THE General Radio EXPERIMENTER

VOLUME XXIII No. 3 AUGUST, 1948

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

THE TYPE 1670-A MAGNETIC TEST SET

Also

IN THIS ISSUE

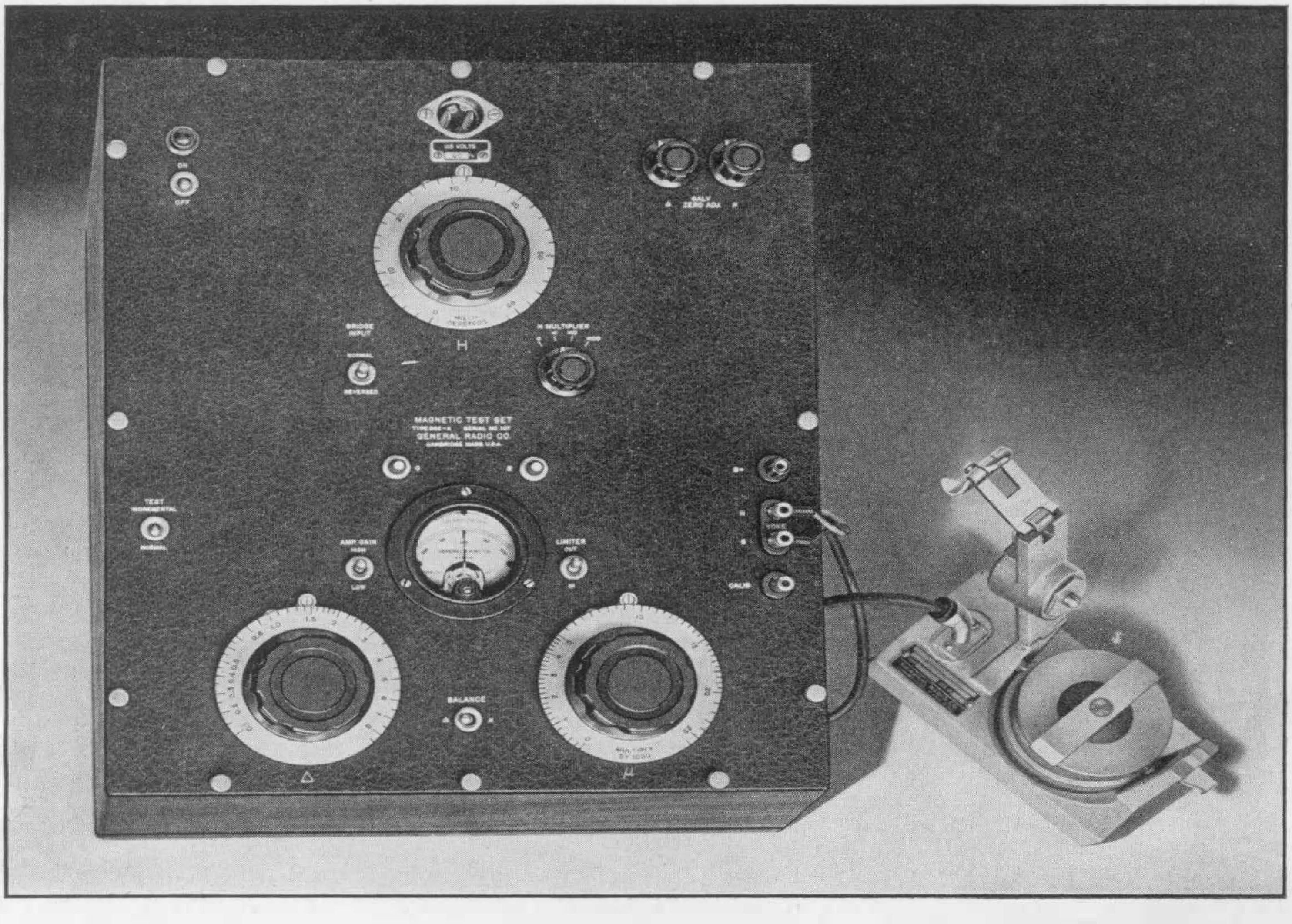
● **FOR A NUMBER OF YEARS** the accepted methods of determining the magnetic properties of laminated ferromagnetic alloys, used in transformer cores or in other electrical devices, have consisted of bridge or wattmeter measurements upon so-called Epstein squares, utilizing the various techniques described in the ASTM specification A34-46. The larger or 50-cm. Epstein square requires a sufficient number of strips of the specimen material, each 50 cm. by 3 cm., to aggregate 10 kilograms; while the smaller or 25-cm. Epstein square requires 2 kilograms of strips, each 28 cm. by 3 cm.

