



Designation: A 697/A 697M – 03

Standard Test Method for Alternating Current Magnetic Properties of Laminated Core Specimen Using Voltmeter-Ammeter-Wattmeter Methods¹

This standard is issued under the fixed designation A 697/A 697M; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

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 A 34/A 34M and Terminology A 340. It depends upon these designated documents and a related reference test manual 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

A 34/A 34M Practice for Sampling and Procurement Testing of Magnetic Materials

A 340 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 A 340.

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].

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.

¹ This test method is under the jurisdiction of 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.

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 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 K Ω for low-voltage tests and 100 K Ω 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

TABLE 1 Test Coils for EI Laminations 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 | | Length Relative to w | Stack Height (h) | | Turns | N_1 | | | N_2 | | | N_3 | | |
| Width (w) | | | in. | cm | | Wire Size | Resistance, Ω | Turns | Wire Size | Resistance, Ω | Turns | Wire Size | Resistance, Ω | |
| in. | cm | | | | | | | | | | | | | |
| 3/8 | 0.9525 | 1.5w | 3/4 | 1.905 | 1000 | 35 | 84.3 | 1000 | 35 | 103.8 | 64 | 34 | 2.84 | |
| 1/2 | 1.270 | 1.5w | 1 | 2.540 | 800 | 34 | 68.3 | 800 | 34 | 80.7 | 72 | 34 | 4.00 | |
| 5/8 | 1.588 | 1.5w | 7/8 | 2.222 | 800 | 33 | 56.6 | 800 | 33 | 67.8 | 83 | 34 | 5.54 | |
| 3/4 | 1.905 | 1.5w | 3/4 | 1.905 | 800 | 31 | 36.6 | 800 | 31 | 43.5 | 100 | 34 | 7.77 | |
| 7/8 | 2.222 | 1.5w | 7/8 | 2.222 | 588 | 28 | 15.4 | 588 | 28 | 18.1 | 116 | 34 | 9.86 | |
| 15/16 | 2.381 | 1.5w | 15/16 | 2.381 | 513 | 26 | 8.75 | 513 | 26 | 10.6 | 136 | 34 | 12.8 | |
| 1 | 2.540 | 1.5w | 1 | 2.540 | 450 | 25 | 6.02 | 450 | 25 | 7.44 | 133 | 34 | 13.3 | |
| 1 1/8 | 2.857 | 1.5w | 1 1/8 | 2.857 | 356 | 24 | 4.45 | 356 | 24 | 5.37 | 150 | 34 | 16.7 | |
| 1 1/4 | 3.175 | 1.5w | 1 1/4 | 3.175 | 288 | 22 | 2.43 | 288 | 22 | 2.92 | 167 | 34 | 20.4 | |
| 1 3/8 | 3.493 | 1.5w | 1 3/8 | 3.493 | 238 | 20 | 1.43 | 238 | 20 | 1.75 | 183 | 34 | 24.3 | |
| 1 1/2 | 3.810 | 1.5w | 1 1/2 | 3.810 | 200 | 18 | 0.82 | 200 | 18 | 0.98 | 200 | 34 | 28.8 | |
| 1 5/8 | 4.127 | 1.5w | 1 5/8 | 4.127 | 170 | 14 | 0.35 | 170 | 14 | 0.46 | 245 | 34 | 38.0 | |
| 1 3/4 | 4.445 | 1.5w | 1 3/4 | 4.445 | 147 | 16 | 0.45 | 147 | 16 | 0.52 | 233 | 34 | 38.7 | |
| 2 1/8 | 5.397 | 1.5w | 2 1/8 | 5.397 | 100 | 12 | 0.16 | 100 | 12 | 0.20 | 283 | 34 | 56.6 | |
| 2 1/4 | 5.715 | 1.5w | 2 1/4 | 5.715 | 89 | 10 | 0.11 | 89 | 10 | 0.13 | 320 | 34 | 67.5 | |
| 2 1/2 | 6.350 | 1.5w | 2 1/2 | 6.350 | 72 | 10 | 0.10 | 72 | 10 | 0.11 | 333 | 34 | 73.9 | |
| 3 | 7.62 | 1.5w | 1 1/2 | 3.810 | 76 | 10 | 0.11 | 76 | 10 | 0.11 | 400 | 34 | 111.0 | |
| 4 | 10.16 | 1.5w | 2 | 5.080 | 57 | 10 | 0.09 | 57 | 10 | 0.10 | 534 | 34 | 148.0 | |

