Designation: A598/A598M – 02 (Reapproved 2015)

Standard Test Method for
Magnetic Properties of Magnetic Amplifier Cores[1]

This standard is issued under the fixed designation A598/A598M; 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 the magnetic performance of fully processed cores for magnetic amplifier-type applications.

1.2 Tests may be conducted at excitation frequencies of 60, 400, 1600 Hz, or higher frequencies.

1.3 Permissible core sizes for this test method are limited only by the available power supplies and the range and sensitivity of the instrumentation.

1.4 At specified values of full-wave sinusoidal-current excitation, H_{max}, this test method provides procedures of determining the corresponding value of maximum induction, B_{max}.

1.5 At specified values of half-wave sinusoidal-current excitation, this test method provides procedures for determining the residual induction, B_r.

1.6 At increased specified values of half-wave sinusoidal-current excitation, this test method provides procedures for determining the dc reverse biasing magnetic field strength, H_1, required to reset the induction in the core material past B_r to a value where the total induction change, ΔB_1, becomes approximately one third of the induction change, $2 B_p$. It also provides procedures for determining the additional dc reset magnetic field strength, ΔH, which, combined with H_1, is the value required to reset the induction in the core material past B_r to a value where the total induction change, ΔB_2, becomes approximately two thirds of the induction change $2 B_p$.

1.7 This test method specifies procedures for determining core gain from the corresponding biasing and induction changes, ΔH and ΔB.

1.8 This test method covers test procedures and requirements for evaluation of finished cores which are to be used in magnetic-amplifier-type applications. It is not a test for basic-material magnetic properties.

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

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

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

1.12 *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

A596/A596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens

3. Terminology

3.1 *Definitions*—Below is a list of symbols and definitions as used in this test method. The official list of symbols and definitions may be found in Terminology A340. (See Table 1 where indicated).

3.2 *Symbols:*

TABLE 1 Standard Values of ΔB, ΔB₁, and ΔB₂ for the Commonly Used Materials

Core Material [A]	ΔB_1 (for Test of 10.5)		ΔB_2 (for Test of 10.4)		ΔB or $(\Delta B_2 - \Delta B_1)$	
	kG	Tesla	kG	Tesla	kG	Tesla
Supermendur	14	1.4	28	2.8	14	1.4
Oriented silicon-iron	10	1.0	20	2.0	10	1.0
50 % nickel-iron:						
Oriented	10	1.0	20	2.0	10	1.0
Nonoriented	8	0.8	16	1.6	8	0.8
79 % nickel-iron	5	0.5	10	1.0	5	0.5
Supermalloy	5	0.5	10	1.0	5	0.5

[A] Values for other materials may be used by mutual agreement between seller and purchaser.

A	= cross-sectional area of test specimen core material, cm² [m²].		N_1	= test winding primary, ac excitation winding, turns.
A_1	= ac ammeter for primary circuit, half-wave, average-responsive, A.		N_2	= test winding primary, dc H_1 biasing winding, turns.
A_2	= dc ammeter for H_1 biasing winding, A.		N_3	= test winding primary, dc H_2 biasing winding, turns.
A_3	= dc ammeter for H_2 biasing winding, A.		N_4	= test winding secondary, Δ B pickup winding, turns.
A_4	= dc milliammeter for ac voltage calibrator, V.		SCM	= symmetrical cyclic magnetization (see Terminology A340).

$B_{max} - B_r$ = change in test specimen induction, under half-wave sinusoidal-current excitation specified for this measurement.

B_m = maximum induction in a sine-current SCM ac flux-current loop Gauss [Tesla] (Note 1).

B_p = maximum value of induction in the sine-current half-wave CM flux-current loop, for the reset test Gauss [Tesla] (Note 1).

B_r = residual induction in an ac sine-current flux-current loop Gauss [Tesla].

ΔB = change in magnetic induction Gauss [Tesla] (Table 1).

ΔB_1 = change in induction in the flux-current loop during H_1 test Gauss [Tesla] (Table 1).

ΔB_2 = change of induction in the flux current loop during H_2 test Gauss [Tesla] (Table 1).