It is believed that many suppliers or users of these materials, together with other investigators, would find it convenient to make magnetic tests upon much smaller lamination samples, which, for example, might be cut in any desired direction from parental sheet stock or from small transformer core stampings already available. Furthermore, most of the ASTM procedures are not suited for measurements at the very low levels of induction, approaching initial permeability, which are frequently encountered in the cores of many inductors and transformers used in communication systems. The TYPE 1670-A Magnetic Test Set was developed to meet such a need by providing low-level 60-cycle measurements of permeability and core loss, using a single small strip or a few duplicate strips in parallel.

These midget test strips may have any uniform width up to ⅜″ and any length in excess of 2¼″. They are inserted into a helical coil, contained in the Test Yoke, where they interleave with, and become a diameter of, an assembly of laminated annular rings of a material having a high initial permeability. These rings have a sufficiently large composite cross-section so that a specific length of the specimen strip constitutes essentially the entire reluctance of the magnetic system. For specimens having an exceptionally high permeability, a simple correction can be made for the reluctance of the rings. By means of a spring-backed plunger in the hinged clamping bar, the laminated stack is subjected to a definite force which is more than sufficient to eliminate erratic air-gap errors. The assembly of this Test Yoke is a rapid and easy operation.

The inductor formed by the winding in this Test Yoke is inserted into a Maxwell bridge (see circuit diagram, Figure 2) which is energized at 60 cps through a high series resistance. This resistance insures that the current in the yoke and, hence, the magnetizing force *H* applied to the specimen is sinusoidal. Magnetic measurements are frequently made under conditions approximating a sinusoidal variation of induction or flux density *B*, rather than sinusoidal *H*. However, in the reference quoted (2), the author has advanced arguments favoring the latter procedure in bridge measurements. He has further demonstrated that, for a typical sample of silicon steel, the maximum discrepancy between the two methods occurred approximately at a level of normal induction corresponding to maximum μ and amounted only to about 8 per cent in the evaluation of μ and about 5 per cent in the evaluation of core loss. When the induction was less than one-half or exceeded twice the aforesaid level, the two procedures yielded essentially the same data. For comparative measurements between different specimens either procedure would be satisfactory. It should be noted that,

Figure 1. The Type 1670 Magnetic Test Set with its attached test yoke shown with clamp released.