TABLE 2 Test Coils for *E*/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 (<i>w</i>) | | Length Relative to <i>w</i> | Stack Height (<i>h</i>) | | 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 <i>w</i> | 3/16 | 0.4763 | 722 | 36 | 24.2 | 32 | 30 | 0.37 | 36 | 34 | 0.997 |
| 1/4 | 0.635 | 1.5 <i>w</i> | 1/4 | 0.635 | 888 | 36 | 26.3 | 36 | 40 | 0.82 | 44 | 34 | 1.47 |
| 3/8 | 0.9525 | 1.5 <i>w</i> | 3/8 | 0.9525 | 1278 | 36 | 127.8 | 40 | 24 | 0.30 | 64 | 34 | 2.84 |
| 1/2 | 1.270 | 1.5 <i>w</i> | 1/2 | 1.270 | 1444 | 36 | 180.4 | 60 | 24 | 0.42 | 72 | 34 | 4.00 |
| 5/8 | 1.588 | 1.5 <i>w</i> | 5/8 | 1.588 | 1666 | 36 | 263.2 | 75 | 24 | 0.58 | 83 | 34 | 5.53 |
| 11/16 | 1.746 | 1.5 <i>w</i> | 11/16 | 1.746 | 1822 | 36 | 294.4 | 82 | 23 | 0.55 | 92 | 34 | 6.64 |
| 3/4 | 1.905 | 1.5 <i>w</i> | 3/4 | 1.905 | 2000 | 35 | 278.0 | 90 | 21 | 0.42 | 100 | 34 | 7.77 |
| 7/8 | 2.222 | 1.5 <i>w</i> | 7/8 | 2.222 | 2333 | 34 | 295.7 | 105 | 21 | 0.45 | 116 | 34 | 10.3 |
| 15/16 | 2.381 | 1.5 <i>w</i> | 15/16 | 2.381 | 2711 | 34 | 374.6 | 122 | 20 | 0.55 | 136 | 34 | 12.8 |
| 1 | 2.540 | 1.5 <i>w</i> | 1 | 2.540 | 2666 | 34 | 373.9 | 120 | 20 | 0.55 | 133 | 34 | 13.3 |

TABLE 3 Test Coils for *E*/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 (<i>w</i>) | | Length Relative to <i>w</i> | Stack Height (<i>h</i>) | | Turns | Wire Size | Resistance, Ω | Turns | Wire Size | Resistance, Ω | Turns | Wire Size | Resistance, Ω | $G = A_s/A_\Omega$ |
| in. | cm | | in. | cm | | | | | | | | | | |
| 3/8 | 0.9525 | 1.5 <i>w</i> | 3/8 | 0.9525 | 458 | 33 | 19.06 | 458 | 33 | 24.2 | 64 | 34 | 2.84 | 1.308 |
| 1/2 | 1.270 | 1.5 <i>w</i> | 1/2 | 1.270 | 262 | 30 | 6.46 | 262 | 30 | 7.68 | 72 | 34 | 4.00 | 1.327 |
| 5/8 | 1.588 | 1.5 <i>w</i> | 5/8 | 1.588 | 162 | 27 | 2.37 | 162 | 27 | 2.74 | 83 | 34 | 5.52 | 1.329 |
| 3/4 | 1.905 | 1.5 <i>w</i> | 3/4 | 1.905 | 134 | 24 | 1.16 | 134 | 24 | 1.38 | 100 | 34 | 7.77 | 2.519 |
| 7/8 | 2.222 | 1.5 <i>w</i> | 7/8 | 2.222 | 82 | 20 | 0.34 | 82 | 20 | 0.40 | 116 | 34 | 10.3 | 3.407 |
| 1 | 2.540 | 1.5 <i>w</i> | 1 | 2.540 | 62 | 20 | 0.29 | 62 | 20 | 0.32 | 133 | 34 | 13.3 | 4.425 |

