Designation: A 773/A 773M – 01

Standard Test Method for dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with dc Electronic Hysteresigraphs[1]

This standard is issued under the fixed designation A 773/A 773M; 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 provides dc hysteresigraph procedures (*B-H* loop methods) for the determination of basic magnetic properties of materials in the form of ring, toroidal, link, double-lapped Epstein cores, or other standard shapes that 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 continuous sweep magnetization. Rate of sweep may be varied, either manually or automatically at different portions of the curves during tracing. Total elapsed time for tracing a hysteresis loop is commonly 10 to 120 s per loop.

1.2 The values and equations stated in customary (cgs-emu and inch-pound) or SI units are to be regarded separately as standard. Within th is standard, SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this standard.

1.3 *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 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 Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame[2]

A 596/A 596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens[2]

2.2 *Other:*

IEC Publication 404-4: Magnetic Materials—Part 4: Methods of Measurement of dc Magnetic Properties of Iron and Steel (1995)[3]

3. Summary of Test Method

3.1 As in making most magnetic measurements, a specimen is wound with an exciting winding (the primary) and a search coil (the secondary) for measuring the change in flux. When an exciting current, I, is applied to the primary winding, a magnetic field, H, is produced in the coil, and this in turn produces magnetic flux ϕ in the specimen. In uniform specimens that do not contain air gaps, such as ring samples, all of the exciting current is used to magnetize the specimen, and H is proportional to I in accordance with the following equation:

$$H = KI \tag{1}$$

where:

H = magnetic field strength, Oe [A/m];

I = current in the exciting coil A; and

K = constant determined by the number of primary turns the magnetic path length of the specimen and system of units.

3.1.1 The magnetic flux may be determined by integration of the instantaneous electromotive force that is induced in the secondary coil when the flux is increased or decreased by a varying H. The instantaneous voltage, e, is equal to:

$$e = -NK^{1}\frac{d\phi}{dt} \tag{2}$$

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[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, 25 W. 43rd St., 4th Floor, New York, NY 10036.

or

$$\phi = \frac{1}{K_1 N}\int e\,dt$$

where:

dt = time differential,

N = number of turns, and

K_1 = 10^{-8} for cgs-emu system, or $K_1 = 1$ for SI system.

The flux ϕ can be obtained if $\int e\,dt$ can be determined. This can be accomplished by several means, as described in *ASTM STP 526*. **(1)** [4] The most common method uses an electronic integrator consisting of a high-gain dc amplifier with resistive-capacitive feedback. The relationship to $\int e\,dt$ is:

$$E = \frac{1}{RC}\int e\,dt \tag{3}$$

where:

E = output voltage, V;

R = input resistance of the integrator in the secondary circuit, Ω; and

C = the feedback capacitance, F.

By combining the two equations:

$$\phi = \frac{ERC}{K_1 N} \text{ or } E = \frac{\phi N K_1}{RC} \tag{4}$$

If the voltage, *E*, is applied to the *Y* axis of an *X-Y* recorder, the *Y* deflection of the pen is proportional to the flux, ϕ.

3.1.2 Measurements of magnetic field strength and flux by the hysteresigraph method is illustrated in the block diagram of Fig. 1. The system consists of a magnetizing power source, an exciting current controller, an electronic flux integrator, and a data recorder. As exciting current is applied to the coil, a voltage proportional to *I* is produced across the shunt resistor which is connected in series with the primary coil. This voltage determines the value of *H*.

3.1.3 In the testing of hard magnetic materials, or soft magnetic materials in the form of wire, bars or rods, it is usually necessary to use a permeameter. This is shown in the block diagram of Fig. 2. When using permeameters, the value of *H* in the gap is generally not proportional to *I* that flows through the exciting coil of the yoke. In these cases, the value of *H* is determined by integration of the electromotive force that is induced in an *H* coil (or Chattock potentiometer) or from the signal developed by a Hall probe which is placed near the specimen. When using an *H* coil, the determination of *H* is accomplished with an *H* integrator in exactly the same manner as that used to determine flux with the *B* integrator described in 3.1. When using a Hall sensor, the *H* values are determined from the voltage output which is proportional to *H*. In some cases, the *H* versus *I* relationship may be sufficiently linear from 0 to the coercive field strength (H_c) of the material under test. In such cases, it is acceptable to determine the second quadrant of the hysteresis loop by determining *H* from the value of *I* in the exciting winding.

4. Significance and Use

4.1 Hysteresigraph testing permits more rapid and efficient collection of dc hysteresis (*B-H* loop) data as compared to the point by point ballistic Test Methods A 341/A 341M and A 596/A 596M. The accuracy and precision of testing is comparable to the ballistic methods. Hysteresigraphs are particularly desirable for testing of semihard and hard magnetic materials where either the entire second quadrant (demagnetization curve) or entire hysteresis loop is of primary concern.

4.2 Provided the test specimen is representative of the bulk sample or lot, this test method is well suited for design, specification acceptance, service evaluation and research and development.