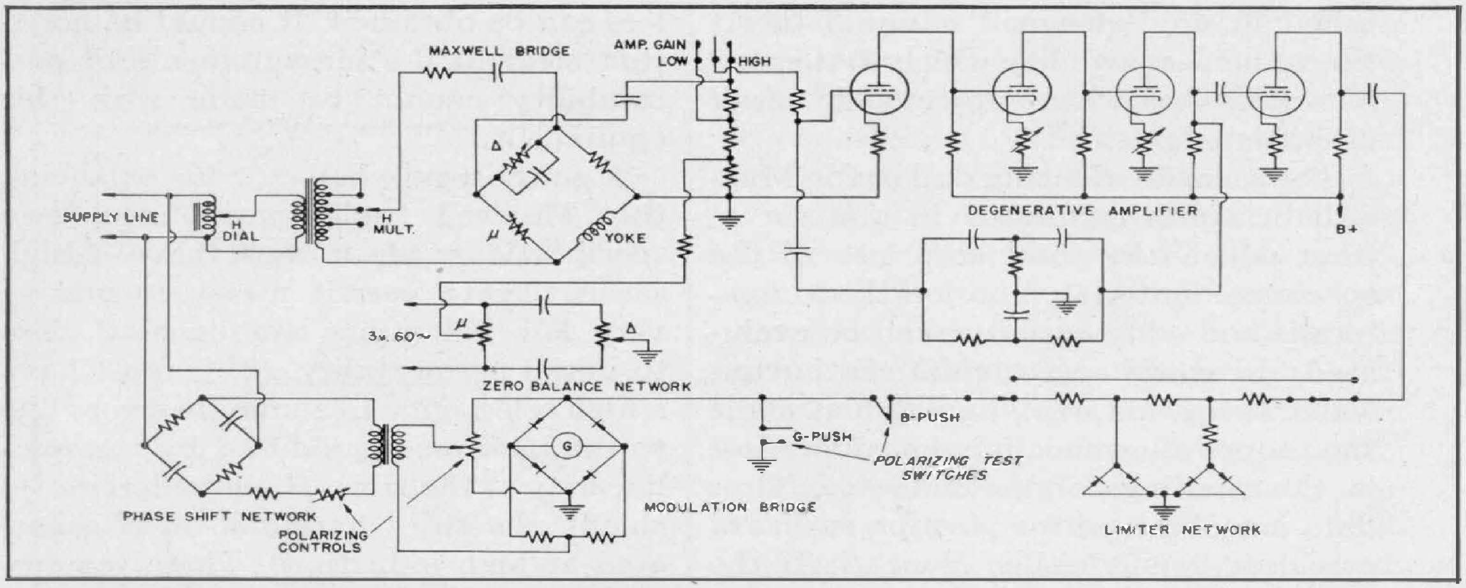


Figure 2. Schematic wiring diagram showing principal elements: Adjustable H supply, Maxwell bridge, degenerative amplifier, zero balance network, phase shift network, and modulation bridge.

while sinusoidal flux occurs in low-resistance power transformers energized by a low impedance source, if the combined resistance of the winding and the generator is appreciable compared to the reactance of the winding, then the flux will have a substantial harmonic content which may actually exceed the harmonic content of the exciting current, so that H becomes more sinusoidal than B.

By means of a Variac (H dial) and a supply transformer having 3 decade voltage steps (H multiplier), the magnetizing force applied to the specimen may be preset at any desired value from one millioersted to six oersteds, regardless of the existing impedance of the yoke. The H dial is calibrated in oersteds when the supply line voltage is 115 volts. Otherwise H is proportional to the existing supply voltage.

The two balancing components of the Maxwell bridge are rheostats. The μ-dial reading on one of these is proportional to the permeability of the specimen in terms of its arbitrary cross-section, which can be determined: (1) by micrometer measurements of width and thickness, or (2) from the length, mass, and density of the specimen strip or strips. In most cases it is the precision with which this cross-section can be evaluated that determines the accuracy of the absolute values of the magnetic data obtained. A knowledge of the cross-section is not required in *comparative* measurements between specimen strips having identical dimensions. The μ-dial is calibrated in terms of a specimen cross-section of 10 sq. mm., in which case the maximum scale reading indicates a permeability of 25,000. Higher permeabilities can be measured if an appropriate cross-section less than 10 sq. mm. is used.

With any preset value of H and the corresponding measured value of μ, the simultaneous induction B existing in the specimen may be computed as the product μH. In this manner data for the familiar B vs. H, μ vs. H, and μ vs. B curves may be obtained. The maximum induction which can be established in any specimen is equal to six times the permeability which that specimen possesses when subjected to an H of 6 oersteds.

The second balancing dial of the Maxwell bridge is calibrated in a factor Δ, from which the total core loss of the specimen material, due jointly to hysteresis and eddy currents, can be evaluated in watts per cubic centimeter, watts per pound, etc., having first made the proper allowance for the copper loss in the windings of the inductor. Thus data are obtained for plotting curves of core loss versus either H or B. If the resistivity of the specimen material is known, this core loss may be analyzed into its hysteresis and eddy-current components.