CM = cyclic magnetization (see Terminology A340).

D_1 and D_2 = solid state diodes or other rectifiers.

D_3 to D_6 = silicon diodes.

d = lamination thickness, cm [m].

E_{avg} = average value of voltage waveform, V.

f = frequency of test, Hz.

G = core gain $\Delta B_2 - B_1/H_2, - H_1$,

$$\frac{Gauss}{Oe}\left[\frac{T}{A/m}\right].$$

H_c = coercive field strength in an SCM flux-current loop Oe [A/m].

H_{max} = maximum magnetic field strength in a sine-current SCM ac flux-current loop, Oe [A/m] (Note 1).

H_p = maximum value of the sine-current ac magnetic field strength for the CM reset tests, Oe [A/m] (Note 1).

H_1 = dc biasing (reset) magnetic field strength for the H_1 test point, Oe [A/m].

H_2 = dc biasing (reset) magnetic field strength for the H_2 test point, Oe [A/m].

ΔH = change in dc biasing (reset) magnetic field strength, Oe [A/m].

NOTE 1—Note that H_{max} and B_{max}, as used in this test method, are maximum points on the sine-current SCM or corresponding half-wave CM flux-current loops. Also, that H_p and B_p are maximum points on a CM flux-current loop corresponding to the ac half-wave sine current which is established in the exciting winding, N_1, and held constant, during the dc current measurements for H_1, H_2, or ΔH. These definitions are different from those used for these symbols in Terminology A340 for use with dc or sinusoidal-flux ac measurements.

4. Summary of Test Method

4.1 This test method uses the procedures commonly referred to as the "Constant Current Flux Reset Test Method" (C.C.F.R.). For graphic representation of the magnetic amplifier core test see Appendix X3.

4.2 Under its provision, a specific predetermined value of sinusoidal-current excitation, H_{max}, (Table 2) is established and the corresponding induction change is measured to determine the value of maximum induction which is then designated B_{max}.

4.3 The excitation is then changed to a unidirectional half-wave sinusoidal current of the same magnitude as that used for determining maximum induction. The change in induction under this excitation then is measured to determine the property designated $(B_{max} - B_r)$, or the change between the maximum and residual values of induction.

4.4 The ac half-wave sinusoidal-current excitation, as measured in the ac exciting winding, is then increased to a new value, designated H_p (Table 2), which causes the ac induction in the test specimen to rise to a new value which is designated B_p. A dc reverse-polarity magnetic field strength is then applied. The opposing dc magnetic field strength resets the flux or induction in the core material, between each half cycle of ac magnetization, to a value that provides the specified ΔB_1 induction change (Table 1). This dc excitation, designated H_1, is the value required to reset past B_r to a point that provides the specified change in induction of ΔB_1 which is approximately

TABLE 2 Standard Values of Peak Sine Current Magnetic Field Strength to Be Established for Testing the Commonly Used Materials

Core Material [A]	Full-Wave SCM Value of H_{max}, (for Measurement of B_{max} in Test of 10.2)		Half-Wave CM Value of H_{max}, (for Measurement of $B_{max} - B_r$ in Test of 10.3)		Half-Wave CM Value of H_p, (for Determining H_1 and H_2 or ΔH in Testing of 10.4 and 10.5 and adjustments of 10.1)	
	Oe	A/m	Oe	A/m	Oe	A/m
Supermendur	3	240	3	240	6	480
Oriented silicon-iron	3	240	3	240	6	480
50 % nickel-iron	1	80	1	80	2	160
79 % nickel-iron	0.5	40	0.5	40	1	80
Supermalloy	0.25	20	0.25	20	0.5	40

[A] Values for other materials may be used by mutual agreement between seller and purchaser.

equal to one third of 2 B_p. This value of H_1 has some correlation to the coercive field strength, H_c, of the material.