5. Interferences

5.1 Test methods using suitable ring-type specimens are the preferred methods for determining the basic magnetic properties of a material. However, 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 material and the measured parameters

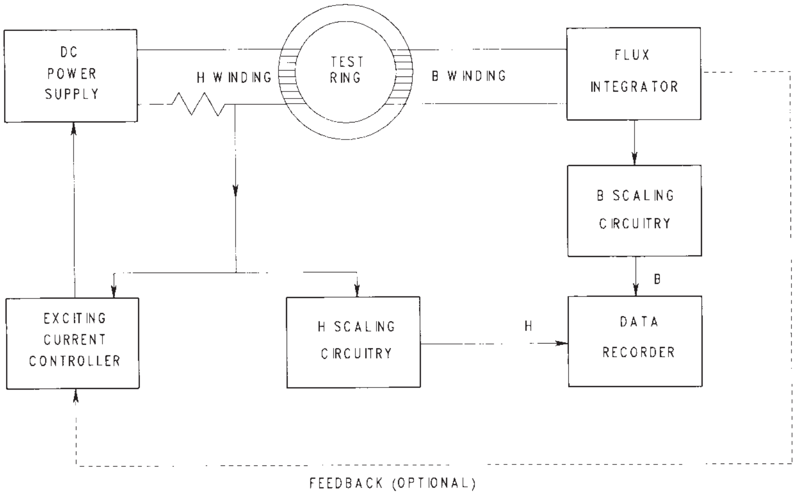

FIG. 1 Block Diagram of Ring Test Apparatus

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[4] The boldface numbers in parentheses refer to the list of references at the end of this test method.

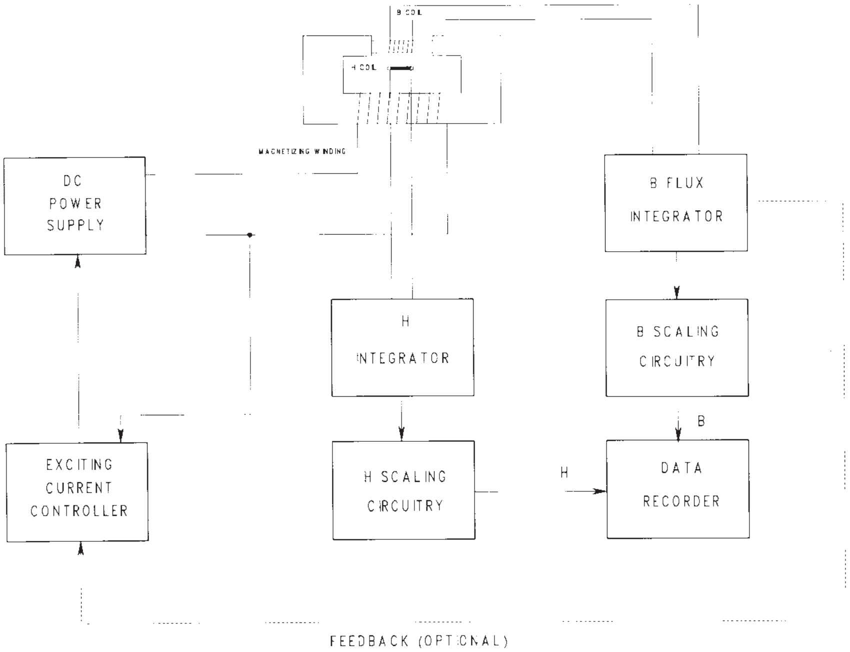

FIG. 2 Block Diagram of Permeator Test Apparatus

TABLE 1 Permeameters Recommended for Use With Hysteresigraphs

NOTE 1—Other permeameters may be suitable for use with dc hysteresigraphs where appropriate modifications are made. Refer to Test Method A 341/A 341 for other permeameters.

Permeameter	Magnetic Field Strength Range		*H* Measurement Device
	Oe	kA/m	
Babbit **(2,3)**	40/100	3.2/8	current, *H* coil
Fahy Simplex **(4,5,6)**	0.1/300	0.008/24	*H* coil
Fahy Simplex Super H Adapter **(6)**	100/2500	8/200	*H* coil
IEC Type A	12/2500	1/200	*H* coil, Hall probe
IEC Type B	12/620	1/50	*H* coil
Isthmus **(6, 7)**	100/20 000 +	8/1600 +	*H* coil, Hall probe

cannot be represented as material properties. The basic quality of materials having directional sensitive properties cannot be tested satisfactorily with punched rings or laminations. With them it is necessary to use Epstein specimens cut with their lengths in the direction of specific interest or use long link-shaped or spirally wound core test specimens whose long dimensions are similarly oriented. The acceptable minimum width of strip used in such test specimens is also sensitive to the material under test. At present, it is believed the silicon steels should have a strip width of at least 3 cm [30 mm]. Unless ring specimens are large, it is difficult to provide sufficient magnetizing turns or current-carrying capacity to reach high magnetic field strengths. In general, magnetic materials tend to have nonuniform properties throughout the body of the test specimens; for this reason, uniformly distributed test windings and uniform specimen cross-sectional area are highly desirable to average nonuniform behavior to a tolerable degree.