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 electro-dynamometer 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 which the test coil resistance is already high, the ammeter's input resistance may be higher (Note 2). A true rms responsive voltmeter (Note 1) of suitable accuracy connected across an ammeter shunt resistor provides an rms ammeter having an adequate range and ability of adjustment.

NOTE 2—At any test induction the voltage drop across the rms ammeter (or shunt resistor) should be less than 1 % of the voltage across the test coil primary windings.

6.7 *Ammeter Shunt Resistor, R_1* —This is a high quality resistor that is placed in series with the primary test winding and shall carry the full primary exciting current. A voltmeter across its terminal completes an ammeter.

6.7.1 This resistor should have an accuracy of at least 0.1 % and should have a very low-temperature coefficient so that its errors do not appreciably increase the overall ammeter errors.

6.7.2 When testing larger Category 1 (power size) cores at high inductions this resistor may carry several amperes and the power dissipation capabilities should be such that the maximum primary current will not result in destructive heating or loss of specified accuracy as a result of self heating.

6.7.3 For smaller cores tested at low or moderate inductions, the power dissipation capabilities may be as low as 5 W without causing errors as a result of self heating.

6.8 *Tapped Transformer*—This transformer shall be capable of supplying sufficient current and voltage for the excitation of all common Category 1 (power size) laminations. Its core should consist of high-quality silicon iron laminations and be designed to operate at inductions of 12 kG or below and should be able to handle 750 to 1000 VA when operating at a primary voltage of 115 V and 60 Hz. For convenience, it should have taps at 50, 75, 100, and 125 V. Lower voltage taps may also be useful.

6.9 *Variable Transformer or Autotransformer*—For tests of larger Category 1 cores, the variable transformer or autotransformer should have a rating of 1 or 1.5 kVA. For Category 2 or smaller Category 1 cores it is often desirable to use a smaller variable transformer because it may provide smaller steps of voltage adjustment.

6.10 *Choke Coil*—This is a high-inductance choke coil having an air gap to prevent magnetic saturation. It shall have a wire size sufficiently large to handle the dc incremental currents and a core size and number of turns that provide sufficient inductance to meet the requirements of 9.5.7.

6.11 *Power Source*—To provide satisfactory voltage stability it is recommended that a 1-kVA constant voltage transformer of good quality be used. It shall have voltage regulation of at least 1 % and harmonic correction or filtering to provide a voltage waveform which has 3 % or less harmonic distortion. For more precise testing, both voltage regulation and harmonic distortion should be no larger than 0.1 %.

NOTE 3—Test power may alternatively be supplied by an electronic source of sinusoidal test power that is characterized by low internal impedance and excellent voltage and frequency stability. Voltage stability within 0.1 % and frequency accuracy within 0.1 % should be maintained. The tapped transformer and variable transformer may not be needed when such test power sources are used. Electronic power sources using negative feedback from the secondary winding of the test fixture to reduce flux waveform distortion may be used.

6.12 *Wattmeter*—An electronic wattmeter with appropriate voltage, current, and frequency ratings is the preferred instrument. The voltage circuit shall be capable of accepting the maximum peak voltage that is induced in the secondary winding during testing. The current input circuitry shall be capable of handling the maximum rms current and the maximum peak current drawn by the primary winding of the test fixture when core loss tests are being performed. The wattmeter shall be capable of accurate measurements at all frequencies of interest and at low-power factors.

