Designation: A697/A697M – 13

Standard Test Method for Alternating Current Magnetic Properties of Laminated Core Specimen Using Voltmeter-Ammeter-Wattmeter Methods[1]

This standard is issued under the fixed designation A697/A697M; 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 laminated cores made from flat-rolled magnetic materials.

1.2 This test method covers test equipment and procedures for the determination of impedance permeability and exciting power from voltage and current measurements, and core loss from wattmeter measurements. These tests are made under conditions of sinusoidal flux.

1.3 This test method covers tests for two general categories (1 and 2) of cores based on size and application.

1.4 Tests are provided for power and control size cores (Category 1) operating at inductions of 10 to 15 kG [1.0 to 1.5 T] and at frequencies of 50, 60, and 400 Hz.

1.5 Procedures and tests are provided for coupling and matching type transformer cores (Category 2) over the range of inductions from 100 G [0.01 T] or lower to 10 kG [1.0 T] and above at 50 to 60 Hz or above when covered by suitable procurement specifications.

1.6 This test method also covers tests for core loss and ac impedance permeability under incremental test conditions (ac magnetization superimposed on dc magnetization) for the above core types and at inductions up to those that cause the ac exciting current to become excessively distorted or reach values that exceed the limits of the individual test equipment components.

1.7 This test method shall be used in conjunction with Practice A34/A34M and Terminology A340. It depends upon these designated documents for detailed information which will not be repeated in this test method.

1.8 The values and equations stated in customary (cgs-emu and inch-pound) or SI units are to be regarded separately as standard. Within this standard, SI units are shown in brackets. 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.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A34/A34M Practice for Sampling and Procurement Testing of Magnetic Materials

A340 Terminology of Symbols and Definitions Relating to Magnetic Testing

3. Terminology

3.1 The terms and symbols listed below apply only to this test method. The official list of symbols and definitions may be found in Terminology A340.

3.2 *Symbols:*

A_s = *E* lamination surface area, one side only,
A_{ss} = *EI* lamination surface area, one side only,
h = lamination stack height,
A_{dc} = dc ammeter,
I_{dc} = dc current,
N_1 = primary turns,
N_2 = secondary turns,
N_3 = tertiary turns,
R_1 = ammeter shunt resistance,
V_f = flux voltmeter,
w = lamination center leg width,
W = wattmeter, and
Z = choke coil impedance.

4. Summary of Test Method

4.1 For Category 1 cores, the recommended tests are made at a frequency of 60 Hz and at a test induction within the range from 10 through 15 kG [1.0 to 1.5 T].

[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.

4.2 For Category 2 cores, the recommended tests are made at a frequency of 50 or 60 Hz and at inductions of 40, 100 or 200, 2000, 5000, 6000, 7000, and 10 000 G [0.004, 0.01 or 0.02, 0.2, 0.5, 0.6, 0.7, and 1.0 T]. Any or all may be required depending on the type of core material.

5. Significance and Use

5.1 This test method was developed for evaluating the ac magnetic properties of laminated cores made from flat-rolled magnetic materials.

5.2 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.

6. Apparatus

6.1 The apparatus for testing under this test method shall consist of as many of the following components, described in 6.2 through 6.12, as required to perform the desired test measurements.

6.2 *Test Coils*—In general, test coils are designed to surround a square center leg stack (lamination stack height equal to center leg width). They consist of two or more windings with the secondary wound on the coil form first. Three groups of standard test coils are described in 6.2.1 through 6.2.3. Each of these has been designed to provide specific features during test. Because of turns, coil resistance, and magnitude of induced voltage, each has a particular field of application.

6.2.1 The coils listed in Table 1, for testing Category 1 cores, have been designed to have equal primary and secondary turns and provide an induced voltage of 115 V when operating at a peak flux density of 15 kG [1.5 T] at 60 Hz.

6.2.2 The coils listed in Table 2, for testing Category 2 cores, have been designed to have characteristics that provide a direct readout capability for incremental permeability. The test coil is designed so that the primary winding $--> N_1 = 100\sqrt{2}\ \pi\ l_1$, the secondary winding $N_2 = 20\ l_1$, and the tertiary winding N_3 is designed so that the $N_3 = 5\sqrt{2}\ \pi\ l_1$ (and $N_1/N_3 = 20$).

6.2.3 The coils listed in Table 3 have been designed for testing Category 1 cores at a frequency of 400 Hz.

6.3 *Flux Voltmeter*—The flux voltmeter shall be a true average responsive 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 on a pure sinusoidal voltage. To produce the estimated precision of tests under this test method, the full-scale errors shall not exceed 0.5 % (0.25 % or better preferred). Either digital or analog flux voltmeters are permitted. The normally high impedance of digital flux voltmeters is desirable to minimize loading effects. The internal resistance of an analog flux voltmeter shall not be less than 1000 Ω/V of full-scale indication.

