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Standard Terminology of Symbols and Definitions Relating to Magnetic Testing[1]

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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.

Part 1—Symbols Used in Magnetic Testing

Symbol	Term
α	cross-sectional area of *B* coil
A	cross-sectional area of specimen
A'	solid area
B	magnetic induction; magnetic flux density
ΔB	excursion range of induction
B_b	biased induction
B_d	remanent induction
B_{dm}	remanence
B_dH_d	energy product
$(B_dH_d)_m$	maximum energy product
B_Δ	incremental induction
B_i	intrinsic induction
B_m	maximum induction in a hysteresis loop
B_{max}	maximum induction in a flux current loop
B_r	residual induction
B_{rs}	retentivity
B_s	saturation induction
cf	crest factor
CM	cyclically magnetized condition
d	lamination thickness
D_B	demagnetizing coefficient
df	distortion factor
D_m	magnetic dissipation factor
E	exciting voltage
E_1	induced primary voltage
E_2	induced secondary voltage
E_f	flux volts
f	cyclic frequency in hertz
$\mathcal{F}$	magnetomotive force
ff	form factor
H	magnetic field strength
ΔH	excursion range of magnetic field strength
H_b	biasing magnetic field strength
H_c	coercive field strength
H_{ci}	intrinsic coercive field strength
H_{cs}	coercivity
H_d	demagnetizing field strength
H_Δ	incremental magnetic field strength
H_g	air gap magnetic field strength
H_L	ac magnetic field strength (from an assumed peak value of magnetizing current
H_m	maximum magnetic field strength in a hysteresis loop
H_{max}	maximum magnetic field strength in a flux-current loop
H_p	ac magnetic field strength (from a measured peak value of exciting current)
H_t	instantaneous magnetic field strength (coincident with B_{max})
H_z	ac magnetic field strength force (from an assumed peak value of exciting current)
I	ac exciting current (rms value)
I_c	ac core loss current (rms value)
I_{dc}	constant current
I_m	ac magnetizing current (rms value)
J	magnetic polarization
k'	coupling coefficient
ℓ	flux path length
ℓ_1	effective flux path length
ℓ_g	gap length
$\mathcal{L}$ (also ϕN)	flux linkage
$\mathcal{L}_m$	mutual flux linkage
L	self inductance
L_1	core inductance
L_Δ	incremental inductance
L_i	intrinsic inductance
L_m	mutual inductance
L_0	initial inductance
L_s	series inductance
L_w	winding inductance
$\mathfrak{m}$	magnetic moment
M	magnetization
m	total mass of a specimen
m_1	active mass of a specimen
N_D	demagnetizing factor
N_1	turns in a primary winding

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N_2	turns in a secondary winding
N_1I/ℓ_1	ac excitation
p	magnetic pole strength
$\mathcal{P}$	permeance
P	active (real) power
P_a	apparent power
$P_{a\ (B;f)}$	specific apparent power
P_c	total core loss
$P_{c\ (B;f)}$	specific core loss
$P_{c\Delta}$	incremental core loss
P_e	normal eddy current core loss
$P_{\Delta e}$	incremental eddy current core loss
P_h	normal hysteresis core loss
$P_{\Delta h}$	incremental hysteresis core loss
P_q	reactive (quadrature) power
P_r	residual core loss
P_w	winding loss (copper loss)
P_z	exciting power
$P_{z\ (B;f)}$	specific exciting power
Q_m	magnetic storage factor
$\mathcal{R}$	reluctance
R_1	core resistance
R_w	winding resistance
S	lamination factor (stacking factor)
SCM	symmetrically cyclically magnetized condition
T_c	Curie temperature
w	lamination width
W_h	hysteresis loop loss
$\bar{\alpha}$	linear expansion, coefficient (average)
$\Delta\chi$	incremental tolerance
β	hysteretic angle
γ	loss angle
$\cos\gamma$	magnetic power factor
γ_p	proton gyromagnetic ratio

Γ_m	magnetic constant
δ	density
κ	susceptibility
ac Permeabilities:	
μ_a	ideal permeability
μ_L	inductance permeability
$\mu_{\Delta}L$	incremental inductance permeability
μ_{0d}	initial dynamic permeability
μ_p	peak permeability
$\mu_{\Delta p}$	incremental peak permeability
μ_i	instantaneous permeability
μ_z	impedance permeability
$\mu_{\Delta z}$	incremental impedance permeability
dc Permeabilities:	
μ	normal permeability
μ_{abs}	absolute permeability
μ_d	differential permeability
μ_{Δ}	incremental permeability
μ_{eff}	effective circuit permeability
μ_i	intrinsic permeability
$\mu_{\Delta i}$	incremental intrinsic permeability
μ_m	maximum permeability
μ_0	initial permeability
μ_r	relative permeability
μ_v (also Γ_m)	space permeability
μ_{rev}	reversible permeability
$\mu'/\cot\gamma$	figure of merit
ν	reluctivity
π	the numeric 3.1416
ρ	resistivity
ϕ	magnetic flux
ϕN	flux linkage (see $\mathcal{L}$)
χ	mass susceptibility
χ_0	initial susceptibility
ω	angular frequency in radians per second

Part 2—Definition of Terms Used in Magnetic Testing

ac excitation, N_1I/ℓ_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.

