Standard Test Method for Alternating-Current Magnetic Properties of Toroidal Core Specimens Using the Voltmeter-Ammeter-Wattmeter Method[1]

This standard is issued under the fixed designation A927/A927M; 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 the determination of several ac magnetic properties of either laminated ring or toroidal tape wound cores made from flat rolled product.

1.2 This test method covers test equipment and procedures for determination of specific core loss, specific exciting power, and peak permeability for power and audio frequencies (50 to 20 000 Hz) under sinusoidal flux conditions.

1.3 This test method, because of the use of a feedback-controlled power amplifier, is well suited for determination of ac magnetic properties at magnetic flux densities above the knee of the magnetization curve and is particularly useful for testing of high-saturation iron-cobalt alloys (for example, alloys listed in Specification A801), although use of this test method is not restricted to a particular type of material.

1.4 This test method shall be used in conjunction with Practice A34/A34M and Terminology A340.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. 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 non-conformance with the standard.

1.6 *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

A697/A697M Test Method for Alternating Current Magnetic Properties of Laminated Core Specimen Using Voltmeter-Ammeter-Wattmeter Methods

A801 Specification for Wrought Iron-Cobalt High Magnetic Saturation Alloys (UNS R30005 and K92650)

3. Significance and Use

3.1 This test method is a derivative of Test Method A697/A697M specifically designed for testing of toroidal cores which are not covered in Test Method A697/A697M and for testing at magnetic flux densities above the knee of the magnetization curve.

3.2 Specimen size typically ranges from 1 to 1.25 in. [25.4 to 31.8 mm] in inside diameter to 1.5 in. [38.1 mm] in outside diameter with weights ranging from 30 to 60 g. Provided the test equipment is suitably chosen, there is no obvious limit to the overall size of core that can be tested. If basic material properties are desired, then the requirements of 5.1 must be observed.

3.3 The reproducibility and repeatability of this test method are such that this test method is suitable for design, specification acceptance, service evaluation, and research and development.

3.4 When testing under sinusoidal flux conditions at magnetic flux densities approaching saturation, highly peaked magnetizing waveforms will be present, and the test instruments used must have crest factor capabilities of at least 3; otherwise erroneous results will be obtained.

[1] This test method is under the jurisdiction of ASTM Committee A06 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. Apparatus

4.1 The apparatus for testing under this test method shall consist of as many of the components, described below and schematically illustrated in Fig. 1, as required to perform the measurements.

4.2 *Signal Generator*—For testing at other than line frequency (50 or 60 Hz), a low distortion sine wave signal generator is required. The frequency accuracy of the signal generator should be within ±0.1 %. To prevent dc biasing of the magnetizing current waveform, a blocking capacitor or isolation transformer should be installed between the signal generator and power amplifier.

4.3 *Power Amplifier*—A linear power amplifier should be used (see Note 1). The signal from the secondary winding of the test specimen is used for negative feedback control of the magnetizing waveform. Depending on the power amplifier used, it may be necessary to install feedback signal conditioning equipment such as an attenuator or amplifier; however, the signal conditioning equipment must not distort the feedback waveform nor load the secondary winding. Fig. 1 also shows an audio choke connecting the output and feedback terminals of the amplifier. This choke is intended to prevent dc bias being introduced into the magnetizing waveform by providing dc feedback to the power amplifier. Without such a choke, the dc offset current present in certain power amplifiers will result in large dc output currents. This choke may not be needed depending on the make and model of power supply. Further reduction or elimination of bias can be achieved by installing an isolation transformer to transformer couple the primary circuit.

NOTE 1—Audio amplifiers are suitable in some instances, although the small specimen cross section and the relatively few primary turns typically used results in a low Q circuit and, therefore, difficulty in maintaining sinusoidal flux at magnetic flux densities approaching saturation. In addition, an impedance matching transformer may be required to improve power transfer.

