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Standard Terminology of Symbols and Definitions Relating to Magnetic Testing¹

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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	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
B	$\left\{ \begin{array}{l} \text{magnetic induction} \\ \text{magnetic flux density} \end{array} \right.$	H_c	coercive field strength
ΔB	excursion range of induction	H_{ci}	intrinsic coercive field strength
B_b	biased induction	H_{cs}	coercivity
B_d	remanent induction	H_d	demagnetizing field strength
B_{dm}	remanence	H_{Δ}	incremental magnetic field strength
$B_d H_d$	energy product	H_g	air gap magnetic field strength
$(B_d H_d)_m$	maximum energy product	H_L	ac magnetic field strength (from an assumed peak value of magnetizing current)
B_{Δ}	incremental induction	H_m	maximum magnetic field strength in a hysteresis loop
B_i	intrinsic induction	H_{max}	maximum magnetic field strength in a flux-current loop
B_m	maximum induction in a hysteresis loop	H_p	ac magnetic field strength (from a measured peak value of exciting current)
B_{max}	maximum induction in a flux current loop	H_t	instantaneous magnetic field strength (coincident with B_{max})
B_r	residual induction	H_z	ac magnetic field strength force (from an assumed peak value of exciting current)
B_{rs}	retentivity	I	ac exciting current (rms value)
B_s	saturation induction	I_c	ac core loss current (rms value)
cf	crest factor	I_{dc}	constant current
CM	cyclically magnetized condition	I_m	ac magnetizing current (rms value)
d	lamination thickness	J	magnetic polarization
D_B	demagnetizing coefficient	K'	coupling coefficient
df	distortion factor	ℓ	flux path length
D_m	magnetic dissipation factor	ℓ_1	effective flux path length
E	exciting voltage	ℓ_g	gap length
E_1	induced primary voltage	$\mathcal{L}$ (also ϕ M)	flux linkage
E_2	induced secondary voltage	$\mathcal{L}_m$	mutual flux linkage
E_f	flux volts	L	self inductance
f	cyclic frequency in hertz	L_1	core inductance
$\mathcal{F}$	magnetomotive force	L_{Δ}	incremental inductance
ff	form factor	L_i	intrinsic inductance
		L_m	mutual inductance
		L_o	initial inductance
		L_s	series inductance
		L_w	winding inductance
		m	magnetic moment
		M	magnetization

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m	total mass of a specimen	$\cos \gamma$	magnetic power factor
m_1	active mass of a specimen	γ_p	proton gyromagnetic ratio
N_D	demagnetizing factor	Γ_m	magnetic constant
N_1	turns in a primary winding	δ	density
N_2	turns in a secondary winding	κ	susceptibility
$N_1 I / \ell_1$	ac excitation	<i>ac Permeabilities:</i>	
p	magnetic pole strength	μ_a	ideal permeability
$\mathcal{P}$	permeance	μ_L	inductance permeability
P	active (real) power	$\mu_{\Delta L}$	incremental inductance permeability
P_a	apparent power	μ_{Od}	initial dynamic permeability
$P_a (B, f)$	specific apparent power	μ_p	peak permeability
		$\mu_{\Delta p}$	incremental peak permeability
P_c	total core loss	μ_i	instantaneous permeability
$P_c (B, f)$	specific core loss	μ_z	impedance permeability
		$\mu_{\Delta z}$	incremental impedance permeability
$P_{c\Delta}$	incremental core loss	<i>dc Permeabilities:</i>	
P_e	normal eddy current core loss	μ	normal permeability
$P_{\Delta e}$	incremental eddy current core loss	μ_{abs}	absolute permeability
P_h	normal hysteresis core loss	μ_d	differential permeability
$P_{\Delta h}$	incremental hysteresis core loss	μ_{Δ}	incremental permeability
P_q	reactive (quadrature) power	μ_{eff}	effective circuit permeability
P_r	residual core loss	μ_i	intrinsic permeability
P_w	winding loss (copper loss)	$\mu_{\Delta i}$	incremental intrinsic permeability
P_z	exciting power	μ_m	maximum permeability
$P_z (B, f)$	specific exciting power	μ_o	initial permeability
		μ_r	relative permeability
Q_m	magnetic storage factor	μ_v (also Γ_m)	space permeability
$\mathcal{R}$	reluctance	μ_{rev}	reversible permeability
R_1	core resistance	$\mu' / \cot \gamma$	figure of merit
R_w	winding resistance	ν	reluctivity
S	lamination factor (stacking factor)	π	the numeric 3.1416
<i>SCM</i>	symmetrically cyclically magnetized condition	ρ	resistivity
T_c	Curie temperature	ϕ	magnetic flux
w	lamination width	ϕN	flux linkage (see $\mathcal{L}$)
W_h	hysteresis loop loss	χ	mass susceptibility
$\bar{\alpha}$	linear expansion, coefficient (average)	χ_o	initial susceptibility
$\Delta \chi$	incremental tolerance	ω	angular frequency in radians per second
β	hysteretic angle		
γ	loss angle		

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.

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:

- 100 h at 150°C or
- 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.

ASTM A 340 – 01e1

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 $(9\,274\,078 \times 10^{-21} \text{ erg/gauss or } 9\,274\,078 \times 10^{-24} \text{ J/T})$.

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, 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 intrinsic 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 symmetrically 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, $P_{\Delta c}$ —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 plate—a generic term for any insulating material, formed metallurgically 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 7—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 8—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 9—Examples of customary units used in ASTM A-6 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	$P_c(B;f)$	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 in



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 10—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.

NOTE 11—The intrinsic induction, B_i , is oppositely directly to the applied magnetizing force H .

dissipation factor, magnetic, D_m —the tangent of the hysteresis 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 12—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 13—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.

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

NOTE 14—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 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

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

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

energy product, $B_d H_d$ —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 15—The maximum value of the energy product, $(B_d H_d)_m$, corresponds to the maximum value of the external energy.

NOTE 16—The demagnetization curve is plotted by the following method:



vertical axis and usually the energy-product curve to the right.

energy product, maximum ($B_d H_d$)_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 17—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 18—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 19—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 20—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.

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

$$E_f = 2.221 \Delta B A' N f \times 10^8 \text{ V (CM excitation)}$$

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

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 21—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 22—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 traverses in the