Designation: A 596/A 596M – 95 (Reapproved 1999)

Standard Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens[1]

This standard is issued under the fixed designation A 596/A 596M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers dc ballistic testing for the determination of basic magnetic properties of materials in the form of ring, toroidal, link, double-lapped Epstein cores, or other standard shapes which may be cut, stamped, machined, or ground from cast, compacted, sintered, forged, or rolled materials. It includes tests for normal induction and hysteresis taken under conditions of steep wavefront reversals of the direct-current magnetic field strength.

1.2 This test method shall be used in conjunction with Practice A 34/A 34M.

1.3 This test method is suitable for a testing range from very low magnetic field strength up to 200 or more Oe [15.9 or more kA/m]. The lower limit is determined by integrator sensitivity and the upper limit by heat generation in the magnetizing winding. Special techniques and short duration testing may extend the upper limit of magnetic field strength.

1.4 Testing under this test method is inherently more accurate than other methods. When specified dimensional or shape requirements are observed, the measurements are a good approximation to absolute properties. Test accuracy available is primarily limited by the accuracy of instrumentation.

1.5 This test method permits a choice of test specimen to permit measurement of properties in any desired direction relative to the direction of crystallographic orientation without interference from external yoke systems.

1.6 The symbols and abbreviated definitions used in this test method appear in Fig. 1 and Sections 5, 6, 9, and 10. For the official definitions see Terminology A 340. Note that the term flux density used in this document is synonymous with the term magnetic induction.

1.7 The values stated in either customary (cgs-emu and inch-pound) units or SI units are to be regarded separately as standard. Within this test method, the SI units are shown in brackets except for the sections concerning calculations where there are separate sections for the respective unit systems. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this method.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 34/A 34M Practice for Sampling and procurement Testing of Magnetic Materials[2]

A 340 Terminology of Symbols and Definitions Relating to Magnetic Testing[2]

A 341/A 341M Test Method for Direct Current Magnetic Properties of Materials Using D-C Permeameters and the Ballistic Test Methods[2]

A 343 Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using the Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame[2]

A 773/A 773M Test Method for dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with dc Electronic Hysteresigraphs[2]

2.2 *IEC Standard:*

Publication 404-4, Magnetic Materials—Part 4: Methods of Measurement of the D-C Magnetic Properties of Solid Steels, IEC, 1982[3]

[1] This test method is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.01 on Test Methods.

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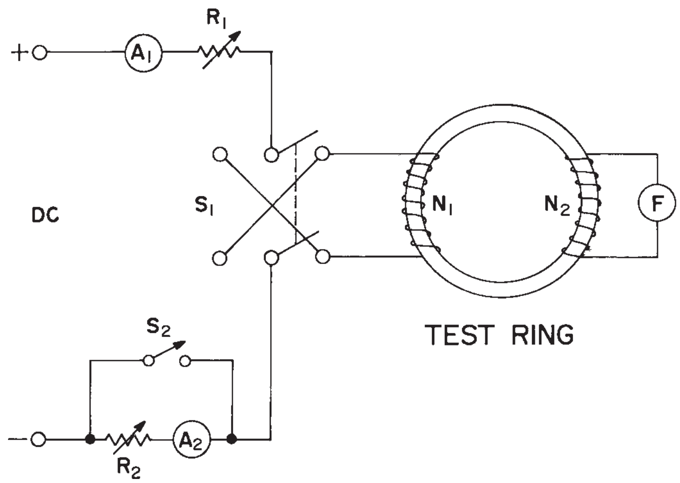
[2] *Annual Book of ASTM Standards*, Vol 03.04.

[3] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.