5.2 When conducting permeameter tests on bars, rods, and other appropriate specimens, this test method covers a range of magnetic field strengths from about 0.05 Oe [4 A/m] up to about 20 000 Oe [1600 kA/m] or more, depending on the specimen geometry and the particular permeameter that is used. In general, the lower limit of magnetic field strength is determined by the area-turns of the *H* coil (or the sensitivity of the Hall probe if it is used), the sensitivity of the integrator, and the sensitivities of the measuring and recording components. The upper limitation in magnetic field strength is determined by the type of permeameter appropriate for the specimen, the power supply, and the heat generated in the yoke windings. Recommendations of the useful range of magnetic field strength for the various permeameters are shown in Table 1. Other types may be used with appropriate precautions.

5.2.1 In general, permeameters do not maintain a uniform magnetic field in either the axial or radial directions around the test specimen. The field gradients in both of these directions will differ in the various permeameters. Also the *H*-sensing and *B*-sensing coils of the different permeameters are not identical in area, in turns, or in length or identically located. Although test specimens are prepared to have uniform physical cross section, they may have undetected nonuniform magnetic properties radially or axially along the specimen length adjacent to the *H* or *B* coils. Some permeameters may also introduce clamping strains into the test specimen. For these reasons test results obtained on a test specimen with one type of permeameter may not compare closely with those obtained on the same specimen from another type permeameter, and both may differ from more precise testing methods.

5.2.2 The limitation in the *B* measurement by this test method is determined by the number of turns on the specimen, the cross-sectional area, the permeability, and the sensitivities of the *B* integrator and *X*-*Y* recorder. In general, normal induction and hysteresis data may be determined from a flux linkage corresponding to 1000 Maxwell turns [10^{-5} Weber turns] to an upper induction that corresponds to the intrinsic saturation for most materials.

5.2.3 Some permeameters use compensation coils and require continual adjustment of the current flowing through these coils. This may not be compatible with commercially available hysteresigraphs and can be a source of significant error.

5.2.4 The magnetic test results, particularly for high permeability alloys, may not exactly agree with test results obtained by the ballistic methods, Test Methods A 341/A 341M and A 596/A 596M. This is due to the influence of eddy currents and the different nature of the magnetizing waveform between hysteresigraph and ballistic testing.

6. Apparatus

6.1 The apparatus shall consist of as many of the components described in 6.2-6.6 as required to perform the tests.

6.1.1 All apparatus used in this test method shall be calibrated against known standards to ensure the accuracy limits given below.

6.2 *Balance or Scales*:

6.2.1 The balance or scales used to weigh the test specimen shall be capable of weighing to an accuracy of 0.2 %.

6.2.2 The micrometer or dimensional measuring scales used to determine specimen dimensions for calculation of cross-sectional area shall be capable of measuring to an accuracy of at least 0.1 %.

6.3 *Magnetizing Power Source*—The power source may range from simple batteries to sophisticated regulated, low-ripple, protected, programmable types. It shall have sufficient capacity to produce the maximum currents required for magnetization of the specimen under test.

6.4 *Exciting Current Controller*—Instantaneous value of magnetizing current, and its rate of change, may be controlled entirely manually by means of rheostats, potentiometers, shunts, reversing switches, and so forth; semiautomatically by means of variable-speed motors or sweep generators, and so forth; or entirely automatic by means of rate sensors, and so forth. In all cases, components shall be capable of carrying the required currents without overheating, and controls shall be of such design that magnetizing current may be increased or decreased in a uniform manner so that smooth traces are plotted on the *X-Y* recorder.

6.5 *B or H Integrator*—The flux integrator(s) may be any of the types described in *ASTM STP 526* (or other) and should have sufficient sensitivity, stability, linearity, and freedom from drift to ensure an accuracy of at least 0.5 % of full scale.

6.6 *Data Recorder*—The B and H values can be recorded and displayed by either analog or digital *X-Y* chart recorders, dataloggers, or computers. The recording device shall be capable of resolving B or H values of 1 % of the full-scale value. For analog to digital converters, twelve-bit resolution is desirable.

7. Test Specimens for Ring-Type Measurements

7.1 The specifications in 7.2-7.8 cover the general case for specimens in which magnetic field strength is proportional to the exciting current, that is, $H = kI$.

7.2 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.

7.3 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 data should not be represented as material properties but should be called core properties because of nonuniform flux distribution.

7.4 When link, oval-shaped, or rectangular test specimen forms are used, the requirements of 7.3 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 1 % of the total path length. When this uncertainty in path length (shortest or longest relative to the mean-path length) exceeds 1 %, the test values should be reported as core properties and not basic material properties.

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

7.6 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 Annex A3 of Test Method A 343). 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.

7.7 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 induction, B, or magnetic field strength, H, in the test specimen.

7.8 When required for material properties development, the test specimen shall have received a stress relief or other anneal after preparation. This anneal is subject to agreement between manufacturer and purchaser.

8. Test Specimens for Permeameter Measurements

8.1 The specifications in 8.2-8.11 cover the general case for specimens in which the magnetizing force is not proportional to exciting current and the specimen must be tested in conjunction with a suitable permeameter.

