

Standard Terminology of Symbols and Definitions Relating to Magnetic Testing¹

This standard is issued under the fixed designation A340; 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.

INTRODUCTION

In preparing this glossary of terms, an attempt has been made to avoid, where possible, vector analysis and differential equations so as to make the definitions more intelligible to the average worker in the field of magnetic testing. In some cases, rigorous treatment has been sacrificed to secure simplicity, but it is believed that none of the definitions will prove to be misleading.

It is the intent of this glossary to be consistent in the use of symbols and units with those found in ANSI/IEEE 260-1978 and USA Standard Y 10.5-1968.

¹This terminology is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.92 on Terminology and Definitions.

Part 1—Symbols Used in Magnetic Testing

Symbo	I Term	Ŧ	magnetomotive force
		ff	form factor
α	cross-sectional area of B coil	H	magnetic field strength
A	cross-sectional area of specimen	ΔH	excursion range of magnetic field strength
A'	solid area	H_b	biasing magnetic field strength
В	(maximum attice flows along attac	H_{cB}	coercive field strength
	magnetic flux density	H_{cJ}	intrinsic coercive field strength
	(magnetic induction	H_d	demagnetizing field strength
		H_{Δ}	incremental magnetic field strength
ΔB	excursion range of induction	H_g	air gap magnetic field strength
B_b .	biased induction	H_L	ac magnetic field strength (from an assumed
B _d	remanent induction		peak value of magnetizing current)
B _{dm}	remanence	H _m	maximum magnetic field strength in a hyster-
$B_d H_d$	energy product		esis loop
$(B_d H_d)_m$	maximum energy product	H _{max}	maximum magnetic field strength in a flux-
B_{Δ}	incremental induction		current loop
Bi	intrinsic induction	H_p	ac magnetic field strength (from a measured
B _m	maximum induction in a hysteresis loop		peak value of exciting current)
B _{max}	maximum induction in a flux current loop	H_t	instantaneous magnetic field strength (coinci-
B _r	residual induction		dent with B _{max})
B _{rs}	retentivity	H_z	ac magnetic field strength force (from an as-
B _s	saturation induction		sumed peak value of exciting current)
cf	crest factor	1	ac exciting current (rms value)
СМ	cyclically magnetized condition	I _c	ac core loss current (rms value)
d	lamination thickness	I _{dc}	constant current
D_B	demagnetizing coefficient	I _m	ac magnetizing current (rms value)
df	distortion factor	J	magnetic polarization
D_m	magnetic dissipation factor	K	coupling coefficient
E	exciting voltage	ℓ	flux path length
E ₁	induced primary voltage	ℓ_1	effective flux path length
E ₂	induced secondary voltage	ℓ_g	gap length
E _f	flux volts	\mathscr{L} (also φ N)	flux linkage
f	cyclic frequency in hertz	\mathcal{L}_{m}	mutual flux linkage

Current edition approved July 1, 2017. Published July 2017. Originally approved in 1949. Last previous edition approved in 2016 as $A340 - 16^{\varepsilon_1}$. DOI: 10.1520/A0340-17.

🕈 A340 – 17

L	self inductance	$\Delta \chi$	incremental tolerance
L_1	core inductance	β	hysteretic angle
L	incremental inductance	γ	loss angle
L	intrinsic inductance	COS γ	magnetic power factor
Ĺ,	mutual inductance	γ _e	proton gyromagnetic ratio
L	initial inductance	μ _o	magnetic constant
L	series inductance	δ	density
L _w	winding inductance	κ	susceptibility
m	magnetic moment	ac Permeabilities:	
М	magnetization	Иа	ideal permeability
т	total mass of a specimen	Га Ц	inductance permeability
m ₁	active mass of a specimen	μ	incremental inductance permeability
No	demagnetizing factor	Hod	initial dynamic permeability
N ₁	turns in a primary winding	и _р	peak permeability
Na	turns in a secondary winding	и р Ило	incremental peak permeability
N.1/l.	ac excitation	μ_i	instantaneous permeability
D	magnetic pole strength	и	impedance permeability
P	permeance	Г <u>2</u> Ил –	incremental impedance permeability
Р	active (real) power	dc Permeabilities:	, , , , , , , , , , , , , , , , , , ,
P。	apparent power	μ	normal permeability
P _a (B:f)	specific apparent power	μ_{abs}	absolute permeability
P_c	total core loss	μ_d	differential permeability
P _c (B:f)	specific core loss	μ_{Λ}	incremental permeability
Pc	incremental core loss	μ _{eff}	effective circuit permeability
Pe	normal eddy current core loss	$\mu_{\Delta i}$	incremental intrinsic permeability
P _{Ae}	incremental eddy current core loss	μ _m	maximum permeability
P_h	normal hysteresis core loss	μ_i	initial permeability
$P_{\Lambda h}$	incremental hysteresis core loss	μ _r	relative permeability
P_a	reactive (quadrature) power	μ _ν	space permeability
P _r	residual core loss	μ_{rev}	reversible permeability
P_w	winding loss (copper loss)	μ'/cot γ	figure of merit
P _z	exciting power	v	reluctivity
$P_{z(B:f)}$	specific exciting power	π	the numeric 3.1416
Q_m	magnetic storage factor	ρ	resistivity
R	reluctance	φ	magnetic flux
R ₁	core resistance	φΝ	flux linkage (see £)
R_w	winding resistance	χ	mass susceptibility
S	lamination factor (stacking factor)	χο	initial susceptibility
SCM	symmetrically cyclically magnetized condition	ω	angular frequency in radians per second
T _c	Curie temperature		· · · · ·
W	lamination width		
W _b	hysteresis loop loss		

Part 2—Definition of Terms Used in Magnetic Testing

ac excitation, $N_1 I/\ell_1$ —the ratio of the rms ampere-turns of exciting current in the primary winding of an inductor to the effective flux path length of the inductor.

linear expansion, coefficient (average)

active (real) power, P-the product of the rms current, I, in an electrical circuit, the rms voltage, E, across the circuit, and the cosine of the angular phase difference, θ between the current and the voltage.

$P = EI\cos\theta$

DISCUSSION-The portion of the active power that is expended in a magnetic core is the total core loss, P_{a} .

aging coefficient-the percentage change in a specific magnetic property resulting from a specific aging treatment.

DISCUSSION-The aging treatments usually specified are: (a) 100 h at 150°C or

(b) 600 h at 100°C.

ā

aging, magnetic-the change in the magnetic properties of a material resulting from metallurgic change due to a normal or specified aging condition.

DISCUSSION-This term implies a deterioration of the magnetic properties of magnetic materials for electronic and electrical applications, unless otherwise specified.

air-gap magnetic field strength, H_{g} —the magnetic field strength required to produce the induction existing at some point in a nonmagnetic gap in a magnetic circuit.

DISCUSSION—In the cgs-emu system of units, H_{ρ} is numerically equal to the induction existing at such a point and exceeds the magnetic field strength in the magnetic material.

- amorphous alloy—a semiprocessed alloy produced by a rapid quenching, direct casting process resulting in metals with noncrystalline structure.
- ampere (turn), A-the unit of magnetomotive force in the SI system of units. The symbol A represents the unit of electric current, ampere, in the SI system of units.
- ampere per metre, A/m-the unit of magnetic field strength in the SI system of units.
- anisotropic material-a material in which the magnetic properties differ in various directions.
- anisotropy of loss-the ratio of the specific core loss measured with flux parallel to the rolling direction to the specific core loss with flux perpendicular to the rolling direction.

anisotropy of loss =
$$\frac{P_{c (B;f)}}{P_{c (B;f)}}$$

where:

- $P_{c (B;f) l}$ = specific core loss value with flux parallel to the rolling direction, W/lb [W/kg], and
- $P_{c (B;f) t}$ = specific core loss value with flux perpendicular to the rolling direction, W/lb [W/kg].

DISCUSSION—This definition of anisotropy normally applies to electrical steels with measurements made in an Epstein frame at a flux density of 15 kG [1.5 T] and a frequency of 60 Hz (see Test Method A343).

anisotropy of permeability—the ratio of relative peak permeability measured with flux parallel to the rolling direction to the relative peak permeability measured with flux perpendicular to the rolling direction.

anisotropy of permeability =
$$\frac{\mu_{pro}}{\mu_{pro}}$$

where:

- μ_{prl} = relative peak permeability value with flux parallel to the rolling direction, and
- μ_{prt} = relative peak permeability value with flux perpendicular to the rolling direction.

DISCUSSION—This definition of anisotropy normally applies to electrical steels with measurements made in an Epstein frame at a flux density of 15 kG [1.5 T] and a frequency of 60 Hz (see Test Method A343).