NOTE 1—
A_1—Multirange ammeter, main-magnetizing current circuit
A_2—Multirange ammeter, hysteresis-current circuit
N_1—Magnetizing (primary) winding
N_2—Flux-sensing (secondary) winding
F—Electronic integrator
R_1—Main current control rheostat
R_2—Hysteresis current control rheostat
S_1—Reversing switch
S_2—Shunting switch for hysteresis current control rheostat

FIG. 1 Basic Circuit Using Ring-Type Cores

3. Significance and Use

3.1 Test methods using suitable ring-type specimens[4] are the preferred methods of determining the basic magnetic properties of a material caused by the absence of demagnetizing effects and are well suited for specification acceptance, service evaluation, and research and development.

3.2 Provided the test specimen is representative of the bulk material as is usually the case for thin strip and wire, this test is also suitable for design purposes.

3.3 When the test specimen is not necessarily representative of the bulk material such as a ring machined from a large forging or casting, the results of this test method may not be an accurate indicator of the magnetic properties of the bulk material. In such instances, the test results when viewed in context of past performance history will be useful for judging the suitability of the current material for the intended application.

4. Interferences

4.1 This test method has several important requirements. Unless adequate inside diameter to outside diameter ratios are maintained in the test specimens, the magnetic field strength will be excessively nonuniform throughout the test specimen and the measured parameters cannot be represented as material properties.

4.2 The basic quality of materials having directionally sensitive properties cannot be tested satisfactorily with rings or laminations. With them it is necessary to use Epstein specimens cut with their lengths in the direction of specific interest or to use long link-shaped or spirally wound toroidal core test specimens whose long dimensions are similarly located. The acceptable minimum width of strip used in such test specimens is also sensitive to the material under test. At present, it is believed that the grain-oriented silicon steels should have a strip width of at least 3 cm [30 mm].

4.3 Unless ring specimens are large in diameter, it is difficult to provide a sufficient number of primary turns needed to reach the highest magnetic field strength. In general, magnetic materials tend to have nonuniform properties throughout the body of the test specimen; for this reason, uniformly distributed test windings and uniform specimen cross-sectional area are highly desirable to suppress nonuniform behavior to a tolerable degree.

5. Apparatus

5.1 The apparatus shall consist of as many of the components described in 5.2-5.10 as are required to perform the desired test. The basic circuit is shown in Fig. 1.

5.2 *Balance and Scales*:

5.2.1 The balance used to weigh the test specimen shall be capable of weighing to an accuracy of better than 0.1 %.

5.2.2 The micrometer, caliper, or other length-measuring device used in the determination of magnetic path length and cross-sectional area shall be capable of measuring to an accuracy of better than 0.1 %.

5.3 *dc Power Supply*—The preferred source of dc current is a high quality linear power supply of either unipolar or bipolar operation. The power supply must exhibit high stability and very low ripple to achieve the most accurate results. Programmable bipolar operational amplifier power supplies have proven to be very satisfactory for this type of testing. Other stable sources of dc current such as storage batteries are permitted.

5.4 *Main-Current-Control Rheostat* R_1—When nonprogrammable sources of dc current such as storage batteries are used, rheostats must be used to control the current. These rheostats must have sufficient power rating and heat-dissipating capability to handle the largest test current without undesirable changes in resistance and, therefore, magnetizing current during conduct of the test.

5.5 *Hysteresis-Current-Control Rheostat* R_2—The hysteresis-current-control rheostat, when required, must have the same power rating and resistance as the main-current-control rheostat.

5.6 *Main-Current Ammeter* A_1—Measurement of the magnetizing current can be accomplished with either a dc ammeter or a combination of a precision shunt resistor and dc voltmeter. The meters and shunt resistor, if used, must have an accuracy of at least 0.25 %. To improve test accuracy multirange digital ammeters or voltmeters are preferred. Autoranging capability is desirable for convenience but is not essential for this test method. If analog meters are used, the ranges must be such that all test readings are made in the upper two thirds of the scale.

[4] Lloyd, M. G., "Errors in Magnetic Testing with Ring Specimens," *Technical News Bulletin*, National Institute for Standards and Technology, Vol 5, 1909, p. 435 (S108).