8.2 Where possible, test specimen cross-sectional area shall be directly measured using calipers or micrometers. If not possible because of cross-sectional shape or surface roughness, then the cross-sectional area shall be determined from the mass, length, and assumed density of the test specimen.

8.3 Test specimens in bar form may be of round, square, or rectangular cross-sectional shape. In some permeameters, the bar specimen may be a half round or any shape having a uniform cross-sectional area. Permeameters must have a good magnetic joint between the ends of the test specimen and the permeameter yoke or pole faces. Generally, to achieve a good magnetic joint, the test specimen must be of square or rectangular cross section and must be machined or ground to have straight and parallel surfaces. For permeameters using specimens butted to the pole tips, the specimen ends must be smooth and parallel.

8.4 When the material is in flat-rolled form and is to be evaluated as half transverse-half longitudinal, the test sample shall be sheared to have strip specimens in multiples of four in accordance with Table 2. When flat-rolled material is to be evaluated in only one direction, the test specimen shall conform to Table 2 or to the requirements for best test quality for the particular permeameter being used. For flat-rolled materials of thickness 0.0100 in. [0.254 mm] or thinner, the test specimen cross-sectional area shall be not less than 0.310 in.^{2}[200 mm^2] and not more than 0.620 in.^{2}[400 mm^2].

8.5 When the test specimen for strip materials is to be half transverse and half longitudinal, the strips shall be positioned to be composed of alternately transverse and longitudinal throughout the specimen and a transverse strip shall be placed adjacent to the permeameters yoke or pole face.

8.6 For full testing accuracy, the length and size of the test specimen must meet the requirements of the permeameter being used. Generally for most permeameters, a test specimen length of 10 in. [254 mm] or more is required. Shorter specimens with some permeameters require the use of pole-piece extensions and may cause a reduction in testing accuracy. Other permeameters are designed for short specimens without loss of testing accuracy.

8.7 When the test specimen is short and is to butt endwise directly against the pole piece or pole piece extensions, it shall have ends with flat, smooth, and parallel surfaces.

8.8 All test specimen forms shall be cut, machined, or ground to have a uniform cross-sectional area along the active length of the test specimen. The cross-sectional area shall be sufficiently uniform so that its nonuniformity does not materially affect the accuracy of establishing and measuring induction in the test specimen.

8.9 When required for development of material properties, the test specimen shall receive a stress relief or other anneal after preparation. This anneal is subject to agreement between manufacturer and purchaser.

8.10 Specimens of permanent-magnet material shall be processed previous to testing in accordance with a procedure acceptable to both the manufacturer and the purchaser.

8.11 The test specimen shall conform to the requirements of Practice A 34/A 34M.

9. Calibration of Integrator(s)

9.1 The integrator(s) may be calibrated by any convenient means that will ensure an integration accuracy of at least 0.5 %. Calibration may be accomplished by means of a certified Maxwell-turns generator, or volt-seconds generator, or mutual inductor, or by verification of input resistors and feed-back capacitors in operational amplifier-type integrators.

TABLE 2 Number of Test Strip

Nominal Thickness		Electrical Sheet Gage Number	Number of Strips
in.	mm		
0.0100 to 0.0250	0.254 to 0.635	32 to 24	12
0.0280 to 0.0435	0.711 to 1.105	23 to 19	8
0.0500 and over	1.270 and over	18 and thicker	4

10. Calibration of Magnetizing Circuit

10.1 In cases in which the magnetic field strength is proportional to current, such as in ring specimens, long solenoids, special permeameters, and so forth, the shunt resistor(s) through which the magnetizing current flows shall be verified to at least 0.1 %, at rated current.

11. Calibration of Data Recorder

11.1 The various scales of the data recorder shall be calibrated by means of a verified voltage source to at least the quoted accuracy of the recorder in use.

12. Procedure

12.1 The following test procedure is based on a hysteresigraph which features both manual and automatic control of magnetizing current, operational amplifier-type integrators, and an analog *X-Y* recorder. The use of other hysteresigraphs, including fully computerized units, is permissible and detailed operating steps will vary. However, the general test procedure is similar in all units. The following procedure covers manual current sweeping, automatic current sweeping, and automatic current sweeping with symmetrical tracing.

12.2 *Setup*—The procedures of 12.2.1-12.2.6 should be observed for all methods of current sweep.

12.2.1 Before beginning a test, allow a minimum warmup period of 10 min for all apparatus and instrumentation.

12.2.2 Connect the specimen, observing polarity so that the pen of the recorder moves in the first quadrant on initial application of exciting current. (It is imperative that proper polarity be established before demagnetization of the test specimen.)

12.2.3 Before test, demagnetize the specimen through the coils by ac or dc techniques by establishing a magnetic field strength sufficiently large to reach a point well above the knee of the magnetization curve. Then, while continuously cycling the magnetization, slowly reduce the magnetizing current to zero. (In the demagnetization process, down-switching of voltage taps to reduce current may result in current surges. It is advisable to select voltage sources and controls that have the ability to reduce current to a low value without switching taps, preferably to a current level that does not exceed a value of 0.1 times the coercivity of the material.)

12.2.4 For the B measurement, set the B integrator range and scaling potentiometer so that B is read directly on the Y axis of the recorder.

