TERMS DEFINITIONS AND EXPLANATIONS

1. PERMEABILITY

1.1 INITIAL PERMEABILITY, μ_i

The initial permeability of a material is determined by the following formula, on the basis of the effective self-inductance exhibited by a test coil for a low AC magnetic field induced(approx.: 0.4A/m max.) in the toroidal core which is made of that material and on which the test coil is wound: (Fig. 1)

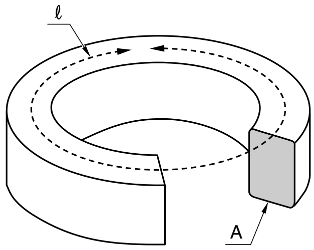

Fig. 1

$$\mu_i = \frac{L}{4\pi N^2} \cdot \frac{\ell}{A} \cdot 10^{10}$$

where, L = effective self-inductance(H)
N = number of turns
ℓ = average length of magnetic path in the core(mm)
A = cross-sectional area of toroidal cores(mm^2)

1.2 INCREMENTAL PERMEABILITY, μ_Δ, AND REVERSIBLE PERMEABILITY, μ_{rev}

Incremental permeability is determined by the following formula and is defined as the permeability of a material to a low AC magnetic field superposed on a larger DC magnetic field:

$$\mu_\Delta = \frac{\Delta B}{\Delta H}$$

where, ΔB = incremental flux density(gauss)
ΔH = incremental field intensity(oersted)

Reversible permeability is defined as the limiting value of incremental permeability occurring at the zero amplitude of the alternating magnetic field. It is a function of the DC flux density B and takes the maximum value when B is the zero. Its value decreases as B increases.
Since the DC flux density varies with the core shape and also with the magnitude of the gap, it is not proper to apply a reversible permeability determined on a toroidal core to cores of other shapes such as E type, P type, etc. Hence, values of reversible permeability are determined separately for individual core shapes and gaps.

1.3 EFFECTIVE PERMEABILITY, μ_e

The effective permeability is determined by the following formula:

$$\mu_e = \frac{L \times 10^{10}}{4\pi N^2} \cdot \Sigma \frac{\ell}{A}$$

where, L = effective self-inductance(H)
N = number of turns
$\Sigma \frac{\ell}{A}$ = C_1 = core constant(mm^{-1})

This formula is used also when some leakage flux exists in the magnetic circuit due to an air gap introduced in it.*

Note* :Magnetic-core loss coefficient, temperature coefficient, disaccommodation and other magnetic characteristics due to an air gap in the magnetic circuit very nearly directly with effective permeability, as long as the leakage flux at the air gap is not appreciably large. If the leakage is not negligible, a correction must be made on these characteristics for the leakage flux.

1.4 APPARENT PERMEABILITYM, μ_{app}

Apparent permeability is defined as the ratio of the two inductance values measured. One on the test coil only(L_0), the other on coil and core(L). This is determined by the following formula:

$$\mu_{app} = \frac{L}{L_0}$$

where, L = inductance of test coil with core(H)
L_0 = inductance of test coil without core(H)

Normally, an apparent effective permeability refers to an open magnetic circuit.

2. MAGNETIZATION CURVE

2.1 STATIC MAGNETIZATION CURVES

In magnetic material that has been completely demagnetized, the curve traced by the rising value of flux density B as a function of the field intensity H being raised from the point of origin(0) is referred to as INITIAL MAGNETIZATION CURVE.
If field intensity is raised further, a point will be reached where the material becomes saturated with flux and the curve levels off: the SATURATION FLUX DENSITY, B_{sat}, refers to that value of flux. As the field intensity is reduced to zero from the saturation point, the flux density decreases and settles at a certain value above zero: this value of remaining flux density is referred to as REMANENCE, B_r. To reduce the remanence to zero, field intensity must be increased in the negative(reverse) direction: the level of this reversed field intensity required for reducing remanence to zero is termed COERCIVITY, H_{CB}.

