OPERATING INSTRUCTIONS

for

TYPE 1670-A
MAGNETIC TEST SET

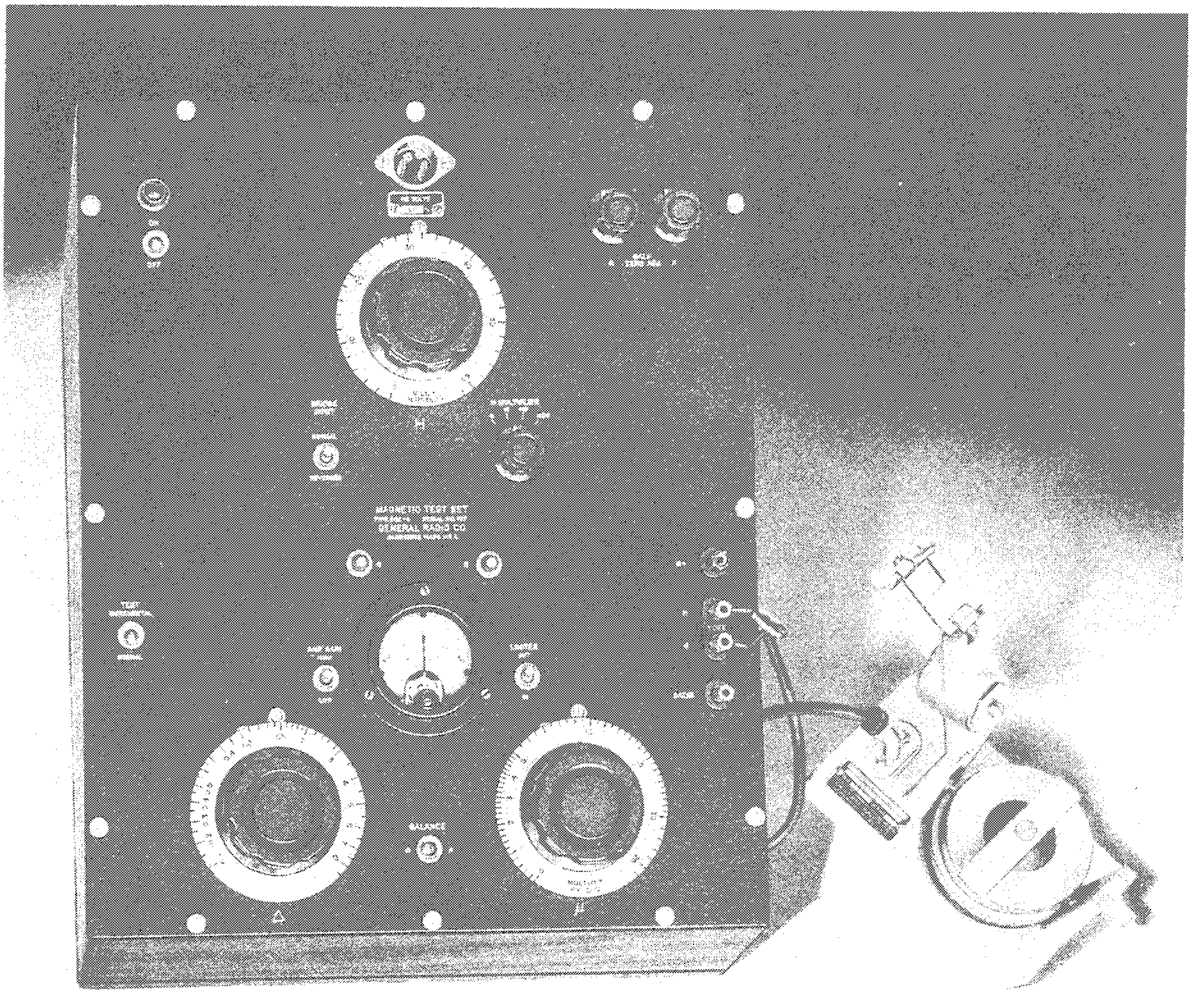
FORM 698-A

GENERAL RADIO COMPANY

CAMBRIDGE 39 MASSACHUSETTS

NEW YORK CHICAGO LOS ANGELES

U. S. A.



Panel View of the Type 1670-A Magnetic Test Set

SPECIFICATIONS

Range of Magnetizing Force: The 60-cycle normal magnetizing force is adjustable from one millioersted to 6 oersteds (gilberts per centimeter) for a line voltage of 115 volts. A biasing magnetizing force (dc) up to 2 oersteds can also be applied. The necessary d-c power, up to 1.5 oersteds, can be obtained from the internal power supply of the test set.

Permeability and Core-Loss Range: The range for permeability and core-loss measurements varies with the cross-section area. For a sample cross section of 10 sq. mm. full scale on the μ dial is 25,000. The permeability and core loss of any ferromagnetic sample can be measured if a sample of proper cross section is chosen. It may sometimes be necessary to calculate corrections for high-permeability materials.

Accuracy of Measurement: The accuracy of data obtained with this instrument is chiefly determined by the precision with which the cross-section of the specimen is known. Similar samples of identical cross section can be compared, at any given H, with an accuracy of 1 to 2 percent.

Power Supply: 115 volts, 60 cycles; by a change of connections on the power transformer primary, the instrument can be operated from a 230-volt line.

Power Input: 90 watts.

Tubes: 2 6C8-G, 1 6X5-G, and 1 0D3/VR150.

Accessories Supplied: Test yoke and line cord.

Accessories Required: When a d-c magnetizing force is applied, a milliammeter and a rheostat for varying the dc are required. The TYPE 371-A 50,000Ω Rheostat is suitable when the internal voltage source is used.

Mounting: The test set, exclusive of the test yoke, is housed in a walnut cabinet with sloping front panel.

Dimensions: Test set, (width) 16 x (depth) 18 x (height) 10 inches over-all; test yoke, 8 x 4 x 5½ inches.

Net Weight: Test set, 44 pounds; test yoke, 10 pounds.

Manufactured and sold under United States Letters Patent 2,009,013, 2,104,336, and 2,173,426.

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FOR

TYPE 1670-A MAGNETIC TEST SET

INTRODUCTION

This Magnetic Test Set is designed for the rapid and convenient measurement of the 60-cycle permeability and core loss of small samples of laminated ferromagnetic material when subjected to a definite and adjustable magnetizing force.

A Maxwell bridge with a phase-sensitive null detector is used to balance the reactive and resistive components of a solenoid surrounding the specimen in the test yoke. These two parameters can be evaluated in terms of either the normal or incremental permeability and the core loss of the specimen material. Measurements close to initial permeability (H equals one millioersted) can be obtained. Corresponding values of normal induction can be computed.

Using the standard Type 1670-P1 Test Yoke, peak values of magnetizing force H up to a maximum of six oersteds, evaluated in terms of the full magnetizing current, may be applied to the specimen. The corresponding maximum peak induction B which can be developed in the specimen will be six times the permeability which the specimen material possesses when subjected to this maximum H value. The product of the permeability μ and the aggregate cross section A' of the specimen, in square millimeters, is limited to a maximum value of 2.6×10^5. By using special yoke windings, having their number of turns increased n-fold, the maximum magnetizing force obtainable will be increased n-fold, but the maximum value of the product $\mu A'$ will be reduced by the factor n^2.

The Type 1670-A Magnetic Test Set is the result of a development described in a paper[1] by Horatio W. Lamson to which the reader is referred for the theoretical derivation of certain equations. A second paper[2] by the same author gives a general analysis of magnetic measurements and will be referred to in this text.

In this booklet the nomenclature and symbols adopted by the ASTM[3] will be used. They are outlined below.

NOMENCLATURE AND UNITS OF MEASUREMENT

The ASTM specifications embody the CGS electromagnetic system of units (non-rationalized) in which magneto-motive force F, measured in gilberts, is given by 0.4π times the ampere-turns (NI) circumscribing the flux path, and the unit of reluctance $\mathcal{R}$, sometimes called the "magnetic ohm", is the reluctance across a centimeter cube of free space. Magnetic flux ϕ, measured in maxwells or "lines", is then given by

$$\phi = \frac{F}{\mathcal{R}}$$

In a symmetrical and homogeneous flux path of length λ cm. and uniform cross-section A sq. cm., perpendicular to the flux, the magnetic parameters which are specific for any material regardless of the geometry of the flux path are the magnetizing force:

$$H = \frac{F}{\lambda}$$

measured in oersteds, i.e. gilberts per cm; the induction or flux density:

$$B = \frac{\phi}{A}$$

measured in gausses, i.e. maxwells per sq. cm; and the permeability:

$$\mu = \frac{B}{H}$$

evaluated in gausses per oersted and having a value of unity for free space. It can readily be demonstrated that μ has also the dimensions of henry/cm./turns squared.

In a non-symmetrical system the values of H and B at any point are given by the derivatives $dF/d\lambda$ and $d\phi/dA$.

Two other systems of electromagnetic units are used in modern practice and should be defined here. In both of these systems space dimensions are evaluated in meters.

In the practical MKS non-rationalized system F is measured in pragilberts and given by 4π times the ampere-turns. A pragilbert is, therefore, a deci-gilbert. The unit of reluctance (unnamed) may be defined as 10^{-9} magnetic ohms. Flux is measured in webers, one weber being 10^8 maxwells. H is measured in praoersteds (pragilberts per meter) so that a praoersted is a millioersted. B is measured in a unit (weber per square meter) which equals 10 kilogausses. Hence in this system the permeability of free space has a value of 10^{-7}.

In going from the non-rationalized MKS system to the rationalized MKS system the units of flux and induction remain unchanged, while the factor 4π is dropped from the definition of magneto-motive force which is now measured directly in ampere-turns. The magnitude of the units of F, $\mathcal{R}$, and H are increased by the factor 4π and the permeability of free space becomes $4\pi \times 10^{-7}$.

To convert data evaluated in the CGS units which are used in this equipment into either of the MKS systems the following conversion factors apply.

CGS to MKS non-rationalized:

To convert F in gilberts into F in pragilberts multiply by 10.
To convert $\mathcal{R}$ in magnetic ohms into $\mathcal{R}$ in MKS (N-R) units multiply by 10^9.
To convert ϕ in maxwells into ϕ in webers multiply by 10^{-8}.
To convert H in oersteds into H in praoersteds multiply by 10^3.
To convert B in gausses into B in webers/sq. meter multiply by 10^{-4}.
To convert μ(CGS) into μ(MKS, N-R) multiply by 10^{-7}.

CGS to MKS rationalized:

To convert F in gilberts into F in ampere-turns multiply by $\frac{10}{4\pi}$.
To convert $\mathcal{R}$ in magnetic ohms into $\mathcal{R}$ in MKS-R units multiply by $\frac{10^9}{4\pi}$.
To convert ϕ in maxwells into ϕ in webers multiply by 10^{-8}.
To convert H in oersteds into H in ampere-turns/meter multiply by $\frac{10^3}{4\pi}$.
To convert B in gausses into B in webers/sq. meter multiply by 10^{-4}.
To convert μ(CGS) into μ(CGS-R) multiply by $4\pi \times 10^{-7}$.

1) "A Method of Measuring the Magnetic Properties of Small Samples of Transformer Laminations", Proceedings IRE, Vol. 28, No. 12, December 1940, pp. 541-548.

2) "Alternating Current Measurements of Magnetic Properties", Proceedings IRE, Vol. 36, No. 2, February 1948, pp. 266-277.

3) Specification A-127-46, American Society for Testing Materials 1946 Book for Metals, pp. 674-681.

SECTION I
ASSEMBLY OF TEST YOKE

1.1 DESCRIPTION

The test yoke contains a solenoid winding upon a hollow core that is square in cross-section. This winding is embedded in a phenolic cylinder, which is surrounded by a stack of annular laminated leaves. Fabricated of high-permeability metal and subsequently hydrogen annealed, these leaves form a two-way magnetic return path of essentially negligible reluctance. Bending one of these leaves would destroy its desirable magnetic properties.

On the top of the stack of leaves is a horizontal brass clamping block having a wide slot milled in its bottom surface. This block fits loosely into a slot milled in the top of the phenolic cylinder. A force of about 100 pounds is exerted upon this block by means of a spring-backed plunger which is carried in a horizontal arm over the yoke. This force is sufficient to minimize the air gap reluctance between the test strip or strips and the adjacent leaves of the stack.

1.2 ARRANGING SAMPLE STRIPS

The core of the solenoid will accommodate strips of the test material up to a width of about 0.400 inch. Care should be taken that these strips, freed of burrs, pass into the core freely without binding. The test strip specimens should be at least 2-1/4 inches in length and may preferably be longer, even to projecting outside of the leaves. Each strip should be of uniform width and devoid of holes or notchings over the portion of its length which spans the hole in the leaves. Careful measurements have shown the effective magnetic length λ of the test strips to be greater than the diameter of the hole in the leaves and to have a value of 4.825 centimeters.

The lower 17 leaves are of somewhat larger external diameter and form a nonremovable stack of sufficient height to clear the bottom surface of the solenoid core. The smaller leaves, 33 in all, form the upper removable portion of the stack.

When one test strip is used it should have some 7 removable l below and the remainder above it, thus placing the strip approximat the center of the core.

When two test strips are used, the first should be placed dire on the nonremovable stack, then covered by some 10 or 11 leaves, f fowed by the second strip and the remainder of the leaves.

When three test strips are used, one should be at the bottom, at the center, and one at the top of the core.

The principle in assembling the stack, with any multiple numb of test strips through the core of the yoke, is to have a maximum nu usually at least four, leaves interposed between adjacent test strips. Care should be taken that the top strip is not strained in the assemb stack. The test strips should overlap symmetrically, by eye, onto th leaves on both ends. If multiple strips are used they should be of ap mately the same width.

1.3 CLAMPING TEST YOKE

The travel of the plunger in the clamp arm permits some vari in the overall stack height. However, with multiple test strips, it is desirable to remove from the top of the stack a thickness of leaves a proximating the total thickness of the test specimen. On the other ha the stack should have a sufficient height to produce a noticeable depr sion of the plunger when the clamp is set.

In setting the clamp, care must always be taken that the assem stack is "free" so that the leaves will not become buckled, and that th clamp bar does not exert any force upon the phenolic cylinder. The stack should be left unclamped when not in use.

SECTION II
OPERATION OF THE TEST SET FOR NORMAL MEASUREMENTS
(SCM CONDITION)

2.1 GENERAL

A careful reading of this section is recommended for any user who is not familiar with the operation of this equipment.

In measuring normal permeability and core loss, the specimen is subjected to any desired sinusoidal magnetizing force, H, by passing a sinusoidal current through the yoke winding. This sinusoidal H, used alone, produces a symmetrically cyclically magnetized (SCM) condition, wherein the algebraic mean values of F, H, Ø, and B are all zero. The positive or negative <u>peak</u> values of these quantities are designated as their <u>normal</u> values and the ratio of normal B to normal H defines the normal permeability of the specimen for that specific value of H or B. Initial permeability μ_o is defined as normal μ obtained by applying a vanishingly small value of normal H.

2.2 PRELIMINARY PROCEDURE

2.2a <u>Arrangement of Equipment</u>: The test set should be placed on a horizontal bench, with the test yoke to the right at a maximum distance permitted by the interconnecting leads. The equipment is electrostatically shielded by the metallic panel and lining of the cabinet. Ordinarily, <u>this shield (G terminal) need not be grounded unless touching the panel produces a visible effect on the galvanometer needle. Other apparatus</u> or circuits which are known to be radiating any substantial magnetic field of the same frequency should be kept free from the immediate vicinity of this test equipment.

2.2b Attach the assembled test yoke to the terminals marked YOKE, the black lead to the G and the white lead to the H terminal.

2.2c Set the TEST and BRIDGE INPUT switches in the NORMAL positions.

2.2d Set the H MULTIPLIER switch at the zero position (extreme left).

2.2e Set the H dial at zero.

2.2f Set the AMP. GAIN switch in the HIGH position and the LIMITER switch IN.

2.2g See that the galvanometer needle is at the exact center of the scale by means of a screw adjustment on the meter (mechanical centering). As always, face the meter squarely to avoid parallax erro

2.2h Connect the set to the 60-cycle power supply line of the specified voltage and turn power switch on; pilot lamp should light. Unless otherwise specified, the test set is furnished equipped for use with single-phase a-c mains having a nominal voltage of 115. If desir it is easy to modify for 230 volt supply mains. To do this <u>remove</u> the two jumpers connecting terminals 1-3 and 2-4 on the power transform T-1, and <u>add</u> a single jumper across terminals 2-3. This puts the two primary windings of the transformer in series (instead of in parallel), but keeps the H control T-2 across one primary winding and hence sub jected to 115 volts as formerly.

