Designation: A 772/A 772M – 9500

An American National Standard

Standard Test Method for ac Magnetic Permeability of Materials Using Sineusoidal Current[1]

This standard is issued under the fixed designation A 772/A 772M; 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 sine-current tests for determination of the impedance permeability (μz_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. I The method is intended as a means for determining the relative quality magnetic performance of ferromagnetic strip, ≤0.025-in. [0.635-mm] thick materials by both supplier and purchaser. 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 A 34.

1.3 This test method is suitable for impedance permeability (μ_z) measurements at very low magnetic inductions at power frequencies (50 to 60 Hz) to moderate inductions below the 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 means that the flux has appreciable harmonic frequency components. The upper limit is given by the availability of pure sine current which is a function of the power source and also a large ratio (≥10) of the total series resistance of the primary circuit to the primary coil impedance in the magnetizing circuit. With the proper apparatus, this test method is suitable for use at frequencies up to 1 MH.

1.4 The A 34/A 34M.

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

1.5 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:*

[1] This test method is under the jurisdiction of ASTM Committee A-6 A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.01 on Test Methods.
Current edition approved Feb. 15, 1995. Oct. 10, 2000. Published April 1995. January 2001. Originally published as A 772 – 80. Last previous edition A 772/A 772M – 895.

A 34/A 34M Practice for Procurement Testing, and Sampling and Procurement Testing of Magnetic Materials[2]
A 340 Terminology of Symbols and Definitions Relating to Magnetic Testing[2]

3. Apparatus (Fig. 1) Terminology

3.1 *Flux Voltmeter*—An average responding digital voltmeter (*M2*) calibrated to read rms volts [($\pi/(2\sqrt{2}) \times$ avg] with a wide voltage rangeDefinitions—The terms and rated tolerance of no more than 1 % at full scale. The input impedance shall be ≥1 MΩ to prevent voltage dropping in the windings of the test specimen.

3.2 *Primary Series Resistor (R)*—A noninductive resistor having sufficiently high resistance to maintain sine current conditions at the highest magnetizing current of interest and also have a sufficiently high power rating to prevent resistance changes caused by heat effects. Its true resistance should be known within 1 % and should not vary from low to maximum current flow more than ½ % from its normal value. In practice, resistance values of 10, 100 (multiples of 10 Ω) with 100-W capability are symbols used for convenience in current determinations.

3.3 *Power Supply*—A step-down transformer, having multiple secondary windings to supply ~3 to 60 V, with at least 5 A output capability delivered from a primary winding for 110 V, 60-Hz, commercial service. Two or three autotransformers of sufficient power rating in series with the isolation line transformer will provide a continuously variable-current source to energize the test core; primary circuit. Other suitable power delivery systems that can provide a sinusoidal waveform of sufficient output can be used.

3.4 *Ammeter*—An ammeter (*M1*) in series with the primary side of the test core for convenience in monitoring the current during demagnetization. Since readings from this meter are not necessary for computations of test values, no tolerance or meter requirements method are needed. This should be shorted out of the circuit, after demagnetization, by switch *S2*. defined in Terminology A 340.

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 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 sinosoidal 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

[2] *Annual Book of ASTM Standards*, Vol 03.04.

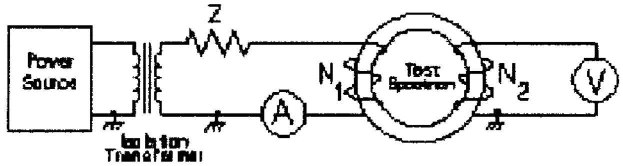

FIG. 1 Schematic Circuit for Sinusoidal Current Permeability Test

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

4.1 *Sample*

6.1 *Specimen Preparation*—After determining the active mass (m_1) and dimensions of the core, the laminated test specimen, it should be enclosed in a suitable core 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 size shape and form should size shall approximate that of the core test specimen so that a minimum of air flux is enclosed within the secondary winding encloses minimal air flux. All test winding. The specimens shall have a uniform rectangular cross section.

6.1.1 The cross-sectional area and mean magnetic path lengths of the test core should specimen shall be determined as suggested calculated using the equations in 5.1 7.1 and 5.2 7.2 or 6.1 8.1 and 6 8.2. To obtain reasonable acceptable uniformity of induction magnetic field strength throughout the specimen, the following dimensional constraints shall be observed:

(*1*) for a toroid the inside diameter must exceed 82 % of the to outside diameter, ratio shall exceed 0.82 and

(*2*) for a the link core specimen shown in Fig. 2, the separation (*s* must) shall exceed 9× nine times the radial width (*w*.