- **antiferromagnetic material**—a feebly magnetic material in which almost equal magnetic moments are lined up antiparallel to each other. Its susceptibility increases as the temperature is raised until a critical (Neél) temperature is reached; above this temperature the material becomes paramagnetic.
- **apparent power**, P_a —the product (volt-amperes) of the rms exciting current and the applied rms *terminal* voltage in an *electric* circuit containing inductive impedance. The components of this impedance as a result of the winding will be linear, while the components as a result of the magnetic core will be nonlinear. The unit of apparent power is the voltampere, VA.
- **apparent power, specific,** $P_{a(B;f)}$ —the value of the apparent power divided by the active mass of the specimen, that is, volt-amperes per unit mass. The values of voltage and current are those developed at a maximum value of cyclically varying induction *B* and specified frequency *f*.
- **area**, *A*—the geometric cross-sectional area of a magnetic path which is perpendicular to the direction of the induction.
- **Bloch wall**—a domain wall in which the magnetic moment at any point is substantially parallel to the wall surface. See also **domain wall**.
- **Bohr magneton**—a constant that is equal to the magnetic moment of an electron because of its spin. The value of the constant is $(9\ 274\ 078 \times 10^{-21}\ \text{erg/gauss}\ \text{or}\ 9\ 274\ 078 \times 10^{-24}\ \text{J/T}).$

- **cgs-emu system of units**—the system for measuring physical quantities in which the base units are the centimetre, gram, and second, and the numerical value of the magnetic constant, μ_0 , is unity.
- **coercive field strength,** H_{cB} —the absolute value of the applied magnetic field strength (*H*) required to restore the magnetic flux density (*B*) to zero.

DISCUSSION—The symbol H_c has historically been used to denote the coercive field strength determined from a (B,H) loop. Further use of this symbol in ASTM A06 standards is deprecated.

DISCUSSION—The coercive field strength monotonically increases with increasing maximum magnetic field strength (H_m) reaching a maximum or limiting value termed the **coercivity**. Unless it is known that the material has been magnetized to saturation, the term coercive field strength is preferred.

DISCUSSION—The coercive field strength is not completely described without knowing the maximum magnetic flux density (B_m) or maximum magnetic field strength (H_m) used in the measurement.

coercive field strength, intrinsic, H_{cJ} —the absolute value of the applied magnetic field strength (*H*) required to restore either the magnetic polarization (*J*) or magnetization (*M*) to zero.

DISCUSSION—The symbol H_{ci} has historically been used to denote the intrinsic coercive field strength determined from a (B_i, H) loop. Further use of this symbol in ASTM A06 standards is deprecated.

DISCUSSION—The intrinsic coercive field strength monotonically increases with increasing maximum magnetic field strength (H_m) reaching a maximum or limiting value termed the **intrinsic coercivity**. Unless it is known that the material has been magnetized to saturation, the term intrinsic coercive field strength is preferred.

DISCUSSION—The measured value of intrinsic coercive field strength will be the same whether it is measured from a magnetic polarization (J,H) or a magnetization (M,H) hysteresis loop and will always be numerically larger than the coercive field strength (H_{cB}) measured from a magnetic flux density (B,H) hysteresis loop.

DISCUSSION—The intrinsic coercive field strength is not completely described without knowing the maximum magnetic polarization, maximum magnetization or maximum magnetic field strength (H_m) used in the measurement.

coercivity—see coercive field strength.

coercivity, intrinsic—see coercive field strength, intrinsic.

- **core, laminated**—a magnetic component constructed by stacking suitably thin pieces of magnetic material which are stamped, sheared, or milled from sheet or strip material. Individual pieces usually have an insulating surface coating to minimize eddy current losses in the assembled core.
- **core, mated**—two or more magnetic core segments assembled with the magnetic flux path perpendicular to the mating surface.
- **core, powder (dust)**—a magnetic core comprised of small particles of electrically insulated metallic ferromagnetic material. These cores are characterized by low hysteresis and eddy current losses.
- **core, tape-wound**—a magnetic component constructed by the spiral winding of strip material onto a suitable mandrel. The

strip material usually has an insulating surface coating which reduces interlaminar eddy current losses in the finished core.

- core loss, ac eddy current, incremental, $P_{\Delta e}$ —the power loss caused by eddy currents in a magnetic material that is cyclically magnetized.
- core loss, ac eddy current, normal, P_e —the power losses as a result of eddy currents in a magnetic material that is symetrically cyclically magnetized.

DISCUSSION—The voltage is generally assumed to be across the parallel combination of core inductance, L_1 , and core resistance, R_1 .

- **core loss, ac, incremental**, $P_{c\Delta}$ —the core loss in a magnetic material when the material is subjected simultaneously to a dc biasing magnetizing force and an alternating magnetizing force.
- **core loss, residual,** P_r —the portion of the core loss power, P_c , which is not attributed to hysteresis or eddy current losses from classical assumptions.
- **core loss, ac, specific,** $P_{c(B;f)}$ —the active power (watts) expended per unit mass of magnetic material in which there is a cyclically varying induction of a specified maximum value, *B*, at a specified frequency, *f*.
- **core loss, ac, (total),** P_c —the active power (watts) expended in a magnetic circuit in which there is a cyclically alternating induction.

DISCUSSION—Measurements of core loss are normally made with sinusoidally alternating induction, or the results are corrected for deviations from the sinusoidal condition.

core loss density—the active power (watts) expended in a magnetic core in which there is a cyclically varying induction of a specified maximum value, B, at a specified frequency, f, divided by the effective volume of the core.

DISCUSSION—This parameter is normally used only for non-laminated cores such as ferrite and powdered cores.

- **core plate**—a generic term for any insulating material, formed metallurigically or applied externally as a thin surface coating, on sheet or strip stock used in the construction of laminated and tape wound cores.
- **coupling coefficient,** *k'*—the ratio of the mutual inductance between two windings and the geometric mean of the individual self-inductances of the windings.
- **crest factor,** *cf*—the ratio of the maximum value of a periodically alternating quantity to its rms value.

Discussion—For a sinusoidal variation the crest factor is $\sqrt{2}$.

- **Curie temperature**, T_c —the temperature above which a ferromagnetic or ferrimagnetic material becomes paramagnetic.
- current, ac core loss, I_c —the rms value of the in-phase component (with respect to the induced voltage) of the exciting current supplied to a coil which is linked with a ferromagnetic core.
- current, ac exciting, *I*—the rms value of the total current supplied to a coil that is linked with a ferromagnetic core.

DISCUSSION—Exciting current is measured under the condition that any other coil linking the same core carries no current.

- current, ac, magnetizing, I_m —the rms value of the magnetizing component (lagging with respect to applied voltage) of the exciting current supplied to a coil that is linked with a ferromagnetic core.
- **current, dc,** I_{dc} —a steady-state dc current. A dc current flowing in an inductor winding will produce a unidirectional magnetic field in the magnetic material.
- **customary units**—a set of industry-unique units from the cgs-emu system of units and U.S. inch-pound systems and units derived from the two systems.

DISCUSSION-Examples of customary units used in ASTM A06 standards include:

Quantity Name	Quantity Symbol	Unit Name	Unit Symbol
Magnetic field strength	Н	oersted	Oe
Magnetic flux density	В	gauss	G
(magnetic induction)			
Specific core loss	$P_{c(B:f)}$	watt/pound	W/lb

- **cyclically magnetized condition,** *CM*—a magnetic material is in a cyclically magnetized condition when, after having been subjected to a sufficient number of identical cycles of magnetizing field, it follows identical hysteresis or fluxcurrent loops on successive cycles which are not symmetrical with respect to the origin of the axes.
- **demagnetization curve, normal**—the portion of a normal hysteresis loop that lies in the second quadrant, that is, between H = 0 and the coercive field strength H_{cB} .
- **demagnetization curve, intrinsic**—the portion of an intrinsic hysteresis loop (either B_i , J or M vs H) that lies in the second quadrant, that is, between H = 0 and the intrinsic coercive field strength H_{cJ} .

demagnetizing coefficient, D_B —is defined by the equation:

$$D_B = \left[\mu_0 (H_a - H)\right] / B_i$$

where:

 H_a = applied magnetic field strength,

- H = magnetic field strength actually existing in the magnetic material,
- B_i = intrinsic induction, and
- $\mu_0 = 1$ in the cgs system and $4\pi \times 10^{-7}$, henry/metre in the SI system.

DISCUSSION—For a closed, uniform magnetic circuit, the demagnetizing coefficient is zero.

- **demagnetizing factor,** N_D —defined as 4π times the demagnetizing coefficient, D_B .
- **demagnetizing field strength**, H_d —a magnetic field strength applied in such a direction as to reduce the induction in a magnetized body. See **demagnetization curve**.
- **density**, δ —the ratio of mass to volume of a material. In the cgs-emu system of units, g/cm³. In SI units, kg/m³.
- **diamagnetic material**—a material whose relative permeability is less than unity.
 - DISCUSSION—The intrinsic induction, B_i , is oppositely directly to the applied magnetizing force H.

- **disaccommodation**—a time dependent change of magnetic properties, especially the initial permeability, that occurs after demagnetization of a magnetic material. This change is usually due to the motion of point defects such as vacancies and interstitial atoms, occurs over a time period measured in seconds or minutes, and is reversible by demagnetization. It is a different phenomenon than magnetic aging which (*a*) typically involves the clustering of impurity atoms or precipitation of a new phase, (*b*) occurs over a much longer time period (normally weeks or months at room temperature), and (*c*) the changes are not reversible by demagnetization.
- **dissipation factor, magnetic,** D_m —the tangent of the hysteretic angle that is equal to the ratio of the core loss current, I_c , to the magnetizing current, I_m . Thus:

 $D_m = \tan \beta = \cot \gamma = I_c/I_m = \omega L_1/R_1 = I/Q_m$

DISCUSSION—This dissipation factor is also given by the ratio of the energy dissipated in the core per cycle of a periodic *SCM* excitation (hysteresis and eddy current heat loss) to 2π times the maximum energy stored in the core.

distortion, harmonic—the departure of any periodically varying waveform from a pure sinusoidal waveform.

