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MAGNETIC DEFINITIONS

SECTION	PAGE

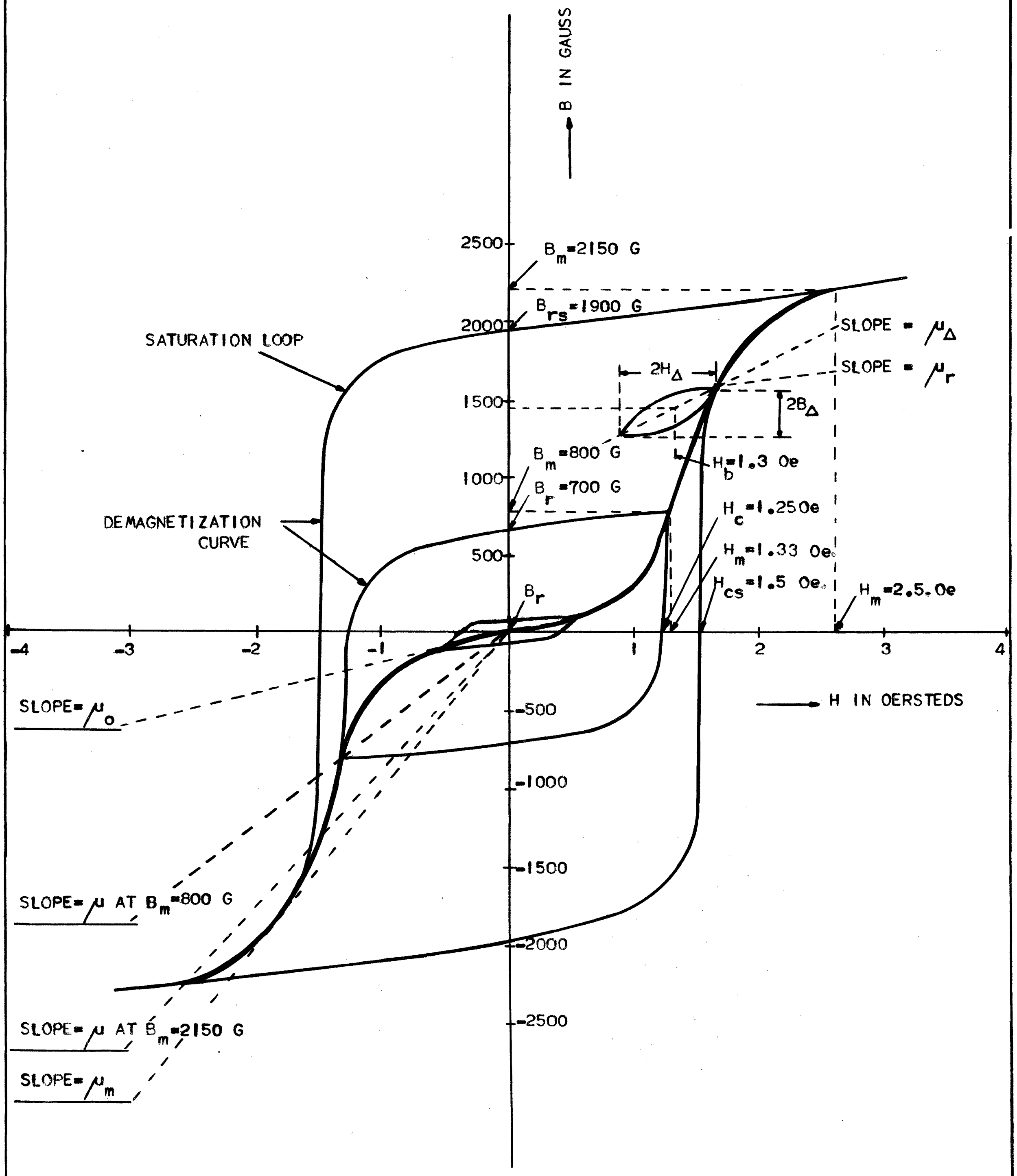


FIGURE I

HYSTERESIS CURVE OF A SQUARE LOOP MATERIAL

NOTES: B_s + H DOES NOT APPEAR IN THIS DRAWING. IT WILL BE ABOUT 2500 G

——— = VIRGINAL CURVE

1. FERROMAGNETIC MATERIAL

Ferromagnetic Material	A material which, like iron, generally exhibits hysteresis, i.e. the induction fails to follow the magnetic field, it lags: See fig. 1.
Ferrite	A ceramic material that is sintered at about 1300°C. It mainly consists of iron oxide with a certain additive of, usually, two metal oxides. Most current are the Manganese-Zinc, Nickel-Zinc, Manganese-Magnesium and Manganese-Copper ferrites. These are called soft magnetic materials because of comparatively low coercive forces, say smaller than 20 oersteds (e.g. Ferroxcube). See fig. 1. Barium ferrites have a very high coercive force (say 1000 Oe) and are called hard magnetic materials (e.g. Magnadur). See fig. 11.

2. FLUX

SYMBOL	UNIT	TERM	DESCRIPTION
ϕ	maxwells	(Magnetic) Flux	The cause of the electromotive force (voltage) induced in the secondary windings of a core (see fig. 2), magnetized by an A.C. current in the primary windings. In the c.g.s. system:

$$e_{ind} = -N_2 \times \frac{d\phi}{dt} \times 10^{-8}$$

where e_{ind} = induced e.m.f. in volts;

N_2 = number of secondary windings;

$\frac{d\phi}{dt}$ = change of flux per second in maxwells/sec.

ϕ itself is in maxwells.

Note: If ϕ is an alternating flux with frequency f, then, the more times per second that ϕ reverses its direction, e_{ind} will be proportionally larger. In case of a sinus wave:

$$\hat{e}_{ind} = N_2 \times 2\pi f \times \hat{\phi} \times 10^{-8},$$

where: $\hat{e}_{ind}$ and $\hat{\phi}$ indicate the peak-values of e_{ind} and ϕ.

f = frequency in cycles per sec.