2.3 ADJUSTMENT OF DETECTOR POLARIZING VOLTAGE

2.3a In addition to being mechanically centered (Paragraph 2.2g the galvanometer must also be electrically centered when the polarizi voltage alone is applied to it. This check need only be made at infrequent intervals, since the magnitude of the polarizing voltage is not changed by the operation of the test set. Having followed the procedure outlined in the previous Section 2.2 proceed with the following adjustments, 2.3b and 2.3c, utilizing two resistive controls R-36 and R-25, which are accessible for screw-driver manipulation through two holes in the rear wall of the cabinet, R-36 being the upper control (adjacent to the instrument panel) and R-25 being directly below R-36.

2.3b Depress the "ground" switch G (thereby shunting the input of the detector system) and, if necessary, manipulate R-36 (upper contr to bring the needle as close as possible to center scale. N.B. In some instruments the needle will remain centered regardless of the adjustment of R-36. In this case it is preferable to leave R-36 turned to its extreme clockwise position (viewed from the rear).

2.3c Release the G switch and depress the "break" switch B, thereby disconnecting the input of the detector system from the amplifier. If necessary, manipulate R-25 (lower control) to bring the needle exactly to center scale. Then release the B switch. Do not be concerned here if the needle is off center when both switches are released. It is essential that these two adjustments, 2.3b and 2.3c, be made in the sequence noted. Subsequently, this polarizing balance may be checked at any time merely by depressing the B switch and observing that the needle is accurately centered.

2.4 ADJUSTMENT OF COMPENSATING (ZERO ADJUST) NETWORK

2.4a The null balance detector of this test set employs an amplifier of substantial gain, which is tuned to 60 cycles and energized from the 60-cycle source. The difficult problem of obtaining zero output from such an amplifier, when no intentional input is applied to it, is here met by cancelling any residual output, due to various sources, with a compensating input voltage of proper magnitude and phase. This compensating voltage is obtained by adjusting two small ZERO ADJ. knobs located in the upper right corner of the panel and labeled respectively μ and Δ. Having completed the procedures outlined in Sections 2.2 and 2.3 and without changing any of the other switches or controls, proceed with this compensating adjustment as follows:

2.4b Throw the LIMITER switch to the OUT position.

2.4c Place the BALANCE switch in the μ position, and manipulate the μ ZERO ADJ. knob to bring the galvanometer needle to its zero position.

2.4d Shift the BALANCE switch to the Δ position and manipulate the Δ ZERO ADJ. knob to bring the galvanometer needle again to its zero position.

2.4e Repeat 2.4c and 2.4d alternately until the needle remains accurately centered at zero with either position of the BALANCE switch. Disregard any transient throw of the needle as the switch is shifted.

In certain instruments it may be found desirable to adjust the μ ZERO ADJ. knob with the BALANCE switch in the Δ position, and to shift this switch to the μ position when adjusting the Δ ZERO ADJ. knob.

2.4f It will be noted that this zero adjustment is facilitated by the fact that the galvanometer needle moves in the same direction in which either knob is turned. With the amplifier properly compensated, any galvanometer deflection in subsequent operations can be attributed entirely to a lack of balance of the Maxwell bridge. Any change in substantial magnetic fields from other nearby 60-cycle apparatus may require a repetition of this zero adjustment. Under certain conditions reversal of the input power cord may facilitate this balancing operation. Once made, this compensating adjustment should be valid in subsequent measurements using HIGH gain and with the limiter either IN or OUT. This may be verified by occasional observations of the galvanometer needle when both the H-MULTIPLIER switch and the H-DIAL are set at zero. See also Paragraph 6.1c.

2.5 USE OF LIMITER SWITCH

The limiter is a non-linear attenuation network which may be inserted at will between the output of the amplifier and the galvanometer system by throwing the LIMITER switch to the IN position. It functions to limit the throw of the galvanometer needle to a small portion of the scale range, and also to reduce the high sensitivity of the detector which is necessary for measurements with small values of H, but which is bothersome when balancing the Maxwell bridge with larger values of applied H.

While the use of the limiter is optional with the operator, it will, in general, be found beneficial to insert it when working with H values in excess of about 100 millioersteds. The limiter should be regarded as the principal sensitivity control of the detector.

2.6 USE OF AMPLIFIER GAIN SWITCH

2.6a When this switch is in the HIGH position, the detector corners of the Maxwell bridge are connected directly to the input of the amplifier; when it is in the LOW position, a voltage divider reduces the voltage applied to the amplifier about tenfold. This switch should not, however, be used as a sensitivity control. Ordinarily it should be left in the HIGH position. When the Maxwell bridge is correctly balanced for the fundamental frequency, 60 cycles, it is not balanced for any harmonic frequencies generated by the non-linear character of the test specimen. Usually these harmonics are obliterated from the galvanometer response by the high selectivity of the detector system.

In measuring, at high H values, specimens which possess hysteresis loops of excessive area and attendent high hysteresis loss, it is possible for the harmonic components from the bridge, balanced to the fundamental, to overload the amplifier and render an exact balance of the bridge to 60 cycles somewhat difficult and uncertain. In this rather unusual case it would be beneficial to throw the AMP. GAIN switch to the LOW position.

2.6b It should be remembered that whenever the AMP. GAIN switch is changed, a rebalancing of the compensating (ZERO ADJ.) controls would be required. This is because the magnitude and phase of both the spurious and compensating voltages actually applied to the amplifier are modified thereby. However, with conditions requiring the LOW position of the AMP. GAIN switch (see above) the input voltage applied to the detector will ordinarily be sufficiently large so that a slight unbalance of the detector will be of no practical significance.

2.7 AUXILIARY CONTROLS

2.7a Use of BRIDGE INPUT Switch: Preceding the Maxwell bridge circuit is a BRIDGE INPUT switch which reverses the phase of the a-c input to the bridge circuits. This switch should ordinarily be kept in the NORMAL position. When working with extremely low H values the test set may be subjected to sufficient magnetic pickup from stray fields in the vicinity to introduce an error in the observed results. In this case, the bridge should be balanced first with the BRIDGE INPUT switch in the NORMAL position and then balanced again with this switch in the REVERSED position. The mean value of the two μ and the two Δ dial readings thus obtained should then be taken as their true dial values. When this switch is in the REVERSED position both the μ and Δ dials should be turned in a direction opposite to that in which it is desired to have the galvanometer needle move towards zero. The position of the BRIDGE INPUT switch will not effect the GALV. ZERO ADJ. balance.

2.7b Use of TEST Switch: The TEST switch is in the Maxwell bridge circuits and is placed in the NORMAL position when making all normal measurements upon the test specimen, and thrown to the INCREMENTAL position for incremental measurements; see later.

2.8 APPLYING A GIVEN MAGNETIZING FORCE (SCM CONDITION)

2.8a Be sure that the TEST switch is in the NORMAL position. Set the H dial and the H multiplier switch to give any desired value of H to the test specimen.

2.8b When working in a region where the μ versus H curves have steep slopes, erratic fluctuations in the bridge balance may be attributed to lack of regulation of the power-supply line. The use of a regulator to stabilize the line voltage is prohibited unless it can be demonstrated that such a device introduces no appreciable harmonic components into the current supplied to the bridge. This point may be checked by the use of a cathode-ray oscillograph equipped with a horizontal linear sweep. Attach the vertical deflector plates of the oscillograph to the CALIB. and H-YOKE terminals on the test set. Apply a substantial H to the test specimen. Then compare the good sinusoidal wave form observed when the test set is energized directly from the power line with the wave form obtained when the proposed regulator is used. If the latter shows any appreciable distortion that regulator should not be employed.

2.8c Any value of H from one millioersted to six oersteds may be obtained. For maximum accuracy use the smallest multiplier possible, i.e., use:

Multiplier X1	from zero to 60 millioersteds.
Multiplier X10	from 60 to 600 millioersteds.
Multiplier X100	from 600 to 6000 millioersteds.

thus avoiding an H-dial setting below 6 unless an H value of less than six millioersteds is desired.

CAUTION: While this instrument is safely rated to supply a maximum of 6 oersteds to the specimen, it is desirable to avoid prolonged applications of values in excess of two oersteds in order to minimize internal heating in the test set.

2.8d The test set is calibrated to be direct reading in values of H millioersteds in conjunction with a line voltage of 115 (or 230) volts, n.s. For accurate data when the line voltage departs from this value, e a suitable external voltmeter, and use either of the two following ocedures:

1. Interpose a Variac, Type 200-B or V-5, between the supply line and e test set and adjust the voltage to its nominal value.
2. Merely record the existing voltage and apply a correction factor m, described later.

) BALANCING THE MAXWELL BRIDGE

2.9a General: As in any impedance bridge, two separate controls e required to obtain a complete balance by setting each to a specific lue. These two controls, designated as the μ and the Δ dials, are not tirely independent of each other.

Ordinarily, the balancing of such a bridge must be made by several ternate adjustments of the two controls to positions of successively de-easing minima of null-detector response. The null detector used in this st set embodies two features which simplify this balance operation con-derably -- especially since the Maxwell bridge (when measuring induc-rs of low Q value) is subjected to pronounced "sliding zero".

(a) The detector can be rendered more sensitive to the individual ad-stment of one or the other of the two controls by means of the BALANCE vitch located on the panel between them.

(b) The position of the galvanometer needle gives an indication of the rection in which the bridge control, either μ or Δ, should be turned to ring the galvanometer to zero.

The rapid operation of this convenient system is easily mastered ith no chance of error or confusion if the following rules are always lhered to:

2.9b Never turn the μ dial unless the BALANCE switch is in the μ osition.

2.9c Never turn the Δ dial unless the BALANCE switch is in the Δ osition.

2.9d If the galvanometer needle is to the left of center zero, always irn the control dial (μ or Δ) with a clockwise motion, regardless of the direction in which needle may start to move, until the needle is brought to zero.

2.9e Conversely, if the needle is to the right of zero, it should be brought to center by a counter-clockwise rotation of the control dial. Thus the universal rule: "Always turn either bridge dial in the same direction in which the needle must be rotated to reach center." This is the convenient directional feature of this null detector.

2.9f Preliminary Balance: In making the first measurement on a new sample, or whenever the approximate balance positions of the μ and Δ dials are not known, proceed as follows: Set the μ dial at about 5000 and the Δ dial at about 1.0. Throw the balance switch to the μ position and center the galvanometer needle with the μ dial. Throw the balance switch to the Δ position and center the galvanometer needle with the Δ dial. Under certain conditions, when the bridge is decidedly off-balance, time may be saved by employing the principle of "partial compensation" in the foregoing operations, i.e. by bringing the needle back about two-thirds rather than all the way to zero.

2.9g Final Balance: Repeat, alternately, these μ and Δ dial adjustments until the bridge is balanced satisfactorily on both dials. The selective polarization of this null detector reduces considerably the required number of these alternate adjustments. It should be remembered that both the μ and Δ dials control tapered rheostats which can be adjusted only by successive discreet increments corresponding to the resistance of one turn of wire on each. Consequently, in general, an absolutely perfect balance of this bridge is impossible. These discreet wire-to wire adjustments, which lie within the precision of dial scale readability, will become more apparent as the lower ends of the dials are approached. In this case, the final adjustment should be made upon the dial which is more sensitive. The Maxwell bridge will be balanced, within the practical limits to which each rheostat bridge control may be set, when and only when a shift of the BALANCE switch does not move the galvanometer significantly from its center-scale (zero) position. Disregard any transient throw of the needle on shifting the BALANCE switch. When testing specimens energized at a level where their permeability versus H changes rapidly, line voltage variations may sometimes cause perceptible erratic fluctuations of the galvanometer needle at balance; see Paragraph 2.8b.

2.9h Having obtained the balanced bridge data for a specific value of H, refer to Section III to evaluate these data in terms of normal permeability and core-loss. In making a run on a given specimen with progressively decreasing values of H only brief "final balance" operations will be necessary for each observation.

SECTION III
COMPUTATIONS -- SCM CONDITION
NORMAL DATA

.1 MODIFICATIONS REQUIRED

To evaluate the true normal parameters of the test specimen it is ecessary to modify the Maxwell bridge data to allow for four circum-tances.

3.1a The H dial, of necessity, was calibrated in terms of the total urrent supplied to the Maxwell bridge with an assumed line voltage of .15 (or 230) volts. For precise results the line voltage applied to the test set must be adjusted to this value by means of an external Variac inter-osed between the supply line and the instrument, or a correction factor, n, must be used.

3.1b The exciting current supplied to the yoke winding is a large but ariable portion of the calibrated current supplied to the Maxwell bridge it any specific setting of the H dial, thus requiring a correction factor η .

3.1c The true magnetizing current, actually producing H, is only a portion of the exciting current supplied to the yoke winding, thus requiring correction factor S, which is a function of the bridge dial settings.

3.1d A portion of the measured loss in the yoke will consist of copper oss in its windings, thus requiring a correction for the copper-loss dissi-ation factor D_c.

3.2 INITIAL DATA

For each balanced bridge observation the following data should be available:

3.2a The line voltage applied to the test set.

3.2b H_d = the value of the H dial setting, including the H multiplier, expressed in millioersteds, and having a maximum value of about 6000.

3.2c μ_d = the μ dial reading, including the multiplying factor of 1000, and thus having a maximum value of about 26,000.

3.2d Δ = the numerical value read directly on the Δ dial.

3.2e A' = the aggregated cross-sectional area of the specimen, evaluated in square millimeters. One inch = 25.4 millimeters, one square inch = 645 square millimeters. The quantity A' may be computed from micrometer measurements of width and thickness, or from the length, mass and known density of the specimen.

3.3 INITIAL COMPUTATIONS

With these data proceed as follows:

3.3a Compute the ratio:

$$m = \frac{\text{Actual Line Voltage}}{115 \text{ (or 230)}} \qquad (1)$$

and the products mH_d and $(mH_d)^2 \times 10^{-9}$, omitting the latter if loss data are not required. See Table V for typical data.

3.3b Using Table I, for the specific value of Δ obtain the corresponding values of the factors η, U, and D. For high values of Δ it may be desirable to compute the dissipation factor D from the equation:

$$D = \frac{2}{3\Delta} \qquad (2)$$

3.3c Using Table II, for the specific value of μ_d record the corresponding value of the dissipation factor D_c due to copper loss.

3.3d Next evaluate the difference $D - D_c$ and, from Table III, obtain the corresponding values of the two functions S and T.

3.3e It will now be convenient to compute the two ratios η/S and μ_d/A'.

3.4 FINAL COMPUTATIONS

3.4a The true value of the normal magnetizing force will then be given by the product:

$$\text{Normal H (millioersteds)} = \left(\frac{\eta}{S}\right)\left(mH_d\right) \qquad (3)$$

If the factor S in (3) is made unity, a psuedo-H peak value is ob-
:ained which is based on the geometry of the yoke and the total value of
:he exciting current.

3.4b The true value of the normal permeability will then be given by
he product:

$$\text{Normal } \mu = T\left(\frac{\mu_d}{A'}\right) \qquad (4)$$

If the factor T in (4) is given a value of 10, a psuedo-μ is obtained
vhich is based on the geometry and the series inductance of the yoke.

3.4c The core loss will be given by the multiple product:

$$\frac{\text{Milliwatts}}{\text{Cubic Centimeter}} = U\left(\frac{\mu_d}{A'}\right)\left(D - D_c\right)\left(mH_d\right)^2 \times 10^{-9} \qquad (5)$$

3.4d The core loss in watts per pound may be obtained by multi-
ılying the result obtained in equation (5) by the ratio 0.4536/d, where d is
he known density of the specimen material in grams per cubic centimeter.