Alternatively, a direct reading low-power factor electrodynamic wattmeter of high sensitivity may be used. For general testing the resistance of the potential circuit of this

instrument should not be less than 100 Ω/V of full-scale potential-circuit voltage rating. The inductance of the potential-circuit coil should be such that the inductive reactance at the test frequency will not exceed 1 Ω per 1000 Ω of resistance of this circuit unless the potential circuit is compensated for its reactance.

7. Test Specimen

7.1 The test specimen may consist of any size lamination described in Table 4. It shall be composed of sufficient laminations to provide a lamination stack having a square cross section in the leg which is to be surrounded by the test winding (lamination stack height equal to center leg width).

7.2 If the test specimen consists of *EI*, *UI*, *EE*, or other two-piece laminations, there shall be equal numbers of both types in the test specimen. If it consists of an *F* type or other one-piece lamination, there shall be an even number of laminations in the test specimen.

8. Test Specimen Preparation

8.1 Check the specimen before test to see that it contains no dented or bent pieces and that the laminations are reasonably flat, without noticeable curvature.

8.2 Weigh the part of the test specimen upon which calculations are based with a balance of sufficient sensitivity and accuracy to determine the specimen mass to an accuracy of 0.1 %. This eliminates the mass as a source of testing error and assures that any rounding of test specimen mass will be in the correct direction.

8.3 When correlations are to be obtained between the properties of the lamination stack and the properties of the magnetic material of which it is composed, the laminations shall have a proper stress-relieving anneal after punching and before test.

8.4 The laminations shall be assembled into the test coils by alternatively interleaving the joints (Note 4) *one by one* unless otherwise agreed upon between the producer and the user. Take care to have all burrs the same direction, for example, burrs *up* on both *Es* and *Is* (or other shapes). One method of stacking is to set equal height piles of *Es* and *Is* on either side of the coil with its cover plate inverted. (The test fixture is described in Appendix X2.) Beginning with the left hand pick up an *E*, insert it, repeat with right hand. Simultaneously use other hand to place an *I*. Keep *Es* and *Is* from butting as the whole stack can be butted closely afterwards. Continue stacking *Es* and *Is* until desired stack height is reached. Insert final missing *I* at bottom. Butt pile, invert, and place into stand.

NOTE 4—Care should be exercised in stacking the core to avoid bending any of the laminations beyond their elastic limit or otherwise damaging them unduly.

8.5 The winding forms for the test coils shall provide a clearance of $\frac{1}{32}$ in. [0.8 mm] over the lamination stack width to prevent binding and permit ease of stacking the laminations during assembly. This also provides freedom of lamination movement to facilitate good joint alignment after the coils are energized before and during test.

8.6 When making measurements the test specimen and coil assembly shall be held loosely in a test fixture similar to that of