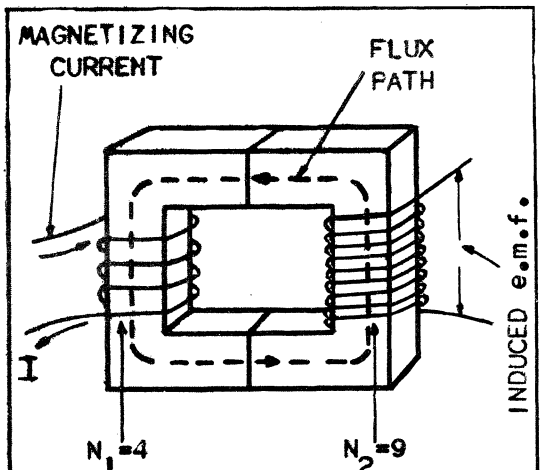
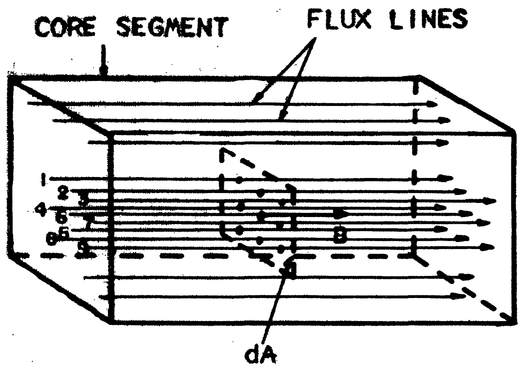


FIGURE 2

3. INDUCTION

SYMBOL	UNIT	TERM	DESCRIPTION
B	gauss	(Magnetic) Induction (Magnetic) Flux Density	Magnetic flux per unit area in an area element at right angles to the direction of the flux lines. In the c.g.s. system: $B = \frac{d\phi}{dA}$. Here $d\phi$ denotes a very small fraction of the total flux passing through a very small fraction of the area at a right angle: theoretically B changes from place to place in a material. In practice, when B is constant across the area, we use: $B = \frac{\phi}{A}$ Where: B = induction in gausses; ϕ = flux in maxwells; A = area in cm^2. See fig. 3.



OF ALL FLUX-LINES THE NUMBERS 1 THROUGH 9, TOGETHER AMOUNTING TO A FLUX $d\phi$, PASS THROUGH dA.

$$B = \frac{d\phi}{dA}$$

FIGURE 3

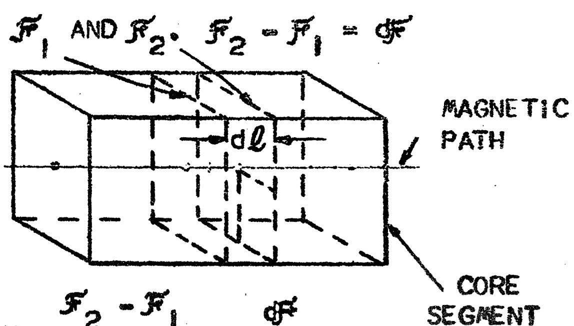
SYMBOL	UNIT	TERM	DESCRIPTION
B_r	gauss	Residual Induction	Induction that remains, when the magnetizing force H = 0. Compare with B_d and see fig. 1.
B_d	gauss	Remanent Induction Remenence	Induction that remains in a magnetic circuit of any shape after removal of an applied magnetomotive force, $\mathscr{F}$. In a permanent magnet with an air gap the magnetomotive force = 0, but the magnetic field in the magnet itself, H, is not zero, its value depending on the form of its hysteresis loop (energy product, see page 19) and width of the air-gap.
B_i	gauss	Intrinsic Induction	The induction in the magnetic material minus the induction in air at the existing magnetic field, H. The induction in air = $\mu_{air}H$. In c.g.s. units: $\mu_{air} = 1$, therefore $B_i = B - H$. (See μ_i.)

SYMBOL	UNIT	TERM	DESCRIPTION
B_{max} or B_m	gauss	Maximum Induction	Maximum instantaneous value of the induction on a hysteresis loop. It can be measured by means of an integrating network, which converts the induced A.C. e.m.f. into an A.C. voltage V proportional to B. The peak value of V yields: $\hat{B} = \frac{RC\,\hat{V} \times 10^8}{N_2 A}$ gauss where RC = time constant of the integrator in sec., $\hat{V}$ = the peak value of the integrated e.m.f. in volts, N_2 = the number of secondard windings, A = the area in cm^2. See fig. 1 and 2.
B_Δ	gauss	Incremental Induction	Amplitude (= peak value) of the varying part of the induction, when the core is operated with a biasing magnetizing force. See fig. 1.
B_{rs}	gauss	Retentivity	The maximum value of the residual induction, B_r or the value of B_r on the saturation loop. See fig. 1.
B_{sat} or B_s	gauss	Saturation Induction	The maximum intrinsic induction possible in a material. It is usually reached at magnetic fields of thousands of oersteds, while at the point where the saturation loop is closed, B_i is 10 to 30 percent lower than B_s, and H is roughly 10 oersteds. See fig. 1.

