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Standard Guide for Measuring Power Frequency Magnetic Properties of Flat-Rolled Electrical Steels Using Small Single Sheet Testers[1]

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1. Scope

1.1 This guide covers procedures for interpreting the specific core loss and peak permeability determined using small single-sheet test systems. It is limited to single-sheet test systems that require a test specimen or coupon be cut from the material being tested and are designed such that the entire width of that test specimen is magnetized during testing.

1.2 This guide is primarily intended for measurements of the magnetic properties of flat-rolled electrical steels at frequencies of 50 Hz or 60 Hz under sinusoidal flux conditions.

1.3 This guide includes procedures to provide correlation with the 25-cm Epstein test method (Test Method A 343/A 343M).

1.4 The range of magnetic flux densities is governed by the properties of the test specimens and the instruments and test power source. Nonoriented electrical steels may be tested at magnetic flux densities up to about 16-kG [1.6T] for core loss. The maximum magnetic field strength for peak permeability testing is limited by the current carrying capacity of the magnetizing winding and the test power source. Single sheet testers are typically capable of testing at magnetic field strengths up to 50 Oe [4000 A/m] or more.

1.5 Within this guide, a small single sheet tester (small SST) is defined as a magnetic tester designed to test flat, rectangular sheet-type specimens. Typical specimens for these testers are square (or nearly so). The design of the small SST test fixture may be small enough to accommodate specimens about 5 by 5 cm or may be large enough to accommodate specimens about 36 by 36 cm. Specimens for a particular SST must be appropriate for the particular test fixture.

1.6 This guide covers two alternative test methods: Method 1 and Method 2.

1.6.1 Method 1 is an extension of Method 1 of Test Method A 804/A 804M, which describes a test fixture having two windings that encircle the test specimen and two low-reluctance, low-core loss ferromagnetic yokes that serve as flux return paths. The dimensions of the test fixture for Method 1 are not fixed but rather may be designed and built for any nominal specimen dimension within the limits given in 1.5. The power loss in this case is determined by measuring the average value of the product of primary current and induced secondary voltage.

1.6.2 Method 2 covers the use of a small single sheet tester, which employs a magnetizing winding, a magnetic flux sensing winding, and a magnetic field strength detector. The power loss in this case is determined by measuring the average value of the product of induced secondary voltage and magnetic field strength.

1.6.3 The calibration method described in the Annex of this guide applies to both test methods.

1.7 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.

1.8 *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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 34/A 34M Practice for Sampling and Procurement Testing of Magnetic Materials

A 340 Terminology of Symbols and Definitions Relating to Magnetic Testing

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

A 677/A 677M Specification for Nonoriented Electrical Steel Fully Processed Types

A 683/A 683M Specification for Nonoriented Electrical Steel, Semiprocessed Types

[1] This guide 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.

A 726 Specification for Cold-Rolled Magnetic Lamination Quality Steel, Semiprocessed Types
A 804/A 804M Test Methods for Alternating-Current Magnetic Properties of Magnetic at Power Frequencies Using Sheet-Type Test Specimens
A 840/A 840M Specification for Fully Processed Magnetic Lamination Steel

3. Terminology

3.1 *Definitions*:

3.1.1 *General*—The definitions of terms, symbols, and conversion factors relating to magnetic testing found in Terminology A 340 are used in these methods.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *sheet specimen*—a rectangular specimen comprised of a single piece of material or paralleled multiple strips of material arranged in a single layer.

3.2.2 *small single sheet tester*—a magnetic tester designed to determine the magnetic properties of small rectangular sheet-type specimens.

4. Significance and Use

4.1 *Materials Evaluation*—Small single sheet testers were developed to supplement the testing of Epstein specimens for various applications. They are especially appropriate for determining the magnetic properties of samples when insufficient material is available for preparation of an Epstein specimen. Although the small specimen size is attractive, the precision of the small sheet testers is not expected to be as good as that of the test method Test Method A 343/A 343M. Small sheet testers are frequently used to measure the properties of both fully processed and semiprocessed nonoriented and magnetic lamination steels. Specimens of semiprocessed steels are normally subjected to an appropriate quality development anneal prior to testing. Small sheet testers may also be used to evaluate oriented electrical steels in either the as sheared or stress-relief annealed condition.