TABLE 4 Dimensional Characteristics of EI Lamination Stacks

| Lamination | | | E Lamination Only | | | | | | EI Combined | | | |
|------------|------------------|---------------|-------------------|--------|--------------------------|---------------------------------|-----------------|------------------------------------|-----------------|--------------------------------|-------|------------------------|
| Size | Special Features | Computer Code | Center Leg | | | One Side Surface Area (A_s) | | One Side Surface Area (A_{ss}) | | Magnetic Path Length (l_1) | | Ratio $G = A_{ss}/A_s$ |
| | | | Width (w) | | Length Relative to Width | in. ² | cm ² | in. ² | cm ² | in. | cm | |
| | | | in. | cm | | | | | | | | |
| EI-18 | SHT | ... | 3/16 | 0.4761 | ... | 0.1985 | 1.281 | 0.2680 | 1.729 | ... | ... | 1.350 |
| EI-18 | H | ... | 3/16 | 0.4761 | ... | 0.2336 | 1.507 | 0.3031 | 1.956 | ... | ... | 1.298 |
| EI-18 | NO | 0018 | 3/16 | 0.4761 | 1.5w | 0.2344 | 1.512 | 0.2947 | 1.901 | 1.625 | 4.127 | 1.300 |
| EI-25 | ... | 0025 | 1/4 | 0.6350 | 1.5w | 0.3733 | 2.409 | 0.4965 | 3.203 | 2.000 | 5.080 | 1.330 |
| EI- | ... | ... | 1/4 | 0.6350 | ... | 0.3750 | 2.420 | 0.5000 | 3.226 | ... | ... | 1.333 |
| EI-31 | ... | 0031 | 5/16 | 0.7938 | 1.5w | 0.6962 | 4.492 | 0.9042 | 5.834 | 2.937 | 7.460 | 1.299 |
| EI-37 | ... | 0037 | 3/8 | 0.9525 | 1.5w | 0.8134 | 5.248 | 1.064 | 6.865 | 2.875 | 7.302 | 1.308 |
| EI-50 | ... | 0050 | 1/2 | 1.270 | 1.5w | 1.206 | 7.781 | 1.600 | 10.32 | 3.250 | 8.255 | 1.327 |
| EI-62 | ... | 0062 | 5/8 | 1.588 | 1.5w | 1.746 | 11.27 | 2.319 | 14.96 | 3.750 | 9.525 | 1.329 |
| EI-62 | LH | 0063 | 5/8 | 1.588 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-68 | ... | 0068 | 11/16 | 1.746 | 1.5w | 2.115 | 13.65 | 2.811 | 18.14 | 4.125 | 10.48 | 1.329 |
| EI-75 | VOP | 0074 | 3/4 | 1.905 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-75 | Std. | 0075 | 3/4 | 1.905 | 1.5w | 2.519 | 16.25 | 3.350 | 21.61 | 4.500 | 11.43 | 1.330 |
| EI-75 | S | 0076 | 3/4 | 1.905 | ... | 2.473 | 15.96 | 3.260 | 21.03 | ... | ... | 1.318 |
| EI-75 | H2L | 0077 | 3/4 | 1.905 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-75 | H2L | 0078 | 3/4 | 1.905 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-75 | H4 | 0079 | 3/4 | 1.905 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-87 | H | 0087 | 7/8 | 2.222 | 1.5w | 3.407 | 21.98 | 4.517 | 29.14 | 5.250 | 13.34 | 1.326 |
| EI-87 | HS | 0088 | 7/8 | 2.222 | ... | 3.355 | 21.65 | 4.416 | 28.49 | ... | ... | 1.317 |
| EI-87 | RH | 0089 | 7/8 | 2.222 | ... | 3.407 | 21.98 | 4.517 | 29.14 | ... | ... | 1.326 |
| EI-93 | ... | 0092 | 15/16 | 2.381 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-93 | H | 0093 | 15/16 | 2.381 | 1.5w | 4.261 | 27.49 | 5.502 | 35.50 | 6.125 | 15.56 | 1.312 |
| EI-93 | HS | 0094 | 15/16 | 2.381 | ... | 4.204 | 27.12 | 5.479 | 35.35 | ... | ... | 1.303 |
| EI-93 | H6 | 0095 | 15/16 | 2.381 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-100 | H | 0100 | 1 | 2.540 | 1.5w | 4.425 | 28.55 | 5.850 | 37.74 | 6.000 | 15.24 | 1.322 |
| EI-100 | RH | 0102 | 1 | 2.540 | ... | 4.425 | 28.55 | 5.850 | 37.74 | ... | ... | 1.322 |
| EI-100 | HS | 0101 | 1 | 2.540 | ... | 4.366 | 28.17 | 5.735 | 37.00 | ... | ... | 1.313 |
| EI-100 | RHS | 0103 | 1 | 2.540 | ... | 4.366 | 28.17 | 5.735 | 37.00 | ... | ... | 1.313 |
| EI-112 | H | 0112 | 1 1/8 | 2.857 | 1.5w | 5.620 | 36.25 | 7.443 | 48.02 | 6.750 | 17.15 | 1.324 |
| EI-112 | RH | 0114 | 1 1/8 | 2.857 | ... | 5.620 | 36.26 | 7.443 | 48.02 | ... | ... | 1.324 |
