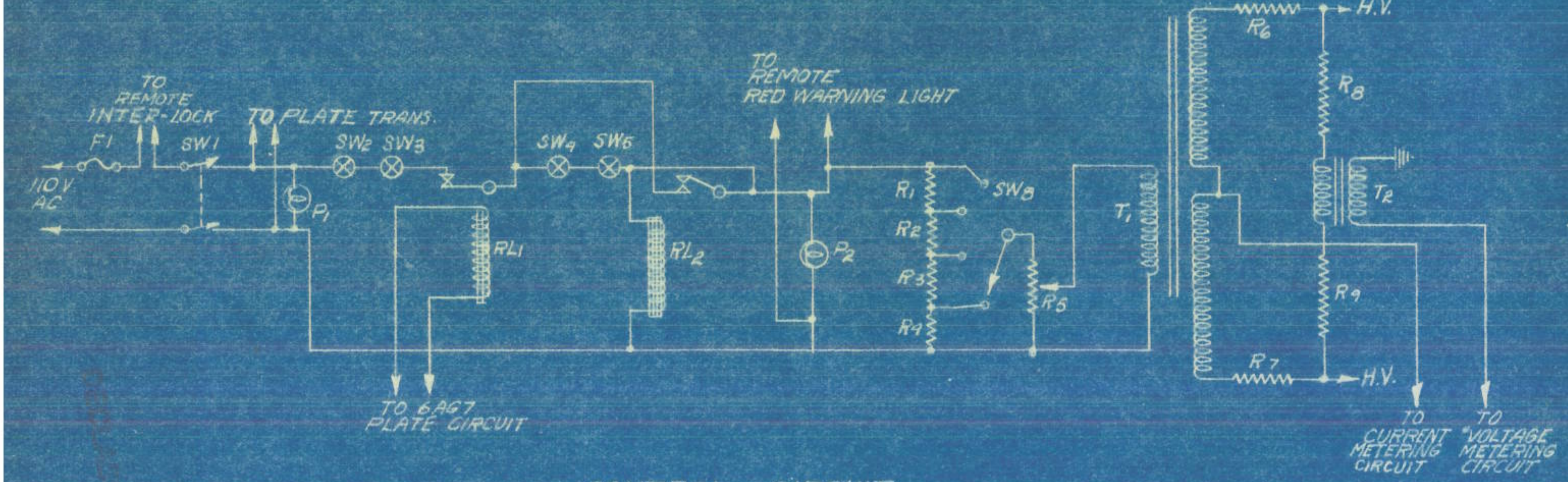
