Standard Test Method for AC Magnetic Permeability of Materials Using Sinusoidal Current[1]

This standard is issued under the fixed designation A772/A772M; 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 a means for determination of the impedance permeability (μ_z) of ferromagnetic materials under the condition of sinusoidal current (sinusoidal H) excitation. Test specimens in the form of laminated toroidal cores, tape-wound toroidal cores, and link-type laminated cores having uniform cross sections and closed flux paths (no air gaps) are used. The method is intended as a means for determining the magnetic performance of ferromagnetic strip having a thickness less than or equal to 0.025 in. [0.635 mm].

1.2 This test method shall be used in conjunction with those applicable paragraphs in Practice A34/A34M.

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 except for the sections concerning calculations where there are separate sections for the respective unit systems. 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 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

A340 Terminology of Symbols and Definitions Relating to Magnetic Testing

3. Terminology

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

4. Significance and Use

4.1 The permeability determined by this method is the impedance permeability. Impedance permeability is the ratio of the peak value of flux density (B_{max}) to the assumed peak magnetic field strength (H_z) without regard to phase. As compared to testing under sinusoidal flux (sinusoidal B) conditions, the permeabilities determined by this method are numerically lower since, for a given test signal frequency, the rate of flux change (dB/dt) is higher.

4.2 This test method is suitable for impedance permeability measurements at very low magnetic inductions at power frequencies (50 to 60 Hz) to moderate inductions below the point of maximum permeability of the material (the knee of the magnetization curve) or until there is visible distortion of the current waveform. The lower limit is a function of sample area, secondary turns, and the sensitivity of the flux-reading voltmeter used. At higher inductions, measurements of flux-generated voltages that are appreciably distorted mean that the flux has appreciable harmonic frequency components. The upper limit is given by the availability of pure sinusoidal current, which is a function of the power source. In addition, a large ratio (≥10) of the total series resistance of the primary circuit to the primary coil impedance is required. With proper test apparatus, this test method is suitable for use at frequencies up to 1 MHz.

4.3 This test method is suitable for design, specification acceptance, service evaluation, quality control, and research use.

5. Apparatus

5.1 The test circuit, which is schematically illustrated in Fig. 1, shall consist of the following components.

5.2 *Power Supply*—For power frequency (50- or 60-Hz) testing, a suitable power supply consists of two or three series connected autotransformers of sufficient power rating. This

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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.

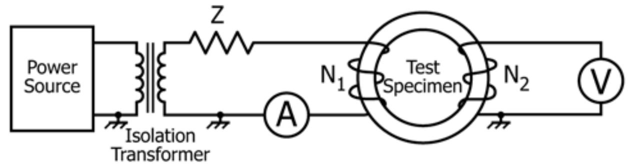

FIG. 1 Schematic Circuit for Sinusoidal Current Permeability Test

will provide a continuously variable current source to excite the test specimen. For testing at other than power frequency, an ac power source consisting of a low distortion sinusoidal signal generator and linear amplifier are required. The use of feedback control of the power amplifier is permitted.

5.3 *Isolation/Stepdown Transformer*—The use of a low distortion isolation/stepdown transformer is highly recommended for operator safety and to eliminate any dc bias current present when using electronic power supplies. A combined isolation/stepdown transformer can provide greater control when testing is done at very low magnetizing currents.

5.4 *Primary Series Resistor (Z)*—A noninductive resistor having sufficiently high resistance to maintain sinusoidal current conditions at the highest magnetizing current and test signal frequency of interest. In practice, resistance values of 10 to 100 Ω are used. If this resistor is used to measure the magnetizing current, the resistance shall be known to better than 0.5 % and the resistance shall not increase by more than 0.5 % at the rated maximum current of the power supply.

5.5 *True RMS Ammeter (A)*—A true rms ammeter or a combination of a noninductive, precision current viewing resistor and true rms voltmeter shall be used to measure the magnetizing current. The meter shall have an accuracy of better than 0.5 % full scale at the test frequency. The current viewing resistor, if used, shall have an accuracy better than 0.5 % and shall have sufficient power rating such that the resistance shall not vary by more than 0.5 % at the rated maximum current of the power supply.

5.6 *Flux Measuring Voltmeter (V)*—The flux shall be determined from the voltage induced in the secondary winding using one of the following type of voltmeter:

(1) an average responding digital voltmeter calibrated to read rms volts for a sine wave, or

(2) a true average responding digital voltmeter.

The voltmeter shall have input impedance greater than 1 MΩ, a full-scale accuracy of better than 0.5 % at the test frequency, and a crest factor capability of 3 or greater.