5.7 *Hysteresis-Current Ammeter, A_2*—The hysteresis-current measuring system shall conform to the requirements in 5.6. In general, a separate measuring system is not required since the main current ammeter (A_1) can also be used to measure the hysteresis current.

5.8 *Reversing Switch, S_1*—Because of the low resistance nature of the magnetizing circuit, it is imperative that high quality switches be used. Changes in switch resistance upon reversal will cause deviation from the cyclically magnetized condition which, if excessive, will impair test accuracy and precision. Experience has shown that mercury switches are the best suited for this application. Knife blade switches or mechanical or electrically operated contractors can also be used provided the requirement for uniform and equal contact resistance can be maintained. Because of the presence of leakage currents in the open condition, solid state relays are not permitted. The difficulties inherent in the use of main current reversing switches can be minimized by use of linear power supplies capable of accepting a remote programming signal. Such power supplies are permitted provided that the magnetizing current is equal (to within 0.1 %) in either polarity when normal induction testing is conducted, current reversals can be conducted with no overshoot or oscillation and the magnetizing current is truly zero for the zero current programming signal.

5.9 *Hysteresis Switch, S_2 (When Required)*—This switch should conform to requirements in 5.8.

5.10 *Integrator, F*—Because of their superior accuracy, stability, and ease of operation, electronic charge integrators are the preferred means of measuring magnetic flux. Integrators using either operational amplifier and capacitor feedback (analog integrator) or pulse counting are permitted. The accuracy of the integrator must be better than 1 % full scale. If analog display meters are used to read the value of flux, the measurement should be made on the upper two thirds of the scale. Analog integrators must have drift adjust circuitry and the drift should not exceed 100 Maxwell-turns [10^{-6} Wb-turns] per minute on the most sensitive range. It is also desirable that the integrator have appropriate scaling circuitry to permit direct reading of either flux (ϕ) or flux density (B). Ballistic galvanometers or moving coil fluxmeters are allowed provided the 1 % full-scale accuracy requirement is met.

6. Test Specimen

6.1 When the test specimen represents a test lot of material, its selection shall conform to the requirements of Practice A 34/A 34M or of an individual specification.

6.2 To qualify as a test specimen suitable for evaluation of material properties the effective ratio of mean diameter to radial width shall be not less than 10 to 1 (or an inside diameter to outside diameter ratio not less than 0.82). When the test specimen has smaller ratios than the above requirements, the test results should not be represented as material properties but should be called core properties because of nonuniform flux distribution.

6.3 When link, oval-shaped, or rectangular test specimen forms are used, the requirements of 6.2 apply to the end or corner sections where flux crowding occurs. When straight-sided test specimens are very long relative to the length of the corner or end sections, they are suitable for basic material properties evaluation with relatively unoriented materials provided the uncertainty in determination of true-path (effective) length is less than 5 % of the total path length. When this uncertainty in path length (shortest or longest relative to the mean-path length) exceeds 5 %, the test values should be reported as core properties and not basic material properties.

6.4 The test specimen may be constructed of solid laminated or strip materials and in any of the shapes described in 1.1.

6.5 Test specimen cores made from strip may be laminated, machined, spirally wound, or Epstein specimens (the method of selection for Epstein specimens is described in Test Method A 343, Appendix 3). When the material is to be tested half transverse and half longitudinal, the material shall be cut into Epstein strips or square laminations of adequate dimensional ratio.

6.6 Test specimens used for basic material evaluation shall be cut, machined, ground, slit, or otherwise formed to have a cross section that remains sufficiently uniform that its nonuniformity will not materially affect the accuracy of establishing and measuring flux density, B, or magnetic field strength, H, in the test specimen.