4.5 Holding the same increased value of ac half-wave sinusoidal-current excitation, as described in 4.4, the dc reverse-polarity excitation is increased by the amount ΔH and the total value of dc reverse biasing $(H_1 + \Delta H)$ is designated H_2. It is the value of dc reverse biasing required to reset the flux between ac magnetizing cycles to a value which provides the specified total change in induction of ΔB_2 (Table 1) that is approximately equal to two thirds of 2 B_p.

4.6 From the change in dc bias ΔH and the changes in induction ΔB corresponding to the change between the H_1 and H_2 operating points, the core gain may be determined. It is usually reported as a ΔH value for the core. When required for special reasons, it may be reported in terms of core gain, G (see 11.5).

4.7 It is standard practice to assign values to the change of induction ΔB_1 and ΔB_2 (Table 1). This in turn determines the magnitude of the H_1 and H_2 biasing values corresponding to these changes of induction.

4.8 The normal test specimen may have any size or shape. When used specifically to evaluate materials for core construction, it is limited in size, weight, and method of manufacture.

4.9 Heat treatment appropriate to the core material and core construction may be required before test.

5. Significance and Use

5.1 The method of excitation simulates, to a practical degree, the operation of a magnetic core in a self-saturating magnetic amplifier. The properties measured are related to the quality of performance of the cores in magnetic amplifiers and are useful for the specification of materials for such cores.

6. Apparatus (see Fig. 1)

6.1 *Sinusoidal Voltage Supply*—The source of excitation shall be an ac source of sinusoidal voltage which shall have sufficient power to magnetize the largest core to be examined to the levels of excitation as specified in Table 2. Its harmonic distortion under load shall be less than 3 %. Its frequency should be constant to within 1 % or less. Standard test frequencies are 60, 400, and 1600 Hz.

6.2 *Series Impedance, Z_1, or Resistor, R_1*—This impedance should provide a voltage drop much larger than the voltage appearing across the excitation winding. Then, the distortion of current waveform as a result of the nonlinear impedance of the core will be minimized. It may be a power resistor for small size cores. For larger cores, a series resonant circuit may be used, which reduces the voltage requirements of the power
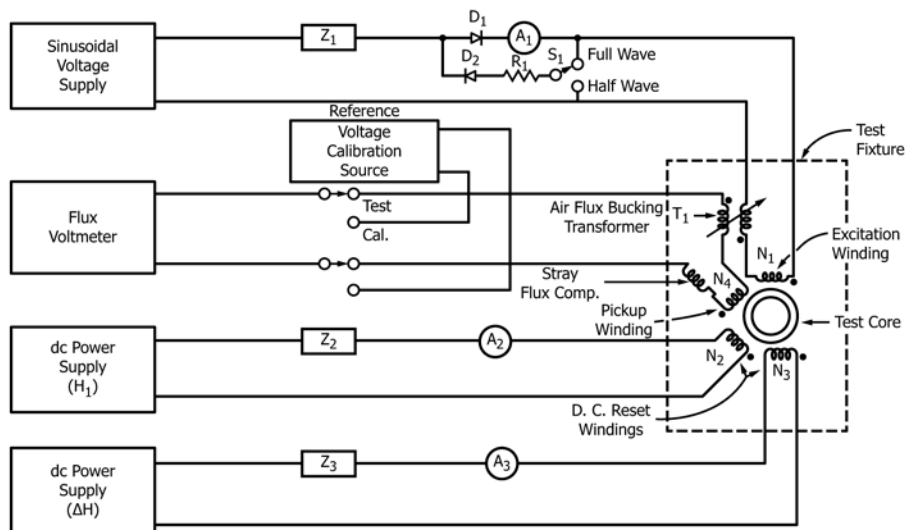

FIG. 1 Basic Diagram for Magnetic Amplifier Core Test

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source. The voltage across this impedance or a reactive element in Z_1 must be greater than 25 times the average voltage induced in the excitation turns, N_1.

6.3 *Diodes* (Note 2), D_1 and D_1 may be fast solid state devices (Note 3), high-vacuum rectifiers, or Schottky rectifiers.

NOTE 2—During the interval between half-wave pulses, when the excitation should be nominally zero, the average leakage current shall be less than 0.1 % of the peak value of excitation current during a pulse.

