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Standard Test Method for Alternating-Current Magnetic Properties of Amorphous Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method with Toroidal Specimens[1]

This standard is issued under the fixed designation A 912/A 912M; 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 covers tests for various magnetic properties of amorphous materials at power frequencies [25 to 400 Hz] using a toroidal test transformer. The term toroidal test transformer is used to describe the test device reserving the term specimen to refer to the material used in the test. The test specimen consists of toroidally wound flat strip.

1.2 This test method covers the determination of core loss, exciting power, rms and peak exciting current, several types of ac permeability, and related properties under ac magnetization at moderate and high inductions at power frequencies [25 to 70 Hz].

1.3 With proper instrumentation and specimen preparation, this test method is acceptable for measurements at frequencies from 5 Hz to 100 kHz. Proper instrumentation implies that all test instruments have the required frequency bandwidth. Also see Annex A2.

1.4 This test method also provides procedures for calculating impedance permeability from measured values of rms exciting current and for calculating ac peak permeability from measured peak values of total exciting current at magnetizing forces up to about 10 Oe [796 A/m].

1.5 Explanation of symbols and brief definitions appear in the text of this test method. The official symbols and definitions are listed in Terminology A 340.

1.6 This test method shall be used in conjunction with Practice A 34/A 34M.

1.7 The values and equations stated in ~~either~~ customary (cgs-emu and inch-pound) units or SI units are to be regarded separately as standard. Within ~~the text, the~~ this standard, SI units are shown in brackets. 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 ~~test method.~~ 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 limitations 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 901 Specification for Amorphous Magnetic Core Alloys, Semi-Processed Types
C 693 Test Method for Density of Glass by Buoyancy

3. Significance and Use

3.1 This test method provides a satisfactory means of determining various ac magnetic properties of amorphous magnetic materials.

3.2 The procedures described herein are suitable for use by manufacturers and users of magnetic materials for materials specification acceptance and manufacturing control.

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[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.
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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*~~,~~ ~~Vol 03.04.~~ volume information, refer to the standard's Document Summary page on the ASTM website.

3.3 The procedures described herein may be adapted for use with specimens of other alloys and other toroidal forms.

4. Interferences

4.1 Test methods using toroidal test transformers are especially useful for evaluating the magnetic properties of a material. There are, however, several important requirements to be met when determining the material characteristics.

4.1.1 The ratio of the mean diameter to radial build (annular width) must be at least ten to one, or the magnetizing force will be excessively nonuniform throughout the test specimen and the measured parameters will not represent the basic material properties.

4.1.2 To best represent the average material properties, the cross-sectional area of the toroid should be uniform and the winding should be designed to avoid nonuniform induction.

4.1.3 Preparation of test specimens, especially of stress sensitive alloys, is critical. Stresses that are introduced into flat strip material when it is wound into a toroid depend on the diameter of the resulting toroid, the thickness and uniformity of the material, and the winding tension. These stresses shall be removed or reduced by annealing. The annealing conditions (time, temperature, and atmosphere) are a function of the material chosen. The details of sample preparation must be agreed upon between the manufacturer and user. Suggested conditions for preparation of amorphous specimens are contained in Annex A2, Annex A3, Annex A4, and Annex A5.

5. Apparatus

5.1 The apparatus shall consist of as many of the component parts shown in the basic block circuit diagram (Fig. 1) as are required to perform the desired measurement functions.

5.2 *Toroidal Test Transformer*—The test transformer shall consist of a toroidal specimen, prepared as directed in Annex A2, enclosed by primary and secondary windings. When the test specimen is small or especially stressed, the use of a protective case, bobbin, spool, or core form is necessary.

5.2.1 The primary and secondary windings may be any number of turns suited to the instrumentation, mass of specimen, and test frequency. A 1:1 turns ratio is recommended. An air-flux compensator is to be used whenever the air flux is a measurable fraction of the total flux.

5.3 *Instruments*:

5.3.1 Electronic digital instruments are preferred for use in this test method. The use of analog instruments is permitted provided the requirements given in 5.3.2-5.5.2 as well as the requirements given in Test Method A 343/A 343M are met.

5.3.1.1 The electrical impedance and accuracy requirements are given in 5.3.2-5.5.2. The operating principles for the various instruments are not specified.

5.3.1.2 Combination instruments (volt-watt-ammeters) may be used provided the requirements given in 5.3.2-5.5.2 for the individual instruments are met.

5.3.1.3 Automatic or data logging equipment may be used. It is preferable for the operator to have a record available of the specimen identification and measured values of the tests being performed.

5.3.1.4 Although electronic digital equipment usually fails catastrophically and errors are easily detected, it is incumbent upon the user of this test method to ensure that the instruments continue to meet the performance requirements.