DISCUSSION—The distorted waveform that is symmetrical about the zero amplitude axis and is most frequently encountered in magnetic testing contains only the odd harmonic components, that is fundamental, 3rd harmonic, 5th harmonic, and so forth. Nonsymmetrical distorted waveforms must contain some even harmonic components, in addition to the fundamental and, perhaps, some odd harmonic components.

distortion factor, *df*—a numerical measure of the distortion in any ac nonsinusoidal waveform. For example, if by Fourier analysis or direct measurement E_1 , E_2 , E_3 , and so forth are the effective values of the pure sinusoidal harmonic components of a distorted voltage waveform, then the distortion factor is the ratio of the root mean square of the second and all higher harmonic components to the fundamental component.

$$df = \left[E_2^2 + E_3^2 + E_4^2 + \cdots\right]^{1/2} E_1$$

Discussion—There are no dc components $({\cal E}_0)$ in the distortion factor.

- **domains, ferromagnetic**—magnetized regions, either macroscopic or microscopic in size, within ferromagnetic materials. Each domain, in itself, is magnetized to intrinsic saturation at all times, and this saturation induction is unidirectional within the domain.
- **domain wall**—a boundary region between two adjacent domains within which the orientation of the magnetic moment of one domain changes into a different orientation of the magnetic moment in the other domain.
- **eddy current**—an electric current developed in a material as a result of induced voltages developed in the material.
- effective circuit permeability, μ_{eff} —when a magnetic circuit consists of two or more components, each individually homogeneous throughout but having different permeability values, the effective (overall) permeability of the circuit is that value computed in terms of the total magnetomotive force, the total resulting flux, and the geometry of the circuit.

- **electrical steel**—a term used commercially to designate strip or sheet used in electrical applications and historically has referred to flat-rolled, low-carbon steels or alloyed steels with silicon or aluminum, or both. Common types of electrical steels used in the industry are grain-oriented electrical steel, nonoriented electrical steel, and magnetic lamination steel.
- electrical steel, grain oriented—a flat-rolled silicon-iron alloy usually containing approximately 3 % silicon, having enhanced magnetic properties in the direction of rolling and normally used in transformer cores.
- **electrical steel, nonoriented**—a flat-rolled silicon-iron or silicon-aluminum-iron alloy containing 0.0 to 3.5 % silicon and 0.0 to 1.0 % aluminum and having similar core loss in all directions.
- **emu**—the notation emu is an indicator of electromagnetic units. When used in conjunction with magnetic moment, m, it denotes units of ergs per oersted, erg/Oe. A moment of 1 erg/Oe is produced by a current of 10 amperes (1 abampere) flowing in a loop of area 1 cm². The work done to rotate a moment of 1 erg/Oe from parallel to perpendicular in a uniform field of 1 Oe is 1 erg. The conversion to the SI units of magnetic moment J/T (joule/tesla) or A m² is given by:

$$\frac{\text{erg/Oe}(\text{cgs} - \text{emu})}{\text{J/T}(\text{SI})} \equiv \frac{10 \text{ amperes } \text{cm}^2(\text{cgs} - \text{emu})}{\text{A } \text{m}^2(\text{SI})} = 10^{-3} \quad (1)$$

Magnetization, M, the magnetic moment per unit volume, has units erg/(Oe-cm³), often expressed as emu/cm³.

energy product—the product of the coordinate values of any point on a normal demagnetization curve. This is also called the BH product. In the cgs-emu system of units the energy product is expressed in units of gauss-oersted. In the SI system of units, the energy product is expressed in units of joule per cubic metre.

DISCUSSION—Although the energy product is mathematically negative, it is customary to express it as a positive number.

energy-product curve, magnetic—the curve obtained by plotting the product of the corresponding coordinates, B_d and H_d , of points on the demagnetization curve as abscissa against the induction, B_d , as ordinates.

DISCUSSION—The maximum value of the energy product, $(B_dH_d)_m$, corresponds to the maximum value of the external energy.

DISCUSSION—The demagnetization curve is plotted to the left of the vertical axis and usually the energy-product curve to the right.

- energy product, maximum $(B_dH_d)_m$ —for a given demagnetization curve, the maximum value of the energy product.
- equipment test level accuracy—(1) For a single test equipment, using a large group of test specimens, the average percentage of test deviation from the correct average value. (2) The average percentage deviation from the average value obtained from similar tests, on the same test specimen or specimens, when measured with a number of other test equipments that have previously been proven to have both suitable reproducibility of measurement and test level, and whose calibrations and quality have general

acceptance for standardization purposes and where better equipment for establishing the absolute accuracy of test is not available.

exciting current, ac, I-See current, ac exciting.

exciting power, rms, P_z —the product of the ac rms exciting current and the rms voltage induced in the exciting (primary) winding on a magnetic core.

DISCUSSION—This is the apparent volt-amperes required for the excitation of the magnetic core only. When the core has a secondary winding, the induced primary voltage is obtained from the measured open-circuit secondary voltage multiplied by the appropriate turns ratio.

- **exciting power, specific,** $P_{z(B;f)}$ —the value of the ac rms exciting power divided by the active mass of the specimen (volt-amperes/unit mass) taken at a specified maximum value of cyclically varying induction *B* and at a specified frequency *f*.
- **exciting voltage,** E—the ac rms voltage across a winding linking the flux of a magnetic core. The voltage across the winding equals that across the assumed parallel combination of core inductance L_1 , and core resistance, R_1 .
- **feebly magnetic material**—a material generally classified as "nonmagnetic," whose maximum normal permeability is less than 4.
- **ferrimagnetic material**—a material whose atomic magnetic moments are both ordered and anti-parallel but being unequal in magnitude produce a net magnetization in one direction.
- **ferrite**—a term referring to magnetic oxides in general, and especially to material having the formula M O Fe₂ O₃, where M is a divalent metal ion or a combination of such ions. Certain ferrites, magnetically "soft" in character, are useful for core applications at radio and higher frequencies because of their advantageous magnetic properties and high volume resistivity. Other ferrites, magnetically "hard" in character, have desirable permanent magnet properties.
- **ferromagnetic material**—a material whose magnetic moments are ordered and parallel producing magnetization in one direction.
- **figure of merit, magnetic,** μ' **/cot** γ —the ratio of the real part of the complex relative permeability to the dissipation factor of a ferromagnetic material.

DISCUSSION—The figure of merit index of the magnetic efficiency of the core in various ac electromagnetic devices.

- **flux-current loop, incremental (biased)**—the curve developed by plotting magnetic induction, B, versus magnetic field strength, H, when the magnetic material is cyclically magnetized while under dc bias condition. This loop will not be symmetrical about the B and H axes.
- **flux-current loop, normal**—the curve developed by plotting magnetic induction, B, versus magnetic field strength, H, when the magnetic material is symmetrically cyclically magnetized.

DISCUSSION—The area of the loop is proportional to the sum of the static hysteresis loss and all dynamic losses.

flux linkage, \mathcal{L} —the sum of all flux lines in a coil.

$$\mathscr{L} = \varphi_1 + \varphi_2 + \varphi_3 + \cdots \varphi_N$$

where:

- φ_1 = flux linking turn 1;
- φ_2 = flux linking turn 2, and so forth; and

 φ_N = flux linking the *N*th turn.

DISCUSSION—When the coupling coefficient, k', is less than unity, the flux linkage equals the product of the average flux linking the turns and the total number of turns. When the coupling coefficient is equal to unity, the flux linkage equals the product of the total flux linking the coil and the total number of turns.

- **flux linkage, mutual,** \mathcal{L}_m —the flux linkage existing between two windings on a magnetic circuit. Mutual linkage is maximum when the coupling coefficient is unity.
- flux path length, *l*—the distance along a flux loop.
- flux path length, effective, ℓ_1 —the calculated length of the flux paths in a magnetic core, which is used in the calculations of certain magnetic parameters.
- **flux volts,** E_f —the voltage induced in a winding of a magnetic component when the magnetic material is subjected to repeated magnetization under *SCM* or *CM* conditions.

$$E_f = 4.443 B_{\text{max}} A'Nf \times 10^{-8} \text{ V} (SCM \text{ excitation})$$

$$E_f = 2.221 \Delta BA' Nf \times 10^8 \text{ V} (CM \text{ excitation})$$

$$E_f = 1.1107 E_{\text{avg}}$$

which:

- A' = solid cross-sectional area of the core in cm²,
- N = number of winding turns, and
- f = the frequency in hertz.
- form factor, *ff*—the ratio of the rms value of a periodically alternating quantity to its average absolute value.

DISCUSSION-For a sinusoidal variation, the form factor is:

$$\tau/2\sqrt{2} = 1.1107$$

frequency, angular, ω —the number of radians per second traversed by a rotating vector that represents any periodically varying quantity.