5. Apparatus

5.1 *Test Method 1*—The apparatus for Test Method 1 includes a test fixture having two windings that encircle the test specimen (a magnetizing winding and a flux-sensing secondary winding) and two low-reluctance, low-core loss ferromagnetic yokes that serve as flux return paths. Such a test fixture may be constructed by following the instructions given in Annex A1 of Test Method A 804/A 804M. The test power and instrumentation for this method are described as Test Method 1 in Test Method A 804/A 804M. The primary difference between the tests covered by this guide and Test Method 1 of Test Method A 804/A 804M are the dimensions of the yokes and the limitation to the use of double-yoke test fixtures. When selecting test instrumentation and test power source components for Method 1, the devices selected for use with small single-sheet test fixtures must have appropriate ranges for these smaller test fixtures.

5.2 *Test Method 2*—Test systems for Method 2 are supplied as complete test systems: test fixture, test power source, and complete instrumentation.

6. Procedure

6.1 *Determine Correction Factors*—Following the procedures given in Annex A1, determine correction factors for the grades of material that will be evaluated at the magnetic flux densities at which tests will be performed. The samples used to determine the correction factors must be typical of the material that will be evaluated since correction factors vary with class of material, chemical composition, thickness, heat treatment, grain direction, magnetic flux density, and other physical properties.

6.2 *Prepare the Test Specimen*—The type of test fixture and its dimensions govern the dimensions of permissible test specimens. The minimum length of a specimen shall be no less than the outside dimension of the distance between pole faces of the test fixture. The amount of projection of the specimen beyond the pole faces of fixture is not critical but should be no longer than necessary for convenient loading and unloading of the specimen. For maximum accuracy, the specimen width should, as nearly as practicable, be the maximum that can be accommodated by the opening of the test coil. As a minimum, it is recommended that the specimen width be at least one half of the maximum width that can be accommodated by the test coil.

6.2.1 Specimens with length and width appropriate for the small single sheet tester shall be cut by a suitable method. The specimens shall be as rectangular as practicable. Excessive burr and mechanical distortion must be avoided when preparing the test specimens. Specimens may be subjected to any desired heat treatment.

6.3 *Make Initial Determinations*—Depending upon the test equipment used, the appropriate measured values of length, width, thickness, and/or mass of the specimen must be determined prior to conducting magnetic tests. These measured values are needed to set up the instrument for conducting tests. When mass is required, it shall be determined using a balance capable of measuring the specimen mass with an uncertainty less than 0.1 %. The length or width of the specimen shall be measured by any suitable method with an uncertainty less than 0.1 %.

6.3.1 *Cross-sectional Area*—The preferred method of determining cross-sectional area is the mass-density method. Some test systems may require that the width and thickness of the specimen be entered into the test instrument and others may require that the cross-sectional area be entered. The cross-sectional area is determined using the following equation:

$$A = m/(l\delta) \quad (1)$$

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

When required, the thickness may be determined by dividing the cross-sectional area by the width.

6.3.2 *Alternate Cross-sectional Area*—Although the mass-density method of determining the cross-sectional area is the preferred method, direct measurement of the thickness and width of the test specimen is an alternate method. When the thickness is measured directly with a micrometer, the length of the specimen does not need to be measured. Direct measurement of the thickness is likely to increase the uncertainty of measurements, especially for specimens that have applied coatings, have rough surfaces, or are very thin (less than about 0.018 in [0.50 mm]). If direct thickness measurement is used when testing specimens, direct thickness measurement should also be used when making measurements with the small sheet tester to determine calibration constants (the corresponding Epstein tests are always to be conducted according to Test Method A 343/A 343M).