5.3.2 *Flux Voltmeter*—A full-wave, true-average voltmeter, with scale reading in average volts times $\sqrt{\cancel{2\pi}\underline{2\,\pi}}\Big/4$ so that its indications will be identical with those of a true rms voltmeter on a pure sinusoidal voltage, shall be provided for evaluating the peak value of the test induction. To produce the estimated precision of test under this test method, the full-scale meter errors shall not exceed ±0.25 % (Note 1). Meters of ±0.5 % or more error may be used at reduced accuracy.

5.3.3 *RMS Voltmeter*—A true rms-indicating voltmeter shall be provided for evaluating the form factor of the voltage induced in the secondary winding of the test fixture and for evaluating the instrument losses. The accuracy of the rms voltmeter shall be the same as specified for the flux voltmeter.

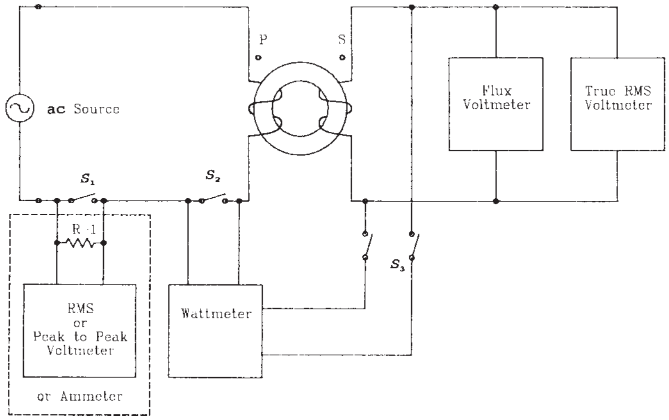

FIG. 1 Basic Circuit Diagram for Wattmeter Method

5.3.3.1 The normally high-input impedance of digital flux and rms voltmeters will minimize loading effects and reduce the magnitude of instrument losses to an insignificant value.

5.3.3.2 An electronic scaling amplifier may be used to cause the flux voltmeter and the rms voltmeter to indicate directly in units of induction. The input impedance of the scaling amplifier must be high enough to minimize loading effects and instrument losses. The combination of a basic instrument and a scaling device must conform to the specifications stated above.

NOTE 1—Inaccuracies in setting the flux voltage produce errors approximately two times as large in the specific core loss.

5.4 *Wattmeter*—The full-scale accuracy of the wattmeter must not be poorer than 0.25 % at the frequency of test and at unity power factor. The power factor encountered by a wattmeter during a core-loss test on a specimen is always less than unity and, at inductions far above the knee of the magnetization curve, approaches zero. The wattmeter must maintain adequate accuracy (1 % of reading) even at the most severe (lowest) power factor that is presented to it. Variable scaling devices may be used to cause the wattmeter to indicate directly in units of specific core loss if the combination of basic instrument and scaling devices conforms to the specifications stated here.

5.4.1 *Electronic Digital Wattmeter*—An electronic digital wattmeter is preferred in this test method because of its high sensitivity, digital readout, and its capability for direct interfacing with electronic data acquisition systems.

5.4.1.1 The voltage input circuitry of the electronic digital wattmeter must have an input impedance high enough that connection of the circuitry, during testing, to the secondary winding of the test fixture does not change the terminal voltage of the secondary by more than 0.05 %. Also, the voltage input circuitry must be capable of accepting the maximum peak voltage, which is induced in the secondary winding during testing.

5.4.1.2 The current input circuitry of the electronic digital wattmeter should have as low an input impedance as possible, preferably no more than 0.1 Ω, otherwise the flux waveform distortion can be corrected for as described in 9.3. The current input circuitry must be capable of accepting the maximum rms current and the maximum peak current drawn by the primary winding of the test transformer when core-loss tests are being performed. In particular, since the primary current will be very nonsinusoidal (peaked) if core-loss tests are performed on a specimen at inductions above the knee of the magnetizing curve, the crest factor capability of the current input circuitry should be 4 or more.

5.4.2 *Waveform Calculator*—A waveform calculator, in combination with a digitizing oscilloscope, may be used in place of the wattmeter for core-loss measurements, provided that it meets the accuracy requirements given in 5.4. This equipment is able to measure, compute, and display the rms, average, and peak values for current and flux voltage, as well as measure the core loss and excitation power demand. It is convenient for making a large number of repetitive measurements. See Appendix X2 for details regarding these instruments.

5.4.2.1 The current and flux sensing leads must be connected in the proper phase relationship.

5.4.2.2 The normal high input impedance of these instruments (approximately 1 MΩ) reduces possible errors as a result of instrument loading to negligible levels.

5.5 *Ammeters*—Two types of current measurements are used in conjunction with this test method. Rms current values are used for calculating exciting power and impedance permeability while peak current values are used for calculating peak permeability. The preferred method for measuring exciting current is to measure the voltage drop across a low value, noninductive resistor in series with the primary windings.