2.2 RELATIONSHIP BETWEEN HYSTERESIS LOOP AND PERMEABILITY

Graphic models of initial permeability and reversible permeability as concepts are given on the magnetization curve in Fig.2.
The constants relative to magnetization curve are graphically represented in Fig.3.

$$\mu_{rev}=\lim_{\Delta H \to 0}\frac{\Delta B}{\Delta H}=\tan\theta_r$$

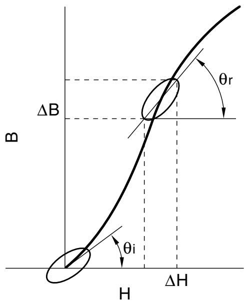

Fig. 2

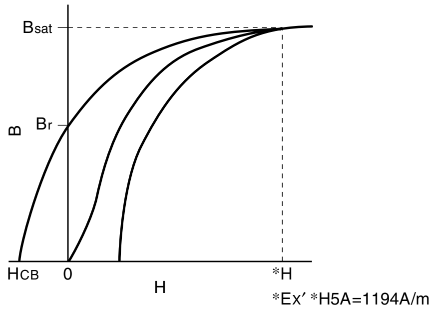

Fig. 3

3. CORE LOSS

3.1 LOSS FACTOR, tanδ

Core-loss factor, tanδ, is defined as the ratio of core-loss resistance to reactance, and consists of three components; namely, hysteresis loss, eddy-current loss and residual loss, and is expressed by the following formula:

$$\tan\delta=\frac{R_m}{\omega L}=h_1\sqrt{\frac{L}{V}}\,i+e_1 f+c_1$$

where, R_m = core-loss resistance(Ω)
- ω = 2πf, angular velocity(radians/sec.)
- L = inductance of test coil with core(H)
- V = volume of core(cm^3)
- f = frequency of test current(Hz)
- h_1 = hysteresis loss coefficient
- e_1 = eddy-current loss coefficient
- c_1 = residual loss coefficient
- i = current(A)

The loss factor is normally determined by effecting measurement with a small magnetic field, and is treated as a loss distinct and apart from the hysteresis loss. In other words, the loss coefficient is defined by the following formula:

$$\tan\delta=e_1 f+c_1$$

3.2 RELATIVE LOSS FACTOR, tanδ/μi

Addition of an air gap to a magnetic circuit changes the values of its loss factor and effective permeability. The amounts of change are nearly proportional to each other, so that the loss factor per unit effective permeability may be used as a coefficient which, as defined as $\tan\delta/\mu_i$, indicates a characteristic of the magnetic material.

$$\tan\delta/\mu_i=\frac{1}{\mu_i}(e_1 f+c_1)$$

It follows therefore that the loss factor for a practical core can be expressed in the following formula:

$$(\tan\delta)_c=\tan\delta/\mu_i\times\mu_e$$

Where $(\tan\delta)_c$ represents the particular loss factor.

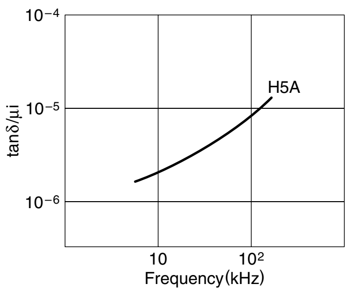

Fig. 4

3.3 RELATIVE HYSTERESIS LOSS COEFFICIENT, h_{10}*

When an air gap is introduced into a magnetic circuit, its hysteresis loss coefficient, h_1, changes approximately as 3/2 power of the effective permeability. On the basis of this fact, relative hysteresis loss coefficient, h_{10}, is defined as the value of this loss h_1 corrected to the condition of μ+1000. The value of h_{10} for different magnetic materials can be compared for comparative evaluation of the materials. For this purpose, the relative hysteresis loss coefficient is determined for and assigned to each material.

$$h_{10}=h_1\cdot\left(\frac{1000}{\mu_i}\right)^{3/2}$$

Thus, the hysteresis loss coefficient, $\tan\delta_h$, for a practical core is expressed by the following formula:

$$\tan\delta_h=h_{10}\cdot\left(\frac{\mu_i}{1000}\right)^{3/2}\cdot\sqrt{\frac{L}{V}}\cdot i$$

Note* : h_{10} is read "h one-zero."

The relationship between η_B and other constants are as follows:

$$\eta_B=19.9h_{10}\times10^{-6}$$
$$\eta_B=1.12\times h'/\mu^2$$
$$\eta_B=896\times h/\mu^2$$
$$h_{10}=50.3\eta_B\times10^3$$

where, η_B = hysteresis material constant in IEC

$\frac{h'}{\mu^2}$ = hysteresis constant in DIN

$\frac{h}{\mu^2}$ = hysteresis constant in Jordan

3.4 QUALITY FACTOR, Q

Quality factor is defined as the reciprocal of the loss coefficient, as follows:

$$Q=\frac{1}{\tan\delta}=\frac{\omega L}{R_m}$$

3.5 EFFECTIVE QUALITY FACTOR, Q_e

The effective quality factor refers to the loss coefficient of a coil complete with a ferrite core, and is the reciprocal of that coefficient:

$$Q_e=\frac{\omega L}{R_{eff}}$$

Where R_{eff} is the effective loss resistance of the coil.

