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

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INTRODUCTION

In preparing this terminology standard, 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 and clarity, but it is believed that none of the definitions will prove to be misleading.

It is the intent of this terminology standard to be consistent in the use of symbols and units with those found in IEC 60050-221:1990 International Electrotechnical Vocabulary Chapter 221: Magnetic materials and components. Although Committee A06 has chosen to make SI units normative, the extensive technical and commercial literature using the older Gaussian units requires that many definitions contain discussion about and use of both unit systems. This is not an endorsement of the older unit system and users of this terminology are encouraged to use SI units where possible.

1. Referenced Documents

1.1 *ASTM Standards:*[2]

A343/A343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame

A772/A772M Test Method for AC Magnetic Permeability of Materials Using Sinusoidal Current

2. Terminology

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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Part 1—Symbols Used in Magnetic Testing

Symbol	Term
a	cross-sectional area of B coil
A	cross-sectional area of specimen
A'	solid area
B	magnetic flux density; magnetic induction
ΔB	excursion range of induction
B_b	biased flux density
B_d	demagnetization flux density
B_dH_d	energy product
$(BH)_{max}$	maximum energy product
B_Δ	incremental flux density
B_i	intrinsic flux density
B_m	maximum value of magnetic flux density in a static hysteresis loop
$B_{\max}$	maximum value of magnetic flux density in a dynamic hysteresis loop
B_r	residual flux density
B_s	saturation flux density
cf	crest factor
CM	cyclically magnetized condition
d	lamination thickness
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_{cB}	coercive field strength
H_{cJ}	intrinsic coercive field strength
H_d	demagnetizing field strength

H_Δ	incremental 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 (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
J_r	residual magnetic polarization
J_s	saturation magnetic polarization
k'	coupling coefficient
ℓ	flux path length
ℓ_1	effective flux path length
ℓ_g	gap length
$\mathcal{L}$ (also φ N)	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
$\mathscr{m}$	magnetic moment
M	magnetization
M_r	residual magnetization
M_s	saturation magnetization
m	total mass of a specimen
m_1	active mass of a specimen
N	demagnetizing factor
N_1	turns in a primary winding
N_2	turns in a secondary winding
p	magnetic pole strength
$\mathcal{P}$	permeance
P	active (real) power
P_a	apparent power
$P_{a\ (B;f)}$	specific apparent power
P_c	core loss
$P_{c\ (B;f)}$	specific core loss
P_e	eddy current loss
P_h	normal 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 energy 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
μ_0	magnetic constant
δ	density
κ	susceptibility
ac Permeabilities:	
$\mu_{a,eff}$	rms amplitude permeability
μ_a	amplitude permeability
μ_L	inductance permeability
$\mu_\Delta L$	incremental inductance 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	absolute permeability
μ_d	differential permeability
μ_Δ	incremental permeability
$\mu_{\Delta i}$	incremental intrinsic permeability
μ_m	maximum permeability
μ_i	initial permeability
μ_r	relative 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

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

$$P = EI\cos\theta$$

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

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

DISCUSSION—The aging treatments usually specified for iron and steel are:

(*a*) 100 h at 150°C or
(*b*) 600 h at 100°C.

aging, magnetic—the time dependent change in magnetic properties; such changes can be due to either intrinsic or extrinsic factors, are not a consequence of improper use of the material and are usually detrimental to magnetic performance; in some instances, it may be possible to reverse the effect of magnetic aging via heat treatment or some other process, but typically the benefits are short-lived, and aging will occur again.

DISCUSSION—Two types of magnetic aging can be defined:

(*a*) Intrinsic magnetic aging due to the material as manufactured not being in its thermodynamically stable state so that further microstructural changes occur during service. Such aging is strongly dependent on temperature. The classic example is the aging of iron and electrical steels due to the precipitation of nitrides and carbides. Other examples would include amorphous, nanocrystalline materials and thin films where residual stresses introduced during manufacturing are slowly relieved during service. Ferrofluids show magnetic aging effects due to time dependent degradation of surfactants which results in a settling of the colloidal particles.

(*b*) Extrinsic or environmental magnetic aging due to changes in the magnetic domain structure or microstructure caused by external factors such as mechanical vibration, corrosion, irradiation, service temperature fluctuations, and external magnetic fields. Unlike intrinsic magnetic aging, this type of aging can occur in materials that are otherwise thermodynamically stable.

amorphous alloy—a semiprocessed alloy produced by a rapid quenching, direct casting process resulting in metals with noncrystalline structure.

ampere-turn—the unit of magnetomotive force in the SI system of units.

ampere per metre, A/m—the unit of magnetic field strength in the SI system of units.

NOTE 1—The term ampere-turn per metre has been used as the unit of magnetic field strength. Further use of this term in ASTM standards is deprecated.

anisotropic material—a material in which the magnetic properties differ in various directions.

anisotropy of loss—the ratio of the specific core loss measured with flux parallel to the rolling direction to the specific core loss with flux perpendicular to the rolling direction.

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

where:

$P_{c\ (B;f)\ l}$ = specific core loss value with flux parallel to the rolling direction, and

$P_{c\ (B;f)\ t}$ = specific core loss value with flux perpendicular to the rolling direction.

DISCUSSION—This definition of anisotropy normally applies to electrical steels with measurements made in an Epstein frame at a flux density of 15 kG [1.5 T] and a frequency of 60 Hz (see Test Method A343/A343M).

NOTE 2—The IEC defines a similar term called the loss anisotropy factor. It is however calculated differently and is not numerically equal to the above definition.

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

$$anisotropy\ of\ permeability = \frac{\mu_{prl}}{\mu_{prt}}$$

where:

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

μ_{prt} = relative peak permeability value with flux perpendicular to the rolling direction.

DISCUSSION—This definition of anisotropy normally applies to electrical steels with measurements made in an Epstein frame at a flux density of 15 kG [1.5 T] and a frequency of 60 Hz (see Test Method A343/A343M).

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 magnetic flux density B and specified frequency f.

area, A—the geometric cross-sectional area of a magnetic path which is perpendicular to the direction of the magnetic flux density.

B(H) loop—a hysteresis loop where the magnetic flux density (B) is plotted as a function of the magnetic field strength (H). Unless otherwise stated, it is assumed that the loop represents the SCM condition and therefore has 180° rotational symmetry about the origin of the coordinate system.

B_i(H) loop—a hysteresis loop where the intrinsic flux density (B_i) is plotted as a function of the magnetic field strength (H). Unless otherwise stated, it is assumed that the loop represents the SCM condition and therefore has 180° rotational symmetry about the origin of the coordinate system.

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, μ_0, is unity.

coercive field strength, H_{cB}—the absolute value of the applied magnetic field strength (H) required to restore the magnetic flux density (B) to zero.

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

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