5.5.1 *RMS Ammeter*—A true rms voltmeter in parallel with the series resistor is required if measurements of rms exciting current are to be made. Rms exciting power, rms specific exciting power, and impedance permeability are calculated from rms exciting current values. A nominal 1 % accuracy is required for this instrument.

5.5.2 *Peak Ammeter*—The peak ammeter consists of a voltmeter whose indications are proportional to the peak-to-peak value of the voltage drop that results when the exciting current flows through a low value of standard resistance connected in series with the primary winding of the test transformer. This peak-to-peak reading voltmeter should have a nominal full-scale accuracy of at least 3 % at the test frequency and be able to accommodate a voltage with a crest factor of 5 or more.

5.6 *Series Resistor*—The standard series resistor (usually in the range 0.1 to 1.0 Ω) that carries the exciting current must have adequate current-carrying capacity and be accurate to at least ±0.1 %. It must have negligible temperature and frequency variation with the conditions applicable to this test method. If desired, the value of the resistor may be such that the peak-reading voltmeter indicates directly in terms of peak magnetizing force provided that the resistor conforms to the limitations stated herein.

5.7 *Power Supply*—A source of sinusoidal test power of low internal impedance and excellent voltage and frequency stability is required for this test. The voltage for the test circuit may be adjustable by use of a tapped transformer between the source and the test circuit or by generator field control. The harmonic content of the voltage output from the source under the heaviest test load should not exceed 1 %. For testing at commercial power frequencies, the volt-ampere rating of the source and its associated voltage control equipment should be adequate to supply the requirements of the test specimen without an excessive increase in the distortion of the voltage waveform. Voltage stability within ±0.1 % is necessary for precise work. For testing at commercial frequencies, low-distortion line voltage regulating equipment is available. The frequency of the source should be accurately controlled within ±0.1 % of the nominal value.

5.7.1 An electronic power source consisting of a low-distortion oscillator (Note 2) and a linear amplifier makes an acceptable source of test power. The form factor of the test voltage should be as close to $\sqrt{2}\,\pi\;/4$ as practicable and must be within ±1 % of this value. The line power for the electronic oscillator and amplifier should come from a voltage-regulated source to ensure voltage stability within 0.1 %, and the output of the system should be monitored with an accurate frequency-indicating device to see that control of the frequency is maintained to within ±0.1 % or better. It is permissible to use an amplifier with negative feedback to reduce the waveform distortion.

NOTE 2—It is advisable when testing at power line frequency to have the oscillator synchronized with the power line.

5.8 *Test Fixture*—A test fixture (board, panel, or console) is recommended for convenience in testing. The test fixture shall consist of terminals for connecting a power source, instrumentation, the test transformer, and necessary switches. It may also contain the standard series current-sensing precision resistor.

6. Basic Circuit

6.1 Fig. 1 shows the essential apparatus and basic circuit connections for this test. Terminals 1 and 2 are connected to a source of adjustable ac voltage of sinusoidal waveform and sufficient power rating to energize the primary circuit without appreciable voltage drop in the source impedance. The primary circuit switches, S_1 and S_2, as well as all primary circuit wiring, should be capable of carrying much higher currents than normally are encountered to limit primary circuit resistance to values that will not cause appreciable distortion of flux waveform in the specimen when relatively high nonsinusoidal currents are being drawn. A primary circuit current rating of 10 A is usually adequate for this purpose.

6.1.1 Although the current drain in the secondary circuit is quite small, the switches and wiring of these circuits should be rated for at least 1 A to ensure that the lead resistance is so small that the voltage available at the terminals of all instruments is imperceptibly lower than the voltage at the secondary terminals of the toroidal test transformer.

6.2 Fig. 2 shows an alternate set of instruments that may be used for this test.

7. Sampling and Test Specimens

7.1 The test specimens for this test method shall be selected and prepared for testing in accordance with provisions of Section 6 of Practice A 34/A 34M. Recommended practices are given in Annex A2, Annex A3, Annex A4, and Annex A5 of this test method.

8. Procedure

8.1 Determine the mass and mean diameter of the toroidal test specimen with sufficient accuracy that the induction may be calculated to ±0.1 %. Record these values so that the tests may be repeated or verified.

8.2 *Demagnetization*—The specimen should be demagnetized before measurements of any magnetic property are made. With the required apparatus connected as shown in Fig. 1, and with switches S_1 and S_2 closed and S_3 open, accomplish this demagnetization by initially applying a voltage from the power source to the primary circuit, which is sufficient to magnetize the specimen to an induction above the knee of its magnetization curve (induction may be determined from the reading of the flux voltmeter by means of the equations of 9.1 or 10.1), and then decrease the voltage slowly and smoothly (or in small steps) to a very low induction. After this demagnetization, test promptly for the desired test points. When multiple test points are required, perform the tests in order of increasing induction values.

