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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 A773/A773M; 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 stated in either SI units or inch-pound units are to be regarded separately as standard. 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 non-conformance with the 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:*[2]

A34/A34M Practice for Sampling and Procurement Testing of Magnetic Materials

A341/A341M Test Method for Direct Current Magnetic Properties of Materials Using D-C Permeameters and the Ballistic Test Methods

A343/A343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame

A596/A596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens

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:

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

or

[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] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

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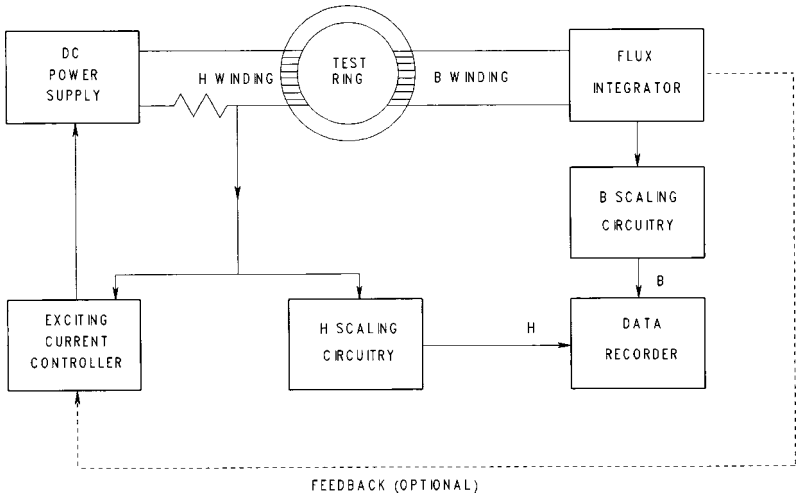

FIG. 1 Block Diagram of Ring Test Apparatus

$$\varphi = \frac{1}{K_1 N} \int edt$$

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 $\int edt$ 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 $\int edt$ is:

$$E = \frac{1}{RC} \int edt \tag{3}$$

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:

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

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 A341/A341M and A596/A596M. 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 may be used

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

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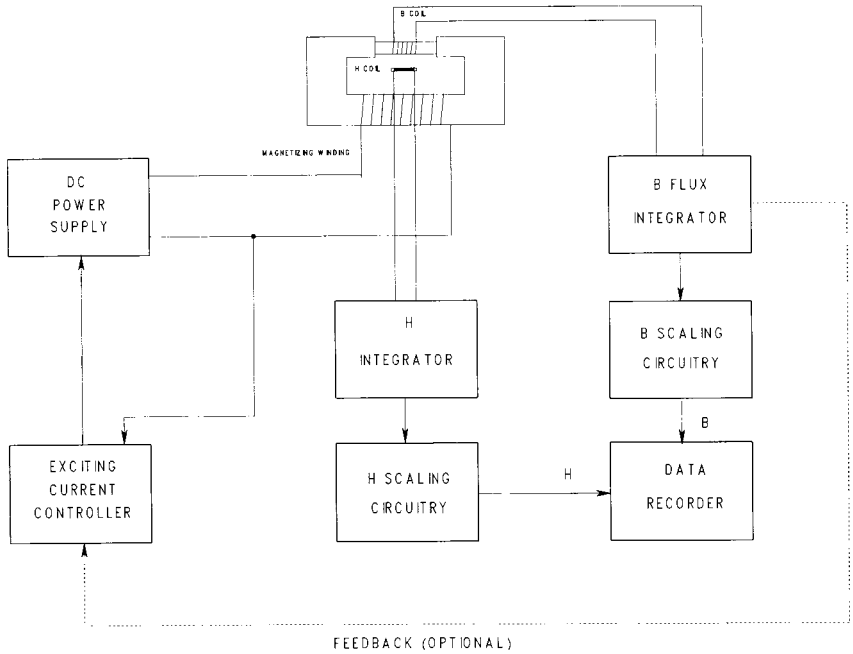

FIG. 2 Block Diagram of Permeator Test Apparatus

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 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 A341/A341M and A596/A596M. This is due to the influence of eddy currents and the different nature of the magnetizing waveform between hysteresigraph and ballistic testing.

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