3.4e If desired, the true value of normal induction may be computed
ıs the product:

$$\text{Normal B (gausses)} = \left[\text{Normal } \mu\right]\left[\text{Normal H (oersteds)}\right] \qquad (6)$$

3.4f Omitting equations (3) and (4), the normal induction can be com-
ıuted directly from the equation:

$$\text{Normal B (gausses)} = \eta S\left(\frac{\mu_d}{A'}\right)\left(mH_d\right) \times 10^{-2} \qquad (7)$$

3.4g The peak value of the flux existing in the specimen is obtained
rom the equation:

$$\hat{\phi} \text{ (maxwells)} = BA = \frac{A'}{100}\left[\text{Normal B (gausses)}\right] \qquad (8)$$

3.4h Actually, a knowledge of the value of A' is not required in
valuating the peak flux which can be computed directly from the equation:

$$\hat{\phi} \text{ (maxwells)} = \eta S \mu_d \left(mH_d\right) \times 10^{-4} \qquad (9)$$

.5 TYPICAL COMPUTATION WITH NORMAL DATA

With a specimen consisting of two strips each 0.375 inches wide and
.0191 inches thick, the H dial was set to read 50, and the H-MULTIPLIER
witch was set at X 10. With a line voltage reading 107 volts (external
ıeter), the bridge was balanced with the μ scale reading 2.65 and the Δ
:ale reading 0.92. The bridge data were then:

$$m = \frac{107}{115} = .930$$

$$H_d = 50 \times 10 = 500 \text{ millioersteds}$$

$$\mu_d = 2.65 \times 1000 = 2650$$

$$\Delta = 0.92$$

The specimen cross-section was:

$$A' = 2 \times .375 \times .0191 = .0143 \text{ sq. inch} = 9.22 \text{ sq. mm.}$$

By computation:

$$mH_d = .930 \times 500 = 465 \text{ millioersteds}$$

$$(mH_d)^2 \times 10^{-9} = 2.16 \times 10^{-4}$$

From Table I, for $\Delta = 0.92$

$$\eta = .975 \qquad U = 14.26 \qquad D = .725$$

From Table II, for $\mu_d = 2650$, $D_c = .062$ so that $D - D_c = .663$, whence from Table III $S = 1.200$, $T = 14.40$

By computation the ratios:

$$\frac{\eta}{S} = \frac{.975}{1.200} = .812 \qquad \frac{\mu_d}{A'} = \frac{2650}{9.22} = 287$$

Substituting these data, we have:

Equation (3): Normal H = .812 (465) = 378 millioersteds.
Equation (4): Normal μ = 14.40 (287) = 4130.
Equation (5): Core Loss = 14.26 (287) (.663) (2.16) x 10^{-4}
= 0.586 milliwatts/cubic centimeter.

Taking the density of the specimen to be 7.82 grams per cubic centimeter:

$$\text{Core Loss} = \frac{.586\ (.4536)}{7.82} = .0340 \text{ watts/lb.}$$

Equation (6): Normal B = 4130 (.378) = 1561 gausses.
Equation (7): Normal B = .975 (1.200) (287) (465) x 10^{-2} = 1561 gausses.
Equation (8): $\hat{\phi} = \frac{9.22}{100}(1561) = 144$ maxwells.
Equation (9): $\hat{\phi} = .975\ (1.200)\ (2650)\ (465) \times 10^{-4} = 144$ maxwells.

The psuedo-values of μ, H, and B would have been 2868, 454 millioersteds, and 1301 gausses respectively. The discrepancy between the psuedo-values and the true normal values of these parameters is evident.

The derivation of Equation (4) presupposes that all of the flux is carried by the test specimen. Actually, a small amount of air-borne flux passes through the core of the solenoid, so that the corrected normal μ is less than that given in (4) by the factor:

$$1 - \frac{150}{\mu A'} + \frac{1}{\mu} \approx 1 - \frac{150}{\mu A'}$$

wherein the numeric 150 is the effective cross-section of the solenoid winding in sq. m.m. In the example cited above, the correction for air flux would have been only 0.37% and thus ordinarily negligible. This air flux correction will exceed one percent only when the product $\mu A'$ has a value less than 15,000.

SECTION IV
COMMENTS

1 COMPARATIVE MEASUREMENTS

While the absolute evaluation of normal permeability and core loss
quires the computation procedure given in Section III, a reasonably accu-
te comparison measurement between a standard specimen and an "un-
own" specimen X having approximately the same magnetic properties
n be made by testing each with the same H dial setting (any desired
lue) and equating the simple ratios:

$$\frac{\mu \text{ (of X)}}{\mu \text{ (of Std.)}} = \frac{\left[\mu_d \text{ (with X)}\right]\left[A' \text{ (of Std)}\right]}{\left[\mu_d \text{ (with Std.)}\right]\left[A' \text{ (of X)}\right]} \qquad (10)$$

With somewhat less accuracy, if the copper loss is relatively small compared to the core loss, then the core loss ratio (per unit volume) is given by:

$$\frac{\text{Core Loss of X}}{\text{Core Loss of Std.}} = \frac{\left[\Delta \text{ (with Std.)}\right]\left[\mu_d \text{ (with X)}\right]\left[A' \text{ (of Std.)}\right]}{\left[\Delta \text{ (with X)}\right]\left[\mu_d \text{ (with Std.)}\right]\left[A' \text{ (of X)}\right]} \qquad (11)$$

Note that these comparisons are made with essentially the same magnetizing force in the two specimens and not the same induction.

Simple measurements of this sort will find a wide use in routine checking of the quality of run-of-the-mill specimens against a standard reference specimen. Equations (10) and (11) are obviously simplified if both specimens have the same cross-section.

4.2 PRECISION OF RESULTS

It will be noted from the foregoing computations that the accuracy with which the absolute values of permeability and core loss are determined is usually limited by the precision with which the actual cross sectional area of the specimen may be evaluated. In general, the precision of A' is less than the accuracy with which the values of H, μ, and Δ may be determined from readings of the dials of the test set. The resultant values of μ, core loss, and B are dependent directly upon the precision of A', but the evaluation of the peak flux in the specimen, given by equation (9) above, is independent of A'. With an assumed value of A' proportional values of μ and core loss, as H is varied, may be obtained with the precision with which the bridge dials can be set and read.

4.3 ALLOWANCE FOR SCALE

In measuring thin laminated samples possessing a scale coating of any sort, it should be remembered that the measured values of μ, B and core loss will be the true values of the specimen material diluted to a certain rather indeterminate degree by the magnetic properties of the scale material. If the permeability of the pure material exceeds considerably that of the scale at all inductions used, this dilution becomes negligible and the accuracy with which the magnetic parameters of the pure material may be measured depends primarily upon the precision with which the cross-sectional area of the specimen, minus scale, can be determined.

4.4 MAGNETIC "SHAKE-DOWN" OF SPECIMEN

A series of bridge balances may be made for successive values of applied H and data obtained for plotting either the normal or the incremental values of μ and loss vs. the corresponding values of H. In order to obtain stabilized and hence repeatable data, it is generally found necessary, before proceeding, to subject the specimen material for a few seconds to a cyclic H equal to or in excess of the maximum value contemplated for the subsequent data. Then slowly reduce the H dial to the desired value.

Likewise it is preferable to take a normal μ-vs-H curve with progressively decreasing values of H. If any change in the value of H and subsequent restoration of the same value requires an appreciable rebalance of the Maxwell bridge, a lack of stability of the test specimen is thereby indicated and further "shake down" at some higher H-value may be necessary to enhance magnetic stability. This procedure insures a cyclically magnetized condition of the core and appears to stabilize the specimen against possible strains produced by the application of yoke pressure.

CAUTION: Always reduce the H dial slowly to zero before turning off the power switch, thus insuring a demagnetized specimen.

4.5 PARTIAL BRIDGE BALANCE

Owing to the selective polarization feature of the null detector, if only the μ data and not the loss values are desired, the Δ dial of the bridge need not be adjusted exactly for balance unless extreme precision of the μ value is required.

4.6 OBTAINING MAGNETIC CURVES

Since, by definition of μ, the flux density B is the product μH, the bridge also furnishes data for obtaining the familiar B vs. H or B vs. μ curves, as well as the loss vs. B and the loss vs. μ curves, of the specimen material. It must be remembered, however, that all these curves will be either normal or incremental in character and will, accordingly, differ somewhat from the corresponding static curves of the material, as discussed in Section 6.2.

4.7 USE OF MULTIPLE TEST STRIPS

Ordinarily, a single test strip of suitable width can be measured on the test set over the entire available range of H. When working near initial permeability or when measuring materials of abnormally low μ, it may be desirable to use two or three strips in parallel and thus increase the actual settings of the μ dial at balance, as well as the sensitivity of balance. The test strips may be cut from a parent sheet with the grain of the metal in any desired direction. The magnetic flux will, of course, be along the long dimension of the strip.

The use of multiple test strips furnishes better average values of the magnetic properties of the test material. However, if the maximum measured μ values of the specimen material are high, it becomes less desirable to use too many multiple test strips, lest the reluctance of the stack leaves becomes a detectable part of the total reluctance of the system. It will be demonstrated subsequently (Section 6.9) that the fractional amount by which the measured μ is less than the true specimen μ is given approximately by:

$$\text{Yoke Error} = 0.15\% \times \frac{\mu_d}{1000}$$

so that the number of test strips of any specimen material may be increased until the μ_d reading at balance reaches 6500 before this error exceeds one per cent.

4.8 SHAPE OF TEST STRIP

The portion of the test strip traversing the interior hole in the yoke leaves must have a constant width (and hence uniform cross-section). However, if the test strip is cut from pre-fabricated transformer core laminations, etc., the portions of the test strip overlapping the annular leaves may have punched holes, rounded corners, etc. without any appreciable detriment to the accuracy of the measurements. If multiple test strips are used they should have approximately the same dimensions.

4.9 MEASUREMENTS AT A SPECIFIED INDUCTION

This equipment was designed to measure the μ and core loss values of the specimen at a given H. If it is desired to obtain these two parameters at a given value of applied B, a sufficient number of points (computing B = μH for each) may be plotted as μ vs B and loss vs B in the neighborhood of the desired B, and the values of μ and loss at the specified induction thus determined by graphical interpolation.

4.10 RELEASE OF SHEARING STRAINS

The magnetic properties of numerous ferromagnetic materials are more or less strain sensitive. It is shown in reference (2) that the fractional change in μ, due to shearing, reaches a maximum at H values somewhat larger than those corresponding to μ_{max}, and becomes relatively insignificant at initial permeability and at high H values.

If a longitudinal shearing operation (not a cross-cut) is required in the preparation of samples for the test yoke, and if absolute magnetic data are desired, it may be advisable to relieve the shearing strains by a suitable metallurgical treatment prior to the measurements. For run-of-the-mill comparison tests, however, (Section 4.1) such a procedure may not be necessary.

4.11 SINUSOIDAL H VS. SINUSOIDAL B

The magnetizing force H may be considered to be the magnetic effort applied to the specimen, while the flux density B may be regarded as the final result attained. It is desirable to test the specimen under conditions corresponding to a sinusoidal variation of either H or B, since both effort and result cannot be sinusoidal simultaneously, due to the non-linear relationship of B and H in ferromagnetic media.

If the solenoid winding around the specimen is energized by the direct application of a sinusoidal emf, then the variation of B will be sinusoidal, provided that the reactance of the solenoid constitutes essentially the entire impedance of the circuit. The current, which will be in quadrature with the applied emf, and the magnetizing force will then contain odd harmonic components of the fundamental frequency. Magnetic measurements made under these conditions definitely require a low loss (high Q) winding and negligible circuit resistance.

In the Type 1670-A Magnetic Test Set, however, a sinusoidal source emf can only be applied to the yoke solenoid in series with a resistance whose value is purposely made very large compared with the non-linear impedance of the solenoid. In this case both the yoke current, which must be in phase with the generator emf, and the magnetizing force must undergo a sinusoidal variation in normal and incremental measurements. The flux density B and the emf induced in the solenoid will now possess odd harmonics of the fundamental frequency. Since the losses in the solenoid winding are appreciable (relatively low Q values) it is easier to keep the solenoid current and the generator emf more closely in phase than in quadrature, so that the second hypothesis, stipulating a sinusoidal effort, was considered desirable for the present equipment.

The sinusoidal nature of the exciting current and applied H can be demonstrated by examining, with a cathode-ray oscillograph, the voltage

:form existing across the CALIB and H-YOKE terminals. Likewise ıination of the voltage waveform existing directly across the two : terminals at higher H values will demonstrate the presence of odd ıonics in the induced emf and flux variation.

Since the cyclic H is to be kept sinusoidal the ratio between its peak .e and its RMS value will be $\sqrt{2}$.

Empirical data given in reference (2) show that, for a certain grade :ilicon steel, the difference between measurements made with sinusoidal nd again with sinusoidal B was quite negligible at low and at high inducıs. The discrepancy reached a maximum of 8% in μ and B and 5% in e loss at the level corresponding to maximum μ.

2 EVALUATION OF HYSTERESIS AND EDDY CURRENT LOSSES

If the resistivity ρ, in ohm-centimeters, of the specimen material is ɔwn, the total core loss P_c given by equation (5) may be divided into its ɔ components due, respectively, to eddy currents and the phenomenon of steresis. The theory of this procedure is given in reference (2) and the :hnique, as applied to this magnetic test set, may be outlined as follows:

Compute the eddy current dissipation factor D_e by the equation:

$$D_e = \frac{395\,\mu\,\delta^2}{\rho \times 10^9} \qquad (12)$$

in which δ is the individual lamination thickness in centimeters and μ is the value obtained in equation (4).

Then the core loss P_e due to eddy currents will be:

$$P_e = \frac{D_e P_c}{D - D_c} \qquad (13)$$

Likewise the core loss P_h due to hysteresis will be:

$$P_h = P_c - P_e \qquad (14)$$

With thin laminations at 60 cycles per second, the eddy current loss (which is proportional to the square of both lamination thickness and frequency) will be a relatively small part of the total core loss. Thus the parameters of equation (12) need to be known with only moderate precision.

Using the numerical data given in Section 3.5 (i.e., $P_c = 0.586$ mw/cc, $\delta = .0191 \times 2.54 = .0485$ cm, $\mu = 4130$, $D - D_c = .663$) and, assuming a resistivity of 60 microhm-centimeters,

$$D_e = \frac{395\,(4130)\,(.0485)^2}{60 \times 10^{-6} \times 10^9} = .064$$

$$\text{Eddy Current Loss} = \frac{.064\,(.586)}{.663} = .057 \text{ mw/cc}$$

$$\text{Hysteresis Loss} = .663 - .057 = .606 \text{ mw/cc}$$

SECTION V

INCREMENTAL MEASUREMENTS OF PERMEABILITY AND CORE LOSS (C.M. CONDITION)

.1 GENERAL

In addition to a sinusoidal component of H, it is sometimes desired to ubject the test specimen simultaneously to a steady direct-current magıetization by superimposing a biasing magnetizing force H_b. The specimen naterial will then be in a cyclically magnetized (CM) condition but will no onger be symmetrically magnetized as in normal measurements (Section 2.1). ;ince the dynamic variation of H is made sinusoidal in this equipment, the ılgebraic mean of the extreme values of the composite magnetizing force vill now be H_b rather than zero. The peak departure of the composite H in either direction from the constant H_b value is designated as the incremental magnetizing force H_Δ, which is identical with the peak value of the sinusoidal component of the composite H. The actual variation of H is thus symmetrical with respect to its static component H_b.

If H_Δ exceeds H_b the composite H will be reversed by unequal amounts on each half-cycle. If H_b exceeds H_Δ the composite H will remain unidirectional and reach a maximum and a minimum value once per cycle of H_Δ.

If the relation between B and H for the specimen material is nonlinear (which is generally the case) the variation of the induction in the CM condition will not be symmetrical about any value. The algebraic mean of the two extreme values of the composite induction is designated as the biased induction B_b, which is different from the static induction which would be produced by the application of H_b alone. One-half of the algebraic difference between the two extreme values is called the incremental induction B_Δ. Due to non-linearity, the time intervals during which the actual induction departs in the opposite directions from the B_b value will be unequal. The actual induction will be alternating in character only when B_Δ exceeds B_b.

The ratio of B_Δ to H_Δ defines the incremental permeability μ_Δ of the specimen material for specific values of H_b and H_Δ. When the value of H_Δ is made vanishingly small the resultant incremental permeability approaches the reversible permeability μ_r for a specific value of H_b and the variation of induction may be assumed to be linear about the B_b value. It will be seen that reversible permeability approaches the value of initial permeability as H_b is also made vanishingly small.