| EI-112 | HS | 0113 | 1 1/8 | 2.857 | ... | 5.555 | 35.84 | 7.315 | 47.20 | ... | ... | 1.317 |
| EI-112 | RHS | 0115 | 1 1/8 | 2.857 | ... | 5.555 | 35.84 | 7.315 | 47.20 | ... | ... | 1.317 |
| EI-125 | H | 0125 | 1 1/4 | 3.175 | 1.5w | 6.956 | 44.88 | 9.225 | 59.52 | 7.500 | 19.05 | 1.326 |
| EI-125 | RH | 0127 | 1 1/4 | 3.175 | ... | 6.956 | 44.88 | 9.225 | 59.52 | ... | ... | 1.326 |
| EI-125 | HS | 0126 | 1 1/4 | 3.175 | ... | 6.891 | 44.46 | 9.096 | 58.69 | ... | ... | 1.320 |
| EI-125 | RHS | 0128 | 1 1/4 | 3.175 | ... | 6.891 | 44.46 | 9.096 | 58.69 | ... | ... | 1.320 |
| EI-125 | H6 | 0129 | 1 1/4 | 3.175 | ... | ... | ... | ... | ... | ... | ... | ... |
| EI-137 | H | 0136 | 1 3/8 | 3.493 | ... | 8.433 | 54.41 | 11.19 | 72.20 | ... | ... | 1.327 |
| EI-137 | HS | 0137 | 1 3/8 | 3.493 | 1.5w | 8.343 | 53.83 | 11.02 | 71.10 | 8.250 | 20.06 | 1.320 |
| EI-137 | RH | 0138 | 1 3/8 | 3.493 | ... | 8.433 | 54.41 | 11.19 | 72.20 | ... | ... | 1.327 |
| EI-137 | RHS | 0139 | 1 3/8 | 3.493 | ... | 8.343 | 53.83 | 11.02 | 71.10 | ... | ... | 1.320 |
| EI-140 | RH | 0140 | 1 3/8 | 3.493 | 1.5w | 9.206 | 59.40 | 12.22 | 78.84 | 9.000 | 22.86 | 1.328 |
| EI-137 | RH6 | 0141 | 1 3/8 | 3.493 | 1.5w | 8.395 | 54.16 | 11.12 | 71.75 | 9.000 | 22.86 | 1.324 |
| EI-150 | H | 0150 | 1 1/2 | 3.810 | 1.5w | 10.05 | 64.84 | 13.35 | 86.13 | 9.000 | 22.86 | 1.328 |
| EI-150 | HS | 0151 | 1 1/2 | 3.810 | ... | 9.952 | 64.21 | 13.16 | 84.91 | ... | ... | 1.322 |
| EI-150 | RH | 0152 | 1 1/2 | 3.810 | ... | 10.05 | 64.84 | 13.35 | 86.13 | ... | ... | 1.328 |
| EI-150 | RHS | 0153 | 1 1/2 | 3.810 | ... | 9.952 | 64.21 | 13.16 | 84.91 | ... | ... | 1.322 |
| EI-150 | LH | 0154 | 1 1/2 | 3.810 | ... | 17.92 | 115.6 | 22.35 | 144.2 | ... | ... | 1.247 |
| EI-162 | H | 0162 | 1 5/8 | 4.127 | 1.5w | 13.13 | 84.71 | 17.72 | 114.3 | 11.00 | 27.94 | 1.350 |
| EI-162 | HS | 0163 | 1 5/8 | 4.127 | ... | 12.99 | 83.81 | 17.45 | 112.6 | ... | ... | 1.343 |
| EI-175 | H | 0175 | 1 3/4 | 4.445 | 1.5w | 13.66 | 88.13 | 18.13 | 117.0 | 10.50 | 26.67 | 1.327 |
| EI-175 | HS | 0176 | 1 3/4 | 4.445 | ... | 13.62 | 87.88 | 18.06 | 116.5 | ... | ... | 1.326 |
| EI-175 | RH | 0177 | 1 3/4 | 4.445 | ... | 13.66 | 88.13 | 18.13 | 117.0 | ... | ... | 1.327 |
| EI-175 | H6 | 0179 | 1 3/4 | 4.445 | ... | 13.56 | 87.49 | 17.94 | 115.7 | ... | ... | 1.323 |
| EI-19 | H | 0190 | 1 3/4 | 4.445 | 1.5w | 16.51 | 106.5 | 22.53 | 145.4 | 13.00 | 33.02 | 1.364 |
| EI-212 | H | 0212 | 2 1/8 | 5.397 | 1.5w | 20.15 | 130.0 | 26.76 | 172.7 | 12.75 | 32.39 | 1.328 |
| EI-225 | S | 0221 | 2 1/4 | 5.715 | 1.5w | 24.81 | 160.1 | 33.52 | 216.3 | 14.38 | 36.51 | 1.351 |
| EI-225 | RH | 0225 | 2 1/4 | 5.715 | 1.5w | 22.63 | 146.0 | 30.07 | 194.0 | 13.50 | 34.29 | 1.329 |
| EI-225 | L | 0230 | 2 1/4 | 5.715 | 1.5w | 40.82 | 263.4 | 49.52 | 319.5 | 21.38 | 54.29 | 1.213 |
| EI-250 | R4N | 0249 | 2 1/2 | 6.350 | ... | 27.89 | 179.9 | 37.02 | 238.9 | ... | ... | 1.328 |
| EI-250 | R6N | 0250 | 2 1/2 | 6.350 | 1.5w | 27.77 | 179.2 | 36.78 | 237.3 | 15.00 | 38.10 | 1.325 |
| EI-250 | R6W | 0251 | 2 1/2 | 6.350 | 1.5w | 38.42 | 247.9 | 49.34 | 318.3 | 20.00 | 50.80 | 1.284 |
| EI-3 | RH1 | 0300 | 3 | 7.620 | 1.5w | 40.28 | 259.9 | 53.56 | 345.6 | 18.00 | 45.72 | 1.330 |
| EI-3 | RH2 | 0301 | 3 | 7.620 | ... | 40.28 | 259.9 | 53.56 | 345.6 | ... | ... | 1.330 |
| EI-3 | H4 | 6300 | 3 | 7.620 | ... | 40.39 | 260.6 | 53.78 | 344.0 | ... | ... | 1.332 |
| EI-4 | R6 | 0400 | 4 | 10.16 | 1.5w | 71.61 | 462.0 | 95.22 | 614.4 | 24.00 | 60.96 | 1.330 |