4.4 *Wattmeter*—An electronic wattmeter with appropriate voltage, current and wattage ranges, and bandwidth must be used. The full-scale accuracy of the wattmeter must be better than ±0.5 %. The wattmeter must have a crest factor capability of at least 3 and be capable of accurate measurements at low-power factors. The wattmeter must be able to measure rms current and rms voltage to an accuracy of ±0.5 % or better; otherwise, separate instruments meeting this accuracy requirement must be used.

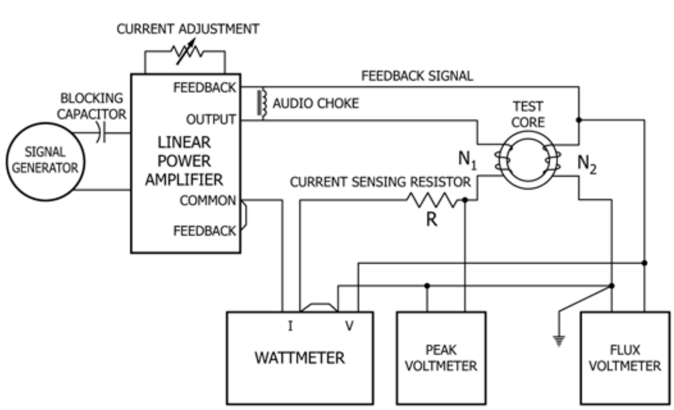

FIG. 1 Schematic Illustration of Test Apparatus

4.5 *Flux Voltmeter*—The flux voltmeter must be a true average responding, high-impedance voltmeter calibrated to read $\sqrt{2}\ \pi/4$ times the full wave rectified average voltage so that its indications will be identical to those of a true rms voltmeter when reading a pure sinusoidal voltage. The rated full-scale accuracy must be ±0.5 % or better.

4.6 *Current-Sensing Resistor (Optional)*—When peak permeability is to be measured, a noninductive, high-precision, low-thermal coefficient of resistance current-sensing resistor shall be used. The resistor must be rated to carry the maximum current used in the test.

4.7 *Peak Voltmeter (Optional)*—When peak permeability is to be determined, a high-impedance peak-reading voltmeter shall be used to measure the voltage drop across the current-sensing resistor. The voltmeter must have a full-scale accuracy of ±1 % or better, a crest factor of at least 3, and appropriate bandwidth.

4.8 *Oscilloscope (Optional)*—An oscilloscope displaying both the magnetizing current waveform and secondary voltage permits the operator to observe the waveforms. This is particularly useful when setting up the test for the first time. The oscilloscope must have a very high input impedance to avoid loading of the secondary winding.

5. Test Specimen

5.1 The test specimen must be either a stack of toroidal (washer ring) laminations formed by punching, machining, or etching or a toroidal tape wound core. For measurement of basic material properties, the ratio of inside to outside diameter must be 0.82 or greater.

6. Procedure

6.1 The test specimen should be heat treated after fabrication. Bent or otherwise damaged laminations or tape cores shall be discarded.

6.2 The core shall be weighed to an accuracy of ±0.1 % or better and the inside and outside diameters measured to an accuracy of 0.1 % or better.

6.3 The laminations or tape core should be enclosed in a rigid, nonconductive case (core box) or placed in a suitable fixture to avoid winding stresses. The test core should fill the core box or fixture as fully as possible to minimize air flux.

6.4 Primary and secondary windings, N_1 and N_2, are applied; the secondary winding should be applied first. Both windings should be uniformly wound over the circumference of the toroid. The secondary winding may use finer diameter wire than the primary winding, which should be of sufficient diameter to carry the magnetizing current without overheating. Alternately, a fabricated magnetizing fixture may be used provided the windings are uniformly distributed over the length of the core.

6.5 If the number of turns on the secondary winding is not equal to the number of turns on the primary winding, additional circuitry such as amplifiers or attenuators may be required to control the "loop gain" in the waveform feedback loop. Failure to control the "loop gain" will normally result in power supply instability.

6.6 The flux voltage, E_f, induced in the secondary winding, N_2, at the required magnetic flux density, B_m, shall be computed using the equation found in 7.2 or 8.2.