5.2 ADJUSTMENT OF H_b

To obtain a desired biasing H_b the well filtered anode supply for the amplifier of the test set may be employed as a source of d-c emf. Set the TEST SWITCH in the INCREMENTAL position. Between the B^+ terminal post and the yoke terminal post marked H connect an external d-c milliammeter in series with an external adjustable resistor R_e chosen to cover the desired range as indicated in the table. The value of biasing H_b in millioersteds will then be 100 times the value of this biasing direct current I_b in milliamperes.

$$H_b \text{ (millioersteds)} = 100\, I_b \text{ (milliamperes)} \qquad (15)$$

Typical values are cited below:

H_b (DC) Millioersteds	I_b (DC) Milliamperes	External R_e Ohms (approx.)
0	0	
200	2.0	65,000
400	4.0	27,500
600	6.0	15,000
800	8.0	8,800
1000	10.0	5,000
1200	12.0	2,500
1400	14.0	700
1500	15.0	0

Higher values of H_b may be obtained by inserting a 45-volt battery (with short leads and low capacitance to ground) in series into this external circuit, the negative terminal of this battery being joined to the B^+ terminal. The current, however, should not exceed a value of 20 milliamperes (giving a maximum H_b of 2 oersteds).

In incremental measurements the specimen should always be demagnetized initially (Section 4.4) and H_b should be increased from zero up to the desired value by a progressive reduction of the resistance of the external rheostat. If H_b is to be varied for a series of tests it ordinarily should be increased from lower to higher values. Subsequently, to demagnetize the specimen again, reduce H_b to zero, apply a normal H value exceeding the largest H_b previously used and reduce this normal excitation to zero by a slow turning of the H dial, NOT by shutting off the power switch.

5.3 BALANCING THE BRIDGE

Independent of the amount of H_b used (Section 5.2), the incremental magnetizing force H_Δ simultaneously applied to the specimen may be controlled by the H dial and its multiplier switch. For any desired H_b and H_Δ combination, the Maxwell bridge is balanced in exactly the same manner as for normal measurements (Section 2.9), except that the TEST SWITCH must be in the INCREMENTAL position. The data, so obtained, will yield the incremental values of permeability and core loss corresponding to the H_b and H_Δ values chosen.

Certain magnetic materials may exhibit an appreciable memory of their previous history so that, following any change in H_Δ or H_b, a noticeable time interval may elapse before the magnetic domains become stabilized in their new cyclic excursion, thus causing a small drift in the balance of the bridge.

5.4 COMPUTATIONS FOR INCREMENTAL DATA

In making incremental measurements the simple Maxwell bridge was modified in two ways, which require correction factors for the data obtained as analyzed in reference (1). Throwing the TEST SWITCH to the INCREMENTAL position inserts a capacitor into one of the bridge arms, so that the simple bridge equations no longer apply. The yoke arm of the bridge now consists of the yoke winding shunted by a resistance which is 10,000 ohms plus whatever external resistance is used to adjust H_b. The exact equations to allow for these modifications become quite cumbersome, but, by making certain valid assumptions, the following procedure may be used.

5.4a Compute the function

$$\beta = \frac{\omega L_s I_b}{10^3 E} = \frac{14.48\ \mu_d I_b}{10^6 E} \tag{16}$$

wherein μ_d is the μ dial value (Paragraph 3.2c) and I_b is the biasing current in milliamperes. If the internal biasing source is used alone, E will have a value of 150 volts, so that:

$$\beta = \frac{9.65\ \mu_d I_b}{10^8} \tag{16a}$$

If an external emf is added, E in (16) should equal 150 plus this added value.

5.4b In terms of β and Δ compute the two functions:

$$\alpha = 1 + \beta^2 + \frac{\beta}{1.5\Delta}\left(2 + \frac{\beta}{1.5\Delta}\right) \tag{17}$$

$$\gamma = 1 + \frac{\beta}{1.5\Delta} + 1.5\Delta\beta \tag{18}$$

5.4c Using Table IV, for the specific value of Δ determine the corresponding values of the two functions σ and θ.

5.4d Then compute the dissipation factor of the yoke winding from the equation:

$$D = \frac{\theta}{\gamma} \tag{19}$$

5.4e Compute the <u>modified</u> μ dial value

$$\mu'_d = \alpha\sigma\left[\mu_d \text{ (as read)}\right] \tag{20}$$

5.4f Using Table I, for the specific value of Δ record the corresponding values of η and U (but NOT the value of D).

5.4g Substituting μ'_d for μ_d in Table II, record the corresponding value of D_c.

5.4h Next evaluate the difference D - D_c and from Table III obtain the corresponding values of S and T.

5.4i Compute the two ratios η/S and μ'_d/A'.

Finally, using these modified values, proceed as in Section 3.4 using equations (3) to (9) inclusive to obtain the <u>incremental</u> instead of the normal parameters H, μ, P_c, B, and ϕ.

5.5 TYPICAL COMPUTATION WITH INCREMENTAL DATA

Suppose that, using the internal biasing voltage alone, the specimen described in Section 3.5 had given the same bridge data in the presence of a biasing current of 12 milliamperes, so that H_b = 1.2 oersteds. Then:

$A' = 9.22 \quad \mu_d = 2650 \quad mH_d = 465 \quad (mH_d)^2 \times 10^{-9} = 2.16 \times 10^{-4}$

For $\Delta = .92$ $\begin{cases}\eta = .975 \\ \theta = .685\end{cases}$ $\quad U = 14.26$ (Table I) $\quad \sigma = 1.052$ (Table IV)

$$\beta = \frac{9.65(2650)12}{10^8} = .00307$$

$1.5\Delta = 1.38 \qquad \beta/1.5\Delta = .00222$

$$\alpha = 1 + .000009 + .00222\ (2.002) = 1.0045$$

$$\gamma = 1 + .00222 + 1.38\ (.00307) = 1.0065$$

$$D = \frac{.685}{1.0065} = .681$$

$\mu'_d = 1.0045\ (1.052)\ 2650 = 2800$ hence $D_c = .059$ (Table II)

$D - D_c = .681 - .059 = .622$ hence $S = 1.177$, $T = 13.87$ (Table III)

$$\eta/S = .975/1.177 = .828 \qquad \mu'_d/A' = \frac{2800}{9.22} = 304$$

Equation (3) Incremental H = .828 (465) = 385 millioersteds.
Equation (4) Incremental μ = 13.87 (304) = 4216.
Equation (5) Incremental loss = 14.26 (304) (.622) 2.16 x 10^{-4} = .582 milliwatts per cubic centimeter.
Equation (6) Incremental B = 4216 (.385) = 1623 gausses.
Equation (7) Incremental B = .975 (1.177)(304)(465) x 10^{-2} = 1623 guasses.
Equation (8) Incremental $\hat{\phi} = \frac{9.22}{100}(1623)$ = 149.5 maxwells.
Equation (9) Incremental $\hat{\phi}$ = .975 (1.177)(2800) 465 x 10^{-4} = 149.5 maxwells.

5.6 COMPARATIVE INCREMENTAL MEASUREMENTS

For comparative measurements (Section 4.1) between two similar specimens subjected to the same H_b and H_d values, the simple equations (10) and (11) may be used to obtain the corresponding incremental μ and core-loss ratios.

SECTION VI
THEORY OF THE TEST SET

6.1 YOKE GEOMETRY

In order to simplify the electromagnetic relationships involved, the ferromagnetic path will be considered to be homogeneous in character, to be continuous with an effective length of λ centimeters, to have a constant cross-section of A square centimeters, and to contain, with uniform distribution, all of the flux produced, thus having no magnetic leakage. The yoke leaves are made of a material having a high permeability at relatively low flux densities and, by using a sufficient number of these leaves per test strip, the effective cross-section of the two-way return path in the yoke becomes large compared to the cross-section of the test sample. Consequently, no appreciable error is introduced in assuming the entire reluctance of the magnetic system to be the reluctance of the test sample, which may consist of one or more test strips. The effective length λ of the magnetic path is somewhat greater than the diameter of the hole in the test leaves, Section 1.2. The validity of these assumptions has been checked by measurements of individual test strips and of their parallel combination.

For interpolation at extreme values of Δ use the equations:

$$\sigma = 1 + \frac{1}{0.1 + 22.5\ \Delta^2}$$

$$\theta = \frac{\Delta}{.0733 + 1.5\ \Delta^2}$$

6.2 STATIC MAGNETIZATION

Under these conditions, if the yoke coil having N turns carries a steady current of I amperes, there will be created at each point in the effective portion of the test strip a static magnetizing force:

$$H = \frac{4\pi NI}{10\lambda} \tag{21}$$

measured in oersteds, and a static flux density or magnetic induction:

$$B = \frac{\phi}{A} \tag{22}$$

measured in gausses. Regarded as a vector, the flux density has two component parts:

$$\underline{B} = C\,\underline{H} + 4\pi\,\underline{J} \tag{23}$$

.ely the magnetization J (measured in gausses) and the field intensity H asured in oersteds and numerically equal to the magnetizing force H), hat the constant C has the dimensions gauss/oersted and a value of unity :e, in this case, the three vectors B, H, and J are mutually parallel, nce C becomes the permeability of free space. The product CH is the :e induction, while $4\pi J$ is the intrinsic induction which is zero in all -magnetic media and has a saturable positive value in ferro-magnetic lia.

The ratios of the scalar values:

$$\mu = \frac{B}{H} \tag{24}$$

$$\text{and } \kappa = \frac{J}{H} \tag{25}$$

ne the static or direct-current permeability and susceptibility of the cimen material and are related by the equation:

$$\mu = 1 + 4\pi\kappa \tag{26}$$

The magnetic linkage of the system, assumed complete, will be $N\phi$, hat the static inductance L of the yoke winding in henries or weber- ıs per ampere (one weber equals 10^8 maxwells of flux) becomes $N\phi/10^8 I$.

Substitution of $\phi = BA$ from (22) and $I = 10H\lambda/4\pi N$ (21) then yields:

$$L = \frac{N\phi}{10^8 I} = \frac{4\pi N^2 BA}{10^9 H\lambda} = \frac{4\pi N^2 \mu A}{10^9 \lambda} \tag{27}$$

ınce the static permeability of the specimen material may be determined n the static inductance of the winding and the geometry of the specimen:

$$\mu = \frac{10^9 \lambda L}{4\pi N^2 A} \tag{28}$$

ıe core of the inductor is composed of ferromagnetic material, and thereby ibits the phenomen of hysteresis, the static values of ϕ, B, μ, κ, and L ı, at any time, depend upon the previous magnetic history of the material.

The Type 1670-P1 Test Yoke was purposely wound with N = 384 turns that the ratio:

$$4\pi N/10\lambda = 100 \tag{29}$$

ing:

$$H = 100I \tag{21a}$$

:

$$\mu = \frac{10^6 L}{NA} = \frac{10^8 L}{384 A' (\text{sq. mm.})} \tag{28a}$$

NORMAL MAGNETIZATION

If the steady current in the yoke winding is replaced by a sinusoidal rent, the instantaneous values of B will follow the contour of the well- ıwn hysteresis loop and the magnetic parameters will acquire a dynamic nificance. The specimen will then be in an SCM (symmetrically cycli- ly magnetized) condition and will exhibit a specific normal permeability ependent of previous magnetic history. While this dynamic normal meability may differ somewhat from a static permeability corresponding he same peak values of the applied H, both the static and normal μ ues will undergo essentially similar variations as the magnetizing ce is increased.

INCREMENTAL MAGNETIZATION

If the specimen material is brought, by a direct current biasing H_b, ıny specific degree of magnetization and then subjected simultaneously ı cyclic excursion by means of a superimposed alternating current, an M condition will no longer exist, so that the instantaneous B values will ce a displaced hysteresis loop and the dynamic parameters will have incremental significance and again be independent of previous magnetic tory. The specimen will now be in a CM (cyclically magnetized) condition.

EVALUATION OF NORMAL H

The H dial, of necessity, is calibrated in terms of the total peak cur- ıt $\hat{I}$ supplied to the bridge when the supply line is adjusted to 115 (or 230) ts. The peak exciting current $\hat{I}_{exc}$ actually supplied to the yoke winding h any line voltage is:

$$\hat{I}_{exc}(\text{ma}) = m\eta\hat{I} = \frac{m\eta H_d}{100} \tag{30}$$

wherein H_d is the peak value in millioersteds, evaluated in terms of the full exciting current. In reference (2) it is demonstrated that the true magnetizing component $\hat{I}_m$ of $\hat{I}_{exc}$ is given by:

$$\hat{I}_m = \frac{\hat{I}_{exc}}{S} = \frac{m\eta H_d}{100\,S} \tag{31}$$

$$\text{wherein} \quad S = \sqrt{1 + (D - D_c)^2} \tag{32}$$

Substituting $\hat{I}_m$ from (31) into (21a) gives the working equation (3) for normal H.

6.6 EVALUATION OF NORMAL μ

At balance the setting of the μ dial of the Maxwell bridge is proportional to the series inductance L_s of the yoke. The μ dial, of necessity, is thus calibrated in terms of L_s by equation (48) on the arbitrary assumption of a specimen cross section of 10 sq. mm. Hence from (28a):

$$\mu_d = \frac{10^7 L_s(\text{Henries})}{384} \tag{33}$$

For any specimen cross-section A' (in sq. mm) in a 384-turn yoke the corresponding psuedo a-c permeability of the specimen will be:

$$\mu_s = 10\left(\frac{\mu_d}{A'}\right) \tag{34}$$

Now in reference (2) it is demonstrated that the true normal permeability equals μ_s increased by the factor $\left[1 + (D - D_c)^2\right]$. Consequently, by defining the function:

$$T = 10\left[1 + (D - D_c)^2\right] \tag{35}$$

we obtain the working equation (4) for normal permeability.

6.7 THE DISSIPATION FACTORS

The setting of the Δ dial at balance is inversely proportional to the dissipation factor D of the yoke and is calibrated from equation (49) in conjunction with equation (2). By definition:

$$D = \frac{R_s}{\omega L_s} \tag{36}$$

wherein R_s is the total series (a-c) resistance representing all the losses in the yoke.

By definition the copper loss dissipation factor is:

$$D_c = \frac{r}{\omega L_s} \tag{37}$$

wherein r is the portion of R_s representing the copper loss of the yoke winding. At the low frequency of 60 cycles r may be taken to be the d-c resistance of this winding, a value which is marked on the bottom of the yoke assembly.

Substituting $\omega = 377$ (at 60 cycles) and L_s from (33) into (37):

$$D_c = \frac{10^9 \lambda r}{4\pi N^2 A \mu_s \omega} = \frac{69.1 r}{\mu_d} \tag{38}$$

The working equations involve only the difference $D - D_c$, and since D_c is a relatively small portion of D, a nominal value of 2.40 ohms for r was substituted into (38) to obtain the data of Table II.

6.8 EVALUATION OF CORE LOSS

The total core loss (hysteresis and eddy currents) is given by:

$$P_c(\text{in watts}) = \frac{\hat{I}_{exc}^2}{2}(R_s - r) \tag{39}$$

since I_{exc} has been made sinusoidal in this test set. The effective magnetic volume of the specimen is $\lambda_{cm} \times A_{sq.cm}$. Substituting R_s from (36) and r from (37) into (39):

$$\frac{\text{milliwatts}}{\text{cubic centimeter}} = \frac{\left[\hat{I}_{exc}(\text{in amp})\right]^2 \pi f L_s (D - D_c) \times 10^3}{\lambda A\ (\text{in sq. cm})} \tag{40}$$

Substituting λ from (29), $\hat{I}_{exc}$ from (30) and L_s from (33) into (40):

$$\frac{\text{milliwatts}}{\text{cubic centimeter}} = \frac{(m\eta H_d)^2 f \mu_d (D - D_c) \times 10^{-11}}{4\ A\ (\text{sq. cm})} \qquad (41)$$

Finally, by replacing A in sq. cm by 10^{-2} x A' in sq. mm and introducing the function:

$$U = \frac{f\eta^2}{4} = 15\eta^2 \text{ at 60 cycles} \qquad (42)$$

into (41), we obtain the working equation (5) for core loss.