Provision is made for the introduction of a d-c or biasing current into the winding of the Test Yoke. Two additional components (not furnished) are then required — a rheostat of about 50 kilohms and a suitable milliammeter. The bias H, which is evaluated from the number of turns in the yoke winding and the measured biasing current, may have any value up to 2 oersteds. Sufficient d-c emf for producing a bias H up to 1.5 oersteds can be obtained directly from the rectifier system of the test set. For higher values this must be augmented by external batteries. Then, when any normal (peak a-c) value of H up to 6 oersteds is superimposed upon this bias H, the corresponding *incremental* values of permeability and core loss can be obtained. It should be noted that straight d-c measurements of permeability cannot be made with this equipment.

A suitable null detector for balancing this Maxwell bridge must meet two specifications: (1) it must have a high sensitivity to permit measurements at very low inductions approaching close to initial permeability, (2) it must have a high selectivity to eliminate errors due to the harmonics produced by the nonlinearity of the B vs. H characteristic — chiefly the third harmonic in B generated at high inductions. These requirements are met by the use of a four-stage amplifier tuned sharply to 60 cycles by a degenerative R-C network.

The use of a sensitive 60-cycle amplifier presents certain difficulties, especially when incorporated into equipment which is energized at the same frequency. This is due to an unavoidable stray pickup of minute 60-cycle voltages induced either by components of the equipment itself or by the 60-cycle electromagnetic fields present, although frequently unrealized, in all laboratories supplied with a-c power. Such stray voltages, greatly amplified, would, of course, result in false indications of bridge balance. Two auxiliary controls in a zero-balance network permit a small voltage of adjustable phase and amplitude to be introduced into the amplifier so as to counteract any stray pickup and to make the amplifier response dependent solely upon the output voltage of the unbalanced bridge.

The null balance indicator is a center-scale-zero galvanometer. This is in-

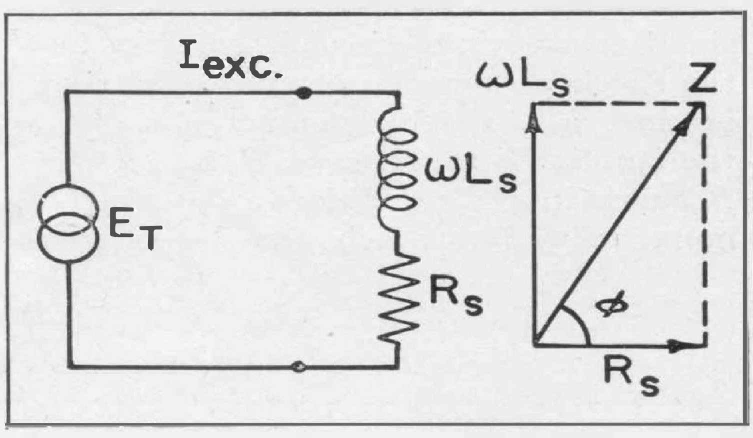


Figure 3. Misleading representation of an a-c iron-cored inductor. Due to core loss the full exciting current does not produce magnetizing force and flux.

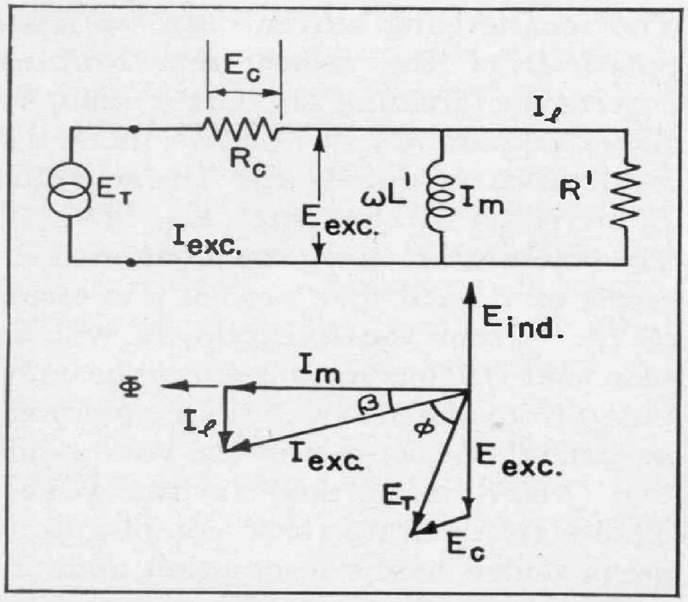


Figure 4. Correct representation of an iron-cored inductor showing the subdivision of exciting current into its magnetizing and loss components.