6. Procedure

6.1 *Specimen Preparation*—After determining the mass and dimensions of the test specimen, it should be enclosed in a suitable insulating case to prevent intimate contact between it and the primary and secondary windings. This will also minimize the stress introduced by winding. The case shape and size shall approximate that of the test specimen so that the secondary winding encloses minimal air flux. All test specimens shall have a uniform rectangular cross section.

6.1.1 The cross-sectional area and mean magnetic path length of the test specimen shall be calculated using the equations in 7.1 and 7.2 or 8.1 and 8.2. To obtain acceptable uniformity of magnetic field strength throughout the specimen, the following dimensional constraints shall be observed:

(1) for a toroid the inside diameter to outside diameter ratio shall exceed 0.82, and

(2) for the link specimen shown in Fig. 2, the separation (*s*) shall exceed nine times the radial width (*w*).

6.1.2 A secondary winding (N_2) using insulated wire shall be uniformly distributed over the test specimen using a sufficient number of turns so that a measurable voltage will be obtained at the lowest flux density of interest. A uniformly distributed primary winding (N_1) of insulated wire shall be applied on top of the secondary winding and be of sufficient diameter to conduct the highest intended magnetizing current safely without significant heating. Twisted leads or biconductor cable shall be used to connect the specimen windings to the test apparatus.

6.2 *Calculation of Test Signals*—Testing is done either at specified values of flux density (B_{max}) or magnetic field strength (H_z). Before testing, the rms magnetizing currents or voltages generated in the secondary shall be calculated using the equations found in 7.3 and 7.4 or 8.3 and 8.4.

6.3 *Demagnetization*—After connecting the primary and secondary windings to the apparatus, the test specimen shall be demagnetized by applying a magnetizing current sufficiently large to create a magnetic field strength greater than ten times the coercivity of the test specimen. The magnetizing current then shall be slowly and smoothly reduced to zero to demagnetize the test specimen. The frequency used should be the same as the test frequency.

6.4 *Measurement*—The magnetizing current shall be carefully increased until the lowest value of either magnetizing current (if measuring at a specified value of magnetic field strength) or flux density (if measuring at a specified value of flux density) is obtained. Both the magnetizing current and secondary voltage shall be recorded. The magnetizing current is then increased to the next test point and the process repeated until all test points have been measured. It is imperative that measurements be made in order of increasing magnetic field strength or flux density. When a prescribed value of magnetic field strength or flux density has been accidentally exceeded during the test, the specimen must be demagnetized and testing resumed at that point.

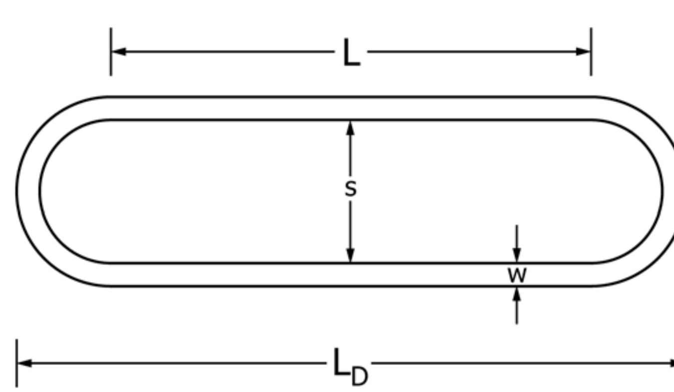

FIG. 2 Schematic of Link-Type Lamination

6.4.1 At the conclusion of testing, the magnetizing current shall be reduced to zero and the specimen removed from the test apparatus. The impedance permeability shall be calculated using the equations found in 7.5 or 8.5.

7. Calculation (Customary Units)

7.1 *Calculation of Mean Magnetic Path Length, l* (assumed to be equal to the mean geometric path):

7.1.1 For toroidal cores:

$$l = \frac{\pi (D + d)}{2} \quad (1)$$

where:

l = mean magnetic path length, cm;
D = outside diameter, cm; and
d = inside diameter, cm.

7.1.2 For link cores of the form shown in Fig. 2:

$$l = 2L + \pi(s + w) = 2L_0 + (\pi - 2)s + (\pi - 4)w \quad (2)$$

where:

l = mean magnetic path length, cm;
L_0 = total length, cm;
L = length of parallel sides, cm;
s = wall separation, cm; and
w = radial width, cm.

7.2 *Calculation of Cross-Sectional Area, A:*

7.2.1 For either toroidal or link-type cores, the cross-sectional area is calculated from the mass and mean magnetic path length as:

$$A = \frac{m}{l\delta} \quad (3)$$

where:

A = cross-sectional area, cm^2;
m = specimen mass, gm;
l = mean magnetic path length, cm; and
δ = specimen density, g/cm^3.