4. MAGNETIC FIELD

SYMBOL	UNIT	TERM	DESCRIPTION
$\mathcal{F}$	gilberts	Magnetomotive Force Magnetic Potential Difference	That which tends to produce a magnetic field. In magnetic testing it is most commonly produced by a current flowing through a coil of wire around the core. Its magnitude is proportional to the number of turns and the current. In the c.g.s. unit-system it is expressed in gilberts and thus defined by: $\mathcal{F} = 0.4 \pi N I,$ where I = current in amperes Magnetomotive force also results from a magnetized body, e.g. a permanent magnet.
H	oersteds	Magnetizing Force Magnetic Field (Intensity)	Magnetomotive force per unit length. In the c.g.s. unit-system it is expressed in oersteds and is defined by $H = \frac{d\mathcal{F}}{d\ell}$. Here $d\mathcal{F}$ denotes a very small change of $\mathcal{F}$ along a very small path length; generally H changes from point to point in direction and intensity. H has the same direction as $d\ell$. In practice H has at all points the same value in most applications. We can then use: $H = \frac{\mathcal{F}}{\ell}$ where H = magnetizing force in oersteds, $\mathcal{F}$ = magnetomotive force in gilberts, ℓ = path length in cm. See fig. 4. In the case of a toroid, $\ell = 2 \pi r$ where r = the average of inside and outside radii of the ring : $H = \frac{0.4 \pi N I}{2 \pi r} = \frac{0.2 N I}{r}$
H_b	oersteds	Biasing (Magnetic) Field	A constant (D.C.) magnetizing force superposed on an alternating (A.C.) magnetizing force. This is realized by applying an extra D.C. current to the same magnetizing windings or to a special coil around the same sample. See fig. 1.

VALUES OF MAGNETOMOTIVE FORCE



$$H = \frac{\mathcal{F}_2 - \mathcal{F}_1}{d\ell} = \frac{d\mathcal{F}}{d\ell}$$

FIGURE 4

SYMBOL	UNIT	TERM	DESCRIPTION
H_c	oersteds	Coercive Force	The magnetizing force required to bring the induction to zero; the larger the H_c, the larger are the hysteresis losses. See fig. I.
H_{cs}	oersteds	Coercivity	The maximum value of the coercive force, H_c, or the value of H_c on the saturation loop. See fig. I.
H_d	oersteds	Demagnetizing Force	A magnetizing force applied in such a direction as to reduce the remanent induction, B_d, in a magnetized body. Fig. I, upper left, and fig. II give examples of a demagnetization curve.
H_Δ	oersteds	Incremental Magnetizing Force	Amplitude of the varying part of the magnetizing force, when the core is operated with a biasing field, H_b. See Fig. I.
H_{max} or H_m	oersteds	Maximum Magnetizing Force	Maximum instantaneous value of the magnetic field on a hysteresis loop. H_m (and B_m) are found on the "tip" of the hysteresis loop.

5. PERMEABILITY

SYMBOL	UNIT	TERM	DESCRIPTION
μ	numeric	Permeability Mu	The slope of the line, which connects the "tip" of a hysteresis loop (H_{max}, B_{max}) with the origin, or $\mu = \frac{B_{max}}{H_{max}}$ (usually written $\mu = \frac{B}{H}$). See Fig. 1. The "tips" of all possible loops that can be performed, depending on the amplitude of the applied magnetic field, H_{max}, are situated on the so-called virginal curve. This curve is straight near the origin; its slope corresponds to the permeability at low values of H or initial permeability, μ_o. Note 1: Depending on the method of measurement and the practical application, the μ can also be defined as the R.M.S. value of the A.C. induction divided by the R.M.S. value of the A.C. magnetic field or $\mu = \frac{B_{R.M.S.}}{H_{R.M.S.}}$. Now the results are dependent among others on the wave shape of the magnetic field and the form of the hysteresis loop. Note 2: In such non-isotropic materials as Magnadur and Ferroxplane, μ depends on the direction of H with respect to the sample: there is a direction or a plane in the sample where μ is maximal.
μ_{max} or μ_m	numeric	Maximum Permeability	Maximum value of the permeability. It is the slope of the line which just touches the "knee" in the virginal curve. See Fig. 1.
μ_o	numeric	Initial Permeability	The permeability at low inductions, say 10 gauss or less. See Fig. 1.
μ_Δ	numeric	Incremental Permeability	The ratio of the incremental induction to the incremental magnetizing force or $\mu_\Delta = \frac{B_\Delta}{H_\Delta}$. When H_Δ and consequently B_Δ become very small, then μ_Δ approaches
μ_{rev}	numeric	Reversible Permeability	a limiting value, the reversible permeability μ_{rev}. (See Fig. 1) μ_{rev} decreases from $\mu_{rev} = \mu_o$ ($H_b = 0$) down to $\mu_{rev} = 1$ when H_b is very high.

SYMBOL	UNIT	TERM	DESCRIPTION
μ_{eff}	numeric	Effective Permeability	The lowered value of μ caused by interruptions in the flux path. If a magnetic circuit, e.g. a toroid, contains an air-gap, then the effective induction B_{eff} has a lower value than in the case without an air-gap at a given value of H. The effective permeability is defined as:

$$\mu_{eff} = \frac{B_{eff}}{H}$$

μ_{eff} is always smaller than μ and can be calculated as follows:

$$\frac{\mu_{eff}}{\mu} = \frac{1}{1 + \mu\,(g/\ell)},$$

where:

g = width of the air-gap in cm,
ℓ = magnetic path length of the core in cm. See figure 5.

Gaps caused by dirt often cause difficulties when testing U cores. In practice they are designed into pot cores in order to reduce both the temperature coefficient of the pot core assembly and the effects of non-linearity.

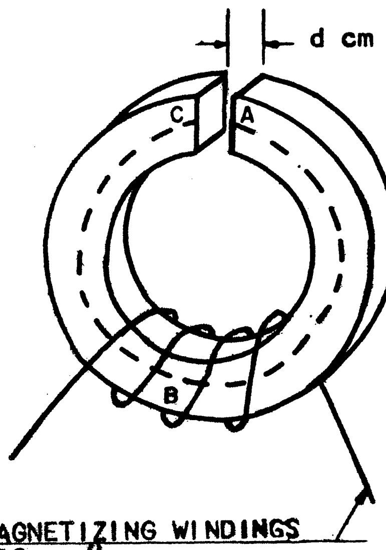


FIGURE 5

SYMBOL	UNIT	TERM	DESCRIPTION
μ_i	numeric	Intrinsic Permeability	The ratio of the intrinsic induction to the corresponding magnetizing force: $\mu_i = \frac{B_i}{H}$. Because $B_i = B - H$, we see that $\mu_i = \frac{B-H}{H} = \mu - 1$. The use of μ_i becomes important for materials with very low μ, say $\mu = 10$. The μ_i in this case is 9.
μ'	numeric	μ prime	Real part of the so-called complex permeability. At low inductions it is identical with the initial permeability.
μ''	numeric	μ double prime	This is the imaginary part of the complex permeability ($\mu' - j\,\mu''$). This is only a formal way of appreciating the core losses relative to the initial permeability μ_o or μ'.