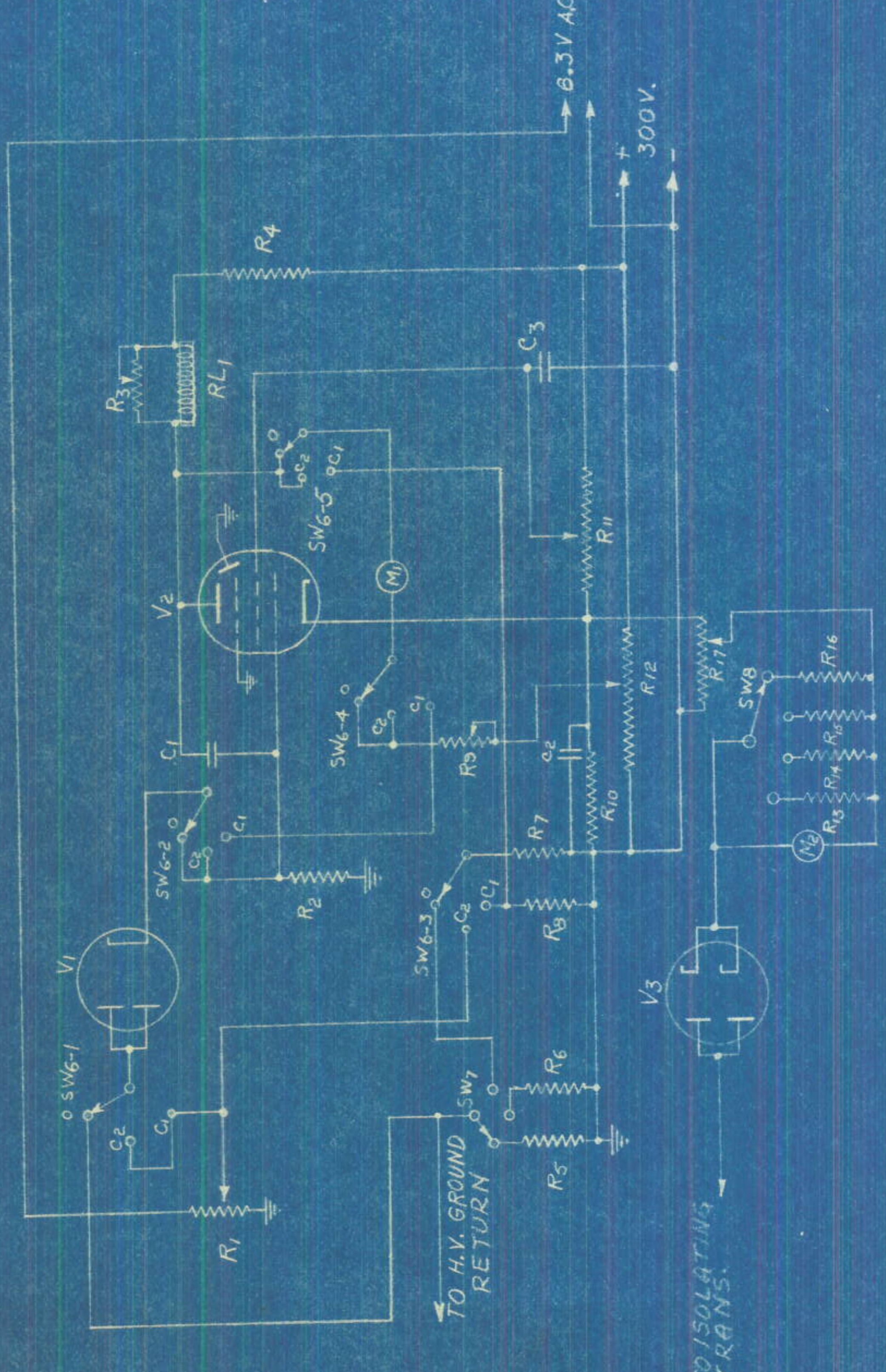