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.

$$P = EI\cos\theta$$

NOTE 1—The portion of the active power that is expended in a magnetic core is the total core loss, P_c.

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

NOTE 2—The aging treatments usually specified are:
(*a*) 100 h at 150°C or
(*b*) 600 h at 100°C.

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

NOTE 3—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.

NOTE 4—In the cgs-emu system of units, H_g 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.

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 volt-ampere, 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 ($9\ 274\ 078 \times 10^{-21}$ erg/gauss or $9\ 274\ 078 \times 10^{-24}$ 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, Γ_m, is unity.

coercive field strength, H_c—the (dc) magnetic field strength required to restore the magnetic induction to zero after the material has been symmetrically cyclically magnetized.

coercive field strength, intrinsic, H_{ci}—the (dc) magnetic field strength required to restore the instrinsic magnetic induction to zero after the material has been symmetrically cyclically magnetized.

coercivity, H_{cs}—the maximum value of coercive field strength that can be attained when the magnetic material is symmetrically cyclically magnetized to saturation induction, B_S.

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.

NOTE 5—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.

NOTE 6—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.

NOTE 7—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.

NOTE 8—For a sinusoidal variation the crest factor is $\sqrt{2}$.

Curie temperature, T_c—the temperature above which a ferromagnetic 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.

NOTE 9—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.

NOTE 10—Examples of customary units used in ASTM A06 standards include:

Quantity Name	Quantity Symbol	Unit Name	Unit Symbol
Magnetic field strength	H	oersted	Oe
Magnetic induction (magnetic flux density)	B	gauss	G
Specific core loss	$P_c(\beta;f)$	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 flux-current loops on successive cycles which are not symmetrical with respect to the origin of the axes.

demagnetization curve—the portion of a flux versus dc current plot (dc hysteresis loop) that lies in the second or fourth quadrant, that is, between the residual induction point, B_r, and the coercive force point, H_c. Points on this curve are designated by the coordinates, B_d and H_d.

demagnetizing coefficient, D_B—is defined by the equation:

$$D_B = [\Gamma_m(H_a - H)]/B_i$$

where:

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

NOTE 11—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/cm^3. In SI units, kg/m^3.

diamagnetic material—a material whose relative permeability is less than unity.

NOTE 12—The intrinsic induction, B_i, is oppositely directly to the applied magnetizing force H.

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:

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

NOTE 13—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.

NOTE 14—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.

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

NOTE 15—There are no dc components (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 cm^2. 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 m^2 is given by

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

Magnetization, *M*, the magnetic moment per unit volume, has units erg/(Oe-cm^3), often expresssed as emu/cm^3.

energy product, B_dH_d—the product of the coordinate values of any point on a demagnetization curve.

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.

NOTE 16—The maximum value of the energy product, $(B_dH_d)_m$, corresponds to the maximum value of the external energy.

NOTE 17—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.

NOTE 18—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 Fe_2 O_3, 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, $\mu'/\cot\gamma$—the ratio of the real part of the complex relative permeability to the dissipation factor of a ferromagnetic material.

NOTE 19—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.

NOTE 20—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.

$$\mathcal{L} = \phi_1 + \phi_2 + \phi_3 + \cdots\phi_N$$

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.

NOTE 21—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.

$$E_f = 4.443\, B_{max}A'Nf \times 10^{-8} \text{ V } (SCM \text{ excitation})$$
$$E_f = 2.221\, \Delta\, BA'\, Nf \times\, 10^{8} \text{ V } (CM \text{ excitation})$$
$$E_f = 1.1107\, E_{avg}$$

which

A′ = solid cross-sectional area of the core in cm^2,
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.

NOTE 22—For a sinusoidal variation, the form factor is:

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

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

NOTE 23—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 induction in the cgs-emu system of units. The gauss is equal to 1 maxwell per square centimetre of 10^{-4} tesla. See **magnetic induction (flux density).**

gilbert, Gb—the unit of magnetomotive force in the cgs-emu system of units. The gilbert is a magnetomotive force of 4π/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.