12.2.5 For the H measurement, select the appropriate shunt resistor (current range) and set the scaling potentiometer so that H is read directly on the X axis.

12.2.6 Before starting the current sweep, adjust the drift in the integrators to minimum.

12.3 *Manual Sweep Method*—If a specimen is completely demagnetized, it is possible to obtain a normal induction curve and symmetrical hysteresis loop by using manual sweep methods. However, since it is difficult to obtain smooth traces by manual control, recording by manual sweep is recommended only when the test specimens have relatively low permeabilities, large cross sections, and a large number of secondary turns. (This permits coarser B and H calibrations, and sweep control is not so crucial.)

12.3.1 Before testing, follow the setup procedure described in 12.2.1-12.2.6.

12.3.2 The controller shall be used in the manual mode. The sweep current is controlled manually by the H-sweep control.

12.3.3 With the origin at the center of the X-Y coordinates and with the recorder pen in the down position, set the H sweep control at zero (center tap of control). Trace the normal induction curve by turning the control until the pen reaches the desired $+H_m$ on the recorder. At $+H_{\mathrm{m}}$ turn the control to decrease the magnetic field strength until the pen traverses to point B_r (center tap of control) where the current reverses. Continue to turn the control, increasing the current negatively, until the pen reaches points $-H_c$ and $-H_m$. Then turn to $+H_m$ to complete the loop tracing. Minor loops are obtainable at any point of the major loop by reversing the control in incremental amounts.

12.3.4 If the loop obtained in 12.3.3 is symmetrical about the origin, the trace from the origin to H_m is similar to a normal induction curve; any point on the major loop is valid and may be read directly. However, if the loop is significantly displaced as a result of incomplete demagnetization, the initial curve is not a valid normal induction curve. If the major loop is only moderately displaced, approximate values for points (H_m, B_m), H_c, and B_r may be obtained by averaging corresponding positive and negative values.

12.3.5 In obtaining magnetization and hysteresis data by hysteresigraph methods, very often the H_c value of the specimen is very small relative to H_m so that H_c and B_r cannot be resolved with high accuracy. However, this is overcome by expanding the H scale (increasing the H sensitivity) when the pen reaches B_r (or $H = 0$). When recording manually, stop the current sweep at $+B_r$ then change the current range setting (shunts) to give the appropriate sensitivity to measure H_c accurately (ratios to 2.5 to 300 are possible). An alternative method is simply to change the x sensitivity on the recorder when the pen reaches $+B_r$. If extreme changes in sensitivity are required, a combination of both methods may be used.

12.3.6 In obtaining a major hysteresis loop, a minimum of two loops shall be traced to assure that the specimen is in a symmetrically cyclically magnetized state and to assure that significant drift has not occurred during the test.

12.4 *Automatic Sweep Method*—In obtaining magnetization and hysteresis data by hysteresigraph methods, automatic sweeps are preferable because of better control of sweep current for tracing smooth loops. If a specimen is completely demagnetized, it is possible to obtain curves similar to normal induction curves and symmetrical hysteresis loops.

12.4.1 Before testing, follow the setup procedure described in 12.2.1-12.2.6.

12.4.2 Switch the controller to the automatic mode. This introduces the controller circuitry for automatic control of the sweep current.

12.4.3 Select the appropriate current range (shunts) and set the H-scaling control to give the desired full-scale magnetic field strength.

12.4.4 Set the control, H control, to give the desired peak magnetic field strength. (The H_m (%)) helipot may be varied to give any whole or fractional part of the full-scale magnetic field strength).

12.4.5 Set the sweep speed of the controller to 20 s or longer per loop, adjust the drift to a minimum, and place the pen of the recorder in the down position at the origin.

12.4.6 Begin the current sweep. If the specimen is completely demagnetized, a normal induction curve will be traced in the first quadrant to ($+H_m$, B_m), then H is automatically reduced and the trace proceeds to (0, $+B_r$). The current sweep is automatically switched in polarity, and the second and third quadrants are traced. At ($-H_m$, $-B_m$) the current sweep is again reduced, and the remaining half of the hysteresis loop is traced. It is advisable to trace at least two complete loops to ascertain if significant drift has occurred during the plot.

12.4.7 If the loop traced in 12.4.6 is symmetrical about the origin, the trace from the origin to H_m is similar to a normal induction curve; any point on the major loop is valid and may be read directly. If the loop is significantly displaced because of incomplete demagnetization, the initial curve is not valid. If the major loop is only moderately displaced, approximate values for points B_r, H_c, (H_m, B_m) or any other may be obtained by averaging corresponding positive and negative values.

12.4.8 If the H_c values of the specimen is very small relative to H_m so that H_c and B_r cannot be resolved with high accuracy, the H scale may be expanded to give increased sensitivities for accurate reading of B_r and H_c. Follow the procedures as described in 12.3.5.

12.4.9 Minor hysteresis loops are obtainable at any point of the major loop by reversing the current sweep in incremental amounts.