DISCUSSION—Angular frequency, ω , is equal to 2π times the cyclic frequency, *f*.

- **frequency, cyclic,** *f*—the number of hertz (cycles/second) of a periodic quantity.
- **gap length,** ℓ_g —the distance that the flux transverses in the central region of a gap in a core having an "air" (nonmagnetic) gap in the flux path may be considered unity in the gap.
- **gauss (plural gausses), G**—the unit of magnetic flux density in the cgs-emu system of units. The gauss is equal to 1 maxwell per square centimetre or 10^{-4} tesla. See **magnetic** flux density.
- **gilbert, Gb**—the unit of magnetomotive force in the cgs-emu system of units. The gilbert is a magnetomotive force of $4\pi/10$ ampere-turns. See **magnetomotive force**.

gyromagnetic ratio, proton, γ_p —the ratio of the magnetic moment of a hydrogen nucleus to its angular momentum.

DISCUSSION—The gyromagnetic ratio is used to calculate the magnetic field from a measured resonance frequency when using the nuclear magnetic resonance technique. The relationship is:

$$B = (2\pi f/\gamma_p)$$
 gausses $= (2 \pi f / \gamma_p) \times 10^{-4}$ teslas

where:

- f = resonance frequency in cycles per second (hertz) and
- γ_p = gyromagnetic ratio (the accepted value at present for water is 2.675 12 × 10⁴ gauss⁻¹ s⁻¹).
- **henry (plural henries), H**—the unit of self- or mutual inductance. The henry is the inductance of a circuit in which a voltage of 1 V is induced by a uniform rate of change 1 A/s in the circuit. Alternatively, it is the inductance of a circuit in which an electric current of 1 A/s produces a flux linkage of one weber turn (Wb turn) or 10^8 maxwell-turns. See **inductance, mutual, and inductance, self.**

hertz, Hz—the unit of cyclic frequency, f.

hysteresis loop, biased—an incremental hysteresis loop that lies entirely in any one quadrant.

hysteresis loop, incremental—the hysteresis loop, nonsymmetrical with respect to the B and H axes, exhibited by a ferromagnetic material in a CM condition.

DISCUSSION—In this case, both of the limiting values H may have opposite polarity, but definitely have different absolute values of H_m . An incremental loop may be initiated at either some point on a normal hysteresis loop or at some point on the normal induction curve of the specimen.

- hysteresis loop, intrinsic—a hysteresis loop obtained with a ferromagnetic material by plotting (usually to rectangular coordinates) corresponding dc values of intrinsic induction, B_i , for ordinates and magnetic field strength *H* for abscissae.
- **hysteresis loop, normal**—a closed curve obtained with a ferromagnetic material by plotting (usually to rectangular coordinates) corresponding dc values of magnetic induction (*B*) for ordinates and magnetic field strength (*H*) for abscissa when the material is passing through a complete cycle between equal definite limits of either magnetic field strength, $\pm H_m$, or magnetic induction, $\pm B_m$. In general, the normal hysteresis loop has mirror symmetry with respect to the origin of the *B* and *H* axes, but this may not be true for special materials.
- hysteresis loop loss, W_h —the power expended in a single slow excursion around a normal hysteresis loop. The energy is the integrated area enclosed by the loop measured in gaussoersteds. Using the cgs-emu system of units:

$$W_h = \left(\int H dB/4\pi\right)$$
 ergs

where the integrated area enclosed by the loop is measured in gauss-oersteds.

hysteresis loss, incremental, $P_{\Delta h}$ —the power (watts) as a result of hysteresis expended in a ferromagnetic material

while being driven through an incremental flux-current loop by a *CM*-type of excitation.

- hysteresis loss, normal, P_h —(1) the power expended in a ferromagnetic material, as a result of hysteresis, when the material is subjected to a *SCM* excitation. (2) The energy loss/cycle in a magnetic material as a result of magnetic hysteresis when the induction is cyclic (but not necessarily periodic).
- **hysteresis loss, rotational**—the hysteresis loss that occurs in a body when subjected to a constant magnetizing force, the direction of which rotates with respect to the body, either in a continuously cyclic or in a repeated oscillatory manner.
- **hysteresis, magnetic**—the property of a ferromagnetic material exhibited by the lack of correspondence between the changes in induction resulting from increasing magnetic field strength and from decreasing magnetic field strength.
- hysteretic angle, magnetic, β —the mean angle by which the fundamental component of exciting current leads the fundamental component of magnetizing current, I_m , in an inductor having a ferromagnetic core.

DISCUSSION—Because of hysteresis, the instantaneous value of the hysteretic angle will vary during the cycle of *SCM* excitation. However, β is taken to be the mean effective value of this angle.

inductance, core, L_1 —the effective parallel circuit inductance of a ferromagnetic core based upon a hypothetical nonresistive path that is exclusively considered to carry the magnetizing current, I_m .

DISCUSSION—The product $I_m^2 \omega L_1$ equals the quadrature power delivered to the core.

- inductance, incremental, L_{Δ} —the self-inductance of an electrical circuit when the ferromagnetic core has an ac cyclic magnetization produced by specified values of both ac and dc components of the exciting current.
- **inductance, initial,** L_0 —the limiting value of the core inductance, L_1 reached in a ferromagnetic core when, under ac symmetrical cyclic excitation, the magnetizing current has been progressively and gradually reduced from a comparatively high value to a zero value.

DISCUSSION—Initial inductance may be obtained by highly sensitive ASTM bridge methods working in the range in which μ_L is a linear function of *H*. A series of decreasing values of μ_L is measured and plotted versus corresponding values of magnetizing current, I_m (or other suitable excitation parameter), and the data extrapolated to zero excitation. See **permeability, initial dynamic**.

inductance, intrinsic (ferric), L_i —that portion of the selfinductance which is due to the intrinsic induction in a ferromagnetic core.

DISCUSSION—It is determined at a specified value of the magnetizing current.

inductance, mutual, L_m —the common property of two electrical circuits that determines the flux linkage in one circuit (the secondary) produced by a given current in the other circuit (the primary). The mutual inductance, L_m , is defined by the equation:

$$L_m = \mathcal{L}_2 I_1$$

DISCUSSION—In this case, both of the limiting values of H and B are in the same direction.

where:

- \mathcal{L}_2 = flux linkage in the secondary and
- I_1 = current in the primary, assuming no current in the secondary.

DISCUSSION—If \mathscr{L}_2 is in maxwell-turns and I_1 is in amperes, then the mutual inductance in henries is defined by the equation:

$$L_m = (\mathcal{L}_2/I_1) \times 10^{-8}$$

DISCUSSION—If the linkage is proportional to the current (no ferromagnetic material present), the inductance is constant and may be obtained from the equation:

$$e_2 = L_m(di_1/dt)$$

where:

 e_2 = instantaneous induced emf in the secondary and $\frac{di_1}{dt}$ = time rate of change of the current in the primary.

Discussion—If ferromagnetic materials or eddy currents are present, the mutual inductance must be regarded as a function of the primary current, its rate of change, and the magnetic history of the material. Thus:

$$e_{2} = -(d(L_{m}i_{1}) / dt) = -[L_{m}(di_{1}/dt) + i_{1}(dL_{m}/dt)]$$

inductance, self, *L*—that property of an electric circuit that determines the flux linkage produced by a given current in the circuit. The self-inductance, *L*, is defined by the equation:

$$L = \mathcal{L}/I$$

where:

 \mathcal{L} = flux linkage and

I = current.

DISCUSSION—If \mathcal{L} is in maxwell-turns and *I* in amperes, then the self-inductance in henries is defined by the equation:

$$L = (\mathcal{L}/I) \times 10^{-8}$$

DISCUSSION—If the linkage is proportional to the current (no ferromagnetic material present), the inductance is constant and may be obtained from the equation:

$$e_2 = -L_m(di/dt)$$

where:

e = instantaneous induced emf and di/dt = time rate of change of the current.

DISCUSSION—If ferromagnetic material or eddy currents are present, the self-inductance must be regarded as a function of the circuit current, its rate of change, and the magnetic history of the material. Thus:

$$e = -(d (Li) / dt) = -[L(di/dt) + i(dL/dt)]$$

inductance, series, L_s —the effective series ac self-inductance exhibited by an inductor having a ferromagnetic core and subjected to an *SCM* excitation after the core has been demagnetized.

DISCUSSION—The value of series inductance is a function of the level of excitation.

inductance, winding, L_{w} —the linear inductance of the magnetizing winding as a result of the flux caused by the ac symmetrical cyclic magnetization exciting current, *I*. The flux linking the winding is that flux outside of the ferromagnetic core material.

induction, B-See magnetic induction (flux density).

induction, biased, B_b —the value of the apparent dc magnetic induction around which the ac cyclic changes are occurring in a magnetic material resulting from the biasing magnetizing field. This value is a function of the incremental magnetizing field and is not determined by the normal induction curve.

induction, incremental, B_{Δ} —one half the algebraic difference of the extreme values of the magnetic induction during a cycle in a magnetic material that is subjected simultaneously to a biasing magnetizing field and a symmetrically cyclically varying magnetizing field. Twice the incremental induction is indicated by the symbol ΔB , thus:

$$B_{\Delta} = \Delta B/2$$

induction, intrinsic, B_i —the vector difference between the dc magnetic induction in a magnetic material and the magnetic induction that would exist in a vacuum under the influence of the same magnetic field strength. This is expressed by the equation:

$$B_i = B - \mu_0 H$$

DISCUSSION—In the cgs-emu system of units, $B_i/4\pi$ is often called magnetic polarization.

induction, maximum—(1) B_m the maximum value of induction, B, in a dc hysteresis loop. The tip of this loop has the magnetostatic coordinates H_m , B_m , which exist simultaneously. (2) B_{max} —the maximum value of induction, B, in an ac flux-current loop.