6.4 A variable voltage divider on the input of the flux voltmeter may be used to scale the voltmeter reading. The voltage divider should provide for ratio adjustments to four significant figures to establish the desired fraction of the secondary voltage that is to be impressed on the flux voltmeter. Care must be taken to assure that the voltage rating of a ratio

TABLE 1 Test Coils for *EI* Used at 60 Hz in Power Applications, Category 1

NOTE 1—Winding forms should allow for at least 0.030-in. [0.076-cm] clearance between lamination stack and coil form, and its walls should not be thicker than necessary to provide adequate insulation and strength for coil support.

NOTE 2—These coils are also suitable for use at 50 Hz and other frequencies.

NOTE 3—N_3 winding is required for setting induction when incremental properties are to be measured or where other instruments interfere with induction measurements. It is composed of one layer of No. 34 wire so that $N_3 = 5\sqrt{2}\pi\ l_1$ where l_1 is the magnetic path length.

Lamination					Test Winding (see 6.2.1)								
Center Leg					N_1			N_2			N_3		
Width (*w*)		Length Relative to *w*	Stack Height (*h*)		Turns	Wire Size	Resistance,Ω	Turns	Wire Size	Resistance, Ω	Turns	Wire Size	Resistance, Ω
in.	cm		in.	cm									
⅜	0.9525	1.5*w*	¾	1.905	1000	35	84.3	1000	35	103.8	64	34	2.84
½	1.270	1.5*w*	1	2.540	800	34	68.3	800	34	80.7	72	34	4.00
⅝	1.588	1.5*w*	⅞	2.222	800	33	56.6	800	33	67.8	83	34	5.54
¾	1.905	1.5*w*	¾	1.905	800	31	36.6	800	31	43.5	100	34	7.77
⅞	2.222	1.5*w*	⅞	2.222	588	28	15.4	588	28	18.1	116	34	9.86
15⁄16	2.381	1.5 *w*	15⁄16	2.381	513	26	8.75	513	26	10.6	136	34	12.8
1	2.540	1.5*w*	1	2.540	450	25	6.02	450	25	7.44	133	34	13.3
1⅛	2.857	1.5 *w*	1⅛	2.857	356	24	4.45	356	24	5.37	150	34	16.7
1¼	3.175	1.5 *w*	1¼	3.175	288	22	2.43	288	22	2.92	167	34	20.4
1⅜	3.493	1.5 *w*	1⅜	3.493	238	20	1.43	238	20	1.75	183	34	24.3
1½	3.810	1.5 *w*	1½	3.810	200	18	0.82	200	18	0.98	200	34	28.8
1⅝	4.127	1.5 *w*	1⅝	4.127	170	14	0.35	170	14	0.46	245	34	38.0
1¾	4.445	1.5 *w*	1¾	4.445	147	16	0.45	147	16	0.52	233	34	38.7
2⅛	5.397	1.5 *w*	2⅛	5.397	100	12	0.16	100	12	0.20	283	34	56.6
2¼	5.715	1.5 *w*	2¼	5.715	89	10	0.11	89	10	0.13	320	34	67.5
2½	6.350	1.5 *w*	2½	6.350	72	10	0.10	72	10	0.11	333	34	73.9
3	7.62	1.5*w*	1½	3.810	76	10	0.11	76	10	0.11	400	34	111.0
4	10.16	1.5*w*	2	5.080	57	10	0.09	57	10	0.10	534	34	148.0

TABLE 2 Test Coils for *EI* Laminations Used in General Magnetic Applications, Category 2

NOTE 1—Winding forms should allow for at least 0.030-in. [0.076-cm] clearance between lamination stock and coil form, and its walls should be not thicker than necessary to provide adequate insulation and strength for coil support.

NOTE 2—These coils may be used at any frequency where voltage does not become excessively large.

NOTE 3—N_3 winding is required for setting production when incremental properties are to be measured or other instruments interfere with induction measurements. It is composed of one layer of No. 34 wire so that $N_3 = 5\sqrt{2}\pi\, l_1$ where l_1 is the magnetic path length.