6.7 When required for material properties development, the test specimen shall have received a stress relief or other heat treatment after preparation. This heat treatment is subject to agreement between manufacturer and purchaser, manufacturers recommendation, or the recommended heat treatment provided by the appropriate ASTM standard for the material. The heat treatment used shall be reported with the magnetic test results.

7. Calibration of Integrator

7.1 Practical operating experience has shown that provided a proper warmup period is allowed, electronic integrators require infrequent calibration and unlike ballistic galvanometers, calibration is not an integral part of this test method. When calibration is required, it can be accomplished with either a mutual inductor or a volt-second source. Because of their traceability to the fundamental units of voltage and time, volt-second sources are the preferred means of calibration. The accuracy of either the mutual inductor or volt-second source must be better than the rated full-scale accuracy of the integrator.

8. Procedure

8.1 In Fig. 1, the dc power source supplies magnetizing current measured by ammeter A_1 or A_2. Rheostats R_1 and R_2 and switches S_1 and S_2 determine the magnitude and direction of the current as required by various operations. In general, three types of switching operations are required in ballistic testing. One is reversal of magnetizing current direction without change of magnitude as required for establishing a cyclically magnetized condition and in normal induction tests. This is accomplished by throwing switch S_1 from one side to the other. A second is reduction of magnitude of magnetizing current without change of direction. This operation is required to measure points on the hysteresis loop in the first quadrant. This is done by opening switch S_2. The third operation combines reversal of magnetizing current direction with a reduction in magnitude. This operation is required to measure points on the hysteresis loop in the second and third quadrants.

Obtain this reversal and reduction by simultaneously throwing switch S_1 from one side to the other and opening switch S_2. Use care to be sure S_2 is opened before S_1 is reclosed for reversal. When determining the hysteresis loop, switches S_1 and S_2 must be operated to traverse the loop in the same direction between successive measurements so as to preserve the cyclically magnetized state of the test specimen.

8.2 Demagnetize the test specimen immediately before testing. To demagnetize with direct current, first establish a magnetic field strength sufficiently large to cause the flux density in the specimen to reach a value greater than the knee of the normal induction or magnetization curve. Then slowly reduce the magnetizing current to zero while simultaneously operating the reversing switch at one half second or longer intervals. An auxillary circuit using a time delay relay to effect switch reversal will make this operation more reproducible and less tedious. When the test specimen consists of thin strip (<0.025 in. [0.635 mm] thick), alternating current demagnetization using 60 Hz or lower frequency and autotransformers can be used.

8.3 To obtain the flux density (B) corresponding to a specific magnetic field strength (H), establish the proper magnetizing current using Eq 1 or Eq 10, cycle the reversing switch several times to establish the cyclically magnetized condition, zero the integrator, and execute the proper switching procedure as found in 8.1. The value of the flux or flux density can then be computed from the integrator reading. Additional test points on the normal induction curve can be obtained without demagnetization if they are obtained in ascending order of B or H. Otherwise, it is necessary to demagnetize before additional testing.

8.4 To obtain the magnetic field strength corresponding to a specific flux density, a procedure similar to 8.3 is used with the exception that the magnetizing current and, therefore, magnetic field strength must be found by trial and error. If the specified flux density is exceeded, demagnetization is usually required before proceeding further unless operating at very low flux densities.

8.5 Electronic integrators do not determine flux densities directly, rather the change in flux linkages ($N_2\Delta\phi$) is measured. This result is converted to changes in flux density by division by the specimen cross-sectional area, A, and number of secondary turns, N_2. To determine the actual value of flux density the starting or reference points must be known. In the case of normal induction or magnetization curve measurements, it is customary to zero the integrator and measure the change in flux density for a fully reversed change in magnetizing current. In this instance, the true value of flux density is one half of the total change in flux density. For hysteresis loop determination, the integrator is zeroed at the point of maximum magnetization. The resulting change in flux density is equal to the difference in flux density between the point of maximum magnetization current and the point corresponding to the hysteresis loop measurement current.