6.4 *Perform Tests*:

6.4.1 *Method 1*—Follow the procedures for conducting tests according to Sections 9 though 11 of Test Method A 804/A 804M to determine the uncorrected core losses or uncorrected magnetic field strengths, or both, at the desired flux densities. When computing the uncorrected core loss and uncorrected magnetic field strength, the effective path length should be the distance between the inner edges of the flux-return yokes measured in the direction of the flux path in the test specimen.

6.4.2 *Method 2*—Follow the instrument manufacturer's instructions to determine the uncorrected core losses or uncorrected magnetic field strengths, or both, at the desired flux densities.

6.5 *Apply Correction Factors*—Using the appropriate correction factors for the test specimen and test magnetic flux density, correct the uncorrected core losses and uncorrected magnetic field strengths determined using the small single-sheet tester (according to either Method 1 or Method 2) using the equations below:

$$P_{C(B;f)} = K_l P_a \quad (2)$$

where:

$P_{C(B;f)}$ = corrected specific core loss, W/lb [W/kg],
K_l = correction factor for core loss at specified test conditions, and
P_a = uncorrected specific core loss by yoke fixture test, W/lb [W/kg].

$$H_P = K_2 H_a \quad (3)$$

where:

H_P = corrected peak magnetic field strength, Oe [A/m],
K_2 = correction factor for magnetic field strength at specified test conditions, and
H_a = uncorrected peak magnetic field strength by yoke fixture test, Oe [A/m].

7. Keywords

7.1 alternating current; core loss; electrical steel; flux density; magnetic; magnetic material; magnetic test; permeability; power frequency; sheet

ANNEXES

(Mandatory Information)

A1. CALIBRATION OF SMALL SINGLE SHEET TESTERS (SSTs)

A1.1 This calibration procedure uses specimens that are suitable for testing using a 25-cm Epstein frame. These specimens are composed of strips that are typically longer than the normal test specimen for the SST being calibrated. The single sheet testers described in both methods discussed in this guide are considered to be insensitive to excess specimen length. If the specimens are longer than the distance between the outside edges of the yoke, the portion of the specimen that extends beyond the yoke should be supported to avoid stress.

A1.2 The specimens used to calibrate the SST shall consist of strips typical of the grade of material that is to be tested in the SST. At least five specimens of each grade are preferred. For oriented materials these specimens shall be stress-relief annealed. For nonoriented materials, the annealed condition of the calibration specimens shall be the same as that of the material to be tested. The width of each strip shall be 3.0 cm [30 mm]. The minimum length of each specimen shall be 28 cm [280 mm]. The number of strips in each specimen shall be a multiple of four and a minimum of twelve.

A1.3 Each specimen shall be tested in a 25-cm Epstein frame in accordance with test method Test Method A 343/A 343M. The magnetic properties to be determined are those which the SST will be used to measure routinely when calibrated.

A1.4 Each specimen shall be tested in the SST. A maximum of 12 strips (limited by test fixture) may be combined in parallel in a single layer when tested in the SST. Depending upon the outside dimension of the distance between the yoke faces of the SST test fixture, tests may be required at more than one position along the length of the specimen to permit evaluation of the average properties.

A1.5 When conducting tests using equipment described in Method 1, an effective magnetic path length must be assumed for calculating the uncorrected specific core loss from measured total power loss. The preferred assumed effective path length is the distance between the inner edges of the magnetic yokes in the direction of the flux path in the test specimen. Test equipment described by Method 2 of this guide does not require an assumed magnetic path length for calculating specific core loss since the specific core loss is determined from the product of scaled secondary voltage and magnetic field strength. The following formula may be used to compute correction factors to convert the uncorrected core loss to an Epstein-equivalent value:

$$K_1 = \frac{P_{C(B;f)}}{P_a} \quad \text{(A1.1)}$$

where:

K_1 = correction factor for core loss,
$P_{C(B;f)}$ = specific core loss by 25-cm Epstein test, W/lb [W/kg], and
P_a = uncorrected specific core loss by yoke fixture test, W/lb [W/kg].