Appendix X2 which permits the proper alignment of the joints by forces of magnetic attraction developed when the core is energized to high inductions. Bolting or clamping of the test specimen should be avoided as this introduces variation which is not reproducible. The cover plate (*D*) shown in the test fixture described in Appendix X2 should be used to provide a mild top pressure.

9. Procedure

9.1 *Preliminary Procedures*—Examine the test specimen for damage or improper preparation.

9.1.1 Select the proper number of laminations (Section 7) to form the test specimen.

9.1.2 Then weigh the portion of the test specimen that is to be used in the calculation of cross-sectional area in accordance with 8.2.

9.1.3 Then stack the test specimen (see 8.4) into a test coil of suitable size and number of turns appropriate for use in conducting the desired tests.

NOTE 5—The number and type of tests desired, as well as available equipment, may influence the test coil selection. For these reasons the coil selected shall be a matter of agreement between the producer and the user.

9.1.4 Assemble the stacked test specimen and coil into the test jig as shown in Appendix X2 and connect into the appropriate test equipment of Fig. 1 or Fig. 2.

9.2 *Procedures for Core-Loss Measurements:*

9.2.1 Connect the equipment as shown in Fig. 1 (see Note 6). Unless otherwise specified, the test coil shall be one of those of Table 1 for Category 1 cores.

NOTE 6—Switches *S1* through *S6* may be omitted if impedances of measurement instruments are such as to cause negligible error in results.