serted into a modulation bridge composed of four rectifier elements and polarized by one or the other of two voltages which have a phase displacement of 90 degrees between them. By the operation of a two-position switch, which changes the resistors of the phase-shift network, this *polarized* indicator can be made predominantly responsive to the manipulation of either the μ-dial or the Δ-dial in the Maxwell bridge. Such a polarized detector permits a more convenient and rapid balancing of the bridge than would be possible with the conventional non-polarized detector, especially with the "sliding zero" which this bridge exhibits in measuring an inductor having a relatively low Q. Furthermore, if only permeability and not core-loss data are desired, a precise setting of the Δ-dial is not required in obtaining an accurate balance of the μ-dial.

In addition, this indicator is *directional,* meaning that the displacement of the galvanometer needle, left or right of center, indicates the direction in which either the μ-dial or the Δ-dial should be turned to approach balance, which is analogous to the directional feature possessed by the galvanometer used in balancing a d-c Wheatstone bridge.

A limiter network, which contains non-linear elements in its shunt branches can be inserted, at will, between the amplifier and the polarized indicator to give the latter a quasi-logarithmic response. This prevents the galvanometer needle from going off-scale with a badly unbalanced bridge and eliminates the necessity for monitoring the gain of the amplifier as balance is approached. These several features combine to give a useful null balance system.

The Maxwell bridge, in common with many other bridges, evaluates an inductive impedance in terms of its series components R_s and $j\omega L_s$, see Figure 3. The μ-dial setting is determined by L_s, while the dissipation factor D, defined as the ratio of R_s to the series reactance ωL_s, determines the setting of the Δ-dial. If a resistance R_c, representing the copper losses of the winding (the d-c resistance when the frequency is as low as 60 cycles), is subtracted from R_s, the remainder multiplied into the square of the exciting current I_{exc}^2 gives the core loss in the specimen.