6.7 The test specimen is connected to the test apparatus and demagnetized. Demagnetization must be done by smoothly reducing the magnetizing current starting from a magnetic flux density above the knee of the magnetization curve and at the test frequency.

6.8 The magnetizing current is increased to obtain the flux voltage corresponding to the lowest required magnetic flux density.

6.9 The form factor of the secondary voltage is computed by dividing the rms secondary voltage by the flux voltage. The form factor must be within ±1 % of the value for a sine wave for testing conducted in accordance with this test method. Once test conditions have been established for a particular test core and material, measurement of the form factor is optional.

6.10 For core loss determination, read and record the power from the wattmeter.

6.11 For specific exciting power determination, read and record both the rms exciting current and rms secondary voltage as displayed on the wattmeter or other rms voltmeters.

6.12 For peak permeability determination, read and record the voltage drop across the current-sensing resistor using the peak-reading voltmeter.

6.13 Repeat 6.8 through 6.12 for all test points in order of increasing magnetic flux density. If the required magnetic flux density is exceeded without acquiring the needed data, the core must be demagnetized before repeating the measurement.

7. Calculation (Customary Units)

7.1 The cross-sectional area of the test specimen is computed from the mass of core, the density of the material, and the magnetic path length. For a toroidal core the magnetic path length, l_m, is equal to the mean circumference or:

$$l_m = \frac{\pi(d_o + d_i)}{2} \tag{1}$$

where:

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

The cross-sectional area, A, in square centimetres is then:

$$A = \frac{m}{\delta l_m} \tag{2}$$

where:

m = core mass, g, and
δ = density, g/cm^3.

7.2 *Flux Voltage*—The flux voltage corresponding to a given flux density (assumed to be sinusoidal) is:

$$E_f = \sqrt{2}\pi BAN_2 f \times 10^{-8} \tag{3}$$

where:

E_f = flux voltage induced in winding N_2, V;
B = maximum flux density, G;
A = cross-sectional area of core, cm^2;
N_2 = number of secondary turns; and
f = frequency, Hz.

7.3 *Specific Core Loss*—The core loss per pound is:

$$P_{c(B;f)} = \frac{453.6\left(\frac{N_1}{N_2}\right)(W - K)}{m} \tag{4}$$

where:

$P_{c(B;f)}$ = specific core loss at magnetic flux density B and frequency f, W/lb;
N_1 = number of primary turns;
N_2 = number of secondary turns;
W = power loss indicated by the wattmeter, W;
K = correction factor for losses due to the wattmeter, W; and
m = mass of test core, g.

The correction factor in electronic wattmeters tends to be very small and is usually negligible. Refer to the wattmeter operating manual for specific instructions on computing this correction factor.

7.4 *Specific Exciting Power*—The specific exciting power is calculated from the rms value of exciting current and rms secondary voltage with all other secondary burden either subtracted or removed. The latter condition usually applies when high-input impedance-measurement equipment is used. The equation is:

$$P_{z(B;f)} = \frac{453.6\left(\frac{N_1}{N_2}\right) VI}{m} \tag{5}$$

where:

$P_{z(B;f)}$ = specific exciting power at magnetic flux density and frequency f, VA/lb;
N_1 = number of primary turns;
N_2 = number of secondary turns;
V = rms value of secondary voltage, V;
I = rms value of exciting current, A; and
m = mass of test core, g.

7.5 *Peak ac Permeability*—The peak ac permeability is calculated as:

$$\mu_p = \frac{B_m}{H_p \Gamma_m} = \frac{B_m R l_m}{0.4\pi N_1 E_p} \tag{6}$$

where:

μ_p = peak ac permeability;
B_m = peak flux density, G, which is equivalent to the test magnetic flux density for sinusoidal waveforms;
H_p = peak magnetic field strength, Oe;
Γ_m = magnetic constant equal to 1, unitless in cgs-emu;
N_1 = number of primary turns;
E_p = peak voltage read across the current-sensing resistor, V;
R = resistance of the current-sensing resistor, Ω; and
l_m = magnetic path length, cm.