Note that the core height or lamination stacking factor is not required in the preceding equation.

7.3 *Calculation of the Assumed Peak Magnetic Field Strength, H_z*—The assumed peak magnetic field strength is calculated from the rms value of magnetizing current as:

$$H_z = \frac{0.4\pi\sqrt{2}N_1 I_m}{l} \quad (4)$$

where:

H_z = assumed peak magnetic field strength, Oe;
N_1 = number of primary turns;
I_m = rms magnetizing current, A; and
l = mean magnetic path length of specimen, cm.

7.4 *Calculation of Peak Flux Density, B_{max}*

7.4.1 The peak flux density when using an average responding voltmeter calibrated to yield rms values for a sine wave is calculated as:

$$B_{max} = \frac{10^8 \; E_f}{\sqrt{2}\pi f N_2 A} \quad (5)$$

7.4.2 The peak flux density when using a true average responding voltmeter is calculated as:

$$B_{max} = \frac{10^8 \; E_{avg}}{4 f N_2 A} \quad (6)$$

where:

B_{max} = peak flux density (induction), gauss;
E_f = flux voltage measured across secondary winding, V;
E_{avg} = average voltage measured across secondary winding, V;
f = test frequency, Hz;
N_2 = number of secondary turns; and
A = cross-sectional area of test specimen, cm^2.

7.5 *Calculation of Impedance Permeability, μ_z*

7.5.1 The impedance permeability is calculated as the ratio of B_{max} to H_z or:

$$\mu_z = \frac{B_{max}}{H_z} \quad (7)$$

8. Calculation (SI Units)

8.1 *Calculation of Mean Magnetic Path Length, l* (assumed to be equal to the mean geometric path):

8.1.1 For toroidal cores:

$$l = \frac{\pi (D + d)}{2} \quad (8)$$

where:

l = mean magnetic path length, m;
D = outside diameter, m; and
d = inside diameter, m.

8.1.2 For link cores of the form shown in Fig. 2:

$$l = 2L + \pi(s + w) = 2L_0 + (\pi - 2)s + (\pi - 4)w \quad (9)$$

where:

l = mean magnetic path length, m;
L_0 = total length, m;
L = length of parallel sides, m;
s = wall separation, m; and
w = radial width, m.

8.2 *Calculation of Cross-Sectional Area, A*

8.2.1 For either toroidal or link type cores, the cross-sectional area is calculated from the mass and mean magnetic path length as:

$$A = \frac{m}{l\delta} \quad (10)$$

where:

A = cross-sectional area, m^2;
m = specimen mass, kg;
l = mean magnetic path length, m; and
δ = specimen density, kg/m^3.

Note that the core height or lamination stacking factor is not required in the preceding equation.

8.3 *Calculation of the Assumed Peak Magnetic Field Strength, H_z*—The assumed peak magnetic field strength is calculated from the rms value of magnetizing current as:

$$H_z = \frac{\sqrt{2} N_1 I_m}{l} \quad (11)$$

where:

H_z = assumed peak magnetic field strength, A/m;
N_1 = number of primary turns;
l_m = rms magnetizing current, A; and
l = mean magnetic path length of specimen, m.

8.4 *Calculation of Peak Flux Density,* B_{max}

8.4.1 The peak flux density when using an average responding voltmeter calibrated to yield rms values for a sine wave is calculated as:

$$B_{max} = \frac{E_f}{\sqrt{2} \pi f N_2 A} \quad (12)$$

8.4.2 The peak flux density when using a true average responding voltmeter is calculated as:

$$B_{max} = \frac{E_{avg}}{4 f N_2 A} \quad (13)$$

where:

B_{max} = peak flux density (induction), tesla;
E_f = flux voltage measured across secondary winding, V;
E_{avg} = average voltage measured across secondary winding, V;
f = test frequency, Hz;
N_2 = number of secondary turns; and
A = cross-sectional area of test specimen, m^2.

8.5 *Calculation of Impedance Permeability,* μ_z

8.5.1 In the SI system of units, the ratio of B_{max} to H_z is the absolute impedance permeability. A more useful form is the relative impedance permeability which is the ratio of the absolute permeability to the permeability of free space or:

$$\mu_z = \frac{B_{max}}{\Gamma_m H_z} \quad (14)$$

Γ_m = magnetic constant equal to $4\pi \times 10^{-7}$ H/m.

9. Precision and Bias

9.1 The precision and bias of this test method have not been established by interlaboratory study. However, it is estimated that the precision of measurement is no worse than ±5 %.

10. Keywords

10.1 magnetic field strength; magnetic flux density; magnetic induction; permeability; sinusoidal current; toroidal core