8.3 *Setting Induction*—With the required apparatus connected as in Fig. 1, and with Terminals 1 and 2 connected to the power source, then with switches closed and S_2 open, adjust the voltage of the power supply to a point at which the flux voltmeter indicates the value of voltage calculated to give the desired test induction in accordance with equations 9.1 or 10.1.

8.4 *Core Loss*—When the voltage indicated by the flux voltmeter has been adjusted to the desired value, read the wattmeter. The combined resistance load of the flux voltmeter, rms voltmeter, and potential circuit of the wattmeter will constitute the total instrument burden on the wattmeter. When instruments other than high impedance electronic types are used, exercise care so that the combined current drain of the instruments does not cause an appreciably large voltage drop in the secondary circuit resistance

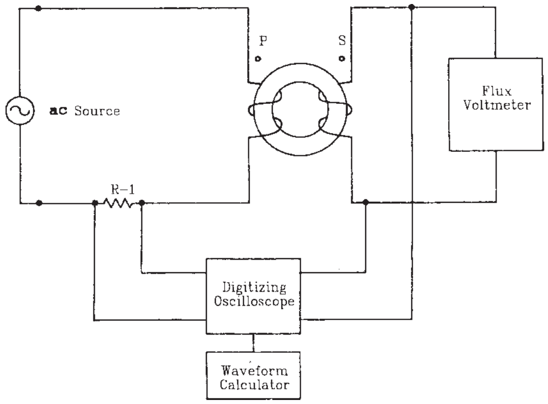

FIG. 2 Basic Circuit Diagram for Waveform Calculator Method

of the test frame. In such a case, the true induction in the specimens may be appreciably higher than is apparent from the voltage measured at the secondary terminals of the test frame. In any event, power caused by any current drain in the secondary circuit at the time of reading the wattmeter must be known so it can be subtracted from the wattmeter indications to obtain the net watts as a result of core loss.

8.5 *Secondary (Induced) RMS Voltage*— Measure the rms value of the secondary voltage by having both S_1 and S_2 closed and the voltage adjusted to indicate the correct value of flux voltage. On truly sinusoidal voltage, both voltmeters will indicate the same value, showing that the form factor of the induced voltage is $\sqrt{2}\pi / 4$. When the voltmeters give different readings, the ratio of the rms value to that of the form factor of the induced voltage deviates from the desired value of $\sqrt{2}\pi / 4$. Determining the induction from the readings of a flux voltmeter assures that the correct value of peak induction is achieved in the specimen, and hence, that the hysteresis component of the core loss is correct even if the waveform is not strictly sinusoidal. But the eddy-current component of the core loss, being due to current resulting from a nonsinusoidal voltage induced in the cross section of the strip, will be in error depending on the deviation of the induced voltage from the desired sinusoidal wave shape. This error in the eddy-current component of loss can be corrected for some materials by calculations based on the observed form factor and the approximate percentage of eddy-current loss for the grade of material being tested, if the correction is reasonably small. The equations involved in determining this correction are given in 9.3.

8.6 *RMS Exciting Current*—Measure the rms exciting current, when required, with S_1 closed and S_2 and S_3 open; adjust the voltage from the power source to the desired test induction and read the ammeter. If the current drain of the two voltmeters in the secondary circuit is not negligible, they should be disconnected when reading the ammeter. Rms exciting current may be used to calculate values of exciting power or specific exciting power (see 9.4 or 10.4), rms exciting force (see 9.5), rms magnetizing force (see 9.5.1 or 10.5), or impedance permeability (see 9.7.2 or 10.7.2).

8.7 *Peak Current*—When peak permeability at a given peak magnetizing force is required, open S_1 and S_2 for peak current measurement. The peak current is measured using a peak-to-peak reading voltmeter across a standard resistor (R_1) in the primary circuit. Adjust the voltage of the power supply such that the peak-to-peak reading voltmeter indicates that the necessary value of the peak exciting current (calculated using the equations in 9.6.1 or 10.6.1) has been established, and then read the corresponding induction on the flux voltmeter. The equation for determining the (relative) peak permeability, μ_p, is given in 9.7.3 and 10.7.3.

9. Calculation (Customary Units)

9.1 Calculate the value of the flux volts, E_f, at the desired test induction in the specimen in accordance with the following basic equation discussed in X1.1.1.4 of this test method:

$$E_f = \sqrt{2}\pi B_i A N_2 f \times 10^{-8} \tag{1}$$

where:

E_f = flux voltage, V;
B_i = maximum intrinsic flux density, G;
A = effective cross-sectional area of the test specimen, cm^2;
N_2 = number of turns in secondary winding; and
f = frequency, Hz.