8.6 The procedures for testing in the Epstein frame[5] are identical to those for other ring type tests.[6] The only differences are the integral air flux compensator and method of sample insertion (see Test Method A 343).

9. Calculation (Customary Units)

9.1 The mean magnetizing force applied to the test specimen by the current through the magnetizing winding is determined from the equation:

$$H = 0.4\pi NI/l_1 \tag{1}$$

where:
H = magnetic field strength, Oe;
N = number of turns in magnetizing winding N_1 of Fig. 1;
I = current through the magnetizing winding, A; and
l_1 = mean magnetic path length, cm.

9.1.1 For a ring specimen, l_1 is determined from the mean circumference. For the Epstein frame, the mean magnetic path length is assumed to be 94 cm, and this equation for the 700-turn Epstein test frame is as follows:

$$\begin{aligned} H &= (0.4\pi \times 700I)/94 \\ &= 9.36I \end{aligned} \tag{2}$$

9.2 When test specimens have very smooth surfaces and precise uniform dimensions, the cross-sectional area may be determined by direct measurement. In all other cases, the effective test specimen cross-sectional area should be determined from measurements of mass, length, and density as follows:

$$A = m/l\delta \tag{3}$$

where:
A = test specimen cross-sectional area, cm^2;
m = test specimen mass, g;
l = test specimen length, cm; and
δ = density of test specimen material, g/cm^3.

9.2.1 For ring specimens, the specimen test length is assumed equal to the mean circumference so that the cross-sectional area is:

$$A = \frac{2m}{\pi(D_o + D_i)\delta} \tag{4}$$

where:
D_o = outer diameter, cm and
D_i = inner diameter, cm.

9.2.2 For the Epstein test frame:

$$A = m/(4l\delta) \tag{5}$$

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[5] Dieterly, D. C., "D-C Permeability Testing of Epstein Samples with Double-Lap Joints," Symposium on Magnetic Testing *ASTM STP 85*, ASTM, 1948, p. 39.

[6] Sanford, R. L. and Cooter, I. L., "Basic Magnetic Quantities and the Measurements of the Magnetic Properties of Materials," National Institute for Standards and Technology, Monograph 47, 1962.

where l is the length of the Epstein strips and this equation becomes:

$$A = m/l12\delta)$$ (6)

when l = 28 cm and

$$A = m/l22\delta)$$ (7)

when l = 30.5 cm.

9.3 The Epstein test frame coils are built considerably larger than the test specimen cross-sectional area. To avoid the need for manual air-flux correction, a compensating mutual inductor is built into the test frame. This means that the flux density measurements are intrinsic flux density, B_i, measurements. To obtain normal flux density, B, the following equation must be used:

$$B = B_i + \Gamma_m H$$ (8)

where:
B = normal flux density in test sample, G;
B_i = intrinsic flux density in test sample, G;
H = magnetic field strength, Oe; and
Γ_m = magnetic constant of free space (in cgs system $\Gamma_m = 1$).

9.4 When ring testing is conducted at high magnetic field strength and particularly when the B-coil surrounds an appreciable air flux in addition to the core flux, the test values must be corrected for air flux as follows. Wind a duplicate set of windings around a nonmagnetic core of identical size. Connect the magnetizing windings in series aiding and the B-sensing windings in series opposition with the respective test-core windings. This provides air-flux compensation and the measurements become intrinsic induction, B_i, as for the Epstein test frames. This method is usually more accurate than estimating the air-flux linking the B-sensing winding.

9.5 When the air flux corrections must be calculated from estimated coil areas the procedures 9.2.1 through 9.2.3 of Test Method A 341/A 341M should be followed.

9.6 Permeability is calculated as follows:

$$\mu = B/H = (B_i/H) + \Gamma_m$$ (9)

where:
μ = normal permeability, G/Oe.