DISCUSSION—In a flux-current loop, the magneto-dynamic values B_{\max} and H_{\max} do not exist simultaneously; B_{\max} occurs later than H_{\max} .

- **induction, normal,** *B*—the maximum induction, in a magnetic material that is in a symmetrically cyclically magnetized condition.
- induction, remanent, B_d —the magnetic induction that remains in a magnetic circuit after the removal of an applied magnetic field.

DISCUSSION—If there are no air gaps or other inhomogeneities in the magnetic circuit, the remanent induction, B_d , will equal the residual induction, B_r ; if air gaps or other inhomogeneities are present, B_d will be less than B_r .

- induction, residual, B_r —the value of magnetic induction corresponding to zero magnetizing field when the magnetic material is subjected to symmetrically cyclically magnetized conditions.
- induction, saturation, B_s —the maximum intrinsic induction possible in a material.
- induction curve, intrinsic (ferric)—a curve of a previously demagnetized specimen depicting the relation between intrinsic induction and corresponding ascending values of magnetic field strength. This curve starts at the origin of the B_i and H axes.
- **induction curve, normal**—a curve of a previously demagnetized specimen depicting the relation between normal induction and corresponding ascending values of magnetic field strength. This curve starts at the origin of the *B* and *H* axes.

- insulation resistance-the apparent resistance between adjacent contacting laminations, calculated as a ratio of the applied voltage to conduction current. This parameter is normally a function of the applied force and voltage.
- International System of Units, SI-a complete coherent system of units whose base units are the metre, kilogram, second, ampere, kelvin, mole, and candela. Other units are derived as combinations of the base units or supplementary units.
- **iron-silicon alloys**—a material composition containing up to 5 % silicon with balance iron.
- isotropic material—material in which the magnetic properties are the same for all directions.
- Jordan diagram—a graph showing the variation of some magnetic parameter versus frequency when the excitation is within the Rayleigh range.
- joule, J—the unit of energy in the SI system of units. One joule is one watt-second.
- lamination factor, (space factor, stacking factor), S-a numeric, less than unity and usually expressed as a percentage, which is defined as the ratio of the uniform solid height h of the magnetic material in a laminated core to the actual height h' (core buildup) when measured under a specified pressure. S is thus equal to the ratio of the volume of magnetic material in a uniform laminated core to the overall geometric volume of the core.
- lamination stack resistance-the electrical resistance measured in the direction perpendicular to the plane of lamination in a stack of laminations.
- lamination surface insulation-the insulation between core laminations produced by a surface condition or layer either formed or applied for this purpose.

DISCUSSION-In commercial practice, this insulating layer is frequently designated as core plate.

- **lamination thickness**, *d*—the active thickness of a single lamination cut from sheet stock, including any core plate material.
- **lamination width**, *w*—the width of a core lamination perpendicular to the direction of the induction therein.
- leakage flux—the flux outside the boundary of the practical magnetic circuit.

linear expansion, coefficient of, $\bar{\alpha}$ —the change in length per unit length per degree change in temperature or:

$$\bar{\alpha} = \frac{L_1 - L_0}{L_0 \cdot \Delta T}$$

where:

 L_1 = length of specimen at the higher temperature,

 L_0 = length at lower temperature, and ΔT = difference between temperatures.

loss angle, magnetic, γ —the mean angle by which the fundamental component of core loss current leads the fundamental component of exciting current, I, in an inductor having a ferromagnetic core.

DISCUSSION—The loss angle, γ , is the complement of the hysteretic angle, β .

DISCUSSION-Because of hysteresis, the instantaneous value of the loss angle will vary during the cycle of SCM excitation; however, γ is taken to be the mean effective value of this angle.

magnet—a body that produces a magnetic field external to itself.

DISCUSSION-By convention, the north-seeking pole of a magnet is marked with an N, +, or is colored red.

DISCUSSION-Natural magnets consist of certain ores such as magnetite (loadstone); artificial (permanent) magnets are made of magnetically hard materials; electromagnetics have cores made of magnetically soft materials which are energized by a current carrying winding.

magnetic circuit—a region at whose surface the magnetic induction is tangential.

DISCUSSION-A practical magnetic circuit is the region containing the flux of practical interest, such as the core of a transformer. It may consist of ferromagnetic material with or without air gaps or other feebly magnetic materials such as porcelain, brass, and so forth.

- **magnetic constant**, μ_0 —the ratio of magnetic flux density (*B*) to magnetic field strength (H) when no matter is present. Synonyms include permeability of (free) space, vacuum permeability, and permeability of unoccupied space. In the cgs-emu system of units, the magnetic constant is considered dimensionless (although it can be thought of as having units of gauss per oersted) and has a value of 1. In the SI system of units, the magnetic constant is dimensional and is equal to $4\pi \times 10^{-7}$ henry per metre.
- magnetic excursion range, ΔB , ΔH —the excursion ranges equaling the algebraic differences between the upper and lower values of B, and between the upper and lower values of *H*, in a hysteresis or flux-current loop.
- magnetic field of induction-the magnetic flux field induced in a region such that a conductor carrying a current in the region would be subjected to a mechanical force, and an electromotive force would be induced in an elementary loop rotated with respect to the field in such a manner as to change the flux linkage.
- magnetic field strength, H—the magnetic vector quantity at a point in a magnetic field which measures the ability of electric currents or magnetized bodies to produce magnetic induction at the given point.

DISCUSSION—The magnetic field strength, H, may be calculated from the current and the geometry of certain magnetizing circuits. For example, in the center of a uniformly wound long solenoid.

$$H = C(NI/l)$$

where:

- H = magnetic field strength,
- С = constant whose value depends on the system of units,
- Ν = number of turns,
- Ι = current, and l
 - = axial length of the coil.

If I is expressed in amperes and l is expressed in centimetres, then $C = 4\pi/10$ to obtain H in the cgs-emu system of units, the oersted.

If *I* is expressed in amperes and *l* is expressed in metres, then C = 1 to obtain *H* in the SI units, ampere-turn per metre.

DISCUSSION—The magnetic field strength, H, at a point in air may be calculated from the measured value of induction at the point by dividing this value by the magnetic constant μ_0 .

magnetic field strength, ac—the value of one of three dynamic magnetic field strength parameters in common use. They are:

(a) H_L —an assumed peak value computed in terms of peak magnetizing current (considered to be sinusoidal).

(b) H_z —an assumed peak value computed in terms of measured rms exciting current (considered to be sinusoidal).

(c) H_p —computed in terms of a measured peak value of exciting current, and thus equal to the value H'_{max} .

magnetic field strength, biasing, H_b —the algebraic mean value of the magnetic field strength in a magnetic material that is subjected simultaneously to a constant magnetizing field and a periodically varying magnetizing field.

DISCUSSION—The biasing magnetizing field and the biased magnetic induction are corresponding coordinates of a single point on the *B*-*H* plane but not necessarily on the normal induction curve.

DISCUSSION—The biasing magnetic field strength, H_b , is equal to the applied constant magnetizing field only when the applied periodically varying magnetizing field is symmetrical.

magnetic field strength, incremental, H_{Δ} —a value equal to one half the algebraic difference of the maximum and minimum values of the magnetic field strength during a cycle in a magnetic material that is subjected simultaneously to a biasing magnetic field strength and a symmetrical periodically varying magnetic field strength.

Twice the incremental magnetic field strength is indicated by the symbol ΔH .

$$H_{\Lambda} = \Delta H/2$$

- **magnetic field strength, maximum**—(1) H_m —the maximum value of H in a dc hysteresis loop. (2) H_{max} —the maximum value of H in an ac flux-current loop.
- **magnetic flux**, φ —the product of the magnetic flux density, *B*, and the area of a surface (or cross section), *A*, when the magnetic flux density *B* is uniformly distributed and normal to the plane of the surface.

$$\varphi = BA$$

where:

- φ = magnetic flux,
- B = magnetic flux density, and
- A =area of the surface.

DISCUSSION—If the magnetic flux density is not uniformly distributed over the surface, the flux, φ , is the surface integral of the normal component of *B* over the area.

$$\varphi = \iint_{s} B \bullet dA$$

DISCUSSION-Magnetic flux is a scalar and has no direction.

magnetic flux density, *B*—that magnetic vector quantity which at any point in a magnetic field is measured either by the mechanical force experienced by an element of electric current at the point, or by the electromotive force induced in an elementary loop during any change in flux linkages with the loop at the point.