Lamination					Test Windings (see 6.2.2)								
Center Leg					N_1			N_2			N_3		
Width (w)		Length Relative to w	Stack Height (h)		Turns	Wire Size	Resistance, Ω	Turns	Wire Size	Resistance,Ω	Turns	Wire Size	Resistance, Ω
in.	cm		in.	cm									
3/16	0.4763	1.5 w	3/16	0.4763	722	36	24.2	32	30	0.37	36	34	0.997
1/4	0.635	1.5w	1/4	0.635	888	36	26.3	36	40	0.82	44	34	1.47
3/8	0.9525	1.5w	3/8	0.9525	1278	36	127.8	40	24	0.30	64	34	2.84
1/2	1.270	1.5w	1/2	1.270	1444	36	180.4	60	24	0.42	72	34	4.00
5/8	1.588	1.5w	5/8	1.588	1666	36	263.2	75	24	0.58	83	34	5.53
11/16	1.746	1.5 w	11/16	1.746	1822	36	294.4	82	23	0.55	92	34	6.64
3/4	1.905	1.5w	3/4	1.905	2000	35	278.0	90	21	0.42	100	34	7.77
7/8	2.222	1.5w	7/8	2.222	2333	34	295.7	105	21	0.45	116	34	10.3
15/16	2.381	1.5 w	15/16	2.381	2711	34	374.6	122	20	0.55	136	34	12.8
1	2.540	1.5w	1	2.540	2666	34	373.9	120	20	0.55	133	34	13.3

TABLE 3 Test Coils for *EI* Laminations Used at 400 Hz in Power and Other Applications, Category 1

NOTE 1—Winding forms should allow for at least 0.030-in. [0.076-cm] clearance between lamination stack and coil form, and its walls should be not thicker than necessary to provide adequate insulation and strength for coil support.

NOTE 2— These coils are also suitable for use at other frequencies.

NOTE 3—This winding is required for setting induction when incremental properties are to be measured or where other instruments interfere with induction measurements. It is composed of one layer of No. 34 wire so that $N_3 = 5\sqrt{2}\pi\, l_1$ where l_1 is the magnetic path length.

Lamination					Test Windings (see 6.2.3)									Ratio
Center Leg					N_1			N_2			N_3			
Width (w)		Length Relative to w	Stack Height (h)		Turns	Wire Size	Resistance,Ω	Turns	Wire Size	Resistance, Ω	Turns	Wire Size	Resistance, Ω	$G = A_{ss}/A_s$
in.	cm		in.	cm										
3/8	0.9525	1.5w	3/8	0.9525	458	33	19.06	458	33	24.2	64	34	2.84	1.308
1/2	1.270	1.5w	1/2	1.270	262	30	6.46	262	30	7.68	72	34	4.00	1.327
5/8	1.588	1.5w	5/8	1.588	162	27	2.37	162	27	2.74	83	34	5.52	1.329
3/4	1.905	1.5w	3/4	1.905	134	24	1.16	134	24	1.38	100	34	7.77	2.519
7/8	2.222	1.5w	7/8	2.222	82	20	0.34	82	20	0.40	116	34	10.3	3.407
1	2.540	1.5w	1	2.540	62	20	0.29	62	20	0.32	133	34	13.3	4.425

transformer is adequate for use at the test frequency and voltage. A resistive voltage divider may be used with high impedance electronic voltmeters. Dividers having a total resistance of at least 10 KΩ for low-voltage tests and 100 KΩ or more for other tests are preferred. When a resistive voltage divider is used, additional correction for instrument burden may be required to eliminate the effect of the resistive losses in the voltage divider upon measurements.

6.5 *RMS Voltmeter, V*—A true rms responsive voltmeter shall be used to indicate the rms voltage for exciting power measurements. It may also be used for evaluating the form factor of the voltage induced in the secondary of the test fixture and for evaluating instrument losses. The accuracy of the rms voltmeter shall be the same as that specified for the flux voltmeter. Either digital or analog voltmeters are permitted. The normally high-input resistance of the digital rms voltmeters is desirable to minimize loading effects. The input resistance of an analog rms voltmeter shall not be less than 1000 Ω/V of full-scale indication.

NOTE 1—Many electronic voltmeters are either peak responsive or average responsive in their indications. Although these meters may have scales that are marked *RMS Volts*, they should not be used for rms current or rms voltage measurements when distorted waves are present. They may indicate the rms values of voltages with little distortion but should not be relied upon for rms voltage measurements in magnetic test circuits. When flux is held closely sinusoidal, these probable errors can sometimes be ignored for rms voltage measurements at the lower inductions. However, the current waveform under these conditions always has too much distortion for proper use of one of these instruments as an rms ammeter.

6.6 *RMS Ammeter*—A true rms responsive meter shall be used to measure the rms exciting current for calculating exciting power or magnetizing force, H_z, for impedance permeability. This meter may be either an electronic or analog type. An analog instrument may be a moving iron-vane, thermal, or electrodynamometer type. Sufficient current ranges should be provided to cover the desired range of exciting currents. This meter shall have an accuracy of 1 % of full-scale indication or better. Its internal impedance should be less than 0.1 Ω for testing Category 1 cores. For Category 2 cores in