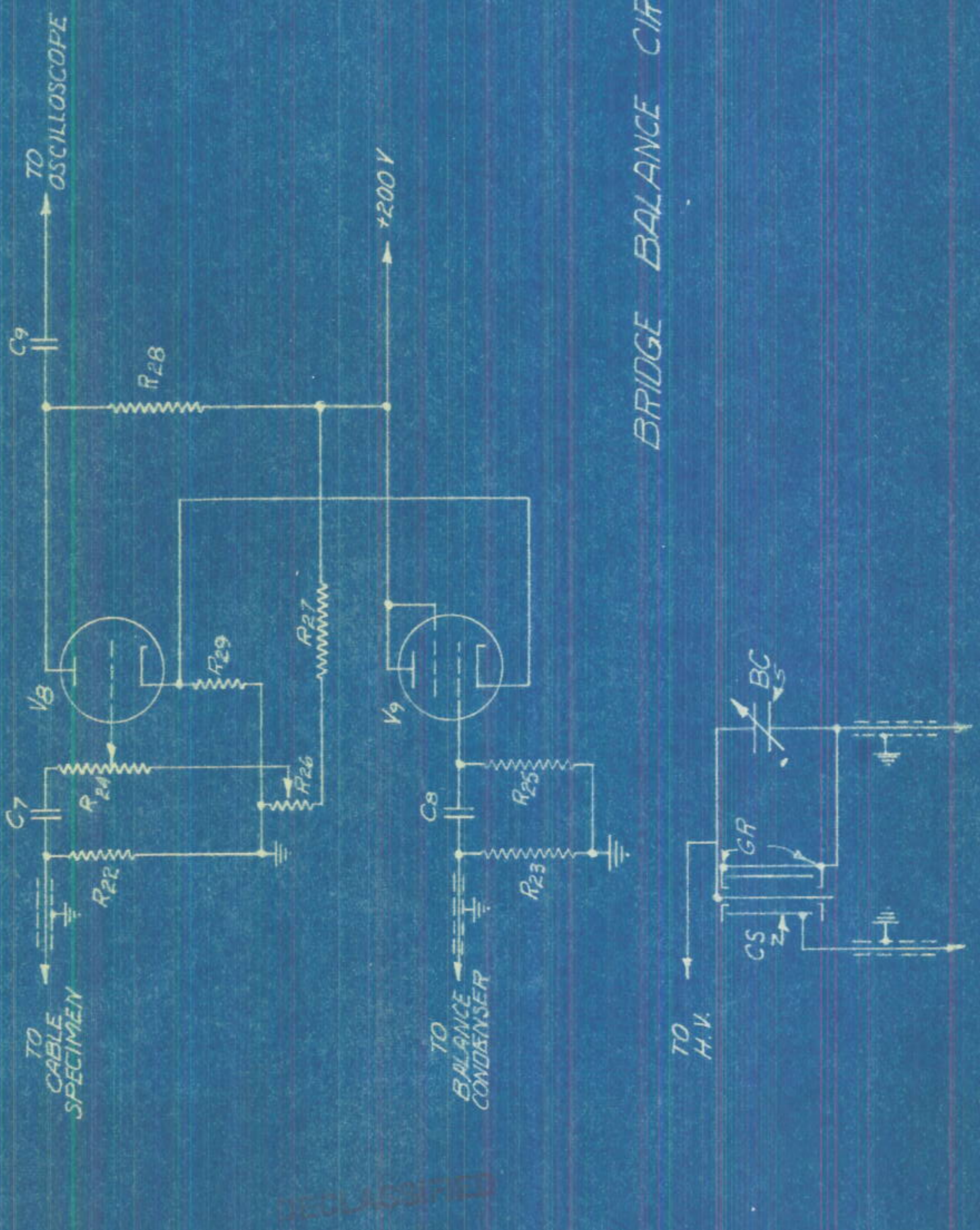
CONTROL CIRCUIT

PLATE I



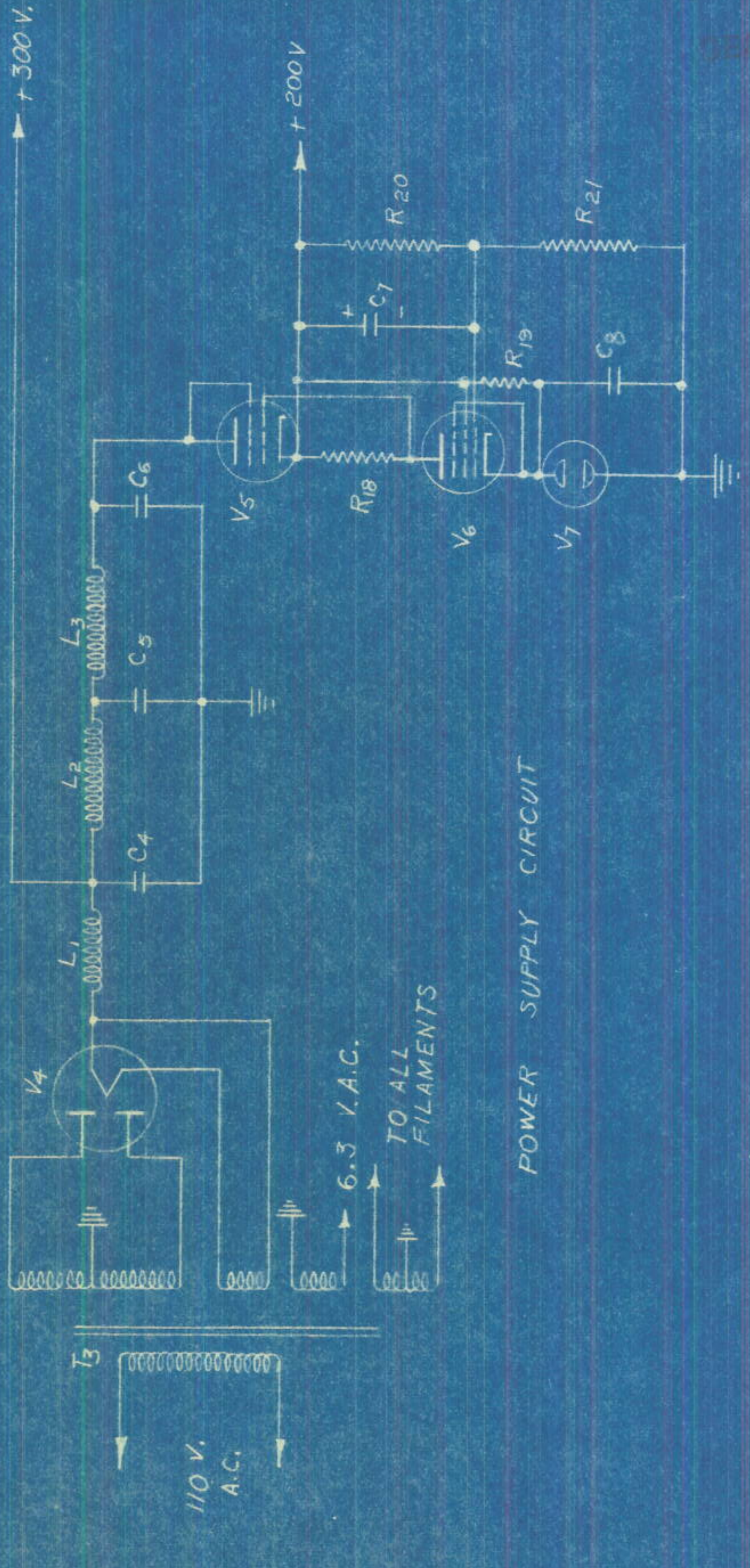