12.5 *Automatic Sweep With Symmetrical Trace Method*—The preferred method for obtaining magnetization and hysteresis data by hysteresigraph methods is to use symmetrical trace circuitry which enables automatic tracing of symmetrical hysteresis loops about the origin. By this method, a loop is traced symmetrically about the origin regardless of the degree of residual magnetism in the specimen. In using the automatic symmetrical method of hysteresigraph testing, a normal induction curve is determined (point by point) from the positive tips of major hysteresis loops. The curve is obtained by tracing a number of symmetrical loops, starting at low values of H and progressively increasing the size of the loops in convenient steps. Plots of the various loop tips will give the normal induction curve. For greater sensitivity and maximum use of chart area, the automatic symmetrical mode may be used to advantage by tracing half loops by placing the origin at a convenient location in the lower left hand section of the chart and recording only the positive tips of the hysteresis loops in the first quadrant. In this case, the pen is over driven in the X and Y directions, but this does not alter the accuracy.

12.5.1 Before testing a specimen, follow the setup procedure described in 12.2.1 to 12.2.6. The use of symmetrical tracing does not eliminate the need for demagnetization when maximum inductions less than those corresponding to the knee of the magnetization curve are to be measured.

12.5.2 Switch the controller to the automatic symmetrical mode. This introduces the circuitry for automatic control of sweep current and automatic tracing of symmetrical hysteresis loops.

12.5.3 Select the appropriate current range (shunts) and set the *H*-scaling control to give the desired full-scale magnetic field strength.

12.5.4 For maximum use of chart area, select the origin at a convenient location in the lower left-hand section of the chart.

12.5.5 Set the sweep speed of the controller to 20 s or longer per loop and adjust the drift to a minimum.

12.5.6 Set the *H* control to give a small value of magnetic field strength for tracing a small loop. Start the current sweep.

12.5.7 If the secondary leads are connected with proper polarity, the pen (in the up position) will first move to the right in the first quadrant then fall sharply to $B = 0$. The pen will move through the fourth quadrant then to $(-H_m, -B_m)$ in the third quadrant. As the pen returns from $(-H_m, -B_m)$, the tracing will be in a symmetrical position with respect to the origin and the pen may be placed in the down position. The positive tip of the loop represents one point of the normal induction curve.

12.5.8 To obtain additional test points, increase the H_m settings by convenient amounts to obtain successively larger loops by repeating the procedure in 12.5.7. A plot of the tips of the various hysteresis loops will give a normal induction curve.

12.5.9 To ascertain if significant drift has occurred and to assure that the specimen is in a symmetrically cyclically magnetized state, it is required that a minimum of two loops be traced for each test point.

12.5.10 If the H_c value of the specimen is very small relative to H_m so that H_c and B_r cannot be resolved with high accuracy, the *H* scale may be expanded to give increased sensitivities for accurate reading of B_r and H_c as described in 12.3.5. When testing in the automatic symmetrical mode, the procedure for obtaining H_c is identical to that in 12.3.5 with the exception that the change in sensitivity is made at $-B_r$, in which case the value of $+H_c$ is recorded on the chart. An alternative and preferred method for obtaining B_r is to stop the current sweep as the pen approaches $+B$ from $(+H_m + B_m)$. The pen will fall to the B_r value.

12.5.11 The procedures described in 12.5.1-12.5.10 cover the point-by-point method for obtaining normal induction properties when using hysteresigraphs with automatic symmetry. Full loop properties, including minor hysteresis loops, may be obtained by the same procedure by placing the origin at the center of the chart and recording the entire loop. Minor hysteresis loops may be traced at any point of a major loop by reversing the current sweep in incremental amounts.

12.6 The procedures for obtaining magnetization properties of rod- and bar-type specimens on either soft or hard magnetic materials typically require the use of an appropriate permeameter. However, the procedures are identical to the methods described in 12.1-12.5 with the following exceptions: First, the *H* measurement is made with an *H* coil (since *H* is not proportional to exciting current); hence, the hysteresigraph must be equipped with a second integrator. Secondly, since the magnetic field strength is not proportional to the current flow in the magnetizing yokes, the current flow in the magnetizing coils for a particular *H* value must be determined by trial and error. Since this is normally done with the test specimen in place, demagnetization may be required before conducting the actual test.

13. Calculations When Using Permeameter Procedures

13.1 Where possible, test specimen cross-sectional area shall be directly measured using calipers or micrometers. If not possible as a result of cross-sectional shape or surface roughness, then the cross-sectional area shall be determined from the mass, length, and assumed density of the test specimen as follows:

$$A_c = \frac{m}{l\delta} \tag{5}$$

where:

A_c = cross-sectional area, cm^2[m^2];
m = specimen mass, g, [kg];,
δ = material density, g/cm^3[kg/m ^{3}]; and
l = specimen length, cm [m].

13.2 In many permeameters, the *B*-coil area is much larger than the test specimen area; when this occurs, a correction, K_2, for air flux in the *B* coil is required. Make this correction as follows:

13.2.1 Determine the correction, K_2, as follows:

$$K_2 = \frac{a_c - A_c}{A_c} \tag{6}$$

where:

a_c = cross-sectional area of test coil, cm^2 [m^2] and
A_c = cross-sectional area of test specimen, cm^2 [m^2].