A1.6 When conducting tests using equipment described in Method 1, an effective magnetic path length must be assumed for calculating the uncorrected peak magnetic field strength from measured peak exciting current. The preferred assumed effective path length is the distance between the inner edges of the magnetic yokes in the direction of the flux path in the test specimen. Test equipment described by Method 2 of this guide does not require an assumed magnetic path length since such equipment is designed to measure the magnetic field strength directly using an H-sensor. The following formula may be used to compute correction factors for the indicated peak magnetic field strength:

$$K_2 = \frac{H_p}{H_a} \quad \text{(A1.2)}$$

where:

K_2 = correction factor for magnetic field strength,
H_p = peak magnetic field strength by 25-cm Epstein test, Oe [A/m], and
H_a = indicated peak magnetic field strength by yoke fixture test at the flux density corresponding to the peak magnetic field strength, Oe [A/m].

A1.7 Experience has shown that the correction factors will vary with class of material, thickness of the material, property under test, grain direction, magnetic flux density, and other parameters. Hence, it is generally required for each particular class of material that a mean effective magnetic path length be determined at each test point for each nominal thickness of material and for each grain direction.

A2. ESTIMATING MAGNETIC PROPERTIES EQUIVALENT TO THOSE OF 25-CM EPSTEIN SPECIMENS FOR MATERIALS SPECIFIED IN SPECIFICATIONS A 677/A 677M, A 683/A 683M, A 726, AND A 840/A 840M

A2.1 When the calibration procedures of Annex A1 are followed closely, the values obtained using a SST will agree closely with those of conventional Epstein specimens for specimens which consist entirely of strips which have the same relationship between the rolling direction and the direction of flux in the test specimen, typically all strips sheared parallel to the rolling direction or all strips sheared transverse to the rolling direction.

A2.2 The Epstein specimens normally used to evaluate nonoriented and magnetic lamination steels (specified in Specifications A 677/A 677M, A 683/A 863M, A 726, and A 840/A 840M) consist of strips one half of which are cut parallel to the rolling direction and one half of which are cut perpendicular to the rolling direction. When these strips are loaded into the Epstein frame, the strips sheared parallel to the rolling direction are placed into two opposite solenoids and the strips sheared perpendicular to the rolling direction are placed into the other two opposite solenoids.

A2.3 The first step is to determine the effective magnetic path lengths or correction factors for core loss and peak permeability for Epstein specimens consisting of strips sheared parallel to the rolling direction only and separately for Epstein specimens consisting entirely of strips sheared perpendicular to the rolling direction.

NOTE A2.1—This must be done for each alloy and nominal thickness at each flux density or magnetic field strength at which calibrated measurements will be made.

A2.4 The second step is to prepare and test specimens using one of the methods in this guide. There may be one or two specimens depending upon the SST. Many of the SSTs covered in this guide will accept specimens which are square. In this case, the parallel grain and transverse grain properties are determined by testing the specimen twice: once with the axis of magnetization parallel to the rolling direction and once with the axis of magnetization perpendicular to the rolling direction.

A2.5 The 50-50 Epstein equivalent core loss, $P_{C\ (B;f)50\text{-}50}$ in W/lb [W/kg] may be calculated using the following formula:

$$P_{C(B;f)50-50} = \frac{P_{C(B;f)parallel} + P_{C(B;f)transverse}}{2} \quad \text{(A2.1)}$$

where:

$P_{C(B;f)parallel}$ = corrected core loss of SST specimen with flux parallel to the rolling direction, W/lb [W/kg] and
$P_{C(B;f)transverse}$ = corrected core loss of SST specimen with flux perpendicular to the rolling direction, W/lb [W/kg].

A2.6 The 50-50 Epstein equivalent magnetic field strength, $H_{p50\text{-}50}$ in Oe [A/m]may be calculated using the following formula:

$$H_{p50-50} = \frac{H_{p,parallel} + H_{p,transverse}}{2} \quad \text{(A2.2)}$$

where:

$H_{p,parallel}$ = corrected peak magnetic field strength of SST specimen with flux parallel to the rolling direction, Oe [A/m] and
$H_{p,transverse}$ = corrected peak magnetic field strength of SST specimen with flux perpendicular to the rolling direction, Oe [A/m].