DISCUSSION—If the flux, ϕ is uniformly distributed and normal to a surface or cross section, then the magnetic flux density through that cross-section is:

$$B = \varphi/A$$

where:

B = magnetic flux density,

$$\varphi$$
 = total flux, and

A = cross-sectional area.

The relationship between magnetic flux density and magnetic field strength depends on the system of units being used. In the cgs-emu system or Gaussian system of units, the magnetic flux density is measured in gauss and is defined as:

$$B = 4\pi M + H$$

where:

$$B = magnetic flux density (gauss),$$

 $4\pi M$ = magnetization (volume) (gauss), and

H = magnetic field strength (oersted).

In the SI system of units, two different conventions or definitions are found. The definition used by the IEC and NIST is the Sommerfeld convention where the magnetic flux density is measured in tesla and is defined as:

$$B = \mu_0 (M + H)$$

where:

- B = magnetic flux density (tesla),
- μ_0 = magnetic constant = $4\pi \times 10^{-7}$ (henry/metre),
- M = magnetization (ampere/metre), and

H = magnetic field strength (ampere/metre).

An alternate SI unit definition is the Kennelly convention and is more likely to be encountered in the technical and commercial literature and used in magnetic measurements. In this case the magnetic flux density is given by:

$$B = J + \mu_0 H$$

where:

- B = magnetic flux density (tesla),
- J = magnetic polarization (tesla),
- $\mu_0 = \text{magnetic constant} = 4\pi \times 10^{-7}$ (henry/metre), and
- H = magnetic field strength (ampere/metre).
- magnetic induction, B—an alternate term for magnetic flux density.
- **magnetic lamination steel**—a flat-rolled, low-carbon (usually below 0.06 %) steel containing 0.0 to 1.0 % silicon and up to 0.4 % aluminum and having similar core loss in all directions.

magnetic line of force—an imaginary line in a magnetic field which at every point has the direction of magnetic induction at that point.

DISCUSSION—Extended lines of force must always form nonintersecting closed loops. **magnetic moment,** *m*—a measure of the magnetic field strength, *H*, produced at points in space by a plane current loop or a magnetized body.

DISCUSSION—The magnetic moment of a plane current loop is a vector, the magnitude of which is the product of the area of the loop and the current; the direction of the vector is normal to the plane of the loop in that direction around which the current has a clockwise rotation when viewed along the vector.

DISCUSSION—The magnetic moment of a magnetized body is the volume integral of the magnetization, M.

DISCUSSION—In the cgs-emu system of units, magnetic moment is usually defined as the pole strength multiplied by the distance between poles. This is sometimes called the magnetic dipole moment.

- **magnetic ohm**—the unit of reluctance sometimes used in the cgs-emu system of units. One magnetic ohm equals one gilbert/maxwell or $4\pi/10^9$ ampere-turns/weber.
- **magnetic particle inspection method**—a method for detecting magnetic discontinuities or inhomogeneities on or near the surface in suitably magnetized materials that uses finely divided magnetic particles that tend to congregate in regions of magnetic nonuniformity associated with the magnetic discontinuities or inhomogeneities.

DISCUSSION—Magnetic particle inspection is an accepted method for the detection of defects.

magnetic polarization, *J*—magnetic dipole moment per unit volume of magnetic material. It is important to note that the calculation of magnetic polarization is different in the two units systems. In the cgs-emu or Gaussian system of units, the magnetic polarization is the intrinsic induction (B_i) divided by 4π . It is expressed in units of emu/cm³. In the SI system, the magnetic polarization is an alternate name for intrinsic induction and is defined as the product of the magnetic constant (μ_0) and the magnetization (*M*) or:

$$J = \mu_0 M \tag{2}$$

In the SI system, the magnetic polarization is expressed in units of tesla.

magnetic pole—the magnetic poles of a magnet are those portions of the magnet toward which or from which the external magnetic induction appears to converge or diverge, respectively.

DISCUSSION—In the hypothetical case of a uniformly magnetized body of constant cross-sectional area, the poles would be located at its ends.

DISCUSSION—By convention, the north-seeking pole is marked with an N, or + , or is colored red.

magnetic pole strength, *p*—the magnetic moment divided by the distance between the poles.

p = m/l

where:

- p = pole strength,
- m = magnetic moment, and

l = distance between the poles.

magnetics (**magnetism**)—that branch of science which deals with the laws of magnetic phenomena and their application to practice.

- **magnetician**—one skilled in the theory and practice of magnetics.
- **magnetization,** *M*—the vector sum of the magnetic moment per unit volume of magnetic material. It is also sometimes referred to as the intensity of magnetization in older literature although this term is now a synonym for magnetic polarization (*J*). For the cgs-emu or Gaussian system of units, the magnetization is expressed in units of emu/cm³. The quantity $4\pi M$ has units of gauss and is numerically equal to the intrinsic induction (*B_i*). For the SI system of units, the magnetization has units of ampere per metre.

magnetizing current, ac, I_m —See current, ac magnetizing. magnetizing force, H—an alternate term for magnetic field strength.

magnetodynamic—the magnetic condition when the values of magnetic field strength and induction vary, usually periodically and repetitively, between two extreme limits.

magnetomotive force, \mathcal{F} —the line integral of the magnetizing field around any flux loop in space.

$$\mathcal{F} = \int H \cdot dl$$

where:

 \mathcal{F} = magnetomotive force,

H = magnetic field strength, and

dl = unit length along the loop.

DISCUSSION—The magnetomotive force is proportional to the net current linked with any closed loop of flux or closed path.

$$F = CN$$

where:

- \mathcal{F} = magnetomotive force,
- N = number of turns linked with the loop,
- I = current in amperes, and
- C = constant whose value depends on the system of units. In the cgs-emu system of units, $C = 4\pi/10$. In the SI system, C = 1.
- **magnetostatic**—the magnetic condition when the values of magnetic field strength and induction are considered to remain invariant with time during the period of measurement. This is often referred to as a dc (direct current) condition.

magnetostriction—the change in dimensions of a body resulting from magnetization.

mass, active, m_1 —the effective value of mass, which may be used with values of ℓ_1 , and A' to evaluate a magnetic core as though it has an equivalent uniform flux path having the same induction at all points.

mass, total, *m*—the actual mass of a magnetic core.

maxwell, φ —the unit of magnetic flux in the cgs-emu system of units. One maxwell equals 10^{-8} weber. See **magnetic flux.**

$$e = -Nd\varphi/dt \times 10^{-8}$$

where:

- *e* = induced instantaneous emf in volts,
- $d\varphi/d t =$ time rate of change of flux in maxwells per second, and
- N = number of turns surrounding the flux, assuming each turn is linked with all the flux.
- **measurement accuracy**—the numerical or percentage deviation of a measured value (or a value computed from one or more measurements) from its true value or from some absolute or standardized value. This deviation may depend upon the procedures used and is caused chiefly by systematic errors in the calibrations of the equipment used, which errors, if known, may be removed from the measured data to enhance the accuracy of the measured or computed value.
- **Néel wall**—in a thin magnetic film (less than about 10^{-6} cm thick for iron), a domain wall in which the magnetic moment at any point is substantially parallel to the film surface. See also **domain wall**.
- **nonmagnetic**—a relative term describing a material which, for practical purposes, may be considered to have a relative permeability close to unity.

DISCUSSION—Certain materials may be nonmagnetic only under limited conditions.

- **nonoriented electrical steel**—a flat-rolled electrical steel which has approximately the same magnetic properties in all directions.
- **oersted, Oe**—the unit of magnetic field strength in the cgsemu system of units. One oersted equals a magnetic field strength of 1 Gb/cm of flux path. One oersted equals $1000/4\pi$ or 79.58 ampere-turns per metre. See **magnetic field strength.**
- **paramagnetic material**—a material having a relative permeability which is slightly greater than unity, and which is practically independent of the magnetizing force.
- **permeability, ac, magnetic**—a generic term used to represent a dynamic material property. It is expressed as the ratio of the magnetic induction, B, to the magnetic field strength, H, that produced the induction. The value of H may be calculated from several different component values of the exciting current. (See **magnetic field strength, ac,** and various permeabilities.)

DISCUSSION—The numerical value for any permeability is meaningless unless the corresponding *B* or *H* excitation level is specified. For incremental permeabilities not only the corresponding dc *B* or *H* excitation level must be specified, but also the dynamic excursion limits of dynamic excitation range (ΔB or ΔH).

permeability, ac, rms, impedance, μ_z —the ratio of the measured peak value of magnetic induction, *B*, to the apparent magnetic field strength, H_z , calculated from the rms value of the total exciting current.

DISCUSSION—The value of the current used to compute H_z is obtained by multiplying the measured value of rms exciting current by 1.414. This assumes that the total exciting current is magnetizing current and is sinusoidal.

permeability, ac, inductance, μ_L —the value developed from the measured inductive component of the electrical circuit

for a material in an *SCM* condition, the permeability is evaluated from the measured inductive component of the electrical circuit representing the magnetic specimen. This circuit is assumed to be composed of paralleled linear inductive and resistive elements, ωL_1 and R_1 .