4.2 All the test cores will have rectangular cross sections which should be relatively uniform and shall have been annealed in a manner that provides the optimum desired magnetic characteristics for each specific material.

4.3 A).

6.1.2 A secondary winding (N_2) using insulated wire shall be uniformly distributed over the test core specimen using a sufficient number of turns so that a measurable voltage will be obtained at the lowest induction flux density of interest. A uniformly distributed primary winding (N_1) winding of insulated wire shall be applied on top of the secondary winding and be of sufficient diameter to safely conduct the highest intended magnetizing current safely without producing noticeable heating in the conductor. In practice the number of primary turns will usually be between 1 and 10 for *R* values between 10 Ω and 100 Ω so that the ratio of *R* to the primary winding impedance (*Z*) is ≥10. significant heating. Twisted leads (or or biconductor cable) are recommended for connection cable shall be used to connect the sample winding.

4.4 *Demagnetization*—After connecting the primary and secondary specimen windings to the proper terminals, increase *1* (*M1*), with *S2* on "meter'' open position, by rotating the autotransformer to a current level that will ensure saturation test apparatus.

6.2 *Calculation of the sample. Then slowly and progressively decrease the current by reverse rotation of the autotransformers (separately), starting with the last in series (fine control), until the current Test Signals*—Testing is zero.

4.5 For μ, tests at given apparent magnetic field strength (H_z), the *S3* switch should be in the E_H position and *S2* in "short'' position. Rotate the autotransformer until the E_H (representing the appropriate value done either as specified values of *I*) is reached on the voltmeter. This is calculated from Eq 7 in 5.3 or Eq 19 in 6.3. Then upscale the voltmeter, switch *S3* to E_B, and record the E_B that represents the measured flux density (B_{max} value. *Bmax) or magnetic field strength (Hm is calculated using Eq 9 in 5.3$_z$). Before testing, the rms magnetizing currents or Eq 21 voltages generated in 6.3 and the impedance permeability* (μ_z) *is then equal*

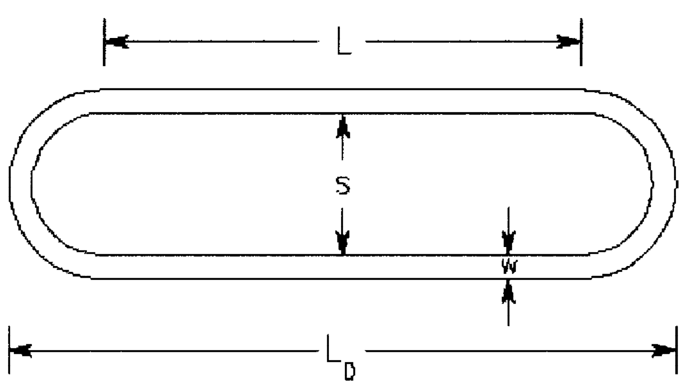

FIG. 2 Schematic of Link-Type Lamination

to B_m/H_z and can secondary shall be calculated from Eq 11 using the equations found in 5.4 7.3 and 7.4 or Eq 23 in 6.4. Permeabilities at different field strengths are always obtained in ascending order of B_m or H_z.

4.6 For given B_m (induction) levels, μ_z values are obtained by first demagnetizing as in 4.4 8.3 and then with switch *S3* on E_B (*S2* on "short"), 8.4.

6.3 *Demagnetization*—After connecting the autotransformers are rotated until primary and secondary windings to the E_B representing apparatus, the desired B_m level is obtained on the voltmeter. This E_B for any given induction is calculated test specimen shall be demagnetized by Eq 10 in 5.3 or Eq 22 in 6.3. Then *S3* is switched applying a magnetizing current sufficiently large to E_H 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 E_H (representing 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 *I*) 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 corresponding H_z magnetizing current is calculated using Eq 9 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 5.3 or Eq 21 in 6.3. μ_z values at varying induction levels are always obtained in ascending order of B_m.

4.7 When increasing magnetic field strength or flux density. When a prescribed setting value of B_m magnetic field strength or H_z flux density has been accidentally exceeded during the test, the specimen must be demagnetized p and testing resumed at that point.