6. INDUCTANCE

SYMBOL	UNIT	TERM	DESCRIPTION
L	henries	Self Inductance	1) Electrically defined by: $e_{ind} = - L \frac{dI}{dt}$, where e_{ind} = induced e.m.f. across the coil windings in volts, L = self inductance in henries, $\frac{dI}{dt}$ = change of current per second in amperes per sec. Measurement of L is based on this principle. 2) An equivalent definition is: $L = \frac{N\phi \times 10^{-8}}{I}$, where $N\phi$ = flux linkage in maxwell-turns, I = magnetizing current in amperes, L = self inductance in henries. "Flux-linkage" means the total flux that is "caught" by the conductor as a whole (usually a coil around a core). If the wire is homogeneously wound around the whole circumference of a toroid, then N equals the total number of turns. With the help of the definition (2) we can derive for the toroid the formula: 3) $L = \frac{0.4 \pi \mu_o \times N^2 \times 10^{-8}}{\ell / A}$, where μ_o = initial permeability, N = number of turns, A = cross section of toroid in cm^2, ℓ = path length in cm (for a toroid about the average of inside and outside circumference). At high inductions μ cannot be considered a constant (fig. 1), hence L is then not well-defined.

SYMBOL	UNIT	TERM	DESCRIPTION
L_o	henries	Air Inductance	Defined as L under (3), except that μ_o is put = 1 (permeability of air). This provides a method of measuring μ_o: $L = \mu_o L_o$, or $\mu_o = \frac{L}{L_o}$, where L is measured and L_o is calculated from the physical dimensions of the core. The general formula for cores with non-uniform cross section is: $L_o = \frac{0.4\,\pi \times N^2 \times 10^{-8}}{\Sigma\, \ell/A}$ Σ or "sigma" denotes that one takes the sum of the ℓ/A's for the different parts of the magnetic circuit (e.g. E core, pot core).
L_m or M	henries	Mutual Inductance	If we have a transformer (see fig. 2) with N_1 primary windings and N_2 secondary windings, then both coils are linked magnetically by the core. This property is characterized by the mutual inductance: $L_m = \frac{N_2\,\phi \times 10^8}{I_1} = \frac{N_1\,\phi \times 10^8}{I_2}$ Where: L_m = mutual inductance in henries, $N_2\phi$ $(N_1\phi)$ = flux linkage "caught" by the secondary (primary) windings in maxwell turns, I_1 (I_2) = current in the primary (secondary) windings in amperes. In an ideal transformer (no flux escaping through surrounding air) $L_m^2 = L_1 \times L_2$, L_1 and L_2 being the the individual self-inductances of the primary and secondary windings.

7. LOSSES

SYMBOL	UNIT	TERM	DESCRIPTION
P_c	watts	Core Loss	Energy per second (= power) dissipated in a core when magnetized by an alternating magnetic field. The dissipated power is identical with the developed heat per second, power (heat per sec.) being in watts. $P_c = P_e + P_h + P_r$: See below.
P_e	watts	Eddy Current	Power dissipated due to currents circulating in the core as a result of e.m.f.'s in the material induced by the varying induction. P_e can be calculated from $P_e = \frac{\omega^2 B^2 \delta^2 V}{\rho} \times 10^{-14} \times C_c$ watts where: ω = angular frequency, B = R.M.S. value of the induction in gauss, δ = smallest dimension in cm of core perpendicular to the flux, V = volume of the core in cm^3, ρ = resistivity in ohm cm, C_c = shape constant, which is 1/8 for cores with a uniformly round or square cross-section.
P_h	watts	Hysteresis Loss	Power dissipated in a ferromagnetic core as a result of its hysteresis. It is proportional to the product of the area of the loop x frequency x volume of the core. P_h can be calculated from: $P_h = \frac{fV}{4\pi} \times$ loop area $\times 10^{-7}$ watts: where: f = frequency in cycles/sec, V = volume of the core in cm^3 Loop area is in gauss-oersteds.
P_r	watts	Residual Loss	Part of the total core losses which is due neither to P_e nor to P_h. It is the most important source of losses in ferrites. The residual losses cannot be precisely calculated, but should be measured.
P_Δ	watts	Incremental Core Loss	The core loss in a ferromagnetic material when subjected simultaneously to a biasing and an incremental magnetizing force.
P_a	watts	Apparent Core Loss	The product of the R.M.S. induced e.m.f. and R.M.S. magnetizing current for a coil containing a ferromagnetic core. The induced e.m.f. must be approximately sinusoidal.