9.2.2 Determine the flux voltages induced in the secondary winding, N_2 , at the desired test inductions.

9.2.3 Open switches *S4* and *S5* and close switches *S3*, *S6*, *S1*, and *S2*. Set *S8* to the lowest tap that permits excitation of the test specimen to an induction level of 15 kG (1.5 T). Set and maintain an induction of approximately 15 kG in the test specimen while tapping the edges of the stack with a small, soft-surfaced mallet. Observe the reading on the ammeter that measures primary current and continue tapping until the current reaches a minimum value. This procedure reduces the air gaps to a minimum value.

9.2.4 Demagnetize the specimen by slowly reducing the excitation from the lowest level of 9.2.3 to the lowest setting of the variable transformer or autotransformer. This shall be accomplished with a steady uniform motion, free of hesitations

or reversals. Randomly variable contacts tend to generate magnetizing force transients which may degrade the quality of the demagnetization.

9.2.5 With *S6* open and *S4* and *S5* closed, set the flux voltage, E_f to the value corresponding to the lowest induction at which core losses are to be measured. Then read the wattmeter and record the power reading for that induction. In ascending order of inductions, repeat the measurement procedure for other inductions.

9.3 *Procedures for RMS Excitation and RMS Exciting Power:*

9.3.1 The equipment and test coil are connected as for core loss in 9.2.1.

9.3.2 Determine the flux voltages induced in the secondary winding, N_2 , at the desired test inductions.

9.3.3 Open switches *S4* and *S5* and close switches *S3*, *S6*, *S1*, and *S2* as for core loss in 9.2.3. Then demagnetize the test specimen using the procedure described in 9.2.3 and 9.2.4.

9.3.4 With *S3* and *S4* open and *S6*, *S1*, and *S2* closed, set the flux voltage to the value corresponding to the lowest desired test induction. Then open *S2* and quickly read and record the rms voltage. Close *S2* to check the induction setting; then open both *S5* and *S2* and quickly read and record the value of rms current. In ascending order of inductions, repeat the measurement procedure for other inductions.

9.4 *Procedures for Apparent ac Magnetizing Force, H_p , and Impedance Permeability, μ_r :*

9.4.1 For this measurement, the equipment is usually connected as shown in Fig. 2 and, unless otherwise specified, the test coil shall be one of those of Table 2 for Category 2 cores.

9.4.2 Determine the flux voltages induced in the secondary winding, N_2 , at the desired test inductions.

9.4.3 Close switch *S1* and set *S8* to the lowest tap which permits excitation of the test specimen to an induction level of 15 kG [1.5 T]. Set and maintain an induction of approximately 15 kG in the test specimen while tapping the edges of the stack with a small, soft-surfaced mallet. Observe the reading on the ammeter that measures primary current and continue tapping until the current reaches a minimum value. This procedure reduces the air gaps to a minimum value.

9.4.4 Observing the precautions of 9.2.4, demagnetize the test specimen by slowly and uniformly reducing the excitation to a zero field level.

9.4.5 With *S1* open and *S2* set to connect the flux voltmeter, V_f to the secondary winding, N_2 , set the flux voltage to the value corresponding to the lowest test induction. Then open *S2* and quickly read and record the value of the rms voltage drop

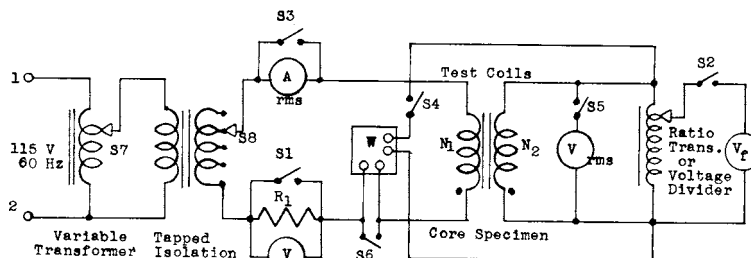


FIG. 1 Basic Circuit for the Measurement of Core Loss and Exciting Volt Amperes