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 A912/A912M; 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 magnetic field strengths up to about 10 Oe [796 A/m].

1.5 Explanations of symbols and brief definitions appear in the text of this test method. The official symbols and definitions are listed in Terminology A340.

1.6 This test method shall be used in conjunction with Practice A34/A34M.

1.7 The values and equations stated in customary (cgs-emu and inch-pound) units 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 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

A343/A343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame

A901 Specification for Amorphous Magnetic Core Alloys, Semi-Processed Types

C693 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 producers and users of magnetic materials for materials specification acceptance and manufacturing control.

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.

[1] This test method is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.01 on Test Methods.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4.1.1 The ratio of inside to outside diameter must be 0.82 or greater, or the magnetic field strength 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 producer 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, see Annex A3.

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 A343/A343M 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.

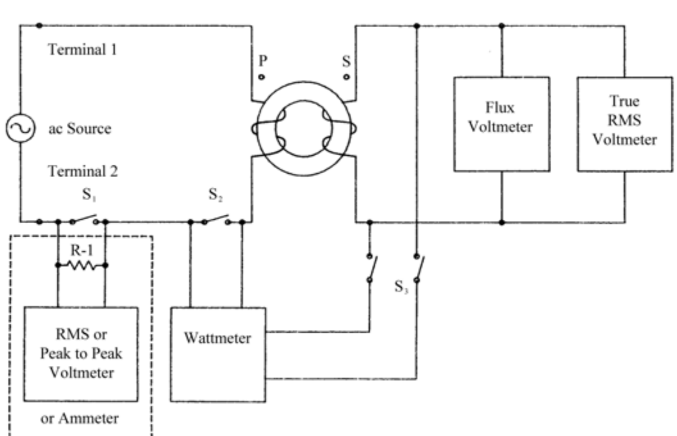

FIG. 1 Basic Circuit Diagram for Wattmeter Method

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 $\sqrt{2}\,\pi/4$ 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.

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 normally 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 magnetic field strength 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 the 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.