SYMBOL	UNIT	TERM	DESCRIPTION
P_{cu}	Watts	Copper Loss	Power dissipated in the coil windings due to the electrical resistance of the copper wire. The resistance increases with the frequency due to the so-called skin effect, when the current flows mainly through the outmost part of the wire. These losses are considerable in pot core applications at high frequencies and have a large influence on the maximum attainable Q. These losses can be reduced by using Litz wire.
Q	numeric	Quality(Factor)	$Q = \frac{\omega L}{R_s}$, where: R_s represents the effective series-resistance in ohms in which the magnetizing current dissipates a power equal to total core losses, L= pure self-inductance of the core in henries, ω= $2\pi f$=angular frequency at which the core resonates with a series or parallel capacitor. The smaller the losses, the larger the Q. Q usually decreases with increasing frequency. At low inductions we can also write: $Q = \frac{\mu'}{\mu''}$.
δ		Loss Angle	$\frac{1}{Q} = \frac{R_s}{\omega L} = \tan\delta$, where: δ = the loss-angle. δ is actually the phase angle with which the magnetizing current lags the induced e.m.f. across the coil at low inductions.
$\frac{1}{\mu_o Q}$		Loss Factor	The loss factor is defined as $\frac{1}{\mu_o Q} = \frac{\tan\delta}{\mu_o} = \left(= \frac{\mu''}{\mu_o^2}\right)$. $\frac{1}{\mu_o Q}$ is an important characteristic for both the losses and the μ_o.
		Core Material Losses	A quantity which is of interest for losses at low inductions. It is written: (compare with $\frac{1}{\mu_o Q} = \frac{R_s}{\mu_o 2\pi f L}$) as $\frac{R_s}{\mu_o f L}$, where: R_s = effective series resistance, μ_o = initial permeability, f = frequency in cycles/sec, L = inductance in henries. The formula can be divided into three parts: $\frac{R}{\mu_o f L} = C_h B_{max.} + C_e f + C_r$, where: C_h, C_e and C_r are the hysteresis, eddy current and residual loss coefficients.

8. MEMORY CORES

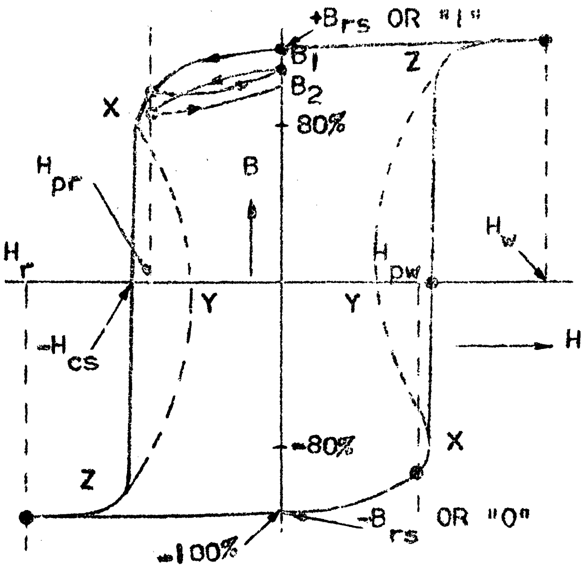


FIGURE 6

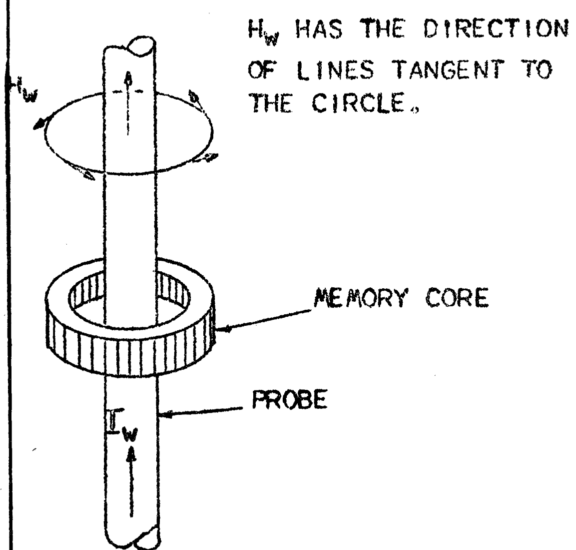


FIGURE 7

MEMORY CORE

A small size toroid of square loop material. If when operated with an a.c. magnetic field with peak values greater than the coercivity H_{cs}, the induction jumps between the positive, $+B_s$, and the negative, $-B_s$, saturation induction, then the core is a ferromagnetic switch. Therefore, when the core receives a sufficiently strong positive magnetizing current pulse, it will jump into $+B_s$ and stay in its positive retentivity, $+B_{rs}$: it "remembers" the positive pulse. $-B_{rs}$ might be called the "0" or zero state and $+B_{rs}$ the "1" state of the core. Memory cores are used in digital computers as storage elements of information or in shift registers. See Fig. 6.

PULSES

A memory core is tested with a succession of magnetizing current pulses of which the repetition frequency, peak values and individual forms are specified by the customer. The pulses are applied via a single wire or probe through the center-hole of the core and cause induced voltages. Their limits are also specified. The same succession is repeated for each core. See Fig. 7 and 9.

PULSE SEQUENCE

Succession of pulses, whether write ("1") or read ("0") and whether full or partial. This determines the change of induction (flux) per second, $\frac{d\phi}{dt}$, and therefore the response ("answer" of the core in terms of the induced e.m.f. in the probe) on a pulse. See Fig. 9.