6.9 NEGLIGIBILITY OF RETURN PATH RELUCTANCE

The negligibility, in general, of the reluctance of the return path core $\mathcal{R}_c$, comprising the annular high-permeability leaves used in the test yoke, can be demonstrated by use of equation (34). The reluctance of the test specimen, in terms of μ_s, is given by:

$$\mathcal{R}_x = \frac{\lambda}{\mu_s A(\text{sq. cm})} = \frac{4\pi N^2}{10^9 L_s} \qquad (43)$$

which, for a given μ-dial setting (L_s value) is proportional to N^2. Combining this with (34), for the 384-turn yoke:

$$\mathcal{R}_x = \frac{10\lambda}{\mu_d} = \frac{48.25}{\mu_d} \qquad (44)$$

Since the maximum value of μ_d is about 26,000 corresponding to a maximum L_s of 1 henry, the minimum reluctance which the test specimen can possess is:

$$\text{Min}\mathcal{R}_x = \frac{4\pi N^2}{10^9} = .00185 \text{ mag. ohms}$$

The individual core leaves have a thickness of 0.0188 inches, a radial width of 0.875 inches (2.22 cm), a mean diameter of 2.625 inches (6.66 cm), and hence a mean circumference of 20.93 cm. There are a total of 50 of these leaves forming a stack height of 0.940 inches (2.39 cm) and thus giving a cross-section of the core of 5.31 sq. cm. If μ_c is the permeability of the core leaves, the reluctance of the core, considered separately as a toroid, will be $20.93/5.32\,\mu_c$, or $3.94/\mu_c$. It should be evident, however, that the reluctance of the return flux path in the yoke core (two semicircular paths in parallel) will be only about one-fourth of the above value and hence given approximately by the reciprocal of μ_c. Hence, taking the minimum (initial) value of μ_c as 13,000, the maximum reluctance of the return path would be:

$$\text{Max}\ \mathcal{R}_c = 0.000077 \text{ mag. ohms}$$

Thus the extreme case when μ_d at balance is 26,000 would yield a minimum value of the ratio:

$$\frac{\mathcal{R}_x\,(\text{minimum})}{\mathcal{R}_c\,(\text{maximum})} = \frac{0.00186}{0.000077} = 24.2$$

indicating that the measured μ_d would be only about 4% less than the value corresponding to the actual μ_s of the specimen.

It will be seen that this low-reading "yoke error" is directly proportional to the μ-dial reading at balance, regardless of the geometry and permeability of the test specimen, and is approximately given by:

$$4\% \times \frac{\mu_d}{26{,}000} = 0.15\% \times \frac{\mu_d}{1000}$$

Correction for the yoke error may thus be made by the equation:

$$\text{Corrected } \mu_d = (1 + .0000015\mu_d)(\mu_d \text{ observed}) \qquad (45)$$

In most cases this correction is less than the precision with which A' is known and hence negligible.

This analysis ignores the existence of any air-gap reluctance, a procedure which is valid to a first approximation since the stack is compressed at the area of contact between specimen and test leaves.

6.10 THE BRIDGE EQUATIONS AND DIAL CALIBRATIONS

A maxwell bridge, shown schematically in Figure 1, is used for measuring the dynamic parameters L_s and Q of the yoke solenoid. The fixed resistor R_b has a value of 100 ohms while the capacitor C_a is chosen to be one microfarad.

When the bridge is balanced:

$$L_s = (C_a R_b) R_n = 10^{-4} R_n \qquad (46)$$

$$Q = \omega C_a R_a = 10^{-6}\omega R_a = \frac{1}{D} \qquad (47)$$

in which L_s is the series inductance of the yoke winding and is proportional to the single variable R_n, while Q is proportional to the single variable R_a.

Eliminating L_s from equations (33) and (46) we obtain:

$$\mu_d = \frac{10^3 R_n}{384} = 2.605 R_n \qquad (48)$$

for calibrating the μ dial in terms of the measured resistance R_n.

Eliminating D from equations (2) and (47) at a frequency of 60 cycles gives:

$$\Delta = \frac{2\omega R_a \times 10^{-6}}{3} = 80\pi R_a \times 10^{-6} = .0002513 R_a \qquad (49)$$

for calibrating the Δ dial in terms of measured values of the resistance R_a.

The calibration of the H dial is made by placing a vacuum-tube voltmeter across the CALIB and the Yoke H terminals so that it measures the sinusoidal voltage drop in the 1000-ohm series resistor R_{30} and, hence, the peak alternating current I in milliamperes flowing to the bridge. The calibration of the H dial is then made on the basis of 100 millioersteds per peak volt of the vacuum-tube voltmeter reading with a standardized supply line of 115 volts.

The H dial is calibrated from zero to 60 millioersteds, peak values in terms of the full exciting current. The multiplier switch permits a tenfold and a one hundred-fold increase of this dial range, thus providing any normal or incremental magnetizing force up to 6 oersteds. This switch gives three separate values to the step-up ratio of the transformer T-3, interposed between the Variac T-2 and the bridge circuits, and thus controls the applied E and the bridge current by decade steps.

6.11 AUXILIARY BRIDGE COMPONENTS

The large series resistance R_{29} serves two purposes:

(1) To keep the test yoke current and the applied emf E in phase and the former devoid of harmonics (see Section 4.11).

(2) With the proper choice of the fixed parameters R_b and C_a, to make the exciting current nearly independent of any changes in the impedance of the yoke winding, so that the factor η approximates unity as closely as possible.

In order to make this test set capable of incremental measurements an additional capacitor C_a' must be added to the Maxwell bridge circuits as indicated in Figure 2. This, together with C-1 and C-15, insures the passage of all the applied direct current through the yoke winding provided that the TEST switch is open (INCREMENTAL position). R-37 is an internal protective resistor and E' the internal source of d-c emf. For incremental measurements an external rheostat R_e and milliammeter measuring the biasing current I_b must be added as shown.

6.12 MEASUREMENT OF OTHER INDUCTORS

In addition to its intended use, this test set is satisfactory for the measurement of any other inductor, with or without d-c polarization, provided that its series inductance does not exceed one henry and its 60-cycle Q value is less than about 13.5. When the bridge is balanced, from equation (33):

$$L_s\ (\text{microhenries}) = 38.4\mu_d \qquad (50)$$

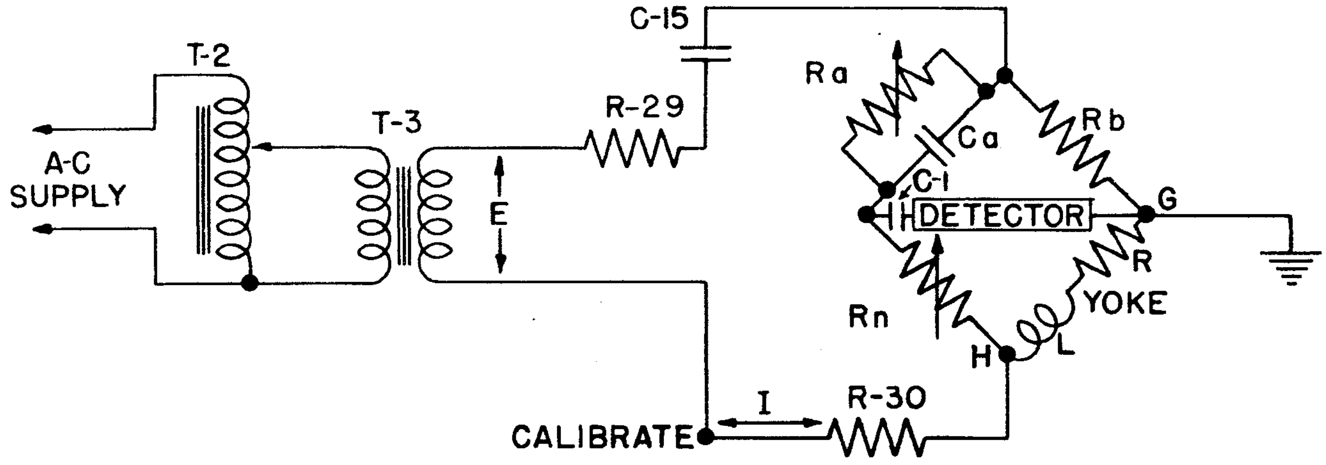


FIG. 1

THE MAXWELL BRIDGE ADAPTED FOR NORMAL MEASUREMENTS

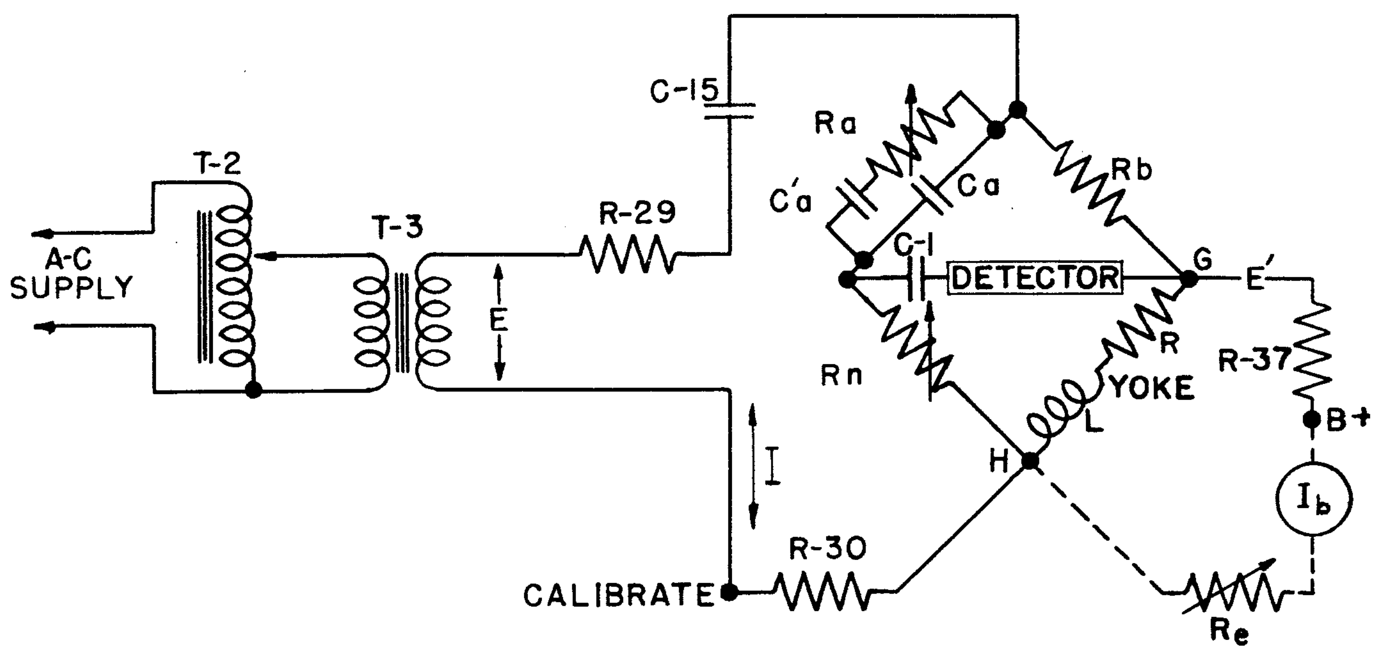


FIG. 2

THE MAXWELL BRIDGE AMENDED FOR INCREMENTAL MEASUREMENTS

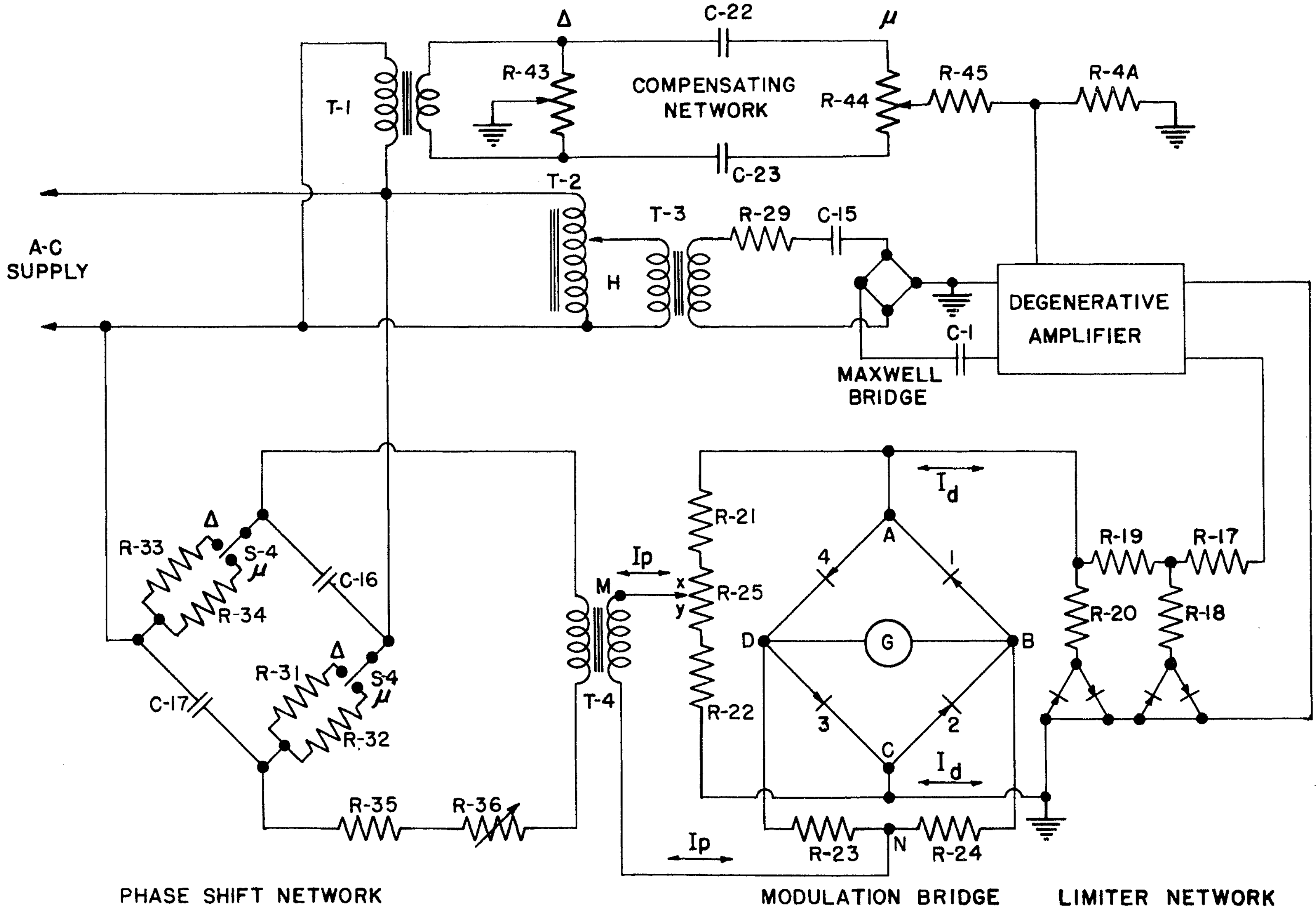


FIG. 3

THE NULL DETECTOR SYSTEM

equation (2):

$$Q = \frac{1}{D} = 1.5\Delta \qquad (51)$$

:OMPENSATING THE DETECTOR UNDER CERTAIN CONDITIONS

: procedure outlined in Section 2.4 removes any bridge errors due magnetic pickup from the power transformer into the Maxwell rcuits. This pickup is independent of the impedance of the yoke asured and of the voltage applied to the bridge. Small terminal ices existing in the bridge transformer may result in minute currents in the yoke arm of the bridge. These spurious currents rectly proportional to the voltage applied to the bridge trans- .e., the reading of the H-dial, but independent of the setting of the r switch.

he impedance of the yoke being measured is relatively high, so ridge balances with the μ dial set near the upper end of its scale ce approaching one henry), these spurious currents may cause the l parameters of the yoke to differ from their true values by as two percent in extreme cases. These errors can be present only iditions that the bridge is balanced with both the H and μ dials set ier regions of their scales and with the H-MULTIPLIER switch X-1 position, which makes the spurious currents an appreciable n of the relatively small bridge current through the yoke. On the d, when the bridge is balanced with the H-MULTIPLIER switch ier the X-10 or X-100 position, the normal bridge current, for g of the H dial, is so large compared with these spurious cur- . any errors due to the latter become totally negligible.

If and when such errors exist, they may be eliminated by the following procedure:

(1) Using the H-MULTIPLIER switch at X-1, set the H dial as desired and balance the Maxwell bridge as directed in Section 2.9.

(2) Shift the H-MULTIPLIER switch to the ZERO position, but do NOT change the settings of the H, μ, and Δ dials.

(3) If the galvanometer remains accurately centered, no detectable errors exist and the data obtained in step (1) above are valid.

(4) If step (2) above causes the galvanometer to go off zero, recompensate the detector by the procedure of Section 2.4 except that the H-dial is left in its original position used in step (1).

(5) Then return the H-MULTIPLIER switch to the X-1 position and rebalance the Maxwell bridge by slight readjustments of the μ and Δ dials.

(6) If detectable errors exist, a subsequent change of the applied H by a displacement of the H dial may require a new compensation of the detector.

CAUTION: Do not be concerned if, having balanced the Maxwell bridge with the H-MULTIPLIER switch in either the X-10 or X-100 positions, the galvanometer lacks perfect compensation (when the H-MULTIPLIER switch is alone returned to zero) provided that the galvanometer needle does become centered when the H dial is also returned to zero.