METERING CIRCUITS

PLATE 2



BRIDGE BALANCE CIRCUIT

PLATE 3



POWER SUPPLY CIRCUIT

PLATE 4

CALIBRATING METER

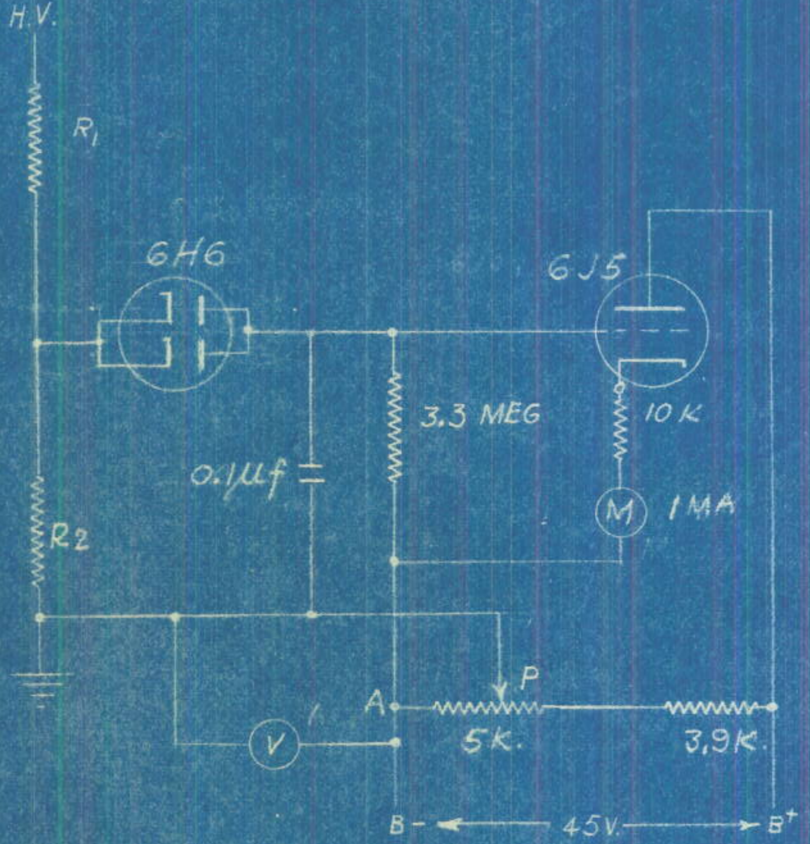
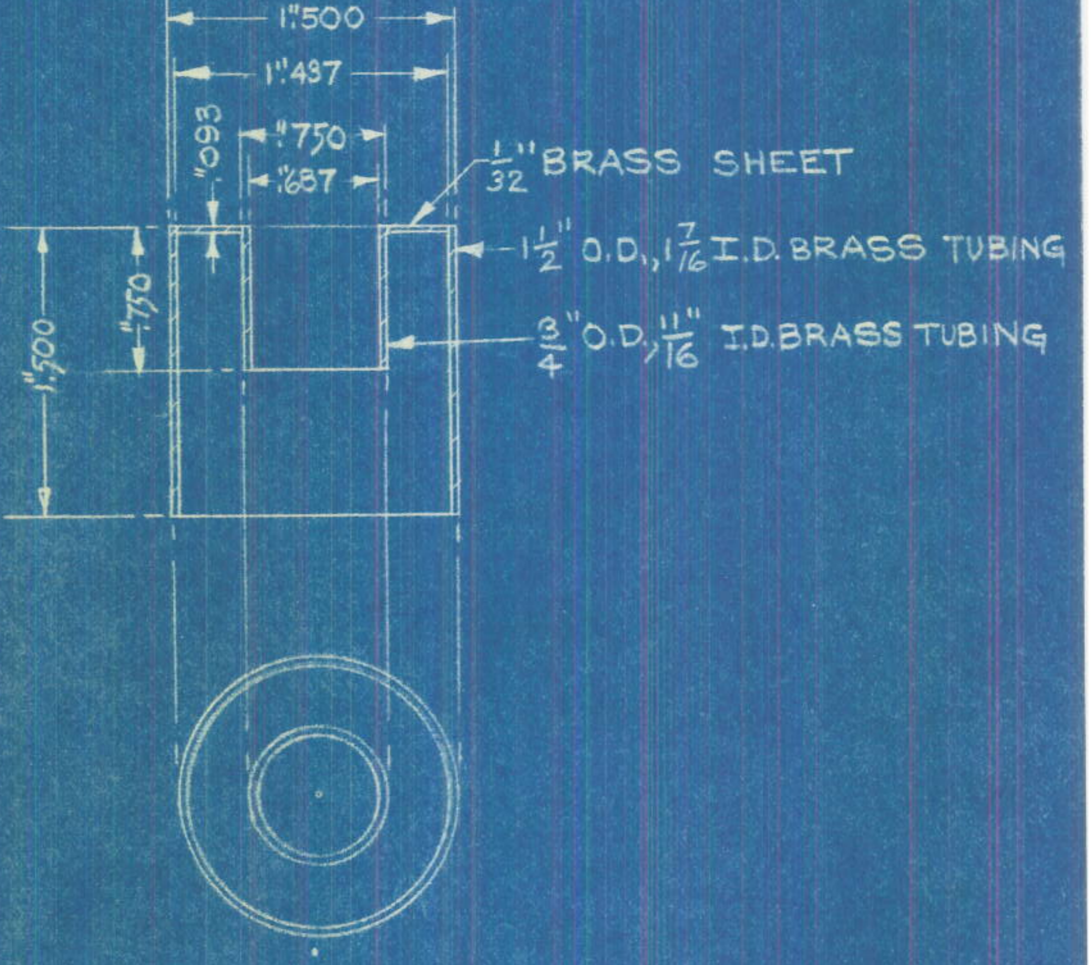