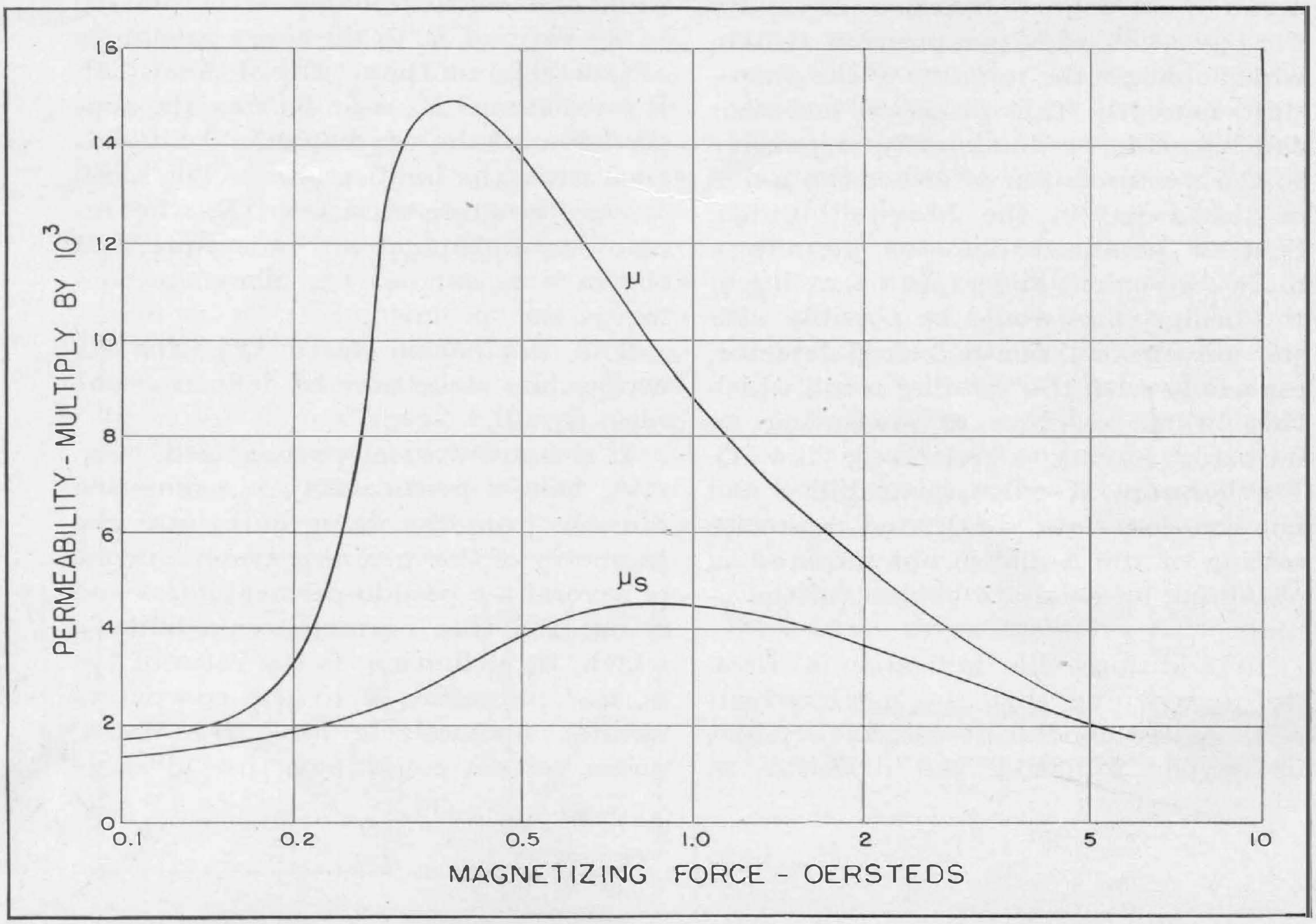
The dissipation factor D_c due to copper loss alone may be defined as the ratio $R_c/\omega L_s$.

It is not universally recognized, however, that a permeability μ_s, computed directly from the value of L_s and the geometry of the magnetic system, is one of several a-c pseudo-permeabilities and is not the true normal permeability μ which, by definition, is the ratio of the normal induction B to the co-existing normal magnetizing force H. While, under certain conditions, this μ_s value is a perfectly legitimate parameter for intercomparing similar ferromagnetic specimens, its magnitude is a function of core loss and, hence, depends upon the thickness of the specimen lamination even though the flux has complete penetration.

To evaluate the true normal permeability, which is a unique parameter of the specimen material, the inductor must be analyzed as depicted in Figure 4. The exciting current I_{exc}, flowing in the copper-loss resistance R_c, divides into two quadrature components: (1) magnetizing current I_m which flows in the inductance L' to create the H which produces the flux, (2) the loss current I_l which flows in the resistance R' representing the core losses I_l^2R' identical with the previous value I_{exc}^2 $(R_s\text{-}R_c)$. The magnetizing current can be computed from the measurable exciting current by dividing the latter value by the expression: $\sqrt{1 + (D\text{-}D_c)^2}$; while the inductance L' equals the bridge value L_s increased by the factor $1 + (D\text{-}D_c)^2$. True normal H must be evaluated in terms of I_m and true normal μ in terms of L'. From the foregoing it will be seen that these true values may be computed from the Maxwell bridge readings and the d-c resistance of the yoke winding (which is marked in the yoke). Tables to facilitate these computations are provided in the instruction manual.

The discrepancy which may exist between these pseudo and true normal values is illustrated in Figure 4, which gives data for a somewhat extreme case encountered in a sample of silicon steel

Figure 5. Comparison of true normal permeability μ with a pseudo-permeability μ_s evaluated in terms of series inductance.



having rather high core losses and, hence, requiring substantial values of the correction factor. The curve marked μ_s represents the pseudo permeability evaluated directly from L_s (Figure 3) and plotted against peak values of pseudo H_s evaluated from the full exciting current. This curve illustrates data obtained directly from the Maxwell bridge and which have been used extensively in the evaluation of "a-c permeability vs. H." The curve marked μ indicates the true normal permeability evaluated from L' (Figure 4) plotted against the true values of normal H computed in terms of the magnetizing current.