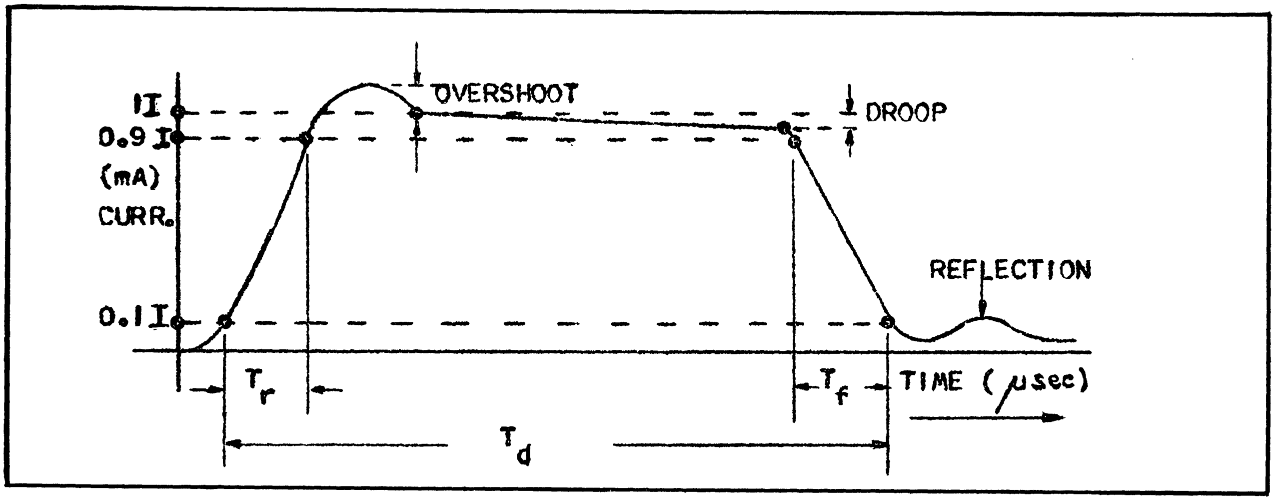


FIGURE 8

THE GENERAL SHAPE OF THE PULSES USED

SYMBOL	UNIT	TERM	DESCRIPTION
I	mA	Peak Current	Peak value (1 I) of current pulse in milliamperes, See fig. 8. The drawing is exaggerated for clarity.
T_r	μ sec	Rise Time	Time for the pulse current to rise from 0.1 I to 0.9 I. See fig. 8.
T_d	μ sec	Duration	Time for the pulse current to stay above 0.9 I. See fig. 8.
T_f	μ sec	Fall Time	Time for the pulse current to drop from 0.9 I down to 0.1 I. See fig. 8.

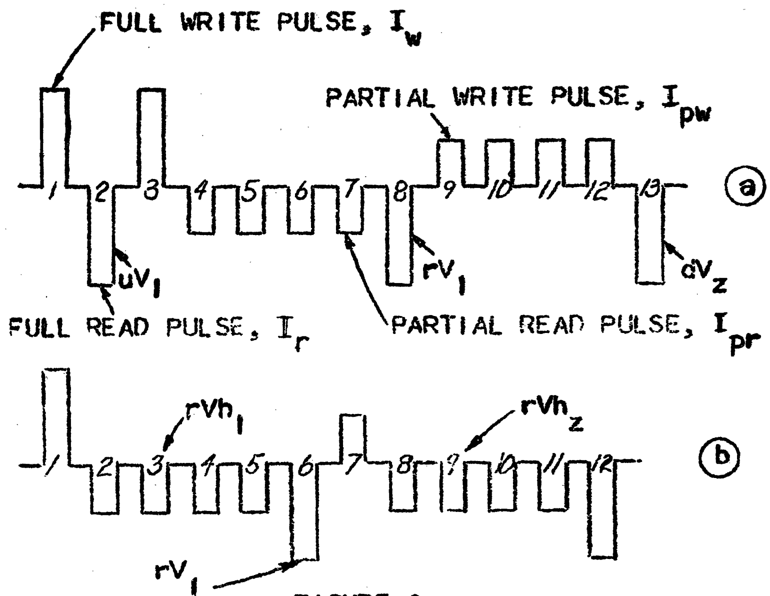


FIGURE 9

TWO CHARACTERISTIC PULSE SEQUENCES USED IN TESTS

SYMBOL	UNIT	TERM	DESCRIPTION
I_w	mA	Full Write Pulse	Peak value of pulse, that brings core into the "1" state or + B_{rs}. The magnetizing force corresponding to I_w is H_w. See Figs. 6 and 7.
I_{pw}	mA	Partial Write Pulse	Peak value of pulse, that does not manage to bring core from the "0" to the "1", but that changes "0" only to a slightly different value (disturbs it). The magnetizing force corresponding to I_{pw} is H_{pw}. See Figs. 6 and 7.
I_r	mA	Full Read Pulse	Peak value of negative pulse, that brings core into "0" from "1". In order to explain the form of uV_1 or rV_1 we must assume that not the static hysteresis loop, but a loop with curved sides (Fig. 6 XYZ) is performed by B and H.
I_{pr}	mA	Partial Read Pulse	Peak value of negative pulse, that disturbs the "1" state of the core. In upper left of figure 6, B_1 and B_2 indicate the residual induction after one and two I_{pr}'s respectively. If more I_{pr}'s are applied, the final residual induction will be very little different from B_1 or B_2.
I_o	mA	Threshold Current	The peak value of the current pulse, whether positive or negative, that brings the residual induction, B_r, a certain amount below the retentivity, B_{rs}, say 20%. These values are indicated in Fig. 6.

SYMBOL	UNIT	TERM	DESCRIPTION
uV_1	mV (peak value)	Undisturbed Voltage One	Response (see fig. 10) of core measured when an I_w is followed immediately by and I_r. See fig. 9a: 1→2.
rV_1 or dV_1	mV (peak value)	Disturbed Voltage One	Peak response of core measured, when an I_w is disturbed by a certain number of I_{pr}'s followed by an I_r. See fig. 9a: 3→4--→7 → 8 or fig. 9b: 1→2---→5→6.
dV_z	mV (peak value)	Disturbed Voltage Zero	Peak response, when an I_r is disturbed by a certain number of I_{pw}'s followed by an I_r. See fig. 9a: 8→9---→12 → 13.
rVh_1	mV (peak value)	Disturbed Half-Selected One	Response of the <u>second</u> I_{pr} after an I_w. See fig. 9b. 1→ 2→3
rVh_z	mV (peak value)	Disturbed Half-Selected Zero	Response of the <u>second</u> I_{pr} after an I_{pw}. See fig. 9b: 7→8 → 9.
T_p	µsec	Peaking Time	Time for rV_1 to rise from reference voltage level to its peak-value. See fig. 10.
T_s	µsec	Switching Time	Time for rV_1 to rise from and drop back to the reference voltage level. See fig. 10.