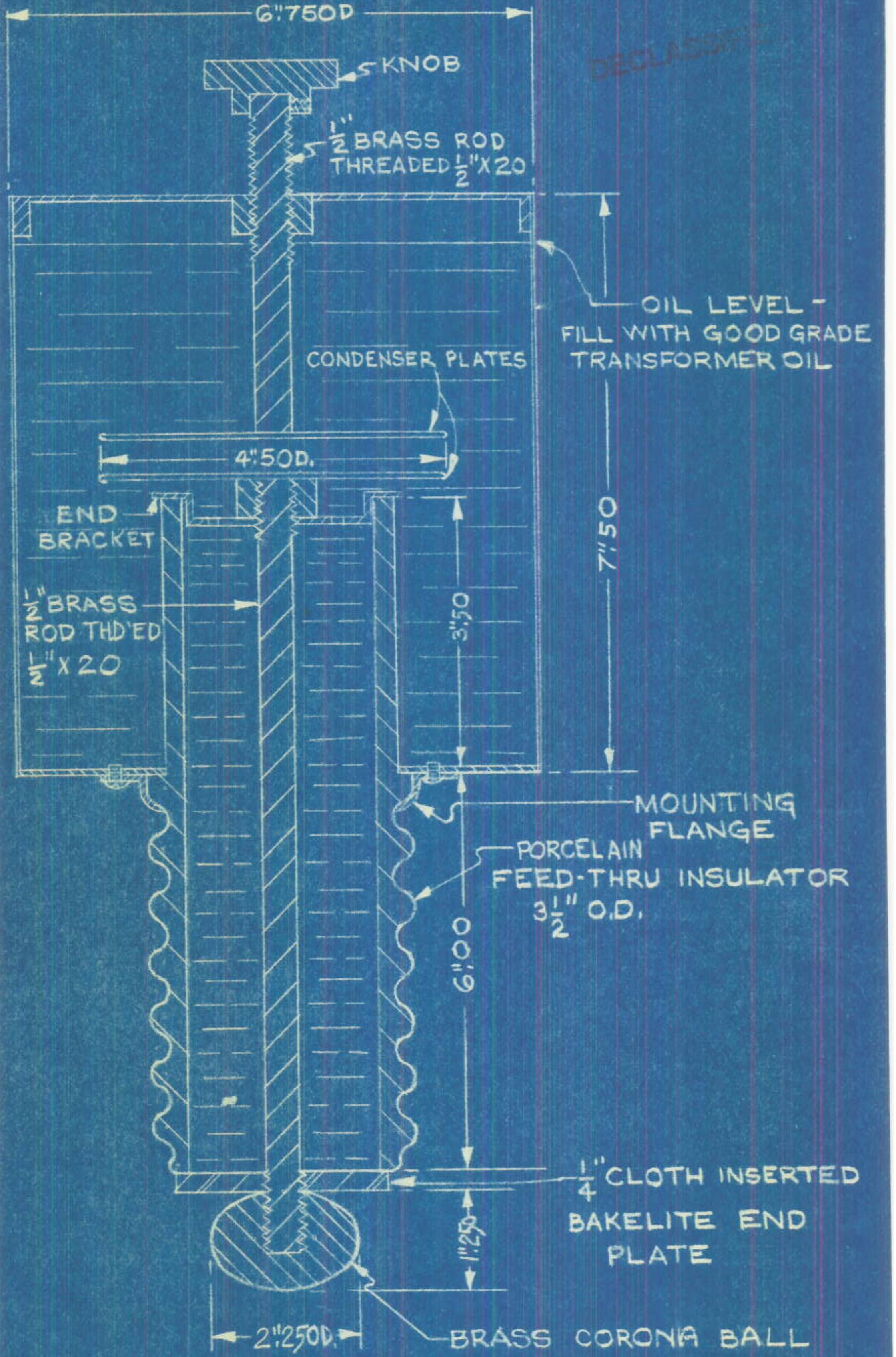
PLATE 5



NOTE:
ONLY CRITICAL DIMENSION IS
11/16" I.D. OF INNER TUBING

GUARD RING
FOR RG-17/U CABLE

PLATE 6



BALANCING CONDENSER
CROSS SECTION VIEW

PLATE 7

DECLASSIFIED