10. Calculation (SI Units)

10.1 The mean magnetic field strength applied to the test specimen by the current through the magnetizing coil is determined from the equation:

$$H = NI/l_1$$ (10)

where:
H = magnetic field strength, A/m;
N = number of turns in magnetizing coil N_1 of Fig. 1;
I = current through the magnetizing coil, A; and
l_1 = mean magnetic path length, m.

10.1.1 For a ring specimen, l_1 is determined from the mean circumference. For the Epstein frame, the mean magnetic path length is assumed to be 0.94 m, and this equation for the 700-turn Epstein test frame is as follows:

$$H = (700I)/0.94 = 745I$$ (11)

10.2 When test specimens have very smooth surfaces and precise uniform dimensions, the cross-sectional area may be determined from physical measurements. In all other cases, the effective test specimen area should be determined from measurements of mass, length, and density as follows:

$$A = m/l\delta$$ (12)

where:
A = test specimens cross-sectional area, m^2;
m = test specimen mass, kg;
l = test specimen length, m; and
δ = density of test specimen material, kg/m^3.

10.2.1 For ring specimens, the specimen test length is assumed equal to the mean circumference so that the cross-sectional area is:

$$A = \frac{2m}{\pi(D_o + D_i)\delta}$$ (13)

where:
D_o = outer diameter, m, and
D_i = inner diameter, m.

10.2.2 For the Epstein test frame:

$$A = m/(4l\delta)$$ (14)

where l is the length of the Epstein strips and this equation becomes:

$$A = m/l.12\delta$$ (15)

when l = 0.28 m, and

$$A = m/l.22\delta$$ (16)

when l = 0.305 m.

10.3 The Epstein test frame coils are built considerably larger than the test specimen cross-sectional area. To avoid the need for manual air-flux correction, a compensating mutual inductor is built into the test frame. This means that the flux density measurements are intrinsic flux density, B_i, measurements. To obtain normal flux density, B, the following equation must be used:

$$B = B_i + \Gamma_m H$$ (17)

where:
B = normal flux density in test sample, T;
B_i = intrinsic flux density in test sample, T;
H = magnetic field strength, A/m; and
Γ_m = magnetic constant of free space (in SI system $\Gamma_m = 4\pi \times 10^{-7}$ H/m).

10.4 When ring testing is conducted at high magnetic field strength, and particularly when the *B*-coil surrounds an appreciable air flux in addition to the core flux, the test values must be corrected for air flux as follows. Wind a duplicate set of windings around a nonmagnetic core of identical size. Connect the magnetizing windings in series aiding and the *B*-sensing windings in series opposition with the respective test-core windings. This provides air-flux compensation and the measurements become intrinsic induction, B_i, as for the Epstein test frames. This method is usually more accurate than estimating the air-flux linking the *B*-sensing winding.

10.5 When the air flux corrections must be calculated from estimated coil areas, the procedures 10.2.1 through 10.2.3 of Test Method A 341/A 341M should be followed.

10.6 Permeability is calculated as follows:

$$\mu = B/H$$
$$= (B_i/H) + \Gamma_m \tag{18}$$

where:

μ = normal permeability, H/m.

11. Report

11.1 When normal induction (flux density) values or hysteresis-loop points have been measured for the purpose of reporting basic material properties, the following shall be reported along with the test data:

11.1.1 Complete identification of test specimen type or shape.

11.1.2 Size and dimensions of the test specimen.

11.1.3 Mean diameter to radial width ratio or the inside to outside diameter ratio of the test specimen.

11.1.4 Heat treatment or other processing applied to the test specimen before testing.

11.1.5 When permeability is reported, the corresponding value of either *B* or *H* must be reported.

11.1.6 When hysteresis-loop properties are reported, the value of peak magnetic field strength or peak flux density used shall be reported.

11.1.7 When saturation or other high flux density values are reported, the value of magnetic field strength must be reported.