13.2.2 Determine the induction in the test specimen, *B*, as follows:

$$B = B_{obs} - K_2\Gamma_m H \tag{7}$$

where:

B = induction in test specimen, G [T];
H = magnetic field strength, Oe [A/m]; and
Γ_m = magnetic constant of free space (in cgs-emu system Γ_m = 1 gauss/oersted; and $\Gamma_m = 4\pi \times 10^{-7} H$/m in the SI system.

13.2.3 For hysteresis loops:

$$B_{true} = B_m - (\Delta B_{obs} - K_2\Gamma_m\Delta H) \tag{8}$$

where:

B_{true} = induction at the test point on hysteresis curve, G [T];
B_m = maximum value of induction for hysteresis, G [T];
ΔB_{obs} = change in induction from B_m to B_{true}, G [T]; and
ΔH = change in magnetic field strength, Oe[A/m].

14. Report When Using Permeameter Procedures

14.1 When normal induction or hysteresis tests are made in a permeameter, report the following along with the test data:

14.1.1 Name or type of permeameter used.

14.1.2 Size and shape of the test specimen.

14.1.3 With hysteresis data, when coercive field strength, residual induction, or other specific hysteresis test points are reported, the value of cyclically symmetrical peak magnetic field strength or induction is required.

14.1.4 When values are reported, as those for saturation induction, the corresponding value of magnetic field strength shall also be reported.

15. Precision and Bias When Using Permeameter Procedures

15.1 The reliability of the results of magnetic tests in permeameters depends not only upon the method or apparatus used, but also upon the nature of the specimen. The most common sources of variations in magnetic properties as a result of the test specimen are: *(1)* lack of uniformity in magnetic properties along the length of the specimen, *(2)* mechanical strain, and *(3)* temperature variations. Variations because of these causes are difficult to measure and may be large.

15.2 In comparing the results of dc magnetic tests, it should be recognized that flux density, B, and magnetizing field strength, H, are independently determined quantities, each of which is separately subject to experimental error. The B errors include those caused by nonuniform induction and nonuniform properties along the specimen length. Field distortion in permeameters may be severe around the test specimen and H coils. For this reason, the determination of H in the test specimen is inherently less accurate than the determination of B induction. With some permeameters the use of flip H coils or multiple H coils with extrapolation to the specimen surface or Hall effect devices may improve the accuracy of H determination. However, the field around these devices and the test specimen is distorted in both the axial and radial directions. To be effective they must be used in such a manner as to integrate the field around the test specimen and over the same length as that covered by the B coil. The magnitudes of the various errors are peculiar to the test permeameter and the characteristics of the material under test. For a given set of corresponding measured values of B and H wherein the errors are $\pm\Delta B$ and $\pm\Delta H$ in B and H, respectively, the true characteristic curve of the test specimen may lie anywhere within the boundaries of the region defined by the two curves $(B + \Delta B)$ versus $(H - \Delta H)$ and $(B - \Delta B)$ versus $(H + \Delta H)$.

15.3 For specimens having a satisfactory degree of uniformity, clamped or mounted so as to be free from mechanical strain, and kept at a constant temperature within 5°C, for H greater than 1 Oe [80 A/m], the methods may be expected to determine average induction, B, to a precision of ±1 % and to determine average magnetic field strength, H, to the precisions of ±4 % or better. When these values are combined to calculate permeability, μ, its precision may be expected to fall within the limits imposed by the sum of the precisions of measurement for the corresponding B and H values.

16. Calculations When Using Ring Test Procedures

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

$$H = \frac{K_3 NI}{l_m} \tag{9}$$

where:

H = magnetic field strength, Oe [A/m];
N = number of turns in magnetizing coil N_1;
I = current through the magnetizing coil, [A];
l_m = mean magnetic path length, cm [m]; and
K_3 = constant equal to 0.4π for cgs-emu units and 1 for SI units.

16.1.1 For a ring specimen, l_m is determined from the mean circumference. For the Epstein frame, the mean magnetic path length is assumed to be 94 cm (940 mm), and this equation for the 700-turn Epstein test frame is as follows:

$$H = \frac{0.4\pi \times 700I}{94} = 9.358I \text{ Oe} \tag{10}$$

$$H = 744.7I \text{ [A/m]}$$

16.1.2 For the 352-turn Epstein frame:

$$H = \frac{0.4\pi \times 352I}{94} = 4.706I \text{ Oe} \tag{11}$$

$$H = 374.5I \text{ [A/m]}$$

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

$$A_c = \frac{m}{l\delta} \tag{12}$$

where:

A_c = test specimen cross-sectional area, cm^2 [m^2];
m = test specimen mass, g [kg];
l = test specimen length, cm[m]; and
δ = density of test specimen material, g/cm^3[kg/m^3].

16.2.1 For the Epstein test frame:

$$A_c = \frac{m}{4l\delta} \tag{13}$$

where l is the length of the Epstein strips.