9.1.1 The cross-sectional area for a toroidal specimen is calculated by:

$$A = m/l\,\delta \tag{2}$$

where:

A = area of specimen, cm^2;
m = total mass of specimen, g;
l = the mean magnetic path length, cm; and
δ = specified density (by agreement between manufacturer and purchaser either as given in Specification A 901 or as measured by Test Method C 693), g/cm^3.

9.1.2 The mean magnetic path length is determined from mean diameter of the test specimen:

$$l = \pi(d_i + d_o)/2 \tag{3}$$

where:

d_i = inside diameter, cm and
d_o = outside diameter, cm.

9.2 *Total Core Loss or Specific Core Loss*—To obtain the total core loss or the specific core loss of the specimen, it is necessary to subtract all secondary circuit power included in the wattmeter indication as follows:

$$P_c = (W - E_2{}^2/R) \tag{4}$$

where:
P_c = total core loss, W;
W = wattmeter indication, W;
E_2 = secondary circuit rms voltage, V; and
R = parallel resistance of wattmeter potential circuit and all other connected secondary loads.

Then

$$P_{c\,(B;f)} = P_c/m \tag{5}$$

where:
$P_{c\,(B;f)}$ = specific core loss, W/lb and
m = mass, lb.

9.3 *Form Factor Correction*—The percent error in form factor is given by the following equation:

$$F = 100(E_2 - E_f)/E_2 \tag{6}$$

assuming (Note 3) that:

$$\text{Observed } P_{c\,(B;f)} = (\text{ corrected } P_{c\,(B;f)})(1 + Ke)/100$$

The corrected core loss, which shall be computed when F is greater (Note 4) than + 1 %, is:

$$\text{Corrected } P_{c(B;f)} = (\text{ observed } P_{c(B;f)})\ 100/(h + Ke) \tag{7}$$

where:
h = percentage hysteresis loss at induction B, %;
e = percentage eddy-current loss at induction B, %; and
K = $(E_2/E_f)^2$.

Obviously, $h = 100 - e$ if residual losses are considered negligible; the values of h and e in the above equation are not critical when waveform distortion is low. Typical values for the class of material being tested may be used, or values may be obtained by core-loss separation tests made by the two-frequency method in which the two frequencies are within the range of not less than half and not more than double the desired test frequency.

NOTE 3—In determining the form factor error, it is assumed that the hysteresis component of core loss will be independent of the form factor if the maximum value of induction is at the correct value (as it will be if a flux voltmeter is used to establish the value of the induction) but that the eddy-current component of core loss, being a function of the rms value of the voltage, will be in error for nonsinusoidal voltages. While it is strictly true that frequency or form factor separations do not yield true values for the hysteresis and eddy-current components, yet they do separate the core loss into two components, one which is assumed to vary as the second power of the form factor and the other which is assumed to be unaffected by form factor variations. Regardless of the academic difficulties associated with characterizing these components as hysteresis and eddy-current loss, it is observed that the equation for correcting core loss for waveform distortion of voltage based on the percentages of first power and second power of frequency components of core loss does accomplish the desired correction under all practical conditions if the form factor is accurately determined and the distortion not excessive.

NOTE 4—It is recommended that tests made under conditions in which the percent error in form factors, F, is greater than 10 % be considered as likely to be in error by an excessive amount, and that such conditions be avoided.

9.4 *Rms Exciting Power* P_z *and Specific Exciting Power,* $P_{z(B;f)}$—The rms exciting power is the product of the induced rms secondary voltage and the ac (rms) exciting current, while the specific exciting power is the rms exciting power per unit mass at a given frequency. Thus:

$$P_z = E_2 I \text{ and}$$
$$P_{z\,(B;f)} = P_z/m = E_2 I/m \tag{8}$$

where:
P_z = rms exciting power, VA;
E_2 = rms secondary voltage, V;
I_l = rms primary current, A;
$P_{z\,(B;f)}$ = specific exciting power, VA/lb; and
m = mass of specimen, lb.

9.5 *Rms Exciting Current*—Rms exciting current is often normalized for circuit parameters by converting to the following forms:

9.5.1 Rms exciting force, which is widely used in design of electromagnetic apparatus, is calculated as follows (Note 5):

$$(\text{Rms exciting force}) = N_1 I/l$$

NOTE 5—The customary units of rms exciting force are A/cm (the definition and symbol are not included in Terminology A 340.)

9.5.2 This quantity then appears in the calculation of apparent ac magnetizing force, H_z, as (Note 6):

$$H_z = 0.4\pi 2(N_1 I/l) \tag{9}$$

where:

H_z = apparent ac magnetizing force, Oe;
N_1 = number of turns in primary winding;
I = rms ac exciting current, A; and
l = effective magnetic path length, cm.

NOTE 6—H_z is computed from the rms value of the complex exciting current by assuming a crest factor of 2 and thus is based on a sinusoidal current having an rms value of the complex current.

