Designation: A773/A773M − 21

Standard Test Method for Direct Current Magnetic Properties of Low Coercivity Magnetic Materials Using 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 for the determination of basic magnetic properties of materials in the form of ring, spirally wound 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 initial and normal magnetization curves and hysteresis loop determination taken under conditions of continuous sweep magnetization. Rate of sweep may be varied, either manually or automatically at different portions of the curves during measurement.

1.2 The equipment and procedures described in this test method are most suited for soft and semi-hard materials with intrinsic coercivity less than about 100 Oersteds [8 kA/M]. Materials with higher intrinsic coercivities should be tested according to Test Method A977/A977M.

1.3 The values and equations stated in customary (cgs-emu and inch-pound) or SI units are to be regarded separately as standard. Within this 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.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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

A340 Terminology of Symbols and Definitions Relating to Magnetic Testing

A341/A341M Test Method for Direct Current Magnetic Properties of Soft Magnetic Materials Using D-C Permeameters and the Point by Point (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

A977/A977M Test Method for Magnetic Properties of High-Coercivity Permanent Magnet Materials Using Hysteresigraphs

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *Other:*

IEC Publication 60404-4 Ed 2.2 – Part 4: Methods of Measurement of d.c. Magnetic Properties of Magnetically Soft Materials (2008)[3]

3. Terminology

3.1 *Definitions*—The terms and symbols used in this test method are defined in Terminology A340.

4. Summary of Test Method

4.1 A specimen is wound with a magnetizing winding (the primary winding) and a search winding (the secondary winding) for measuring the change in flux. When a magnetizing current, I, is applied to the primary winding, a magnetic field, H, is produced in the coil. This in turn produces magnetic flux

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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] 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.

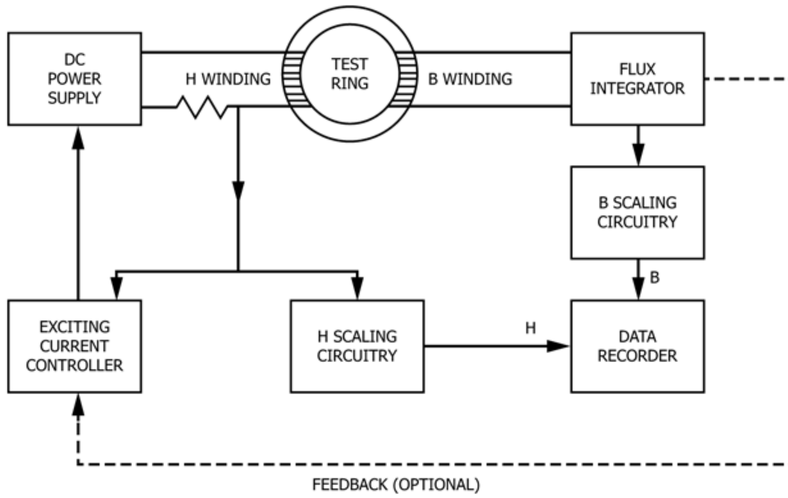

FIG. 1 Block Diagram of Ring Test Apparatus

φ in the specimen and the changing flux induces a voltage in the secondary winding which is integrated with respect to time using a fluxmeter. In specimens with uniform cross-sectional area that do not contain air gaps, such as rings, all of the magnetizing current is used to magnetize the specimen, and the magnetic field strength, *H*, is proportional to *I* in accordance with the following equation:

$$H = KI \quad (1)$$

where:

H = magnetic field strength, Oe [A/m];
I = current in the magnetizing winding A; and
K = constant determined by the number of primary turns, the magnetic path length of the specimen and system of units.

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

$$e = -NK_1 \frac{d\varphi}{dt} \quad (2)$$

or

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

where:

dt = time differential,
N = number of secondary turns,
K_1 = 10^{-8} for cgs-emu system, or $K_1 = 1$ for SI system, and
e = instantaneous voltage in the secondary winging, V.

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 an operational amplifier with capacitive feedback. Some fluxmeters employ analog to digital conversion and digital integration techniques. The output voltage of the integrator is given by:

$$E = \frac{1}{RC} \int edt \quad (3)$$

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:

$$\varphi = \frac{ERC}{K_1 N} \text{ or } E = \frac{\varphi N K_1}{RC} \quad (4)$$

The instantaneous value of flux is thus proportional to the integrated voltage which can be recorded in various ways.

4.1.2 Measurement 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, a magnetizing current controller, an electronic flux integrator, and a data recorder. As magnetizing current is applied to the primary winding, a voltage proportional to *I* is produced across the current measuring resistor which is connected in series with the primary winding. This voltage is proportional to the value of *H*.