12. Precision and Bias

12.1 The accuracy of determining magnetic field strength *H* is usually dependent on the accuracy of current measurement and ability to maintain identical current after reversal and in the accuracy of determining magnetic path length. When the inside diameter to outside diameter ratios are above 0.82 and dimensions are known precisely and the best instrumentation is used, the determination of *H* will be within 1.0 %. For the Epstein frame, because of the corner joints, there is some uncertainty as to the true path length, the determination of *H* will be within 2.0 %. When the effective inside-outside diameter ratios are allowed to fall below 0.82, additional errors in path length occur which may reach 10 % or more for poor ratios. Under these conditions, test data should not be reported as material properties.

12.2 The accuracy of determining flux density, *B*, is usually dependent on the quality of integrator calibration, on the uniformity of material, and accuracy of determining the cross-sectional area of the test specimen. When the best instrumentation and calibrations are used, the flux density, *B*, will be determined within 1.0 %.

12.3 If the inside-outside diameter ratios are held to 0.82 or above, the nonuniformity of flux distribution over the test specimen is minimized for most materials. With lower ratios, the flux distribution is excessively nonuniform, and it is no longer proper to describe the sample material as being tested at a given induction level. For this reason, such test values should not be reported as material properties but as core properties at the indicated flux density.

12.4 When permeability is calculated, the errors associated with both *B* and *H* are included. For ring specimens having inside-outside ratios of 0.82 or higher, the basic material permeability will be determined within 2 %. For the Epstein test frame, the material permeability determinations should be within 3 %. When inside-outside diameter ratios are allowed to drop below 0.82, large errors in determination of material permeability may appear. (With poor ratios, such as those found in many punched lamination stacks, the errors in determination of the basic material permeability may exceed 25 %).

13. Keywords

13.1 ballistic test; coercive force; direct current; Epstein; induction; magnetic field strength; magnetic test; permeability; residual induction

ANNEX

(Mandatory Information)

A1. CALIBRATION OF BALLISTIC GALVANOMETER (MODIFIED cgs UNITS)

A1.1 The galvanometer scale and *B*-circuit may be calibrated using current reversals in the mutual inductor. The following equation shall be used to determine the calibration values:

$$I_c = BNA/(L_m \times 10^5) \tag{A1.1}$$

where:

I_c = current in units of Amperes required for reversal in the primary of the mutual inductor L_m to calibrate the *B*-circuit for a desired deflection;
B = flux density in units of Gausses in the test specimen at calibrated deflection;
N = number of turns in *B*-sensing coil N_2 of Fig. 1;
A = cross-sectional area of test specimen, cm^2; and
L_m = value of calibrating mutual induction in units of mH.

A1.1.1 The equation can also be written as:

$$I_c = \phi N/(L_m \times 10^5) \tag{A1.2}$$

where:

ϕ = BA or total magnetic flux, mx.

A1.2 Using the above equations, substitute in the value of flux density, *B*, which corresponds to the desired calibration flux density and the values of the specimen area turns and mutual inductance. This gives the value of current which must be reversed in the mutual inductor. Set this value of current through the mutual inductor and observe the galvanometer deflection on current reversal. The value of the calibrating resistor is then adjusted to make the galvanometer deflection on current reversal swing from zero to the desired scale deflection for the calibrated deflection point. Usually the scale is calibrated to make the deflections on reversal equal to the *B* value of calibration or some simple multiplier of it.

A1.3 For basic material evaluation, the galvanometer shall be calibrated with sufficient number of current values to provide a calibration curve which is accurate to 0.1 % of full scale or 0.2 % of smallest scale division. When desired because of nonlinearity or other reasons, the test deflection points may be calibrated independently without completing a full-scale calibration.

APPENDIXES

(Nonmandatory Information)

X1. MUTUAL INDUCTOR CONSTRUCTION (MODIFIED cgs UNITS)

X1.1 A standardized mutual inductor for calibrating the galvanometer is required. It should have mutual inductance between 10 to 100 mH and be able to carry a continuous current of at least 1 A in the primary winding without appreciable heating.