NOTE 3—In the case of solid-state devices, a capacitive charging pulse of reverse current is sometimes observed, particularly at the higher frequencies. Its integrated value, in ampere-seconds, at any test frequency shall be limited to 1.0 % of the ampere-seconds of the exciting half-wave.

6.4 The test fixture shall be composed of four sets of windings enclosing the core and a means of compensating for air-flux effect in induced voltage in N_4.

6.4.1 The exciting winding N_1 shall contain as small a number of turns as practical to limit the exciting-current waveform distortion (see 6.1).

6.4.2 The B-coil, pickup winding, N_4, may contain any convenient number of turns. This winding shall be maintained in a fixed position in relation to the excitation windings to eliminate variations in the air-cored inductive or capacitive coupling between them. Compensation for such coupling may be accomplished with the air-cored bucking transformer, T_1.

NOTE 4—The coils of the test fixture, including the air-cored bucking transformer, T_1, if used, shall be initially adjusted such that the voltage coupling between the exciting and pickup windings will be minimized when no specimen is in place, and maximum full-wave exciting current for a given-size core is applied. The cancellation will be considered adequate when the flux voltmeter indicates the equivalent of 15 G [0.0015 T] or less for that size core. The pickup circuit should be shielded from stray fields, when this cannot be accomplished an adjustable coil may be used to buck out voltages picked up from external fields (see 10.1).

6.4.3 The dc reset windings shall use a small number of turns to help minimize the ac transformer loading of the test core. The impedances, Z_2 and Z_3, described in 6.9 and 11.5 also help to limit this loading effect to acceptable values.

6.5 *Flux Voltmeter:*

6.5.1 The flux voltmeter must respond to the true average value of the pickup-winding voltage. The average value of the voltage waveform is directly proportional to the total change of magnetic flux in the core. The flux-voltmeter accuracy shall be 1 % or better.

NOTE 5—For medium- or small-size cores, the ordinary rectifier ac voltmeters are not sensitive enough to accurately measure $B_{max} - B_r$, and conventional average-responsive vacuum-tube voltmeters are subject to excessive errors as a result of the extremely peaked nature of the voltage waveform and to the high ratio of peak to average values. Therefore, special instruments must be used. Some typical schemes appear in Appendix X1.

6.5.2 The input impedance of the flux voltmeter as connected to the pickup winding of the core shall exceed the value of Z for any coil load as specified in 11.6.

6.6 *Calibration Source*—An adequate means shall be provided to calibrate the flux voltmeter. A source of accurately known ac voltage, or the output of a core whose saturation has been carefully measured by dc ballistic methods may be used. The reference voltage calibrator shown in Appendix X2 provides a suitable voltage source having a waveform approxi-

mating that of cores tested by this test method, with a test method for determining the average voltage (see 9.2).

6.7 *DC Power Supply for H_1*—This power supply shall provide sufficient voltage to overcome the voltage drop across impedance, Z_2, and sufficient current capacity to saturate any core to be tested. The rms value of the ac ripple of the dc power-supply voltage shall not exceed 0.25 % of the test voltage required under the conditions of maximum or minimum dc load currents.

6.8 *DC Power Supply for ΔH*—This power supply shall provide sufficient voltage to overcome the voltage drop of impedance, Z_3, and sufficient current capacity to provide ΔH for any core to be tested. Its rms ripple voltage shall not exceed 0.25 % of the test voltage required under the conditions of maximum or minimum dc load currents.

6.9 *AC Blocking Impedances, Z_2 and Z_3*—These impedances are dc current-passing elements that reduce the ac loading effects of the H_1 and ΔH windings and their dc power supplies to acceptable limits. Minimum values for impedances Z_2 or Z_3 may be calculated from the equation of 11.6.

6.10 *Ammeters:*

6.10.1 *Ammeter, A_1*—This ammeter is normally a dc instrument of the d'Arsonval indicating type or a dc digital voltmeter reading voltage across a precision resistor. It shall have a full-scale accuracy of at least ±1.0 % and shall be capable of calibration as a full-wave or half-wave peak-indicating ammeter.