6.4.1 At the conclusion of testing, the magnetizing current shall be reduced to zero and the field strength correction.

5. 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)

5.1 *Determination*

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

57.1.1 For toroidal cores:

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

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

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

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

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

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

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

5.2 *Determination*

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

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

$$V_m = \frac{\pi A (D + d)}{2} = m_1/\delta$$

Therefore,

$$A = \frac{2\, m_1}{\pi\delta\, (D + d)} \quad (4)$$

$$A = \frac{2\, m_1}{\pi\delta\, (D + d)} A = \frac{m}{l\delta} \quad (3)$$

mlδ

where: *A*
A = cross-sectional area, cm^2,
m_1;
m = activespecimen mass, g,
D = outside diameter, cm,
d = inside diameter, cm, and gm;
δ *l* = density, g/cm^3 (assumed value for the specimen material).

5.2.2 For link cores of the form in 5.1.2, in terms of *L*,

$$A = \frac{m_1}{\delta(2L + \pi (s + w))} \quad (5)$$

In terms of L_0,

$$A = \frac{m_1}{\delta[2L_0 + (\pi - 2)\, s + (\pi - 4)\, w]} \quad (6)$$

where:
A = cross-sectional area, cm^2,
m_1 = active mass, g,
L_0 = totalmean magnetic path length, cm,
L = parallel lengths, cm

s = wall separation, cm,
w = radial width, cm, cm; and
δ = specimen density, g/cm³.

Note that the core height (h) (stack build-up) or lamination stacking factor is not required in the preceding equations. equation.

5.3 The relationship between

7.3 *Calculation of the voltage E Assumed Peak Magnetic Field Strength, H$_{Hz}$ and the apparent*

The assumed peak magnetic field strength H_z is as follows: calculated from the rms value of magnetizing current as:

$$E_H = \frac{H_z l R}{0.4\pi\sqrt{2}\ N_1}$$

or

$$H_z = \frac{0.4\pi\sqrt{2}\ N_1 E_H}{lR} \tag{8}$$

$$H_{zH_z} = \frac{0.4\pi\sqrt{2} N_1 I_m}{l} \tag{4}$$

N1lml

where: E_H

H_z = rms voltage representing the apparent magnetizing (exciting) current flowing in the primary series resistor, V,
R assumed peak magnetic field strength, Oe;
N_1 = series resistance inserted in number of primary circuit, ohms,
H_z turns;
I_m = peak apparent magnetic field strength, Oe,
l rms magnetizing current, A; and
l = mean magnetic path length of specimen core, cm, and
N_1 = number of primary turns. specimen, cm.

The peak induction, B

7.4 *Calculation of Peak Flux Density, B_{max}*, represented by the measured E_B

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

$$B_m = \frac{10^8 E_B}{\sqrt{2}\pi f N_2 A}$$

$$B_{max} = \frac{10^8\ E_f}{\sqrt{2}\pi f N_2 A} \tag{5}$$

or, where voltage must be known for a desired

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

$$E_B = \sqrt{2}\ \pi\ 10^{-8} f B_m N_{2A}$$

$$B_{max} = \frac{10^8 E_{avg}}{4fN_2A} \quad (6)$$

EfEavg A

where: E

B_{max} B_m peak flux density (induction), gauss; = rms voltage measured across secondary winding, V,

E_f = peak flux density (induction), gauss,

f flux voltage measured across secondary winding, V;

E_{avg} = test frequency, Hz,

N_2 average voltage measured across secondary winding, V;

f = number of secondary turns, and

A test frequency, Hz;

N_2 = solidnumber of secondary turns; and

A = cross-sectional area cross section of test core, specimen, cm².

57.45 TheCalculation of Impedance p Permeability is, μ_z(G/Oe)

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

$$\mu_z = B_m H_z$$

$$= \frac{10^9 lR}{8\pi^2 fN_1N_2A} (E_BE_H \quad (11)$$

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

68. Calculation (SI Units)

6.1 Determination

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

68.1.1 For toroidal cores:

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

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

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

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

$$l = 2L + \pi(s + w)$$

or

$$l = 2L_0 + (\pi - 2)s - (\pi - 4)\,w \quad (14)$$

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

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

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

6.2 *Determination*

8.2 *Calculation of Solid Cross-Sectional Area, A*:

68.2.1 For either toroidal or link type cores, the magnetic volume, V_m in m^3, cross-sectional area is as follows: calculated from the mass and mean magnetic path length as:

$$V_m = \frac{\pi A(D + d)}{2} = \frac{m_1}{\delta}$$

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

Therefore,

$$A = \frac{2m_1}{\pi\delta\,(D + d)} \quad (16)$$

mlδ

where: A

A = cross-sectional area, m^2,

m_1;

m = activespecimen mass, kg,

D = outside diameter, m,

d = inside diameter, m, and kg;

δ l = density, kg/m^3 (assumed value for the specimen material).