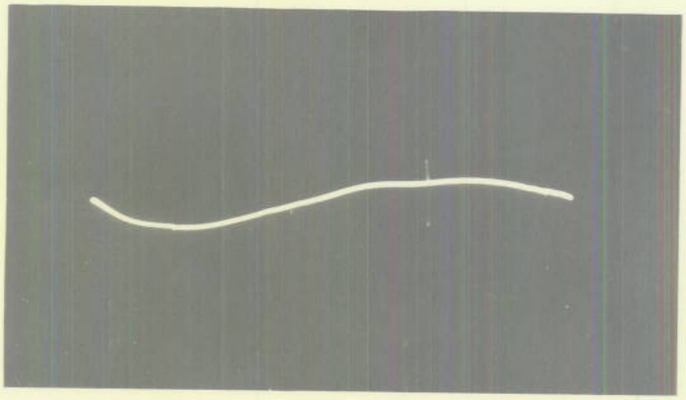


FIG. 1

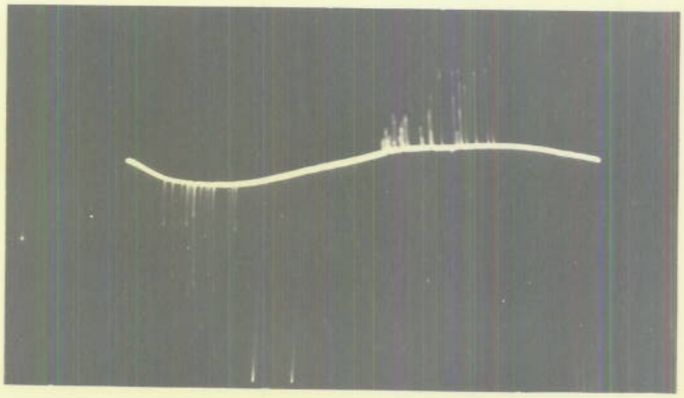


FIG. 2

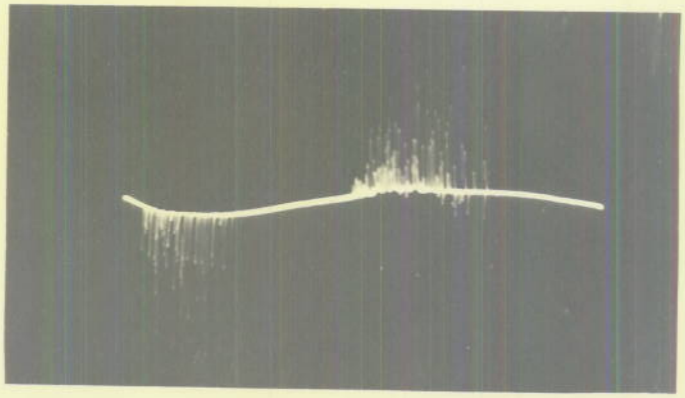


FIG. 3

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