9.6 *Peak Current*:

9.6.1 The peak exciting current, I_p in amperes, may be computed from measurements made using the standard resistor and peak-to-peak reading voltmeter as follows:

$$I_p = E_{p-p} /2R_1 \tag{10}$$

where:

I_p = peak current, A;
E_{p-p} = peak-to-peak voltage indicated by peak reading voltmeter, V; and
R_1 = resistance of standard resistor.

9.6.2 The peak magnetizing force, H_p, may be calculated from the following equation:

$$H_p = 0.4\pi N_1 I_p /l \tag{11}$$

where:

H_p = peak magnetizing force, Oe;
N_1 = number of turns in primary winding of test fixture;
I_p = peak exciting current, A; and
l = effective magnetic path length, cm.

9.7 *Permeability*:

9.7.1 For various types of applications, certain types of ac permeability data are more useful than others.

9.7.2 Impedance permeability, μ_p, is calculated as follows (Note 7):

$$\mu_p = B_i /H_z \tag{12}$$

where:

B_i = intrinsic induction, G and
H_z = ac magnetizing force, Oe, as in 9.4.

NOTE 7—For simplification and convenience in the calculation of ac permeabilities, the value of B_i is used to replace B_m in the permeability equation. This entails no loss of accuracy until the magnetizing force H_z becomes appreciable in magnitude when compared to the value of B_i. If greater accuracy is essential, B_m or $(B_i + H_z)$ should be used to replace the B_i in these equations.

9.7.3 For control work in the production of magnetic materials, it is often desirable to determine an ac permeability value that is more directly comparable to the dc permeability value for the specimen. This is accomplished by evaluating H_p from the measured peak value of the exciting current at some value of H_p sufficiently above the knee of the magnetization curve that the magnetizing component of the exciting current is appreciably greater than the core-loss component. Such a test point for many commercial materials is an H_p value of 10 Oe [796 A/m]. Permeability determined in this way is characterized by the symbol μ_p, and is computed as follows (Note 7):

$$\mu_p = B_i/H_p \tag{13}$$

where:

μ_p = peak permeability, G/Oe;
B_i = intrinsic induction, G; and
H_p = peak magnetizing force, Oe.

10. Calculation (SI Units)

10.1 *Flux Volts*—Calculate the flux volts, E, induced in the secondary winding of the test fixture corresponding to the desired intrinsic test induction in the test specimen as follows:

$$E_f = \sqrt{2}\pi B_i A N_2 f \tag{14}$$

where:

E_f = flux voltage, V;
B_i = maximum intrinsic flux density, T;
A = effective cross-sectional area of the test specimen, m^2;
N_2 = number of turns in secondary winding; and
f = frequency, Hz.

10.1.1 Cross-sectional area, A, of the test specimen is determined as follows:

$$A = m/l\delta \tag{15}$$

where:

A = cross-sectional area of the specimen, m^2;
m = total mass of specimen, kg;
l = the mean magnetic path length, m; and
δ = specified density (by agreement between supplier and purchaser as given in Specification A 901 or as measured by Test Method C 693), kg/m^3.

10.1.2 The mean magnetic path length is calculated as follows:

$$l = \pi(d_i + d_o)/2 \tag{16}$$

where:

l = mean magnetic path length, m;
d_i = inside diameter, m; and
d_o = outside diameter, m.

10.2 *Specific Core Loss*—See 9.2.

$$P_{c(B;f)} = P_c / m \tag{17}$$

where:

$P_{c\,(B;f)}$ = specific core loss, W/kg;
P_c = total core loss, W; and
m = mass of specimen, kg.

10.3 *Form Factor Correction*—See 9.3.

10.4 *Rms Exciting Power P_z and Specific Exciting Power, $P_{z\,(B;f)}$* —The rms exciting power is the product of the induced rms secondary voltage and the ac (rms) exciting current, while the specific exciting power is the rms exciting power per unit mass at a given frequency. Thus:

$$P_z = E_2 I \text{ and} \tag{18}$$

$$P_{z\,(B;f)} = P_z/m = E_2 I/m$$

where:

P_z = rms exciting power, VA;
E_2 = secondary rms voltage, V;
I = primary rms exciting current, A;
$P_{z\,(B;f)}$ = specific exciting power, VA/lb; and
m = mass of specimen, kg.

10.5 *Rms Exciting Current*—Rms exciting current is often normalized for circuit parameters by converting to the following forms:

10.5.1 Rms exciting force, which is widely used in design of electromagnetic apparatus, is calculated as follows (Note 6):

$$H_z = 2N_1 I/l \tag{19}$$

where:

H_z = apparent ac magnetizing force, A/m;
N_1 = number of turns in primary winding;
I = ac exciting current, A; and
l = effective magnetic path length, m.