8. Calculation (SI Units)

8.1 The cross-sectional area of the test specimen is computed from the mass of core, the density of the material, and the magnetic path length. For a toroidal core the magnetic path length, l_m, is equal to the mean circumference or:

$$l_m = \frac{\pi(d_o + d_i)}{2} \quad (7)$$

where:

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

The cross-sectional area, A, in square metres, is then:

$$A = \frac{m}{\delta l_m} \quad (8)$$

where:

m = core mass, kg, and
δ = density, kg/m^3.

8.2 *Flux Voltage*—The flux voltage corresponding to a given flux density (assumed to be sinusoidal) is:

$$E_f = \sqrt{2}\pi BAN_2 f \quad (9)$$

where:

E_f = flux voltage induced in winding N_2, V;
B = maximum flux density, T;
A = cross-sectional area of core, m^2;
N_2 = number of secondary turns; and
f = frequency, Hz.

8.3 *Specific Core Loss*—The core loss per kilogram is:

$$P_{c(B;f)} = \frac{\left(\frac{N_1}{N_2}\right)(W - K)}{m} \quad (10)$$

where:

$P_{c(B;f)}$ = specific core loss at magnetic flux density B and frequency f, W/kg;
N_1 = number of primary turns;
N_2 = number of secondary turns;
W = power loss indicated by the wattmeter, W;
K = correction factor for losses due to the wattmeter, W; and,
m = mass of test core, kg.

The correction factor in electronic wattmeters tends to be very small and is usually negligible. Refer to the wattmeter operating manual for specific instructions on computing this correction factor.

8.4 *Specific Exciting Power*—The specific exciting power is calculated from the rms value of exciting current and rms secondary voltage with all other secondary burden either subtracted or removed. The latter condition usually applies when high-input impedance-measurement equipment is used. The equation is:

$$P_{z(B;f)} = \frac{\left(\frac{N_1}{N_2}\right)VI}{m} \quad (11)$$

where:

$P_{z(B;f)}$ = specific exciting power at magnetic flux density B and frequency f, VA/kg;
N_1 = number of primary turns;
N_2 = number of secondary turns;
V = rms value of secondary voltage, V;
I = rms value of exciting current, A; and
m = mass of test core, kg.

8.5 *Relative Peak ac Permeability*— The relative ac peak permeability is calculated as:

$$\mu_p = \frac{B_m}{H_p \Gamma_m} = \frac{B_m R l_m}{N_1 E_p \Gamma m} \quad (12)$$

where:

μ_p = relative peak ac permeability;
B_m = peak flux density, T, which is equivalent to the test magnetic flux density for sinusoidal waveforms;
H_p = peak magnetic field strength, A/m;
Γ_m = magnetic constant equal to $4\pi \times 10^{-7}$ H/m;
N_1 = number of primary turns;
E_p = peak voltage read across the current-sensing resistor, V;
R = resistance of the current-sensing resistor, Ω; and
l_m = magnetic path length, m.

9. Report

9.1 Report the following information:

9.1.1 Test specimen identification,

9.1.2 Heat treatment parameters (for example, time, temperature, and atmosphere),

9.1.3 Test frequency,

9.1.4 Test magnetic flux densities,

9.1.5 Test results (for example, specific core loss, specific exciting power, and peak ac permeability).

10. Precision and Bias

10.1 The precision and bias of this test method have not been established by interlaboratory testing.

10.2 It is expected that the precision of measurement will be comparable to that specified in Test Method A697/A697M. The values listed in Test Method A697/A697M Precision and Bias section are:

10.2.1 The accuracy of measurement of the secondary rms voltage is within ±2 %.

10.2.2 The precision of exciting current measurement is within ±5 % at 10 kG [1.0 T] and within ±10 % at 15 kG [1.5 T].

10.2.3 The precision of volt-ampere measurements is within ±7 % at 10 kG [1.0 T]) and within ±12 % at 15 kG [1.5 T].

10.2.4 The precision of core loss measurements is within ±3 % at 15 kG [1.5 T].

11. Keywords

11.1 alternating current; core; core loss; flat rolled; laminated core; lamination; magnetic; magnetic material; magnetic test; permeability