- **permeability, ac, peak,** μ_p —the ratio of the measured peak value of magnetic induction to the peak value of the magnetic field strength, H_p , calculated from the measured peak value of the exciting current.
- **permeability, ideal,** μ_a —the ratio of the magnetic induction to the corresponding magnetic field strength after the material has been simultaneously subjected to a value of ac magnetizing field approaching saturation superimposed on a given dc magnetizing field, and the ac magnetizing field has thereafter been gradually reduced to zero. The resulting ideal permeability is thus a function of the incremental field and residual strongly polarized domains that remain after the ac field is reduced to zero.

DISCUSSION—Ideal permeability, sometimes called anhysteretic permeability, is principally significant to feebly magnetic material and to the Rayleigh range of soft magnetic material.

- permeability, ac, impedance, incremental, $\mu_{\Delta z}$ —the value of impedance permeability obtained when ac excitation is superimposed on a dc excitation.
- **permeability, ac, inductance, incremental,** $\mu_{\Delta L}$ —the value of inductance permeability, μ_L , obtained when the ac excitation is superimposed on a dc excitation.
- **permeability, initial dynamic,** μ_{0d} —the limiting value of each of the various ac permeabilities reached in a magnetic material as the magnetizing current is first raised to a moderate value then is progressively and gradually reduced to a zero value. See **initial inductance**.

DISCUSSION—This same value, μ_{0d} , is also equal to the initial values of both impedance permeability, μ_z , and peak permeability, μ_p .

- **permeability, instantaneous**—(Coincident with B_{max}), μ_t with *SCM* excitation, the ratio of the maximum induction B_{max} to the instantaneous magnetic field strength, H_t , which is the value of apparent magnetic field strength, H, determined at the instant when *B* reaches a maximum.
- **permeability, dc,** μ —a generic term used to represent a number of magnetostatic material properties. The value represented is the ratio of the induction, *B*, to the dc magnetic field strength, *H*, producing magnetic flux under the specific magnetizing conditions.

DISCUSSION—The magnetic constant μ_0 is a scalar quantity differing in value and uniquely determined by each electromagnetic system of units. In the cgs–emu system of units, μ_0 is 1 gauss/oersted, and in the SI system, $\mu_0=4\pi\times 10^{-7}$ H/m.

DISCUSSION—Relative permeability is a pure number which is the same in all unit systems. The value and dimension of absolute permeability depends on the system of units used.

DISCUSSION—For any ferromagnetic material permeability is a function of the degree of magnetization. However, initial permeability, μ_0 , and maximum permeability, μ_m , are unique values for a given specimen under specified conditions.

DISCUSSION—Except for initial permeability, μ_0 , a numerical value for any of the dc permeabilities is meaningless unless the corresponding Bor H excitation level is specified.

Discussion—For the incremental permeabilities, μ_{Δ} and $\mu_{\Delta i}$, a numerical value is meaningless unless both the corresponding values of mean excitation level (B or H) and the excursion range (ΔB or ΔH) are specified.

permeability, dc, absolute, μ_{abs} —the ratio of the total induction, ΔB , to the dc magnetic field strength, ΔH , which produced it. Also described as:

$$\mu_{\rm abs} = \mu_0 + \mu_i = \mu_0 \cdot \mu_r$$

permeability, differential, μ_d —the ratio of an increment of induction, ΔB , to an increment of magnetic field strength, ΔH , for any point on a dc hysteresis loop. It is also the absolute slope $(\Delta B/\Delta H)$ of the curve at any point on the normal magnetizing curve.

DISCUSSION-For a symmetrical series circuit in which each component has the same cross-sectional area, reluctance values add directly giving:

$$\mu_{e\!f\!f} = \frac{\ell_1 + \ell_2 + \ell_3 + \cdots}{\frac{\ell_1}{\mu_1} + \frac{\ell_2}{\mu_2} + \frac{\ell_3}{\mu_3} + \cdots}$$

For a symmetrical parallel circuit in which each component has the same flux path length, permeance values add directly giving:

$$\mu_{eff} = \frac{\mu_1 A_1 + \mu_2 A_2 + \mu_3 A_3 + \cdots}{A_1 + A_2 + A_3 + \cdots}$$

- **permeability, incremental intrinsic,** μ_{A_i} —the ratio of the change in the intrinsic induction B_i to the corresponding change in magnetic field strength when the mean induction differs from zero.
- permeability, incremental, μ_{Δ} —the ratio of the change of magnetic induction, B, to the corresponding change in magnetic field strength, H, under dc biasing conditions and when B is not equal to zero. This value is also the slope of a straight line joining the excursion limits of an incremental hysteresis loop.

DISCUSSION—When the change in H is reduced to zero, the incremental permeability, μ_{Δ} , becomes the reversible permeability, μ_{rev} .

- **permeability, initial,** μ_i —the limiting value approached by the normal permeability as the applied magnetic field strength, H, is reduced to zero. The initial permeability is equal to the slope of the normal induction curve at the origin of the linear B and H axes.
- permeability, intrinsic-the ratio of the calculated value of intrinsic induction B_i , to the corresponding magnetic field strength, H.

DISCUSSION-See definition of susceptibility.

permeability, maximum, \mu_m—the highest value of permeability achieved when the magnetic material is subjected to a symmetrically cyclically magnetized condition.

DISCUSSION-Under dc test conditions the maximum permeability, μ_m , is the highest value of normal permeability μ , developed by the magnetic material.

DISCUSSION-Under ac test conditions, the maximum permeability is the highest value of ac permeability achieved under symmetrically cyclically magnetized conditions and with no biasing magnetic field in the magnetic material.

- permeability, normal, dc, μ —the ratio of any magnetic induction, B, to the corresponding dc magnetic field strength, H, when the magnetic material has been subjected to SCM conditions.
- permeability, relative, μ_r —the ratio of the absolute permeability of a material to the magnetic constant μ_0 , giving a pure numeric parameter.

DISCUSSION-In the cgs-emu system of units, the relative permeability is numerically the same as the absolute permeability.

- permeability, dc, reversible, μ_{rev} —the ratio of magnetic induction, ΔB , to the dc magnetic field strength increase, ΔH , when the magnetic field strength is first established at a value, H, then reduced by a small increment H, and then reestablished to the value, H.
- **permeability, unoccupied space,** μ_{ν} —the permeability of space (vacuum), identical with the magnetic constant, μ_0 .
- **permeance**, P—the reciprocal of the reluctance of a magnetic circuit.
- **power factor, magnetic, cos** γ —(1) the cosine of the angle between vectors representing the rms values of the applied voltage of a circuit and the current in circuit. (2) the ratio of the active (real) power to the apparent power in an ac circuit.
- power, reactive (quadrature), P_q —the product of the rms current in an electrical circuit, the rms voltage across the circuit, and the sine of the angular phase difference between the current and the voltage.

$$P_q = EI\sin\theta$$

where:

 P_q = reactive power in vars, E = voltage in volts,

- Ι = current in amperes, and
- θ = angular phase by which E leads I.

DISCUSSION-The reactive power supplied to a magnetic core having an SCM excitation is the product of the magnetizing current and the voltage induced in the exciting winding.

- power, active (real), P—the product of the rms current in a circuit, the rms voltage across the circuit and the cosine of the angular phase difference between the current and voltage.
- relay steel-soft magnetic iron-based alloy used in the construction of electromechanical relays and solenoid switches. High flux densities, low coercive fields, suitable mechanical hardness, and ease of fabrication are primary concerns.
- reluctance, \mathcal{R} —that quantity which determined the magnetic flux, φ , resulting from a given magnetomotive force, \mathcal{F} , around a magnetic circuit.

$$\Re = \mathcal{F}/\varphi$$

where:

 \Re = magnetic reluctance,

 \mathcal{F} = magnetomotive force, and

 φ = flux.

The reluctance is measured in gilberts per maxwell (magnetic ohms) in the cgs-emu system and in ampere-turns per weber in the SI system.

reluctivity, v—the reciprocal of the permeability of a medium.

remanence, B_{dm} —the maximum value of the remanent induction for a given geometry of the magnetic circuit.

DISCUSSION—If there are no gaps or other inhomogeneities in the magnetic circuit the remanence, B_{dm} , is equal to the retentivity, B_{rs} ; if air gaps or other inhomogeneities are present, B_{dm} will be less than B_{rs} .

remanent induction, B_d —See induction, remanent. residual induction, B_r —See induction, residual.

resistance, core, R_1 —the effective ac resistance of a hypothetical parallel resister that is considered to carry exclusively the core loss current, I_c , when a voltage is applied to the terminals of a coil encircling a magnetic core.

DISCUSSION—The product, $I_c^2 R_1$, equals the total core loss, P_c .

resistance, winding, R_w —the effective ac series resistance of an inductor when no ferromagnetic materials are present.

DISCUSSION—At low frequencies, R_w is only slightly greater than the dc resistance of the winding.

DISCUSSION—The product $I^2 R_w$ equals the sum of the copper, eddy current, and dielectric losses in the winding.

DISCUSSION—The total active power, P, delivered to an inductor having a ferromagnetic core is:

 $P = P_c + I^2 R_w$

resistivity, ρ —that property of a material which determines its resistance to the flow of an electric current, expressed by:

 $\rho = R \cdot A / \ell$

where:

R = resistance of the specimen, Ω ;

 $A = \text{cross sectional area, cm}^2$; and

 ℓ = length of specimen, cm.