10.6 *Peak Current*:

10.6.1 The peak exciting current, I_p, may be computed from measurements made using the standard resistor and peak-to-peak reading voltmeter as follows:

$$I_p = E_{p-p}/2R_1 \tag{20}$$

where:

I_p = peak current, A;
E_{p-p} = peak-to-peak voltage indicated by peak reading voltmeter, V; and
R_1 = resistance of standard resistor, Ω.

10.6.2 The peak magnetizing force, H_p, may be calculated from the following equation:

$$H_p = N_1 I_p/l \tag{21}$$

where:

H_p = peak magnetizing force, A/m;
N_1 = number of turns in primary winding of test fixture;
I_p = peak exciting current, A; and
l = effective magnetic path length, m.

10.7 *Permeability*:

10.7.1 For various types of applications, certain types of ac permeability data are more useful than others.

10.7.2 Impedance permeability, μ_z, is directly related to the induction and the rms magnetizing force and is calculated as follows (Note 8):

$$\mu_z = B_i/H_z \tag{22}$$

where:

μ_z = impedance permeability;
B_i = intrinsic induction, T; and
H_z = ac magnetizing force, A/m.

10.7.3 For control work in the production of magnetic materials, it is often desirable to determine an ac permeability value that is more directly comparable to the dc permeability value for the specimen. This is accomplished by evaluating H_p from the measured peak value of the exciting current at some value of H_p sufficiently above the knee of the magnetization curve that the magnetizing component of the exciting current is appreciably greater than the core-loss component. Such a test point for many commercial materials is an H_p value of 796 A/m. Permeability determined in this way is characterized by the symbol μ_p and is computed as follows (Note 8):

$$\mu_p = B_i/H_p \tag{23}$$

where:

μ_p = peak permeability, Tm/A;
B_i = intrinsic induction, T; and
H_p = peak magnetizing force, A/m.

For comparison with established data in the literature, one need only divide the value of μ_p calculated above by Γm to obtain the relative peak permeability:

$$\mu_{pr} = \mu_p/\Gamma_m = (B_i/\Gamma_m H_p) \tag{24}$$

where:

μ_{pr} = relative peak permeability, and
Γ_m = magnetic constant, $4\pi \times 10^{-7}$, H/m.

NOTE 8—For convenience in calculation of peak permeability, the value of B_i (intrinsic induction) is used instead of B (normal induction) under most circumstances of testing. This entails no loss of accuracy until $\Gamma_m H_p$ becomes appreciable in magnitude relative to B_i. If greater accuracy is required, B (equal to $B_i + \Gamma_m H_p$) should be used in place of B_i in the permeability equation of 10.7.3.

11. Precision and Bias

11.1 Experiments performed in one laboratory indicate the repeatability and reproducibility of this method to be +12/−3 %.

11.2 Since there is no acceptable reference material for magnetic properties, the bias of this test method has not been determined.

12. Keywords

12.1 amorphous; core loss; exciting force; exciting power; impedance permeability; peak permeability; specific core loss; specific exciting power; tape wound core; toroidal test specimen; toroidal test transformer; waveform distortion

ANNEXES

(Mandatory Information)

A1. RECOMMENDED STANDARD TEST VALUES

A1.1 *Standard Test Values:*

A1.1.1 For tests at 50 or 60 Hz on amorphous materials in standard thicknesses, the following test points are recommended:

A1.1.1.1 Test for specific core loss (and specific exciting power, if required) at 14.0 kG [1.4 T], 25°C.

A2. PREPARATION OF STANDARD TOROIDAL TEST SPECIMENS

A2.1 The specimen, unless otherwise agreed upon by the producer and buyer, shall have the suggested dimensions listed in A4.1.

A2.2 The test specimen shall consist of tape cut from the master coil.

A2.3 When used as a support for annealing, the core form shall be a cylinder of the same diameter as the inside diameter of the core. The material should be capable of withstanding the temperature at which the core is annealed and as such should be steatite, pyrex, or some other nonconductive ceramic material.

A2.4 The mass of the test specimen shall be sufficient to ensure at least ten wraps around the core form but not large enough to cause the maximum build to exceed limits suggested in A4.1.

A2.5 The last wrap of the specimen tape should be secured with adhesive polyimide tape to keep it from unwinding.

A2.6 The net cross-sectional area of the specimen shall be determined in accordance with 9.1 or 10.1.

A3. CORE FORMS AND PROTECTIVE ENCLOSURES

A3.1 Core forms may be used to support the test material during annealing, also, appropriate protective enclosures are normally needed to support the copper test windings. Core forms should conform to restrictions in A2.3. The protective enclosures may be of any rigid nonmagnetic material such as ceramic or plastic case.

A3.2 There is no restriction on the maximum core form diameter. The minimum core diameters are set to limit the stress induced by bending the tape into coil. These construction stresses must be removed by thermal annealing. A typical annealing temperature-time cycle is given for a typical power transformer-grade amorphous material.