16.3 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 induction measurements are intrinsic induction, B_i, measurements. To obtain normal induction, B, the following equation must be used:

$$B = B_i + \Gamma_m H \tag{14}$$

where:

B = normal induction in test sample, G [T];
B_i = intrinsic induction in test specimen, G [T];
H = magnetic field strength, Oe [A/m]; and
Γ_m = magnetic constant of free space (in cgs-emu system $\Gamma_m = 1$ gauss/oersted in SI system $\Gamma_m = 4\pi \times 10^{-7}$ H/m).

16.4 When ring testing is conducted at high field strength, and particularly when the B coil surrounds an appreciable air flux in addition to the core flux, the test values shall 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.

16.5 When the air-flux corrections must be calculated from estimated coil areas, the procedures described in 13.2.1 and 13.2.2 should be used.

17. Report When Using Ring Test Procedures

17.1 When normal induction values or hysteresis-loop points have been measured for the purpose of reporting basic material properties, report the following along with the test data:

17.1.1 Complete identification of test specimen type or shape.

17.1.2 Size and dimensions of the test specimen.

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

17.1.4 Type test and corresponding values of magnetic field strength and induction or their ratio in terms of permeability. When permeability is reported, the corresponding value of either *B* or *H* shall also be shown.

17.1.5 When hysteresis-loop properties are reported, the value of peak magnetic field strength or peak induction used for the cyclic reversals or test shall also be reported.

17.1.6 When saturation or other high induction values are reported, the value of magnetic field strength shall also be reported.

18. Precision and Bias When Using Ring Test Procedures

18.1 The precision 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 are known precisely and the best instrumentation is used, the determination of *H* is within 1.0 %. For the Epstein frame, caused by the corner joints, there is some uncertainty as to the true path length, and the determination of *H* is 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.

18.2 The precision of determining induction, *B*, is dependent on the quality of the integrator and recorder 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 average induction *B*, is determined within 1.0 %.

18.3 If the inside-outside diameter ratios are held to 0.82 or above, the nonuniformity of flux distribution over the test specimen is minimized. 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 induction.

18.4 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 %.)

19. Keywords

19.1 dc hysteresigraph; dc hysteresis; Epstein test; Hall probe; hysteresis loop; permeameter; ring-type specimen

APPENDIX

(Nonmandatory Information)

X1. SYMMETRICAL HYSTERESIS LOOPS WITH D-C ELECTRONIC HYSTERESIGRAPHS

X1.1 General

X1.1.1 When tracing *B-H* loops on a recorder, it is difficult to obtain symmetrical *B-H* characteristics because of residual magnetism in the test specimen. It is desirable for efficient operation that the controller either be provided with electronic circuitry for centering *B-H* loops or a simple manual procedure be established to accomplish the centering. When digital data acquisition is used, centering can be done mathematically. The manual procedure is outlined in Section X1.2.

X1.2 Manual Procedure

X1.2.1 Centering can be accomplished by attenuating the output of the flux integrator by half, plotting a half-size loop, adjusting the *Y* axis of the recorder to position the loop, and then restoring the output of the integrator to its original state and proceeding to plot the final loop.

X1.2.2 With the recorder pen off the paper, plot an imaginary loop by cycling the test specimen several times from $+H_{max}$ to $-H_{max}$ to ensure that the material under test is on the major hysteresis loop. During these several cycles, the integrator sensitivity should be adjusted to yield the desired excursion of the pen along the *B* axis.

X1.2.3 After the specimen has been conditioned through several cycles and following the $-H$ excursion, the *H* level is returned to zero (which corresponds to $-B_r$). At this point, the integrator sensitivity is set at half value, the integrator is zeroed, and the pen, still off the paper, is positioned at the intersection of the B and H axis.

X1.3 The H drive of the hysteresigraph is then varied from $H = 0$ to $+H_{max}$ back to $H = 0$. The pen is placed on the paper, the integrator sensitivity is restored to its original level, and the desired hysteresis loop is recorded on the paper with the center of this loop coinciding with the intersection of the B and H axis.

REFERENCES

(**1**) Elarde, P. F.,“ All Electronic Magnetic Hysteresigraph,” *Direct-Current Magnetic Hysteresigraphs, ASTM STP 526*, ASTM, 1973, pp. 16–30.

(**2**) Sanford, R. L., “Magnetic Testing,” Circular No. C456, National Bureau of Standards, 1946, p. 18.

(**3**) Babbitt, B. J., “An Improved Permeameter for Testing Magnet Steel,” *Journal of the Optical Soc. and Review of Scientific Instruments*, Vol. 17, 1928, pp. 47–58.

(**4**) Sanford, R. L., “Performance of Fahy Simplex Permeameter,” *Journal of Research*, National Bureau of Standards, Vol. 4, No. 5, May 1930, pp. 703–709 (RP 174).

(**5**) Sanford, R. L. and Bennett, E. G., “Determination of Magnetic Hysteresis with Fahy Simplex Permeameter,” *Journal of Research*, National Bureau of Standards, Vol. 15, pp. 517–522 (RP 845).

(**6**) Harris, F. K., Electrical Measurements, John Wiley and Sons, Inc., New York, 1952, pp. 370–381.

(**7**) Cheney, W. L., “Magnetic Testing of Straight Rods in Intense Fields,” Scientific Paper No. 361, National Bureau of Standards, 1920.

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