6.10.2 *Ammeters, A_2 and A_3*—These instruments are dc ammeters or dc digital voltmeters reading voltages across precision resistors and must have a full-scale accuracy of at least ±0.5 %. For measurement of properties of very-high-gain cores, these ammeters must have an accuracy of at least ±0.25 % of full scale.

6.11 *Resistor, R_1*—This resistor compensates for the ammeter's impedance and nonequality of the two diodes. It is adjusted to provide equal values of crest current, in the two half waves, when full-wave excitation is being used.

6.12 *Switch, S_1*—This switch provides means for applying either full- or half-wave excitation to the core while maintaining full-wave loading on the power source.

7. Sampling

7.1 Unless otherwise agreed upon, test specimens that represent a lot or more than one core shall be selected in accordance with Practice A34/A34M.

8. Test Specimen

8.1 The test specimen may be a core or lamination stack of any size or shape which has been designated for use in magnetic-amplifier applications.

9. Calibration of Test Equipment

9.1 The individual instruments used to measure the three excitation currents must be calibrated against suitable dc reference standards according to good laboratory practice.

9.1.1 Ammeter A_1, used to measure the full-wave and half-wave ac magnetizing currents, is an average-responsive

ammeter connected in such a manner that for both measurements it sees only the positive unidirectional half-cycle current wave trains. This dc instrument is calibrated to indicate the average value of the ac half-wave where $I_{dc} = I_{avg}$, and the peak of the current wave trains is obtained as follows:

$$I_p = \pi I_{avg}$$

where:

I_p = peak value of half-wave ac exciting current, A and
I_{avg} = average value of ac half-wave exciting current, A.

9.1.2 Ammeters A_2 and A_3 are dc instruments used to measure direct current. They require accurate calibration but no conversion factors.

9.2 The ac fluxmeter may be calibrated by either a reference core or a reference-voltage calibrator.

9.2.1 A reference core is one whose flux change is known or can be measured. Such measurements can be made by dc ballistic methods.[3] A supermalloy core or suitable equivalent prepared from 0.001-in. [25-μm] thick material excited to a peak excitation of 10 Oe [796 A/m] is suggested. This reference core is placed in the test fixture and excited with the magnetic field strength for which the flux change is known. The ac flux voltmeter is then calibrated in terms of the known flux change.

9.2.2 The reference-voltage calibrator of Appendix X2 develops a known average voltage having a waveform approximating that of the induced voltage in winding N_4 of Fig. X2.1 for the measurement of B_{max}.

10. Procedure

10.1 Set switch S_1 to the full-wave position and turn all dc power supplies to zero current. Then, with no core in the test jig, raise the level of the ac sinusoidal current in the excitation winding, N_1, to the value which produces the peak excitation, I_p, required in Table 1 for the measurement of B_p. Then adjust the coupling of the air flux compensator, T_1, to give a minimum reading on the flux voltmeter scale (Note 4). The position of the stray-flux compensator must also be adjusted to provide the lowest possible residual-flux voltmeter reading. The exciting current, I_p, value required for this measurement may be calculated from the equation of 11.1.

10.2 Place a test specimen in the test fixture, and with the value of full-wave SCM sinusoidal-current excitation, I_p (calculated from specified H_{max} of Table 2), flowing through the excitation winding, N_1, observe the flux-voltmeter reading across winding, N_4. This voltage corresponds to a total flux change from forward B_{max} to reverse B_{max} (or 2 B_{max} in terms of half-wave parameters).

10.3 Operate switch S_1 to the half-wave excitation position and maintain the same value of peak-excitation current, I_p (used in 9.2), so that the half-wave (CM) value of H_{max} equals the previous full-wave (SCM) value of H_{max}. Again observe and record the flux-voltmeter reading across winding N_4. This voltage is proportional to the flux-density shift in the specimen

material during cyclic changes from maximum to residual induction and is the measure for the quanitity $B_{max} - B_r$.