SECTION VII
THE NULL-BALANCE DETECTOR SYSTEM

:RAL

null detector used in balancing this Maxwell bridge requires a itivity for measurements at low values of H, approaching either reversible permeability, and a considerable degree of frequency at larger values of H in order to eliminate any response to the s of emf inherently introduced by the nonlinear characteristic of nagnetic specimen. These two prime requisites are met by the egenerative amplifier interposed between the Maxwell bridge and or elements.

:NERATIVE AMPLIFIER

s four-stage amplifier utilizes two twin triodes, Type 6C8G, the : stages being direct-coupled and rendered selective by a degen- sistance-capacitance feedback network designed to give zero transmission at the fundamental frequency used (ordinarily 60 The anode voltage supply contains a full-wave rectifier, Type an R-C filter network which as a regulator tube for one of its ients (see the complete wiring diagram). The amplifier is pre- : two-step attenuator which is controlled by the AMP. GAIN i.

:ER

output of the amplifier can be passed through a twin L-pad twork. Each shunt arm of this network contains two copper- ifier elements in parallel and oppositely directed so that they joint rectifying action. However, their impedance decreases nount of voltage impressed upon them so that the network pre- ttenuation which increases with the amplifier output signal.

ADJUSTING NETWORK

re 3 shows how a 3-volt, 60-cycle signal is applied to a compen- 'ork comprising R-43, R-44, C-22, and C-23 which is, in reality, ced capacitance bridge. Adjustment of the two potentiometers l-44, which are, respectively, the Δ and μ ZERO ADJ. controls, to the amplifier, through the 500 to 1 attenuator R-45 and R-4, mpensating voltage of adjustable magnitude and phase to be used pose described in Paragraph 2.4a.

LATION BRIDGE

re 3 also shows how an a-c polarizing signal I_p is obtained from line through a phase shift network and an isolation transformer eans of the BALANCE switch S-4, the phase of this polarizing :rred to the supply line and, hence, to the signal applied to the Maxwell bridge) may alternately be set at two appropriate values ϕ_μ and ϕ_Δ. This polarizing signal is applied in the manner indicated to all four corners of the modulation bridge, which consists of four copper-oxide rectifier elements directed as shown. When this modulation bridge is balanced by means of the two internal controls R-25 and R-36, no response is produced in the d-c galvanometer G by the signal I_p acting alone upon the modulation bridge. The procedure for adjusting this polarizing voltage has been given in Section 2.3

7.6 THEORY OF THE MODULATION BRIDGE

The detector signal I_d from the limiter is applied to the opposite corners A and C of the modulation bridge. In the absence of a polarizing signal I_p, the detector signal I_d per se would produce no galvanometer response. Such a response can be obtained only if both I_p and I_d are applied simultaneously and then only if I_d has a component which is in phase (or 180° out of phase) with I_p. The amount of galvanometer deflection will then depend upon the magnitude of this particular component of I_d.

Now, in general, I_d will have two components, I_μ and I_Δ, with phases θ_μ and θ_Δ, which are due, respectively, to incorrect settings of the μ and Δ dials of the Maxwell bridge. The elements of the phase shift network could be so chosen that the rotating vectors defining ϕ_μ and θ_μ are coincident, while the vectors defining ϕ_Δ and θ_Δ likewise coincide. Then, when using an I_p with the phase ϕ_μ the galvanometer response would depend only upon the component I_μ of I_d, and thus be controlled by the operation of the μ dial only and be brought thereby to a zero value independent of the magnitude of the I_Δ component of I_d. Subsequently, shifting the phase of I_p to ϕ_Δ the galvanometer would be sensitive only to the I_Δ component of I_d, and hence respond only to the manipulation of the Δ dial of the Maxwell bridge. This action gives the convenient selective feature of this null detecting system.

Since the phases θ_μ and θ_Δ depend upon the inductance and resistance of the test yoke, this selectivity will not be perfect under all conditions since fixed values of ϕ_μ and ϕ_Δ are used, but it will be sufficiently pronounced to be a distinct help in obtaining quick balances of the Maxwell bridge. The values of ϕ_μ and ϕ_Δ have been set at the best compromise values and give optimum results over the working range.

Because the phase of either component I_μ or I_Δ of I_d shifts through 180° as the corresponding control is turned through the balance point, the direction of the net rectified current through G will reverse as this current is made to pass through a zero value. The deflection of the galvanometer needle will then give an indication of which way that particular control is off balance. This is the directional feature of this a-c null detector and corresponds to a like feature inherent in the D'Arsonval galvanometer used with any d-c bridge.

The modulation bridge has another advantageous feature. The signals I_p and I_d have the same fundamental frequency. If I_d should have even harmonics of this fundamental which are not present in I_p they would produce absolutely no response in the galvanometer, regardless of their phase. Furthermore, the galvanometer response to any odd harmonics in I_d would be greatly attenuated due to the characteristics of the modulation bridge. This attenuation of odd harmonics depends upon phase relationships and in these circuits is of the order of 20 db for the 3rd harmonic (180 cps). This selectivity augments that of the regenerative amplifier in eliminating the prominent odd harmonics produced by the non-linear characteristics of the test specimen in the yoke and permitting the Maxwell bridge to be balanced in terms of the fundamental frequency alone.

It has been found that a given galvanometer, used in this manner in a modulation bridge, has a considerably greater sensitivity of response to I_d signals than when used in the conventional non-selective and non-directional rectifier bridge employing the same four rectifier elements oriented to produce a direct rectification of I_d through G. This additional sensitivity augments the inherent gain of the amplifier and permits measurements at lower values of H.

PARTS LIST

RESISTORS

R-1	=	0.1	MΩ	±10%	IRC	BT-1
R-2	=	0.1	MΩ	±10%	IRC	BT-1
R-3	=	10	kΩ	±10%	IRC	BT-1
R-4	=	2200	Ω	±10%	IRC	BW-1
R-5	=	470	Ω	±10%	IRC	BW-1
R-6	=	10	kΩ	±10%	IRC	BT-1
R-6A	=	20	kΩ	±10%	G.R.Co.	POSC-11
R-7	=	1	MΩ	±10%	IRC	BT-1
R-8	=	470	kΩ	±10%	IRC	BT-1
R-9	=	220	kΩ	±10%	IRC	BT-1
R-10	=	22	kΩ	±10%	IRC	BT-1
R-10A	=	20	kΩ	±10%	G.R.Co.	POSC-11
R-11	=	2700	Ω	±10%	IRC	BW-1
R-12	=	1	MΩ	±10%	IRC	BT-1
R-13	=	0.1	MΩ	±10%	IRC	BT-1
R-14	=	59	kΩ	±1/4%	IRC	WW-3
R-14A	=	1200	Ω	±5%	IRC	POSW-6
R-15	=	59	kΩ	±1/4%	IRC	WW-3
R-15A	=	1200	Ω	±5%	IRC	POSW-6
R-16	=	29,500	Ω	±1/4%	IRC	WW-3
R-16A	=	600	Ω	±5%	IRC	POSW-6
R-17	=	3300	Ω	±10%	IRC	BT-1
R-18	=	4700	Ω	±10%	IRC	BT-1
R-19	=	3300	Ω	±10%	IRC	BT-1
R-20	=	10,000	Ω	±10%	IRC	BT-1
R-21	=	1000	Ω	±5%	IRC	BW-1
R-22	=	1000	Ω	±5%	IRC	BW-1
R-23	=	200	Ω	±5%	IRC	BW-1
R-24	=	200	Ω	±5%	IRC	BW-1
R-25	=	100	Ω	±10%	G.R.	POSW-862
R-26	=	100	Ω	±1/4%	IRC	WW-4
R-27	=	10	kΩ	±10%	G.R.	371-411
R-28	=	35	kΩ	±10%	G.R.	371-407
R-29	=	20	kΩ	±5%	IRC	
R-30	=	1000	Ω	±1/4%	IRC	WW4
R-31	=	270	Ω	±10%	IRC	BW-2
R-31A	=	1200	Ω	±5%		POSW-4
R-32	=	3300	Ω	±10%	IRC	BW-2
R-32A	=	5000	Ω	±5%		POSW-5
R-33	=	270	Ω	±10%	IRC	BW-2
R-33A	=	1200	Ω	±5%		POSW-4
R-34	=	3300	Ω	±10%	IRC	BW-2
R-34A	=	5000	Ω	±5%		POSW-5
R-35	=	47	kΩ	±10%	IRC	BT-1
R-36	=	50	kΩ	±20%	G.R.	POSC-860
R-37	=	10	kΩ	±5%	Continental	Type X-5
R-38	=	100	Ω	±10%	G.R.	POSW-862
R-39	=	1500	Ω	±10%	IRC	BW-2
R-40	=	1500	Ω	±10%	IRC	BW-2
R-41	=	1500	Ω	±10%	IRC	BW-2
R-42	=	470	Ω	±10%	IRC	BW-1
R-43	=	50	kΩ	±20%		POSC-871
R-44	=	50	kΩ	±20%		POSC-871
R-45	=	1	MΩ	±10%	IRC	BT-1/2

CAPACITORS

C-1	=	0.04	μf	±10%	Dub.	Type 4
C-2	=	0.04	μf	±10%	Dub.	Type 4
C-3	=	0.04	μf	±10%	Dub.	Type 4
C-4	=	0.0025	μf	±10%	Dub.	Type 4
C-5	=	0.045	μf	+0%, -4%	Dub.	Type 4ST
C-6	=	0.045	μf	+0%, -4%	Dub.	Type 4ST
C-7	=	0.090	μf	+0%, -4%	Dub.	Type 4ST
C-8	=	40	μf			
C-9	=	40	μf		G.R.	COEB-15
C-10	=	40	μf			
C-11	=	40	μf			
C-12	=	1	μf	±10%	G.R.	COL5
C-13	=	1	μf	±1/2%	G.R.	COL-32
C-14	=	10	μf	+20%, -0%	G.R.	COW-12
C-15	=	4	μf	±10%	G.R.	COL8
C-16	=	1	μf	±2%	G.R.	COL-4
C-17	=	1	μf	±2%	G.R.	COL-4
C-18	=	40	μf			
C-19	=	40	μf		G.R.	COEB-15
C-20	=	40	μf			
C-21	=	40	μf			
C-22	=	0.04	μf	±10%	Dub.	Type 4
C-23	=	0.04	μf	±10%	Dub.	Type 4

MISCELLANEOUS

T-1	=	365-425 Transformer
T-2	=	200B-400 Variac
T-3	=	485-431 Transformer
T-4	=	345-436 Transformer
P-1	=	Pilot light 6.3 v 2LAP-939
S-1	=	D.P.S.T. Switch SWT-333-NP
S-2	=	S.P.4.T Switch ZSWR-2
S-3	=	D.P.D.T. Switch SWT-335-NP
S-4	=	D.P.D.T. Switch SWT-335-NP
S-5	=	D.P.D.T. Switch SWT-335-NP
S-6	=	S.P.D.T. Switch SWT-320-NP
S-7	=	S.P.S.T. Switch SWT-323-NP
S-8	=	S.P.S.T. Switch (Normally open) SWP-6
S-9	=	S.P.S.T. Switch (Normally closed) SWP-7
GR-1	=	Modulation Bridge (made from 2 matched 492-A elements)
GR-2	=	Rectifier elements of Limiter (492 elements). Tie together DC (+ -) terminals to give common grounded junction.
M-1	=	Meter 588-306-A

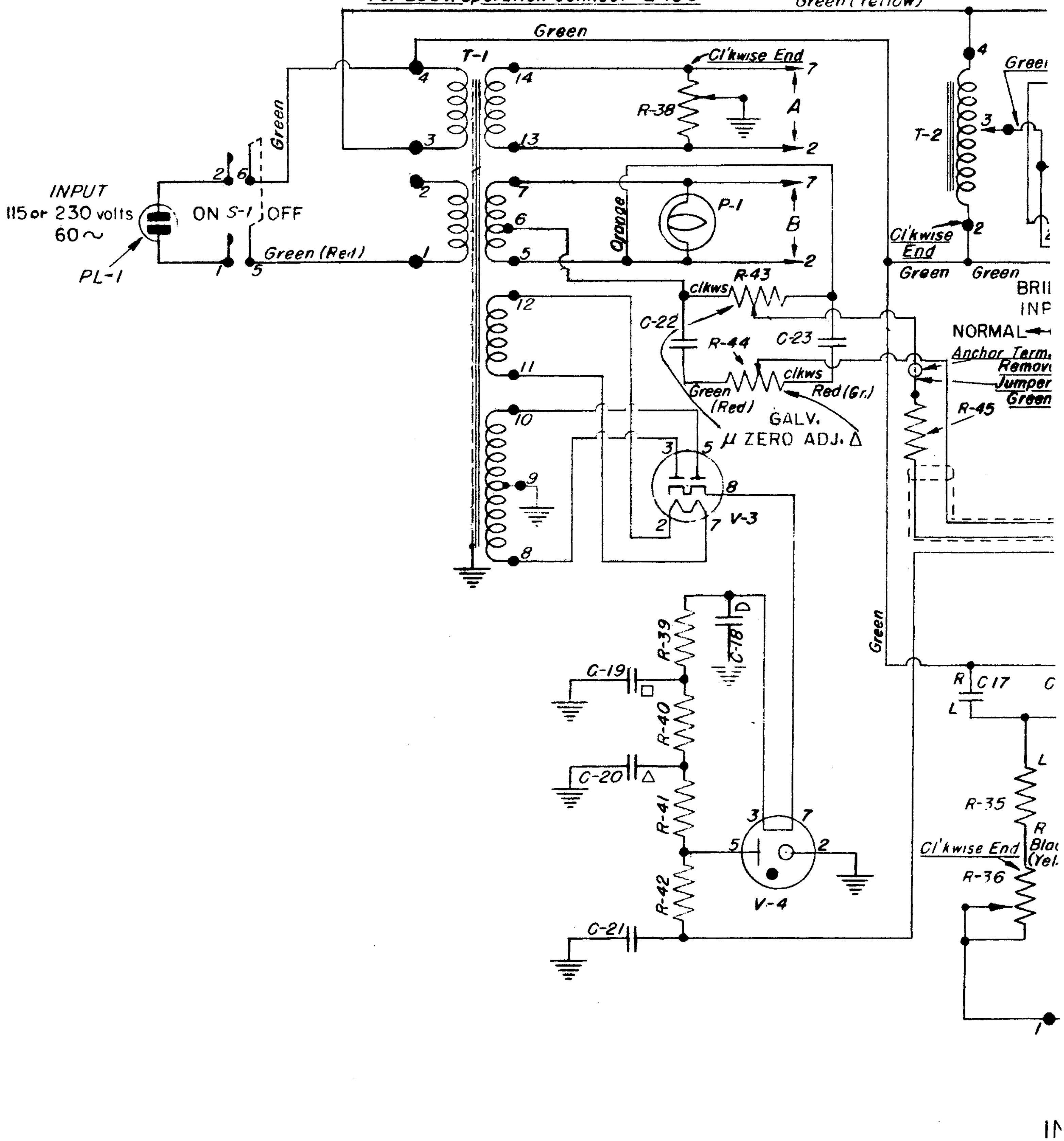
TUBES

V-1	=	RCA	Type 6C8G
V-2	=	RCA	Type 6C8G
V-3	=	RCA	Type 6X5G
V-4	=	RCA	Type 0D3-VR-150

Note for T-1:

For 115v. operation connect 1 to 3 & 2 to 4

For 230v. operation connect 2 to 3



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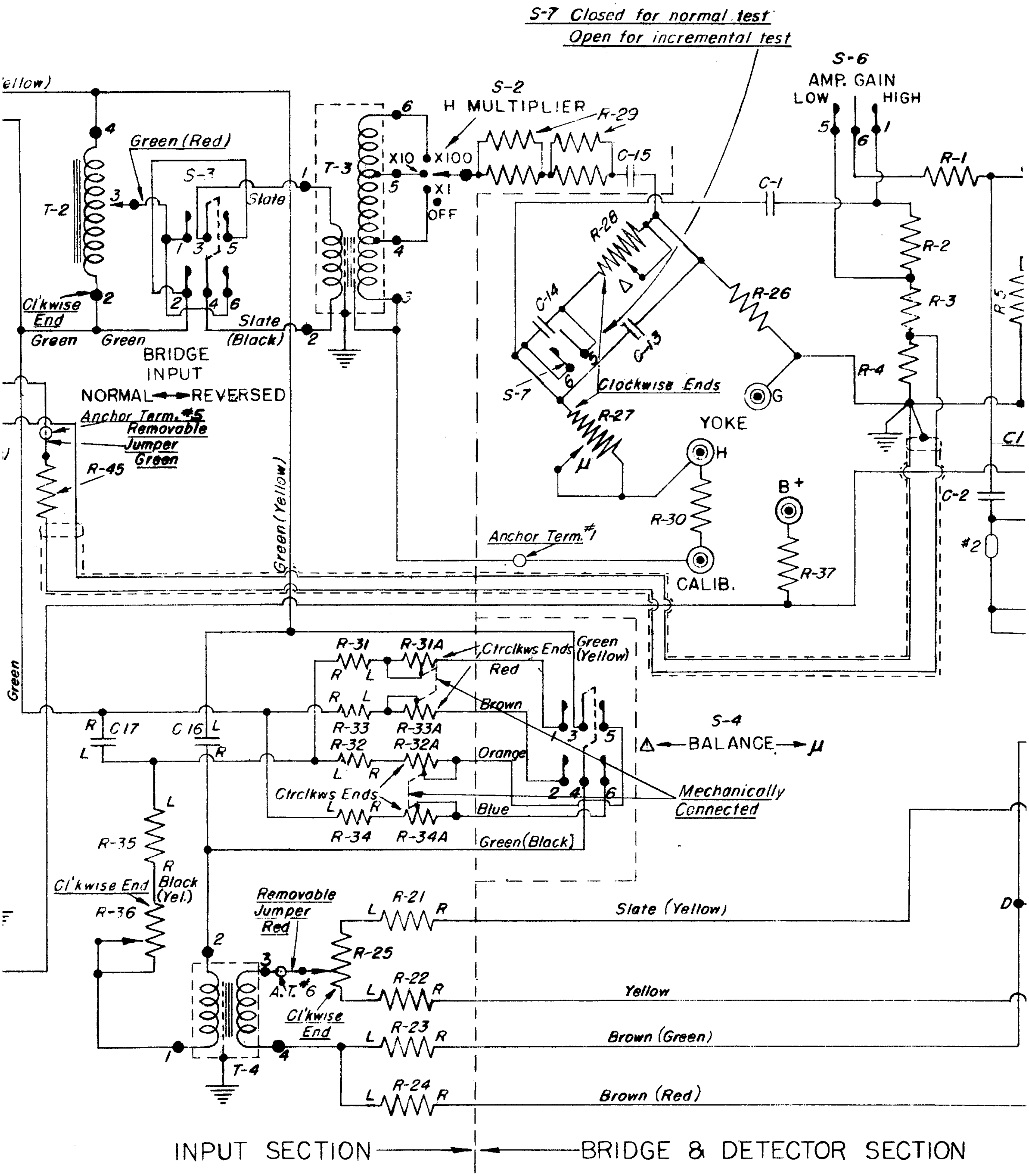
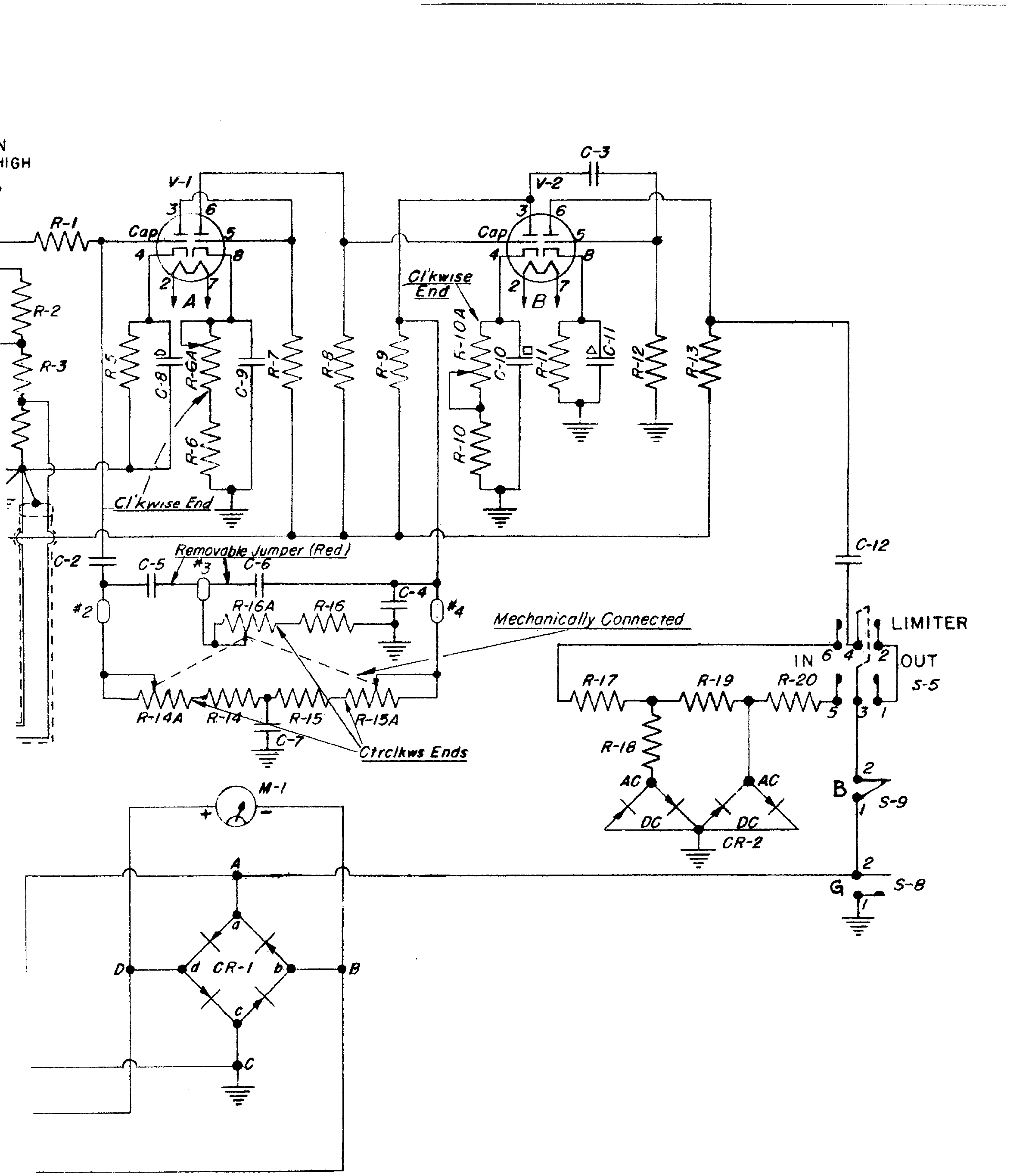
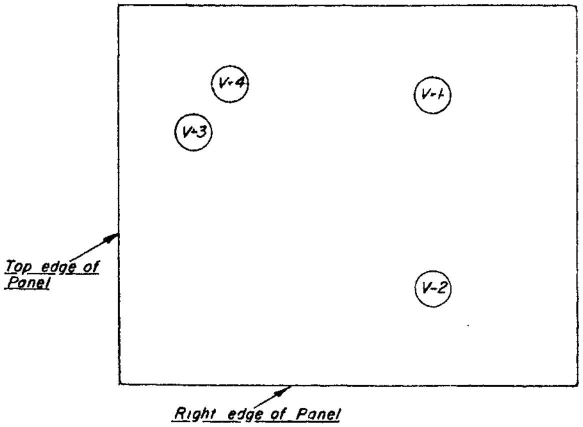

S-7 Closed for normal test
Open for incremental test
S-6
AMP. GAIN
LOW
HIGH
S-2
H MULTIPLIER
R-29
C-15
X10
X100
X1
OFF
R-1
C-1
R-2
R-3
R-4
R-5
R-26
R-28
C-14
C-13
S-7
Clockwise Ends
R-27
YOKE
G
H
R-30
CALIB.
B+
R-37
Anchor Term. #1
C-2
#2
Green (Red)
T-2
S-3
Slate
T-3
Cl'kwise End
Green
Green
Slate (Black)
BRIDGE INPUT
NORMAL ← → REVERSED
Anchor Term. #5
Removable Jumper Green
R-45
Green (Yellow)
R-31
R-31A
Ctrclkws Ends
Green (Yellow)
Red
Brown
R-33
R-33A
R-32
R-32A
Orange
Ctrclkws Ends
Blue
R-34
R-34A
Green (Black)
C17
C16
S-4
Δ ← BALANCE → μ
Mechanically Connected
R-35
Black (Yel.)
Cl'kwise End
R-36
Removable Jumper Red
R-21
R-25
A.T. #6
Cl'kwise End
R-22
R-23
R-24
Slate (Yellow)
Yellow
Brown (Green)
Brown (Red)
D
T-4
INPUT SECTION
BRIDGE & DETECTOR SECTION

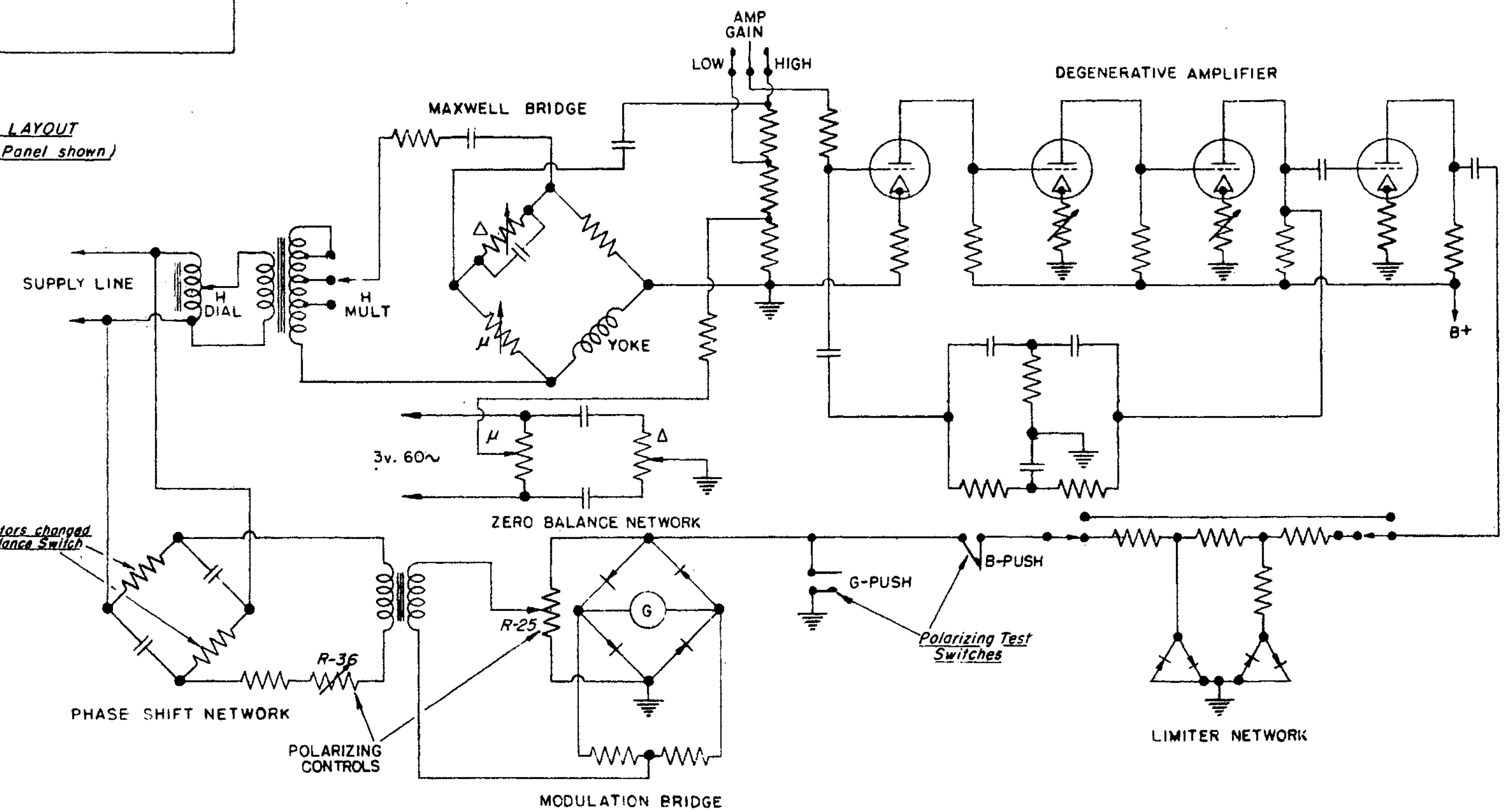


TION

WIRING DIAGRAM FOR TYPE 1670-A MAGNETIC TEST SET



TUBE LAYOUT
(Rear of Panel shown)



Schematic Diagram for Type 1670-A Magnetic Test Set

TYPE 1670-A MAGNETIC TEST SET

TABLES FOR COMPUTING FUNCTIONS USED IN EVALUATING MAGNETIC PARAMETERS OF TEST SPECIMEN

GENERAL RADIO COMPANY

Cambridge 39 Massachusetts

TABLE I η, U and D as Functions of Δ

Δ	η	U	D	Δ	η	U	D
8.0	.995	14.85	.0833	1.90	.989	14.67	.351
7.0	.995	14.85	.0952	1.85	.988	.65	.360
6.0	.995	"	.1111	1.80	"	.64	.370
5.0	.994	14.83	.1333	1.75	.987	.62	.381
4.5	"	.82	.1481	1.70	"	.61	.392
4.0	"	.81	.1667	1.65	.986	14.60	.404
3.9	"	.81	.1709	1.60	"	.58	.417
3.8	"	.81	.1754	1.55	.985	.57	.430
3.7	"	14.80	.1802	1.50	"	.56	.444
3.6	"	.80	.1852	1.48	"	.55	.450
3.5	"	.80	.1905	1.46	"	14.54	.457
3.4	.993	.80	.1960	1.44	.984	.53	.463
3.3	"	.80	.202	1.42	"	.53	.469
3.2	"	14.79	.208	1.40	"	.52	.476
3.1	"	.79	.215	1.38	"	.52	.483
3.0	"	.79	.222	1.36	.983	.51	.490
2.95	"	.79	.226	1.34	"	14.50	.498
2.9	"	.79	.230	1.32	"	.49	.505
2.85	"	14.78	.234	1.30	"	.49	.513
2.8	.992	.78	.238	1.28	.982	.48	.521
2.75	"	.78	.242	1.26	"	.47	.529
2.7	"	14.77	.247	1.24	"	.46	.537
2.65	"	.76	.251	1.22	.981	14.45	.546
2.6	"	.76	.256	1.20	"	.43	.555
2.55	"	.75	.261	1.18	"	.42	.565
2.5	.991	.75	.267	1.16	.980	.41	.575
2.45	"	14.74	.272	1.14	"	14.40	.585
2.4	"	.73	.278	1.12	"	.38	.595
2.35	"	.72	.284	1.10	.979	.37	.606
2.3	"	.72	.290	1.08	"	.36	.617
2.25	.990	.71	.296	1.06	"	.35	.629
2.2	"	14.70	.303	1.04	.978	14.34	.641
2.15	"	.70	.310	1.02	"	.32	.654
2.1	"	.69	.317	1.00	.977	.31	.667
2.05	"	.68	.325	.98	"	.30	.680
2.0	.989	.67	.333	.96	.976	.28	.694
1.95	"	14.67	.342	.94	"	14.27	.709

TABLE I (continued)

Δ	η	U	D
.92	.975	14.26	.725
.90	"	.25	.741
.89	.974	.24	.749
.88	"	.23	.758
.87	.973	.22	.766
.86	"	.21	.775
.85	"	14.20	.784
.84	"	.19	.794
.83	.972	.18	.803
.82	"	.17	.813
.81	"	.16	.823
.80	.971	14.15	.833
.79	"	.14	.844
.78	.970	.13	.855
.77	"	.12	.866
.76	"	.11	.877
.75	.969	.10	.889
.74	"	14.09	.901
.73	"	.08	.913
.72	.968	.07	.926
.71	"	.06	.939
.70	.967	.04	.952
.69	"	.03	.966
.68	.966	14.01	.980
.67	"	13.99	.995
.66	.965	.98	1.010
.65	"	.96	26
.64	.964	.94	42
.63	.963	.93	1.058
.62	"	.91	75
.61	.962	13.89	93
.60	.961	.87	1.111
.59	"	.85	30
.58	.960	.83	49
.57	.959	.80	70
.56	.958	.77	1.190
.55	.957	13.74	1.212