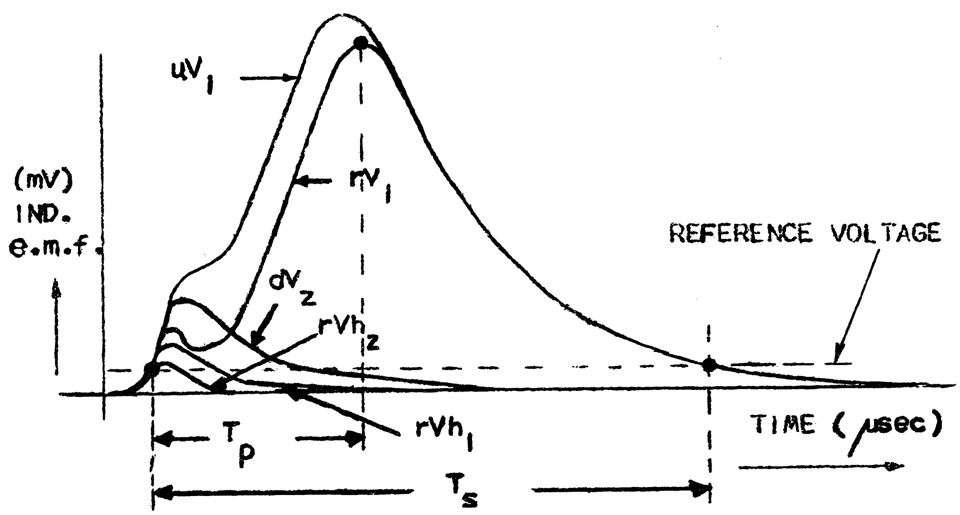


FIGURE 10

9. MISCELLANEOUS

SYMBOL	UNIT	TERM	DESCRIPTION
T_c	°C	Curie Temperature	Temperature in degrees centigrade at which a material becomes non-magnetic, actually indistinguishable from air ($\mu_o = 1$). Generally the μ_o will increase with rising temperature but will decrease quickly to 1 at the Curie temperature. Further, the higher the μ_o, the lower the T_c will be. If for ferrites $\mu_o \approx 10$, then T_c is about 500°C; if $\mu_o \approx 1000$, then T_c is about 150°C.
T.C.	$\frac{\text{percent}}{°C}$	Temperature Coefficient	The relative change of a quantity Y (e.g. μ_o, μ_Δ, B_s, $\frac{\text{Tan}\,\delta}{\mu_o}$) per degree centigrade or: $T.C. = \frac{1}{Y} \times \frac{\Delta Y}{\Delta T}$ where: ΔY = change (increase or decrease) in Y ocurring at a change in temperature, ΔT. $\frac{1}{Y} \times \frac{\Delta Y}{\Delta T} \times 100\%$ gives the percentage change per degree centigrade. In precision applications a very low T.C. for self inductances is desirable. A negative T.C. for the losses would prevent excessive heating up of core.
ρ	gr/cm^3	Density Specific Weight	This is defined as total mass (weight) divided by the volume of a body: $\rho = \frac{\text{total mass}}{\text{total volume}}$ in grams per cubic centimeter.
		Disaccomodation	The decrease of μ_o immediately following the demagnetization of the core. In the course of 24 hours, the lower limit, say 3% lower, is approached. The same seems to happen with the reversible permeability, μ_{rev}. This results that, where the biasing field is changed, a ferrite cannot be used for precision applications. Its effect can be reduced by air gaps.

SYMBOL	UNIT	TERM	DESCRIPTION
ρ	Ωcm	(Volume) Resistivity Specific Resistance	The d.c. resistance of a cylindrical conductor (bar) with a length of 1 cm and a perpendicular cross-section = 1 cm^2. It is measured between the two cross-sections which are wholly contacted by the measuring electrodes. With the resistivity known, we can calculate the d.c. resistance of a bar with a length ℓcm and a cross-section A cm^2 from $R = \rho \times \frac{\ell}{A}$.
f	c/sec	Frequency	The number of times that a periodic quantity (e.g. alternating current) repeats itself during 1 second. It is expressed in cycles per second. 1 Kc/sec.=1 kilocycle per second = 10^3 c/sec. $\omega = 2\pi f$ is called the angular frequency in radians per sec.
λ (lambda)	numeric	Magneto-striction	When a ferromagnetic rod is magnetized by the coil around it, the length of the rod will change by a small amount $\Delta\ell$. The magnetostriction at a given induction B is defined as $\lambda = \frac{\Delta\ell}{\ell}$. $\Delta\ell$ can also be negative. Magnetostriction can be used to convert mechanical vibrations into electrical.
		Permanent Magnets	Hard (high H_{cs}) magnetic materials can be used as permanent magnets (Magnadur), as, for example, in moving coil meters, where we need a strong magnetic field in the air-gap for the moving coil. The maximum possible field H is determined by the maximum value of the energy product, $(BH)_{max}$. The energy product curve is obtained by multiplying H with B at every point of the hysteresis-loop where B is positive and H is negative and plotting these values against B. See Fig. 11