Units of electrical resistivity are ohm-centimetre (cgs) and ohm-metre (SI).

DISCUSSION—This value is equivalent to the resistance between opposite faces of a cube of unit dimensions, and is designated "specific resistivity" or, by usage, "volume resistivity."

- **resistivity, surface insulation (of a single-strip specimen)** the effective resistivity of a single insulative layer tested between applied bare metal contacts and the base metal of the insulated test specimen.
- **resistivity, surface insulation (of multi-strip specimens)** the resistance of a unit area per test strip calculated from a measurement of the electrical resistance of a stack of strips with test current perpendicular to the strip surface.

resistivity, volume ρ —See resistivity.

retentivity, $B_{r\,s}$ — the property of a magnetic material which is measured by its maximum value of the residual induction. DISCUSSION—Retentivity is usually associated with saturation induction. SI—an abbreviation for the International System of Units.

- **skin effect, magnetic**—the nonuniform magnetodynamic term applies to the nonuniform distribution of induction existing at various points in the cross section of a magnetic core. Skin effect is produced primarily by eddy current phenomena and it increases with the frequency of ac excitation. It can ordinarily be neglected in testing at commercial power frequencies.
- **solid area**, *A'*—the effective solid portion of the cross section of a core (perpendicular to the induction) which is composed of magnetic material.
- **stabilization**—a treatment of magnetic material designed to increase the permanency of its magnetic properties or conditions.
- storage factor, magnetic, Q_m —the cotangent of the hysteretic angle that is equal to the ratio of the magnetizing current, I_m , to the core loss current I_c .

 $Q_m = \cot \beta = \tan \gamma = 1/D_m = I_m/I_c = R_1/\omega L_1$

DISCUSSION—The storage factor is also given by the ratio of 2π times the maximum energy stored in the core to the energy dissipated in the core (hysteresis and eddy current heat loss) per cycle of a periodic *SCM* excitation.

susceptibility, κ —a ratio of the intrinsic induction, B_I , as a result of the magnetization of a material to the induction in space because of the influence of the corresponding magnetic field strength, H.

$$\kappa = B_i / \mu_0 H = \mu_r - 1$$

where:

 μ_0 = magnetic constant and

ĸ

 μ_r = relative permeability.

DISCUSSION—The preceding equations apply to an isotropic material if the SI, an abbreviation for the international system of units, are used.

DISCUSSION-In the classical cgs-emu system of units:

$$x = B_i / 4\pi \mu_0 H = (\mu_r - 1) / 4\pi$$

- susceptibility, initial, κ_0 —the limiting value of susceptibility when the intrinsic induction approaches zero.
- **susceptibility, mass,** χ —the susceptibility divided by the density of a body is called the susceptibility per unit mass, χ , or simply the mass susceptibility.

 $\chi = \kappa / \delta$

where:

 δ = density.

- **symmetrically cyclically magnetized condition,** *SCM*—a magnetic material is in a *SCM* condition when, under the influence of a magnetic field strength that varies cyclically between two equal positive and negative limits, its successive hysteresis loops or flux-current loops are both identical and symmetrical with respect to the origin of the axes.
- tesla, T—the SI unit of magnetic flux density. One tesla is equal to 1.0 Wb/m^2 or 10^4 gausses.

tolerance limits, specification or calibration—(1) The permitted degree of departure of the value of some parameter, X, from its nominal value X_n . (2) The guaranteed maximum error in the reading of some instrument scale, or in the calibration of some circuit component, or in the value of any parameter, from its correct value (which may be assumed to be a true value within the resolution of the calibration). Symmetrical tolerance limits, which do not involve the measurement of any parameter, may be quoted in two ways:

(a) incremental tolerance— $\Delta \chi$ —this is satisfied by the following limits:

$$X_n + \Delta \chi \stackrel{=}{>} X \stackrel{\geq}{=} X_n - \Delta \chi$$

(b) fractional tolerance— T_x —this is defined by the following absolute ratio:

$$T_x = \left| \Delta \chi / X_n \right|$$

which is usually as a percentage, so that the allowed limits of X becomes $X_n |1 \pm T_x|$. For a sum or difference function, the incremental tolerance, ΔF , equals the absolute sum of the component Δ values. For a product or ratio function, the fractional tolerance, T_F , equals the absolute sum of the component T values. For any other function, using calculus as follows:

$$\Delta F(x, y, x \cdots) = \left(\frac{\delta F}{\delta x}\right) \Delta x + \left(\frac{\delta F}{\delta y}\right) \Delta y + \left(\frac{\delta F}{\delta z}\right) \Delta z \cdots$$

DISCUSSION—The preceding tolerance limits are symmetrical limits, such as ± 5 %. Occasionally, unsymmetrical limits may be specified such as +5 %, -2 % or 0 %, -5 % or 10 %, -0 %, and so forth.

- **var**—the unit of reactive (quadrature) power. One var is the product of one volt and one ampere in phase quadrature.
- voltage, induced secondary, E_2 —the rms value of the open circuit voltage induced in the secondary winding N_2 of an inductor as a result of cyclic variations of the flux linkages with N_2 .

volt-ampere, P_a —the unit of apparent power.

- watt, W—the unit of active power. One watt is energy, work, or quantity of heat expended at a rate of one joule per second.
- weber, Wb—the SI unit of magnetic flux. The weber is the magnetic flux whose decrease to zero when linked with a single turn induces in the turn a voltage whose time integral is one volt-second. One weber equals 10⁸ maxwells. See magnetic flux.
- winding loss, (copper loss), P_w —the power expended, as heat, in the conductors of an inductor or resistor, or both, as a result of the electric current in them.

APPENDIX

X1. SELECTED CONVERSION FACTORS USED IN MAGNETIC TESTING

Multiply	Ву	To Obtain	
	Sinusoidal Waveform		
Peak current or voltage	0.707 11	Rms current or voltage	
Peak current or voltage	0.636 62	Average current or voltage	
Rms current or voltage	1.4142	Peak current or voltage	
Rms current or voltage	0.900 32	Average current or voltage	
Average current or voltage	1.5708	Peak current or voltage	
Average current or voltage	1.1107	Rms current or voltage	
	Magnetic Flux Density, B		
Gauss	6.4516	Lines per square inch	
Gauss	6.4516×10^{-8}	Weber per square inch	
Gauss	10 ⁻⁴	Weber per square metre	
Gauss	10 ⁻⁴	Tesla	
Lines per square inch	0.155 00	Gauss	
Lines per square inch	1.5500×10^{-5}	Tesla (weber per square metre)	
Lines per square inch	10 ⁻⁸	Weber per square inch	
Weber per square inch	1.5500×10^{7}	Gauss	
Weber per square inch	10 ⁸	Lines per square inch	
Weber per square inch	1550	Tesla (Weber per square metre)	
	Field Strength, H		
Oersted	2.0213	Ampere-turn per inch	
Oersted	0.795 77	Ampere-turn per centimetre	
Oersted	79.577	Ampere-turn per metre	
Ampere-turn per centimetre	1.2566	Oersted	
Ampere-turn per centimetre	2.5400	Ampere-turn per inch	
Ampere-turn per centimetre	100.00	Ampere-turn per metre	
Ampere-turn per inch	0.494 74	Oersted	
Ampere-turn per inch	0.393 70	Ampere-turn per centimetre	
Ampere-turn per inch	39.370	Ampere-turn per metre	
Ampere-turn per metre	0.012 566	Oersted	
Ampere-turn per metre	10 ⁻²	Ampere-turn per centimetre	
Ampere-turn per metre	0.025 400	Ampere-turn per inch	

A340 – 17

Multiply	Ву	To Obtain
	Permeability, µ	
Gauss per oersted	3.1918	Lines per ampere-turn inch
Gauss per oersted	3.1918×10^{-8}	Weber per ampere-turn inch
Gauss per oersted	1.2566×10^{-6}	Weber per ampere-turn metre
Gauss per oersted	1.2566×10^{-6}	Henry per metre
Gauss per oersted	1.2566×10^{-6}	Tesla metre per ampere
Weber per ampere-turn metre	7.9577×10^{5}	Gauss per oersted
Weber per ampere-turn metre	2.5400×10^{4}	Lines per ampere-turn inch
Weber per ampere-turn metre	0.025 400	Weber per ampere-turn inch
Weber per ampere-turn inch	3.1330×10^{5}	Gauss per oersted
Weber per ampere-turn inch	10 ⁶	Lines per ampere-turn inch
Weber per ampere-turn inch	39.370	Weber per ampere-turn metre
Lines per ampere-turn inch	0.313 30	Gauss per oersted
Lines per ampere-turn inch	39.370×10^{-8}	Weber per ampere-turn metre
Lines per ampere-turn inch	10 ⁻⁸	Weber per ampere-turn inch
	Miscellaneous Conversion	S
Magnetic flux (maxwell)	10 ⁻⁸	Weber
Henry	1.0	Weber per ampere
Watts per pound	2.205	Watts per kilogram
Volt ampere per pound	2.205	Volt ampere per kilogram
Volume resistivity (Ωcm)	10 ⁻²	Ohm metre
Energy product (allotted)	7.958×10^{-3}	Joule per cubic metre

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/