NOTE 24—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:

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

where:

f = resonance frequency in cycles per second (hertz) and
γ_p = gyromagnetic ratio (the accepted value at present for water is $2.675\ 12 \times 10^4$ 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.

NOTE 25—In this case, both of the limiting values of *H* and *B* are in the same direction.

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

NOTE 26—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 gauss-oersteds. Using the cgs-emu system of units:

$$W_h = (\int HdB/4\pi) \text{ ergs}$$

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.

NOTE 27—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.

NOTE 28—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.

NOTE 29—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 self-inductance which is due to the intrinsic induction in a ferromagnetic core.

NOTE 30—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:

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

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

NOTE 31—If $\mathcal{L}_2$ is in maxwell-turns and I_1 is in amperes, then the mutual inductance in henries is defined by the equation:

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

NOTE 32—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
di_1/dt = time rate of change of the current in the primary.

NOTE 33—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.

NOTE 34—If $\mathcal{L}$ is in maxwell-turns and I in amperes, then the self-inductance in henries is defined by the equation:

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

NOTE 35—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.

NOTE 36—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.

NOTE 37—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:

$$B_i = B - \Gamma_m H$$

NOTE 38—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.

NOTE 39—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.

NOTE 40—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.

NOTE 41—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.

NOTE 42—The loss angle, γ, is the complement of the hysteretic angle, β.

NOTE 43—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.

NOTE 44—By convention, the north-seeking pole of a magnet is marked with an *N*, +, or is colored red.

NOTE 45—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.

NOTE 46—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 (permeability of space), Γ_m—the dimensional scalar factor that relates the mechanical force between two currents to their intensities and geometrical configurations. That is:

$$dF = \Gamma_m I_1 I_2 dl_1 \times (dl_2 \times r_1)/nr^2$$

where:

Γ_m = magnetic constant when the element of force, dF, of a current element I_1dl_1 on another current element I_2dl_2 is at a distance r,
r_1 = unit vector in the direction from dl_1 to dl_2, and
n = dimensionless factor. The symbol n is unity in unrationalized systems and 4π in rationalized systems.

NOTE 47—The numerical values of Γ_m depend upon the system of units used. In the cgs-emu system of units, $\Gamma_m = 1$, in the SI system, $\Gamma_m = 4\pi \times 10^{-7}$ H/m.

NOTE 48—The magnetic constant expresses the ratio of magnetic induction to the corresponding magnetizing force at any point in a vacuum and therefore is sometimes called the permeability of space, μ_v.

NOTE 49—The magnetic constant times the relative permeability is equal to the absolute permeability.

$$\mu_{abs} = \Gamma_m \mu_r$$

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.

NOTE 50—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,
H = constant whose value depends on the system of units,
N = number of turns,
I = 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.

NOTE 51—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 Γ_m.

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.

NOTE 52—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.

NOTE 53—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.

Thus:

$$H_\Delta = \Delta H/2$$

magnetic field strength, maximum—*(a)* H_m—the maximum value of H in a dc hysteresis loop.

(b) H_{max}—the maximum value of H in an ac flux-current loop.

magnetic flux, ϕ—the product of the magnetic induction, B, and the area of a surface (or cross section), A, when the magnetic induction B is uniformly distributed and normal to the plane of the surface.

$$\phi = BA$$

where:

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

NOTE 54—If the magnetic induction is not uniformly distributed over the surface, the flux, ϕ, is the surface integral of the normal component of B over the area.

$$\phi = \iint_s B \cdot dA$$

NOTE 55—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.

NOTE 56—If the total flux, ϕ is uniformly distributed and normal to a surface or cross section, then the magnetic induction is:

$$B = \phi/A$$

where:

B = magnetic induction,
ϕ = total flux, and
A = area.

NOTE 57—B_{in} is the instantaneous value of the magnetic induction and B_m is the maximum value of the magnetic induction.

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.

NOTE 58—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.

NOTE 59—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.

NOTE 60—The magnetic moment of a magnetized body is the volume integral of the magnetization, *M*.

NOTE 61—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.

NOTE 62—Magnetic particle inspection is an accepted method for the detection of defects.

magnetic polarization, *J*—in the cgs-emu system of units, the intrinsic induction divided by 4π is sometimes called magnetic polarization or magnetic dipole moment per unit volume.

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.

NOTE 63—In the hypothetical case of a uniformly magnetized body of constant cross-sectional area, the poles would be located at its ends.