6.2.2 For link cores of the form in 6.1.2:

$$A = \frac{m_1}{\delta (2L + \pi(s + w))} \quad (17)$$

or

$$A = \frac{m_1}{\delta [2L_0 + (\pi - 2)s + (\pi - 4)w]} \quad (18)$$

where:

A = cross-sectional area, m^2,

m_1 = active mass, kg,

L_0 = totalmean magnetic path length, m,

L = parallel length, m,

s = wall separation, m,

w = radial width, m, m; and

δ = specimen density, kg/m^{-3}.

Note that the core height, *h* (stack build-up), height or lamination stacking factor is not required in the preceding equations.

6.3 The relationship between equation.

8.3 *Calculation of the voltage, E Assumed Peak Magnetic Field Strength, H_{Hz}, and the apparent*

The assumed peak magnetic field strength, H_z, strength is as follows: calculated from the rms value of magnetizing current as:

$$E_H = \frac{H_z lR}{\sqrt{2}N_1}$$

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

or

$$H_z = \frac{\pi N_1 E_H}{lR} \quad (20)$$

$$H_z = \frac{\pi N N_1 I_m}{l} \quad (20)$$

N1lml

where: E_H

H_z = rms voltage representing the apparent magnetizing (exciting) current flowing in the primary series resistor, V, H*assumed peak magnetic field strength, A/m;*

N_{z1} = peak apparent magnetic field strength, A/m,

R number of primary turns;
l_m = series resistance inserted in primary circuit, ohms,
I rms magnetizing current, A; and
l = mean magnetic path length of specimen core, m, and
N_1 = number of primary turns. specimen, m.

The peak induction, B

8.4 *Calculation of Peak Flux Density, B_{max}*, represented by the measured E_B

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

$$B_m = E_B \sqrt{2}\, \pi\, f N_{2A}$$

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

or, where voltage must be known for a desired

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

$$E_B = \sqrt{2}\pi\, B_m\, f N_2 A$$

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

EfEavg A

where: E
$B_{B\max}$ = rms voltage measured across secondary winding, V,
B_{m} peak flux density (induction), tesla;
E_f = peak flux density (induction), T,
f flux voltage measured across secondary winding, V;
E_{avg} = test frequency, H_z,

N_2average voltage measured across secondary winding, V;

f = number of secondary turns, and

Atest frequency, Hz;

N_2 = solidnumber of secondary turns; and

A = cross-sectional area cross-section of test core, m 2 specimen, m^2.

68.45 TheCalculation of Impedance p Permeability, μ_z

8.5.1 In the SI system of units, the ratio of B_{max} to H_z is the abs folute 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:

$$\mu_z = B_m H_z = \frac{lR}{2\pi f N_1 N_2 A}\left(\frac{E_B}{E_H}\right) \quad (23)$$

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

where:

$\mu \Gamma_{zm}$ = impedance permeability, H/m,

R = series resistance inserted in primary circuit, ohms,

l = mean magnetic path of specimen core, m,

E_B = rms voltage measured across secondary winding, V,

f = test frequency,magnetic constant equal to $4\pi \times 10^{-7}$ H_z,

N_1 = number of primary turns,

N_2 = number of secondary turns,

A = solid area cross-section of test core, m ^{2}, and

E_H = rms voltage representing the apparent magnetizing (exciting) current flowing in the primary series resistor, V. H/m.

79. Precision and Bias

7.1 The tolerance (Note 1) limits

9.1 The precision and bias of μ_z using this test method are estimated to be: ±5 % at moderate inductions, ±8 % at low inductions (initial magnetization).

NOTE 1—Tolerance limits may be found to be better than estimated between any particular purchaser and supplier. It have not been established by interlaboratory study. However, it is recommended estimated that round-robin samples be exchanged between purchaser and supplier to establish that correlation.

7.2 The the precision of the test measurement is expected to be better no worse than the above values when precise instruments maintained to standard calibrations are used.

8. ±5 %.

10. Keywords

810.1 magnetic field strength; magnetic flux density; magnetic induction; permeability; sine-usoidal current; toroidal core