10.4 With switch S_1 remaining in the half-wave excitation position, readjust the excitation current, I_p (as calculated for 10.1), to a value that provides the peak magnetic field strength specified in Table 1 which is to be maintained during measurements for the parameters, H_1, ΔH, and ΔB. Then adjust the dc level (form the H_1 power supply) in winding N_2 until the flux voltmeter indicates the voltage that is induced when the desired ΔB_1 (as shown in Table 1) has been established. This reverse dc biasing current, I_2, in amperes is used to calculate the value of H_1 in oersteds or A/m (see 11.3).

10.5 With switch S_1 remaining in the half-wave position and excitation current, I_p, and reverse-biasing current, I_2, held to the values given in 10.4, adjust the dc current level (from the ΔH power supply) in winding N_3 until the flux voltmeter indicates the voltage which is induced when the desired ΔB_2 (as shown in Table 1), has been established. This reverse dc biasing current, I_3, in amperes is used to calculate the value of ΔH oersteds or A/m (see 11.3). This current represents the change in reverse dc biasing current (or biasing field ΔH oersteds or A/m) which causes the induction resulting from the ac excitation to change by the value of ΔB G.

10.6 When a very stable dc power supply is used with 1-dc ammeter of the 0.1 % class or better, this combination with a single dc winding, N_2, may be used for both the H_1 and H_2 or ΔH determinations.

10.7 In this test method, the coercive field strength H_c parameter is not measured directly or calculated from other parameters. An approximate correlation may be found with the parameter H_1.

11. Calculations

11.1 Table 1 specifies the values of full-wave or half-wave sinusoidal-current magnetic field strength to be used in testing various materials. The following equation is used to calculate the peak value of full-wave or half-wave sinusoidal current required to establish the desired magnetic field strength. Where for full-wave excitation,

$$I_p = \ell_1 H_{max}/0.4\pi N_1, \; H_{max} \text{ in Oe}$$
$$I_p = \ell_2 H_{max}/N_1, \; H_{max} \text{ in A/m}$$

and for half-wave excitation,

$$I_p = \ell_1 H_p/0.4\pi N_1, \; H_p \text{ in Oe}$$
$$I_p = \ell_2 H_p/N_1, \; H_p \text{ in A/m}$$

where:

I_p = peak value of current reached during a cycle of the sinusoidal full-wave or half-wave exciting current, A,
ℓ_1 = mean magnetic path length of the test specimen, cm, and
ℓ_2 = mean magnetic path length of the test specimen, m.
H_{max} = predetermined peak value of magnetic field strength H_{max} to be used for a particular test (see Table 2),
H_p = predetermined peak value of magnetic field strength, H_p, to be used for a particular test (see Table 2), and

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[3] See Practice A34/A34M, Terminology A340, and Test Method A596/A596M.

N_1 = number of turns used in the excitation winding.

11.2 When the peak current ammeter used is a dc average-responsive ammeter, the following equation shall be used to calculate the scale indication corresponding to the desired value of peak magnetic field strength, H_{max}. Where for full-wave excitation,

$$I_{avg} = \ell_1 H_{max} / 0.4\pi N_1 \pi, \; H_{max} \text{ in Oe}$$

$$I_{avg} = \ell_2 H_{max} / N_1 \pi, \; H_{max} \text{ in A/m}$$

and for half-wave excitation,

$$I_{avg} = \ell_1 H_p / 0.4\pi N_1 \pi, \; H_{max} \text{ in Oe}$$

$$I_{avg} = \ell_2 H_p / N_1 \pi, \; H_{max} \text{ in A/m}$$

where:

I_{avg} = average value of alternating current as indicated on the dc average responsive instrument scale, A;

ℓ_1 = mean magnetic path length of the test specimen, cm; and

ℓ_2 = mean magnetic path length of the test specimen, m.

H_{max} = peak value of magnetic field strength, H_{max}, from Table 2;

H_p = peak value of magnetic field strength, H_p, from Table 2; and

N_1 = number of turns on excitation winding.