4.1.3 In the testing of soft magnetic materials in the form of wire, bars or rods, or materials which cannot be sufficiently magnetized in ring form, or which are anisotropic, 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 magnetizing winding 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

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

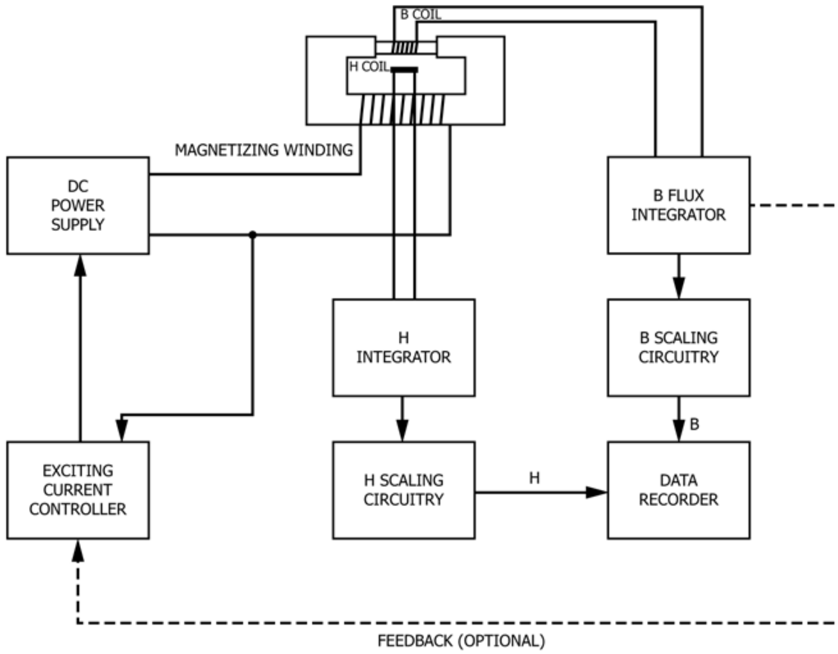

FIG. 2 Block Diagram of Permeator Test Apparatus

4.1. When using a Hall sensor, the *H* values are determined from the voltage output which is linearized to be proportional to *H*.

5. Significance and Use

5.1 Hysteresigraphs permit more rapid and efficient collection of data as compared to the point by point ballistic Test Methods A341/A341M and A596/A596M. The high measurement point density offered by computer-automated systems is often required for computer aided design of electrical components such as transformers, motors, and relays.

5.2 Hysteresigraphs are particularly desirable for testing of semi-hard and hard magnetic materials, where either the entire second quadrant (demagnetization curve) or entire hysteresis loop is of primary concern. Test Method A977/A977M describes the special requirements for accurate measurement of hard magnetic (permanent magnet) materials.

5.3 Hysteresigraphs are not recommended for measurement of initial permeability, μ_i, of materials with high magnetic permeability such as nickel-iron, amorphous, and nanocrystalline materials due to errors associated with integrator drift; in these cases, Test Method A596/A596M is a more appropriate method.

5.4 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.

6. Interferences

6.1 Test methods using suitable ring-type specimens are the preferred methods for determining the basic magnetic properties of a material. When conducting tests on ring specimens, this test method covers a range of magnetic field strengths from about 0.01 Oe [0.8 A/m] up to about 1000 Oe [80 kA/m] or more depending on the specimen dimensions, number of primary turns, available magnetizing power, and the ability to remove heat generated in the primary winding. However, this test method has several important requirements. Unless the inside diameter to outside diameter ratio or ring specimens is greater than 0.82, the magnetic field strength will be excessively nonuniform in the test material and the measured parameters cannot be represented as material properties. The basic quality of materials having directionally sensitive properties cannot be tested satisfactorily with ring specimens. With such materials it is necessary to use Epstein specimens cut with their lengths in the direction of specific interest or to use long link-shaped[5] or spirally wound toroidal core test specimens. The acceptable minimum width of strip used in such test specimens varies with the material under test. At present, it is recommended that the grain-oriented silicon steels should have a strip width of at least 3 cm [30 mm]. When ring specimens are large, it is difficult to provide sufficient magnetizing turns or current-carrying capacity to reach magnetic field strengths above about 1000 Oe [80 kA/m]. 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.

6.2 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 (measuring fixture) that is used. In general, the lower limit of magnetic

[5] Link-shaped specimens are defined in Practice A34/A34M.