Δ	η	U	D
.54	.956	13.71	1.235
.53	.955	.68	58
.52	.954	.65	82
.51	.953	.63	1.307
.50	.952	.60	33
.49	.951	.57	61
.48	.950	.55	89
.47	.949	.52	1.418
.46	.948	.49	49
.45	.947	.46	81
.44	.946	.43	1.515
.43	.945	.40	50
.42	.944	.37	87
.41	.943	.33	1.626
.40	.941	.29	67
.39	.940	.25	1.709
.38	.938	.20	54
.37	.937	.16	1.802
.36	.935	.11	52
.35	.933	.05	1.905
.34	.931	13.00	61
.33	.929	12.95	2.020
.32	.927	.89	83
.31	.925	.82	2.151
.30	.922	.75	2.222
.29	.919	.67	.299
.28	.917	.59	.381
.27	.914	.51	.469
.26	.910	.42	.564
.25	.907	.32	.667
.24	.903	.23	.778
.23	.899	.12	2.899
.22	.895	12.02	3.030
.21	.891	11.91	3.175
.20	.886	.78	3.333
.15	.857	11.01	4.444
.10	.799	9.57	6.667

TABLE II D_c as Function of μ_d

μ_d	D_c	μ_d	D_c	μ_d	D_c	μ_d	D_c
26×10^3	.0064	3700	.045	1560	.106	820	.202
25	66	36	46	40	.108	800	.207
24	69	35	47	20	.109	780	.212
23	72	34	49	1500	.110	60	.218
22	75	33	50	1480	.112	40	.224
21	79	32	52	60	.113	20	.230
20	83	31	53	40	.115	700	.237
19	87	3000	.055	20	.117	680	.244
18	92	2950	56	1400	.118	60	.251
17	.0097	29	57	1380	.120	40	.259
16	.0103	2850	58	60	.122	20	.267
15	110	28	59	40	.124	600	.276
14	118	2750	60	20	.126	580	.286
13	127	27	61	1300	.127	60	.296
12	138	2650	62	1280	.129	40	.307
11	151	26	64	60	.131	20	.319
10	.0166	2550	65	40	.134	500	.331
9.5	174	25	.066	20	.136	480	.345
9	184	2450	68	1200	.138	60	.360
8.5	195	24	69	1180	.140	40	.376
8	207	2350	70	60	.143	20	.394
7.5	221	23	72	40	.145	400	.414
7	237	2250	74	20	.148	380	.436
6.5	255	22	75	1100	.151	60	.460
6.0	.0276	2150	77	1080	.153	40	.487
5.8	286	21	79	60	.156	20	.518
5.6	296	2050	81	40	.159	300	.552
5.4	307	20	.083	20	.162	280	.591
5.2	319	1950	85	1000	.166	60	.637
5.0	.0331	19	87	980	.169	40	.690
4.8	345	1850	90	60	.173	20	.753
4.6	360	18	92	40	.176	200	.828
4.4	376	1750	95	20	.180	180	.920
4.2	394	17	.097	900	.184	60	1.004
4.0	414	1650	.100	880	.188	40	1.18
3.9	425	1600	.104	60	.193	20	1.38
3.8	.0436	1580	.104	40	.197	100	1.66

TABLE III S and T as Functions of $(D - D_c)$

$D-D_c$	S	T	$D-D_c$	S	T	$D-D_c$	S	T
0.08	1.003	10.06	0.61	1.171	13.72	0.98	1.400	19.60
.10	5	10	.62	76	84	.99	07	80
.12	7	14	.63	82	97	1.00	14	20.00
.14	10	20	.64	87	14.10	.01	21	20
.16	13	26	.65	93	23	.02	28	40
.18	16	32	.66	98	36	.03	36	61
0.20	1.020	10.40	.67	1.204	49	.04	43	82
.22	24	48	.68	09	62	1.05	1.450	21.03
.24	29	58	.69	15	76	.06	57	24
.26	33	68	.70	21	90	.07	65	45
.28	38	78	.71	26	15.04	.08	72	66
0.30	44	10.90	.72	32	18	.09	80	89
.32	1.050	11.02	.73	38	33	1.10	87	22.10
.34	56	16	.74	44	48	.11	94	32
.36	63	30	.75	1.250	63	.12	1.501	54
.38	70	44	.76	56	78	.13	09	77
0.40	1.077	11.60	.77	62	93	.14	17	23.00
.41	81	68	.78	68	16.08	1.15	24	23
.42	85	76	.79	74	24	.16	32	46
.43	89	85	.80	81	40	.17	39	69
.44	93	94	.81	87	56	.18	46	92
0.45	1.097	12.03	.82	93	72	.19	1.554	24.16
.46	1.101	12	.83	1.300	89	1.20	62	40
.47	05	21	.84	06	17.06	.21	70	64
.48	09	30	.85	13	23	.22	77	88
.49	14	40	.86	19	40	.23	85	25.13
0.50	1.118	12.50	.87	26	57	.24	93	38
.51	22	60	.88	32	74	1.25	1.601	63
.52	27	70	.89	39	92	.26	09	88
.53	32	81	.90	1.345	18.10	.27	16	26.13
.54	37	92	.91	52	28	.28	24	38
0.55	1.141	13.03	.92	59	46	.29	32	64
.56	46	14	.93	66	65	1.30	40	90
.57	51	25	.94	73	84	.31	48	27.16
.58	56	36	.95	79	19.03	.32	56	42
.59	61	48	.96	86	22	.33	64	69
0.60	1.166	13.60	.97	1.393	19.41	.34	1.672	27.96

TABLE III (continued)

$D-D_c$	S	T	$D-D_c$	S	T	$D-D_c$	S	T
1.35	1.680	28.2	1.72	1.989	39.6	2.09	2.317	53.7
.36	88	.5	.73	98	.9	.10	26	54.1
.37	96	.8	.74	2.007	40.3	.11	35	.5
.38	1.704	29.0	1.75	16	.6	.12	44	.9
.39	12	.3	.76	24	41.0	.13	53	55.4
1.40	20	.6	.77	33	.3	.14	2.362	.8
.41	28	.9	.78	42	.7	2.15	71	56.2
.42	37	30.2	.79	2.050	42.0	.16	80	.7
.43	45	.5	1.80	59	.4	.17	89	57.1
.44	1.753	.7	.81	68	.7	.18	98	.5
1.45	62	31.0	.82	77	43.1	.19	2.407	58.0
.46	70	.3	.83	85	.5	2.20	17	.4
.47	78	.6	.84	94	.9	.21	26	.8
.48	86	.9	1.85	2.103	44.2	.22	35	59.3
.49	94	32.2	.86	12	.6	.23	44	.7
1.50	1.803	.5	.87	21	45.0	.24	53	60.2
.51	11	.8	.88	29	.3	2.25	62	.6
.52	19	33.1	.89	38	.7	.26	71	61.1
.53	28	.4	1.90	2.147	46.1	.27	81	.5
.54	36	.7	.91	56	.5	.28	2.490	62.0
1.55	45	34.0	.92	65	.9	.29	99	.4
.56	1.853	.3	.93	74	47.3	.30	2.508	.9
.57	61	.7	.94	83	.6	.31	17	63.4
.58	70	35.0	1.95	92	48.0	.32	26	.8
.59	78	.3	.96	2.200	.4	.33	36	64.3
1.60	87	.6	.97	09	.8	.34	45	.8
.61	95	.9	.98	18	49.2	2.35	2.554	65.2
.62	1.904	36.2	.99	27	.6	.36	63	.7
.63	12	.6	2.00	36	50.0	.37	72	66.2
.64	21	.9	.01	45	.4	.38	81	.6
1.65	30	37.2	.02	2.254	.8	.39	91	67.1
.66	38	.6	.03	63	51.2	2.40	2.600	.6
.67	47	.9	.04	72	.6	41	09	68.1
.68	55	38.2	2.05	81	52.0	42	18	.6
.69	64	.6	.06	90	.4	43	28	69.1
1.70	72	.9	.07	99	.9	44	37	.5
.71	1.981	39.2	2.08	23.08	53.3	2.45	2.646	70.0

TABLE IV θ and σ as Functions of Δ

Δ	θ	σ	Δ	θ	σ
8.0	.0833	1.001	1.90	.346	1.012
7.0	.0952	1.001	1.85	.355	1.013
6.0	.1110	1.001	1.80	.365	1.014
5.0	.1331	1.002	1.75	.375	1.014
4.5	.1477	1.002	1.70	.385	1.015
4.0	.1661	1.003	1.65	.396	1.016
3.9	.1704	1.003	1.60	.408	1.017
3.8	.1749	1.003	1.55	.421	1.019
3.7	.1796	1.003	1.50	.435	1.020
3.6	.1846	1.003	1.48	.441	1.020
3.5	.1898	1.004	1.46	.447	1.021
3.4	.1953	1.004	1.44	.453	1.022
3.3	.201	1.004	1.42	.459	1.023
3.2	.207	1.004	1.40	.465	1.023
3.1	.214	1.005	1.38	.471	1.024
3.0	.221	1.005	1.36	.478	1.025
2.95	.225	1.005	1.34	.485	1.025
2.9	.229	1.005	1.32	.492	1.026
2.85	.233	1.005	1.30	.499	1.027
2.8	.237	1.006	1.28	.507	1.028
2.75	.241	1.006	1.26	.514	1.028
2.7	.246	1.006	1.24	.521	1.029
2.65	.250	1.007	1.22	.529	1.030
2.6	.255	1.007	1.20	.537	1.031
2.55	.260	1.007	1.18	.546	1.032
2.5	.265	1.007	1.16	.555	1.033
2.45	.270	1.008	1.14	.564	1.034
2.4	.275	1.008	1.12	.573	1.035
2.35	.281	1.008	1.10	.582	1.037
2.3	.287	1.009	1.08	.592	1.038
2.25	.293	1.009	1.06	.602	1.040
2.2	.300	1.009	1.04	.613	1.041
2.15	.307	1.010	1.02	.624	1.043
2.1	.314	1.010	1.00	.636	1.044
2.05	.321	1.010	.98	.647	1.046
2.0	.329	1.011	.96	.659	1.048
1.95	.338	1.011	.94	.672	1.050

TABLE IV (continued)

Δ	θ	σ	Δ	θ	σ
.92	.685	1.052	.54	1.057	1.150
.90	.698	1.055	.53	1.071	1.156
.89	.705	1.056	.52	1.085	1.162
.88	.712	1.057	.51	1.100	1.168
.87	.719	1.058	.50	1.115	1.175
.86	.727	1.059	.49	1.130	1.182
.85	.734	1.060	.48	1.145	1.190
.84	.742	1.061	.47	1.161	1.198
.83	.750	1.063	.46	1.177	1.206
.82	.758	1.065	.45	1.193	1.214
.81	.766	1.067	.44	1.209	1.223
.80	.774	1.069	.43	1.226	1.233
.79	.782	1.071	.42	1.243	1.244
.78	.791	1.073	.41	1.260	1.257
.77	.800	1.075	.40	1.277	1.270
.76	.809	1.077	.39	1.294	1.284
.75	.818	1.079	.38	1.311	1.299
.74	.827	1.081	.37	1.328	1.315
.73	.836	1.083	.36	1.345	1.332
.72	.846	1.085	.35	1.362	1.350
.71	.856	1.087	.34	1.378	1.370
.70	.866	1.090	.33	1.394	1.392
.69	.876	1.093	.32	1.410	1.416
.68	.886	1.096	.31	1.426	1.442
.67	.897	1.099	.30	1.440	1.471
.66	.908	1.102	.29	1.454	1.502
.65	.919	1.105	.28	1.466	1.536
.64	.930	1.108	.27	1.478	1.575
.63	.942	1.111	.26	1.488	1.617
.62	.954	1.114	.25	1.496	1.664
.61	.966	1.118	.24	1.503	1.716
.60	.978	1.122	.23	1.506	1.775
.59	.990	1.126	.22	1.508	1.841
.58	1.003	1.130	.21	1.505	1.916
.57	1.016	1.135	.20	1.500	2.000
.56	1.029	1.140	.15	1.401	2.694
.55	1.043	1.145	.10	1.132	4.076

TABLE V Line Voltage Corrections for Run over Typical Decade of H_d Range

Values of mH_d

H_d / Line Volts	1000	800	600	500	400	300	250	200	160	130
105	913	730	548	457	365	274	228	182.6	146.1	118.7
106	922	737	553	461	369	277	230	184.3	147.5	119.8
107	930	744	558	465	372	279	233	186.1	148.9	121.0
108	939	751	563	470	376	282	235	187.8	150.3	122.1
109	948	758	569	474	379	284	237	189.6	151.6	123.2
110	957	765	574	478	383	287	239	191.3	153.0	124.3
111	965	772	579	483	386	290	241	193.0	154.4	125.5
112	974	779	584	487	390	292	243	194.8	155.8	126.6
113	983	786	590	491	393	295	246	196.5	157.2	127.7
114	991	793	595	496	397	297	248	198.3	158.6	128.9
115	1000	800	600	500	400	300	250	200.0	160.0	130.0
116	1009	807	605	504	403	303	252	201.7	161.4	131.1
117	1017	814	610	509	407	305	254	203.5	162.8	132.2
118	1026	821	616	513	410	308	257	205.2	164.2	133.4
119	1035	828	621	517	414	310	259	206.9	165.6	134.5
120	1043	835	626	522	417	313	261	208.7	166.9	135.6
121	1052	842	631	526	421	316	263	210.4	168.3	136.8
122	1061	849	636	530	424	318	265	212.2	169.7	137.9
123	1070	856	642	535	428	321	267	213.9	171.1	139.0
124	1078	863	647	539	431	323	270	215.6	172.5	140.2
125	1087	870	652	543	435	326	272	217.4	173.9	141.3

$$\text{Normal H (millioersteds)} = \left(\frac{\eta}{S}\right)\left(mH_d\right) \qquad (3)$$

$$\text{Normal } \mu = T\left(\frac{\mu_d}{A'}\right) \qquad (4)$$

TABLE V (continued)

Required only for Core Loss Measurements

Values of $(m H_d)^2 \times 10^{-6}$

N.B. Reduce these values by 10^{-3} for Equation (5)

H_d / Line Volts	1000	800	600	500	400	300	250	200	160	130
105	.834	.534	.300	.208	.1334	.0750	.0521	.0334	.0213	.01409
106	.850	.544	.306	.212	.1359	.0765	.0531	.0340	.0217	.01436
107	.866	.554	.312	.216	.1385	.0779	.0541	.0346	.0222	.01463
108	.882	.564	.317	.220	.1411	.0794	.0551	.0353	.0226	.01490
109	.898	.575	.323	.225	.1437	.0808	.0561	.0359	.0230	.01518
110	.915	.586	.329	.229	.1464	.0823	.0572	.0366	.0234	.01546
111	.932	.596	.335	.233	.1491	.0838	.0582	.0373	.0238	.01574
112	.949	.607	.341	.237	.1518	.0854	.0593	.0379	.0243	.01603
113	.966	.618	.348	.241	.1545	.0869	.0603	.0386	.0247	.01632
114	.983	.629	.354	.246	.1572	.0884	.0614	.0393	.0252	.01661
115	1.000	.640	.360	.250	.1600	.0900	.0625	.0400	.0256	.01690
116	1.017	.651	.366	.254	.1628	.0916	.0636	.0407	.0260	.01719
117	1.035	.662	.373	.259	.1656	.0931	.0647	.0414	.0265	.01749
118	1.053	.674	.379	.263	.1684	.0947	.0658	.0421	.0269	.01779
119	1.071	.685	.385	.267	.1713	.0963	.0669	.0428	.0274	.01809
120	1.089	.697	.392	.272	.1742	.0980	.0680	.0435	.0279	.01840
121	1.107	.708	.398	.277	.1771	.0996	.0692	.0443	.0283	.01871
122	1.125	.720	.405	.281	.1800	.1013	.0703	.0450	.0288	.01902
123	1.144	.732	.412	.286	.1830	.1029	.0715	.0457	.0293	.01933
124	1.163	.744	.419	.291	.1860	.1046	.0727	.0465	.0298	.01965
125	1.181	.756	.425	.295	.1890	.1063	.0738	.0473	.0302	.01997

$$\frac{\text{Milliwatts}}{\text{Cubic Centimeter}} = U\left(\frac{\mu_d}{A'}\right)\left(D - D_c\right)\left(mH_d\right)^2 \times 10^{-9} \qquad (5)$$