NOTE 64—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 component of the total magnetizing force that produces the intrinsic induction in a magnetic material.

$$M = (B - \Gamma_m H)/\Gamma_m \mu_r = B_i/\mu_{abs}$$

where:
M = magnetization,
H = applied magnetizing force,
Γ_m = magnetic constant,
B = total magnetic induction,
μ_r = relative permeability,
μ_{abs} = absolute permeability, and
B_i = intrinsic induction.

NOTE 65—The magnetization can be interpreted as the volume density of magnetic moment.

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.

NOTE 66—The magnetomotive force is proportional to the net current linked with any closed loop of flux or closed path.

$$\mathcal{F} = CNI$$

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.**

NOTE 67—

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

where:

e = induced instantaneous emf in volts,
$d\phi/dt$ = 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.

NOTE 68—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 cgs-emu system of units. One oersted equals a magnetic field strength of 1 Gb/cm of flux path. One oersted equals 1000/4π 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.)

NOTE 69—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 (Δ*B* or Δ*H*).

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.

NOTE 70—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.

NOTE 71—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**.

NOTE 72—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.

NOTE 73—The magnetic constant Γ_m is a scalar quantity differing in value and uniquely determined by each electromagnetic system of units. In the cgs–emu system of units, Γ_m is 1 gauss/oersted, and in the SI system, $\Gamma_m = 4\pi \times 10^{-7}$ H/m.

NOTE 74—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.

NOTE 75—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.

NOTE 76—Except for initial permeability, μ_0, a numerical value for any of the dc permeabilities is meaningless unless the corresponding *B* or *H* excitation level is specified.

NOTE 77—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:

$$\mu_{abs} = \Gamma_m + \mu_i = \Gamma_m \cdot \mu_r$$

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.

NOTE 78—For a symmetrical series circuit in which each component has the same cross-sectional area, reluctance values add directly giving:

$$\mu_{eff} = \frac{\ell_1 + \ell_2 + \ell_3 + \cdots}{\frac{\ell_1}{\mu_1} + \frac{\ell_2}{\mu_2} + \frac{\ell_3}{\mu_3} + \cdots}$$

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, $\mu_{\Delta i}$—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.

NOTE 79—When the change in *H* is reduced to zero, the incremental permeability, μ_Δ, becomes the reversible permeability, μ_{rev}.

permeability, initial, μ_0—the limiting value approached by the normal permeability as the applied magnetic field strength, *H*, is reduced to zero. The permeability is equal to the slope of the normal induction curve at the origin of linear *B* and *H* axes.

permeability, intrinsic, μ_i—the ratio of the calculated value of intrinsic induction B_i, to the corresponding magnetic field strength, *H*.

NOTE 80—See definition of susceptibility.

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

NOTE 81—Under dc test conditions the maximum permeability, μ_m, is the highest value of normal permeability μ, developed by the magnetic material.

NOTE 82—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 Γ_m, giving a pure numeric parameter.

NOTE 83—In the cgs-em 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_v—the permeability of space (vacuum), identical with the magnetic constant, Γ_m.

permeance, $\mathcal{P}$—the reciprocal of the reluctance of a magnetic circuit.

power factor, magnetic, cos γ—(*a*) the cosine of the angle between vectors representing the rms values of the applied voltage of a circuit and the current in circuit.

(*b*) 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,
I = current in amperes, and
θ = angular phase by which E leads I.

NOTE 84—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.

$$\mathcal{R} = \mathcal{F}/\phi$$

where:
$\mathcal{R}$ = 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.

NOTE 85—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.

NOTE 86—The product, $I_c^2R_1$, 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.

NOTE 87—At low frequencies, R_w is only slightly greater than the dc resistance of the winding.

NOTE 88—The product I^2R_w equals the sum of the copper, eddy current, and dielectric losses in the winding.

NOTE 89—The total active power, *P*, delivered to an inductor having a ferromagnetic core is:

$$P = P_c + I^2R_w$$

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 = resistanceof the specimen, Ω;
A = cross sectional area, cm^2; and
ℓ = length of specimen, cm.

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

NOTE 90—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_{rs}— the property of a magnetic material which is measured by its maximum value of the residual induction.

NOTE 91—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.

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

NOTE 92—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*.

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

where:
Γ_m = magnetic constant and
μ_r = relative permeability.

NOTE 93—The preceding equations apply to an isotropic material if the SI, an abbreviation for the international system of units, are used.

NOTE 94—In the classical cgs-emu system of units:

$$\kappa = B_i/4\pi\Gamma_m H = (\mu_r - 1)/4\pi$$

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 induction. 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:

$$X_n + \Delta\chi \geqq X \geqq X_n - \Delta\chi$$

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

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

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:

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

NOTE 95—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 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 10^8 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	By	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

Multiply	By	To Obtain
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
	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 Conversions	
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