A4. SUGGESTED MINIMUM TOROIDAL TEST SPECIMEN

A4.1 *Dimensional Requirements:*

Tape Thickness	Minimum Core Diameter	Maximum Permissible Build
up to 0.002 in. [0.005 08 mm]	4.0 in. [102 mm]	0.40 in. [10.2 mm]
over 0.002 in. [0.005 08 mm]	6.0 in. [152 mm]	0.60 in. [15.2 mm]

A5. ANNEALING PROCEDURE FOR TYPICAL AMORPHOUS METAL

A5.1 The best magnetic properties in amorphous metals (alloys) are developed only after annealing in a nonoxidizing atmosphere. The annealing conditions are normally specified by the manufacturer or developed by the user. A typical annealing cycle for power grade Fe 78 = B13 = Si 9 alloy is given below:

A5.1.1 A gastight annealing furnace is needed and pure, dry argon or nitrogen atmosphere used (O_2 50 ppm, dew point − 20°C).

A5.1.2 The heating and cooling rates should be no less than 15°C per minute.

A5.1.3 A circumferential dc magnetic field of at least 10 Oe [796 A/m] should be applied to the test toroids.

A5.1.4 A typical anneal for a 4-in. [102-mm] diameter toroid is to heat it to 360°C, hold it at temperature for two h with the field applied, and then cool to ambient (or at least to 100°C) without removing the field.

APPENDIXES

(Nonmandatory Information)

X1. BASIC PRINCIPLES

X1.1 *Basic Principles:*

X1.1.1 The basic features involved in these ac methods, which should be strictly adhered to by the user unless otherwise stated in the individual test methods, are as follows:

X1.1.1.1 The test specimen shall be of uniform cross section perpendicular to the direction of the flux path and should have uniform properties in any given direction.

X1.1.1.2 The flux waveform, as judged by the form factor of the voltage wave induced in an unloaded secondary winding, shall be sinusoidal within limits described in the individual test methods. To accomplish this, the power source must generate a closely sinusoidal waveform, and the primary circuit impedance (including the power source) shall be kept as low as possible.

X1.1.1.3 Voltage and frequency shall be very closely controlled within limits given in the individual test methods.

X1.1.1.4 ac normal induction, B, shall be determined (in accordance with 9.1 or 10.1) from measurements made with a voltmeter responsive to the full-wave average value of the voltage (rectifying-type voltmeter), commonly called a flux voltmeter, connected to an essentially unloaded secondary winding enclosing the specimen. The flux voltmeter shall conform to the specifications given in 5.3.2.

X1.1.1.5 The value of the effective cross-sectional area of the test specimen shall be determined from mass, mean test specimen diameter, and density of the test specimen wherever feasible (Section 7 of Practice A 34/A 34M). Equations for calculating this area are given in 9.1 and 10.1.

X1.1.1.6 Core-loss measurements shall be made by using circuitry, as shown in Fig. 1, Fig. 2, or equivalent. Care must be taken that the circuit used avoids the inclusion of the I^2R (conductor resistance loss) of the primary test winding. This requires that the secondary winding of the test transformer is applied to the potential circuit of the wattmeter. The core loss is the averaged product of instantaneous values of primary current and induced voltage.

X1.1.1.7 Exciting-current measurements shall be made with an ammeter whose indications are proportional to the rms value of the current regardless of its waveform. The impedance of the ammeter must be low enough to avoid appreciable distorting effect on the flux waveform.

X1.1.1.8 Secondary-circuit power drain must be negligible, or its effects on the measured properties must be evaluated and corrected by calculation.

X1.1.1.9 Whenever tests are made under conditions in which the effects of accidental polarization of the specimen by handling in the earth's magnetic field, or previous magnetic history, may have a significant effect on the measured properties, demagnetization of the test specimen shall be used, as described in 8.2.

X2. TEST INSTRUMENTS FOR EXTENDED FREQUENCY RANGE

X2.1 For measurements above 400 Hz, electronic test instruments with sufficient bandwidth must be used. True rms and average responding voltmeters are available with bandwidth of 100 kHz and accuracy of ±0.5 %. Thermocouple-type rms voltmeters and rms ammeters are available with bandwidths up to 5 MHz.

X2.2 The wattmeter should be an electronic-multiplier-type instrument. Since the instantaneous power is computed and integrated over the full period, its performance is not affected over a wide range of variations in power factor and frequency. Instruments with accuracy of ±0.15 % of input, regardless of power factor, are available for applications from dc to 30 kHz and with accuracy of ±0.6 % from 30 to 300 kHz.

X2.3 An expedient method for measuring electronic signals is to acquire, digitize, and store in a computer the voltage and current waveforms. The computer (or waveform calculator) then is able to compute the peak, average, and rms values for all parameters, including power. The accuracy of presently available systems is limited to ±2.0 %.

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