A detailed discussion of the theory of this Magnetic Test Set and a general analysis of a-c magnetic measurements can be found in two I.R.E. papers by the author.[1,2] Reprints of these papers may be obtained upon request.

In conclusion it may be noted that this test set is a useful bridge for the 60-cycle measurement of *any* inductor (with or without d-c polarization) provided that its inductance does not exceed one henry and its 60-cycle Q value is less than 13.5. By simple formulae the μ and Δ-dial readings at balance may be converted into corresponding values of L_s and Q.

— Horatio W. Lamson

[1] "A Method of Measuring the Magnetic Properties of Small Samples of Transformer Laminations," *Proc. I.R.E.*, Vol. 28, pp. 541–548, December, 1940.

[2] "Alternating Current Measurements of Magnetic Properties," *Proc. I.R.E.*, Vol. 36, pp. 266–277, February, 1948.

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 (d-c) 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 per cent.

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.

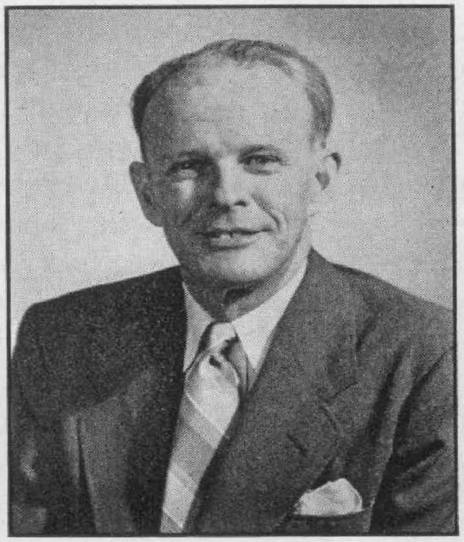
Dimensions: Test set, (width) 16 x (depth) 18 x (height) 10 inches over-all; test yoke, 8 x 4 x 5½ inches.

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

Type		*Code Word*	*Price*
1670-A	**Magnetic Test Set**	AFIRE	**$585.00**

MISCELLANY

Melville Eastham



John M. Clayton

Harold B. Richmond

HONORS — To Harold B. Richmond, Chairman of the Board, and to Melville Eastham, Chief Engineer, the Medal for Merit, for exceptionally meritorious conduct in the performance of outstanding services to the United States. The award to Mr. Richmond was made for his work as Chief of the Guided Missiles Division of National Defense Research Committee, in which capacity he was responsible for all wartime activities in this field, resulting in the development of the missiles Azon, Razon, and Felix.

The medal was awarded to Mr. Eastham for his work as a member of the Microwave Committee of the NDRC and later as Expert Consultant to the Office of the Secretary of War, and, in particular, for his guidance of the Loran development program.

—To John M. Clayton, Advertising Manager, the Meritorious Civilian Service Award, for Outstanding Service to the Navy. The award was made for the outstanding effectiveness with which he handled procurement problems of the Radio Division of the Naval Research Laboratory during the war.

RECENT VISITORS to our plant and laboratories include Mr. Jack Smith of Warburton-Franki, Ltd., distributors for General Radio instruments and manufacturers of Variacs in Melbourne, Australia; Mr. J. A. Jones and Mr. Raoul Rago, of the Direction General de Fabricaciones Militaires, Buenos Aires, Argentina; Mr. Antonio Millan, Instituto L. Torres Quevedo, Madrid, Spain; and Mr. Ronald E. Burgess, National Physical Laboratory, England.

GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE

CAMBRIDGE 39 MASSACHUSETTS

TELEPHONE: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WORTH 2-5837

LOS ANGELES 38, CALIFORNIA
950 NORTH HIGHLAND AVENUE
TEL.—HOLLYWOOD 6201

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WABASH 3820

PRINTED IN U.S.A.