NOTE X1.1—If a mutual inductor must be constructed, the following specifications will provide an inductor of approximately 50 mH. A layer of insulating material should be provided between primary and secondary windings, and the foundation forms should be constructed from nonmagnetic nonconducting materials.

Part	Specifications
Tubular winding form	4-in. outside diameter by 3 ½-in. inside diameter by 2-in. length
Two end disks	each ¼ in. thick by 7-½ in. diameter
Bottom (primary) winding	50 turns of No. 18 single cotton-covered enameled wire
Top (secondary) winding	530 turns of No. 18 single cotton-covered enameled wire

For detailed construction of a precision inductor see National Institute of Standards and Technology Circular No. 74, p. 269.

X2. ARC SUPPRESSION FOR DIRECTLY SWITCHED TEST UNITS

X2.1 The high sensitivity of electronic integrators renders them more susceptible to noise induced error than ballistic galvanometers or moving coil fluxmeters. One potentially significant source of noise is arcing across the contacts of the current reversing switch S_1 shown in Fig. 1. Such arcing is favored by use of a large number of magnetizing turns. If the magnitude and duration of the arc and the transients in the secondary winding are significant, the integrator output will be incorrect.

X2.2 The magnitude of this integrator error can be established by moving the position of S_1 from one side to the other, waiting until the integrator reading stabilizes and then moving S_1 back to its original position. The amount by which the fluxmeter output changes at the completion of this cycle, less the amount caused by integrator drift, is indicative of the magnitude of the error to be expected in normal use. If this error can be attributed to arc noise and not to differences in contact resistance and if the magnitude is unacceptable, the techniques described below should be used to reduce this error to an acceptable level.

X2.3 The sudden interruption of the current flowing in the magnetizing winding can cause the voltage across the winding to become very large, producing arcing at the contacts of S_1. If the magnitizing current were allowed to decay at a slower rate, the voltage across the magnetizing winding would be much lower and the arcing would be reduced accordingly. This can be accomplished by placing a diode bridge with capacitor *(D_1, D_2, D_3, D_4)* C across the magnetizing winding as shown in Fig. X2.1. The diode bridge and capacitor provide a path for the discharge of the stored magnetic energy. The capacitance required depends on the impedance of the power supply and resistors R_1 and R_2 in Fig. 1. The lower these impedances are, the smaller is the capacitance required to reduce arcing.

X2.4 Arc-generated noise can also be reduced by use of a relay with magnetic arc suppression or with mercury-wetted contacts in place of a manually operated switch. However, the use of the diode bridge and capacitor further reduces the noise.

X2.5 All transients and arcing conditions can be eliminated by use of remotely programmed bipolar power supplies, thereby eliminating the use of the current reversing switch.

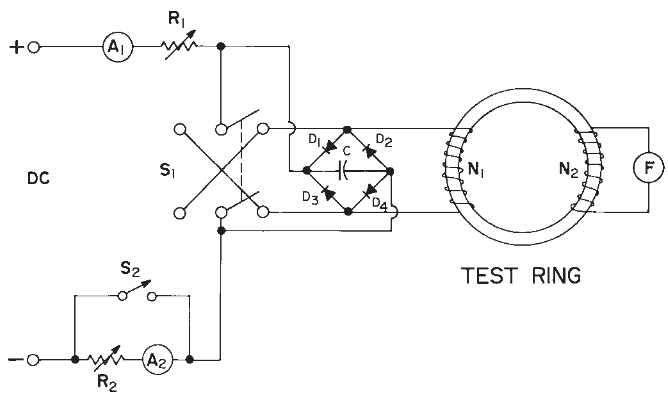

FIG. X2.1 Schematic Illustration of Arc Suppression Diode Bridge Placed in the Circuit Shown Previously in Fig. 1.

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