11.3 The values of reverse dc biasing magnetic field strength for the H_1 and ΔH determinations may be calculated from the following:

$$H_1 = 0.4\pi N_2 I_2 / \ell_1 \text{ in Oe}, \; H_1 = N_2 I_2 / \ell_2 \text{ in A/m}$$

$$\Delta H = 0.4\pi N_3 I_3 / \ell_1 \text{ in Oe}, \; \Delta H = N_3 I_3 / \ell_2 \text{ in A/m}$$

where:

H_1 = dc biasing (reset) magnetic field strength from coil N_2 (H_1 testpoint);

ΔH = dc biasing (reset) magnetic field strength from coil N_3 (N_2 testpoint);

N_2 = magnetizing coil for H_1 dc reverse biasing, turns;

N_3 = magnetizing coil for H_2 dc reverse biasing, turns;

I_2 = direct current required in N_2 for the H_1 testpoint, A;

I_3 = direct current required in N_3 for the H_2 testpoint, A; and

ℓ_1 = mean magnetic path length of the test specimens, cm.

11.4 The value of ΔB may be calculated as follows:

$$\Delta B = \Delta B_2 - \Delta B_1$$

where:

ΔB_1 = total B swing for the H_1 testpoint and

ΔB_2 = total B swing for the H_2 testpoint.

11.5 The gain factor for a core is usually expressed in terms of the ΔH test value required to change the induction swing from the value of ΔB_1 to that of ΔB_2 (see 11.3). This value is very useful for evaluating the quality of cores made from a specific material. For quality comparisons between cores made from two different types of material or for other isolated cases, it may be desirable to express the gain factor of the core as a ratio between ΔB and ΔH as follows:

$$G = \Delta B / \Delta H, \; G[T] = \Delta B / \Delta H$$

where:

G = core gain, G/Oe, or G[T] = core gain, Tesla/A/m.

11.6 The minimum value of impedance that is allowable for an external circuit or instrument which is to be connected to a test winding can be determined from the following equation:

$$Z = 2\pi f N^2 \frac{A}{\ell_1} \frac{\Delta B}{\Delta H} \times 10^{-5} \text{ cnst. units}$$

$$Z = 5 f N^2 \frac{A}{\ell_1} \frac{\Delta B}{\Delta H} \times 10^3 \text{ SI units}$$

where:

Z = total impedance, looking externally from the winding terminals, Ω;

f = frequency, Hz;

N = number of turns in the test winding to be connected to the circuit impedance or instruments;

A = cross-sectional area of the core material, cm^2 [m^2]; and

ℓ_1 = mean magnetic path length of the core, cm [m].

11.7 The core material area, A, is normally determined from the nominal core dimensions and lamination factors of Table 3 and Table A1.2. When the core area is not known, it may be determined by calculation from dimensions and stacking factor.

11.8 The mean path length of the core material shall be determined from the manufacturer's published dimension or from measured dimensions.

11.9 The flux-voltmeter scale may be calibrated to indicate ΔB changes directly from its scale reading (Appendix X2) or to indicate average volts. Voltages corresponding to the desired induction or change in induction may be calculated as follows:

$$E_{avg} = 2(\Delta B) N_4 f A \times 10^{-8} \text{ cnst. units}$$

$$E_{avg} = 2\Delta B N_4 f A \text{ SI units}$$

where:

E_{avg} = average value of voltage induced in winding N_4, V;

ΔB = change in induction in the magnetic core material, G [T];

N_4 = number of turns in winding N_4;

f = frequency, Hz; and

A = cross-sectional area of the core material, cm^2 [m^2].

12. Precision and Bias

12.1 It is not practicable to specify the precision of the procedure in this test method for measuring the gain factor of a core because there are too few laboratories capable of making this test to conduct an interlaboratory study. The procedure in

TABLE 3 Lamination Factor

Tape Thickness			Stacking Factor
in.	[cm]	[m (10^{-6})]	
0.0005	[0.0013]	[13]	0.5
0.0010	[0.0026]	[25]	0.75
0.002	[0.0051]	[51]	0.85
0.004	[0.010]	[100]	0.90
0.006	[0.015]	[150]	0.90
0.010 to 0.014	[0.025 to 0.36]	[250–360]	0.95