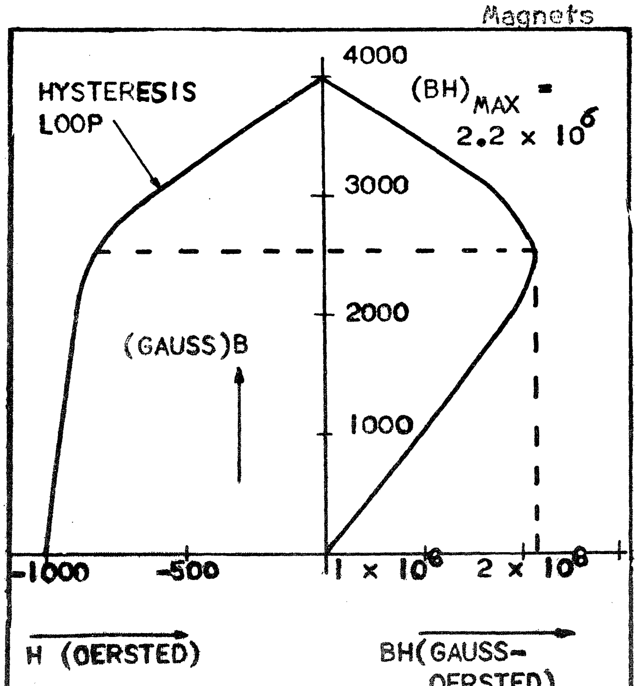


FIGURE 11

SYMBOL	UNIT	TERM	DESCRIPTION
$\mathcal{R}$	1/cm	(Magnetic) Reluctance	The reluctance of a magnetic circuit is defined as: $\mathcal{R} = \frac{\text{Magnetomotive Force}}{\text{Flux}} = \frac{\mathcal{F}}{\phi}$. It can be proven that $\mathcal{R} = \frac{\ell}{\mu A}$ for circuit with uniform cross-section $A(cm^2)$, length ℓ(cm) and a permeability μ. If not, $\frac{\ell}{\mu A}$ has to be replaced by the sum of $\frac{\ell}{\mu A}$ for the different parts of the circuit (e.g. pot core) or generally: $\Sigma \frac{\ell}{\mu A}$. $\mathcal{R}$ can be expressed in $\frac{1}{cm}$ or gilbert/maxwell. Note: Compare definition of electrical resistance. $R = \frac{\text{electromotive force}}{\text{current}} = \frac{V}{I} = \Sigma \rho \frac{\ell}{A}$.

10. UNITS IN THE CENTIMETER-GRAM-SECOND (c.g.s.) SYSTEM AND THE METER-KILOGRAM-SECOND (m.k.s.) SYSTEM

UNIT	ABBREV.	QUALITY	DESCRIPTION
Mega	M	$\times 10^6$	Mega = times one million = $\times 10^6$ written before a unit, it means that the unit is multiplied by 10^6 and thus has become a more practical unit depending on the application. (e.g. 3.2 MΩ = 3.2 megohms = $3.2 \times 10^6 \Omega$; 7 MV = 7 megavolts = 7×10^6V (volts).
Kilo	K	$\times 10^3$	Kilo = times one thousand = $\times 10^3$. 8 KG = 8 kilograms = 8000 g (grams).
Milli	m	$\times 10^{-3}$	Milli = times one thousandth = $\times 10^{-3}$. 1 mV = 1 millivolt = 10^{-3} V.
Micro	μ	$\times 10^{-6}$	Micro = times one millionth = $\times 10^{-6}$. 9 μV = 9 microvolts = 9×10^{-6} V.
Pico or Micro-micro	p $\mu\mu$	$\times 10^{-12}$	Pico / Micro-micro } = $\times 10^{-12}$ 1 $\mu\mu$A = 1 micro-micro ampere = 10^{-12} A (amperes). Usually one writes 1 mmA instead of $\mu\mu$A which is actually incorrect.

UNIT	ABBREV.	QUALITY	DESCRIPTION
Centimeter Square Centimeter Cubic Centimeter	cm cm^2 cm^3	Length Area Volume	Unit of length, originally defined as a certain fraction of the earth's circumference. Consequently we have 1 cm^2 and 1 cm^3 as units of area and volume respectively. 1 inch = 2.54 cm; 1 square inch = 6.45 cm^2; 1 cubic inch = 16.4 cm^3. M.k.s. system: 1 meter = 100 cm; 1 m^2 = $10^4 cm^2$; 1 m^3 = 10^6 cm^3.
Ampere	A	Current	Unit of current defined as the unit of positive electrical charge per second. The same unit is used in the m.k.s. system.
Erg		Work	See Watt
Farad	F	Capacitance	Unit of capacitance, defined as the constant ratio between electrical charge on, and voltage between, two neighboring conductors (plates of a condenser). Same in m.k.s.: 1 μF = 10^{-6} F.
Gauss	G	Induction	The unit of magnetic induction or magnetic flux density. Definition: See "Induction". In the m.k.s. system; the unit of induction is 1 Weber per square meter or 1 voltsecond per square meter. 1 weber/m^2 = 1 voltsec/m^2 = 10^4 gauss.
Gilbert		Magnetomotive Force	The unit of magnetomotive force. It is seldom used.
Gram	g gr	Mass (Weight)	Unit of mass. Kilogram and milligram are also much used. M.k.s. system: 1 kilogram = 1000 grams.
Henry	H	Self Inductance Mutual Inductance	The unit of self inductance and mutual inductance. Definition: see under "Inductance". M.k.s. system: same unit. 1 mH = 1 millihenry = 10^{-3}H.
Maxwell		Flux	The units of flux. M.k.s. system: 1 weber (= 1 voltsec) = 10^8 maxwells. Description: see under "Flux". (In the m.k.s. system the formula of induced e.m.f. is: $e_{ind} = -\frac{d(N\phi)}{dt}$ where: $N\phi$ = flux linkage in weber-turns, e_{ind} = induced voltage in volts.

UNIT	ABBREV.	QUALITY	DESCRIPTION
Ohm	Ω	Resistance	Unit of resistance, defined as : $R = \frac{V}{I}$ where: V = voltage across conductor with the resistance in V, I = current in A, R = resistance in ohms. M.k.s. system same unit.
Oersted	Oe	Magnetizing Force	Unit of magnetizing force. Definition: see under "Magnetic Field". M.k.s. system: 1 ampere turn per meter = 1 At/m = 4π Oe = 1.257×10^{2} Oe. In the m.k.s. system the formula for H in a homogeneously wound toroid is: $H = NI/\ell$ where: N = number of turns, I = current in A, ℓ = pathlength in m, H = in At/m.
Second	sec	Time	Unit of time in both systems. Defined as a certain fraction of the time of revolution of the earth around the sun.
Volt	V	Electromotive Force	Unit of voltage. Can be defined as work per unit charge.
Watt	W Joule/sec	Power Work per sec. Energy per sec. (Heat dissipated per sec.)	Unit of power. The power of a motor is the work it can achieve in one second. Power = $\frac{\text{Work}}{\text{Second}}$. Unit of work is the erg, therefore unit of power = 1 erg/sec. One usually uses the watt or joule/sec from the m.k.s. system: 1 watt = 10^{7} ergs/sec.

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