3.6 APPARENT QUALITY FACTOR, Q_{app}

This factor is the ratio of the two values of effective quality factor measured on a test coil, one(Q_e) is coil with core, and the other(Q_0) is coil without core.

$$Q_{app}=\frac{Q_e}{Q_0}$$

where, Q_e = coil with core

Q_0 = coil without core

4. TEMPERATURE CHARACTERISTICS

4.1 TEMPERATURE COEFFICIENT OF INITIAL PERMEABILITY, $\alpha_{\mu i}$

This temperature coefficient is defined as the change of initial permeability per degree C over a prescribed temperature range. This change is expressed in terms of fraction of the original value of initial permeability. It is determined by the following formula:

$$\alpha_{\mu i}=\frac{\mu_{i2}-\mu_{i1}}{\mu_{i1}}\cdot\frac{1}{T_2-T_1}$$

where, μ_{i1} = initial permeability at temperature T_1

μ_{i2} = initial permeability at temperature T_2

The value of T_1 is normally taken at 20°C. The coefficient is expressed in units of 10^{-6}.

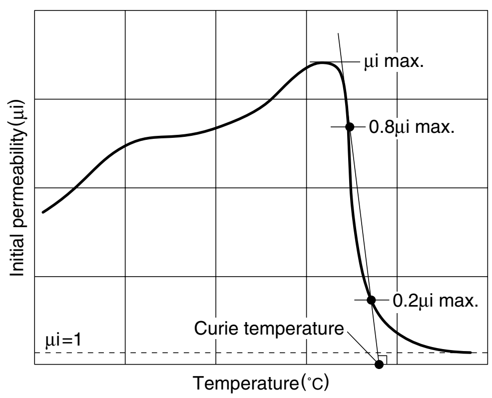

Fig. 5

4.2 TEMPERATURE FACTOR OF INITIAL PERMEABILITY, αF

The change of temperature coefficient, $\alpha\mu$, due to an air gap added to a magnetic circuit is nearly proportional to the change of effective permeability. On the basis of this fact, temperature factor of permeability, αF, is defined as the value of temperature coefficient, $\alpha\mu i$, per unit permeability, and is determined by the following formula:

$$\alpha F=\frac{\alpha\mu}{\mu i}=\frac{\mu i2-\mu i1}{\mu i1^{2}}\cdot\frac{1}{T_2-T_1}$$

The value so determined is assigned to each material as its characteristic. For the temperature coefficient of a practical core, the following formula is used.

$$\alpha\mu=\alpha F\times\mu e$$

4.3 CURIE TEMPERATURE Tc

The critical temperature at which a core transfers from ferromagnetism to paramagnetism.

Note: There are many ways to determine the Curie temperature. At TDK, however, it is determined as shown in Fig.5.

5. PHENOMENON OF GRADUAL DECREASE IN PERMEABILITY
5.1 SPONTANEOUS DECREASE OF PERMEABILITY

In ferrite cores, the permeability begins to decrease upon formation by sintering and continues to decrease with the lapse of time. This property is referred to as the spontaneous decrease of permeability.
In general, the rate of spontaneous permeability decrease is approximately linear when it is related to the logarithm of time(log t) and, therefore, becomes negligibly small in about a month's time after sintering. The magnitude of this decrease in terms of $\mu e/\mu i$ can be reduced substantially with increasing air gap.

5.2 DISACCOMMODATION, D

Disaccommodation, as will be noted in the following formula which determines its value: The time rate of initial permeability changes at normal temperature in a core that has just been AC demagnetized, where the core is kept free from mechanical or thermal stress of any kind.

$$D=\frac{\mu 1-\mu 2}{\mu 1}\times 100(\%)$$

where, $\mu 1$= initial permeability noted immediately after the material is AC demagnetized.
$\mu 2$= initial permeability noted some time after the material is AC demagnetized.

Disaccommodation and spontaneous decrease are two distinct concepts but some correlation is noted to exist between the two. The disaccommodation of a material is considered suggestive of its property of spontaneous decrease and also the permeability change that the material would exhibit when subjected to mechanical or magnetic shocks.

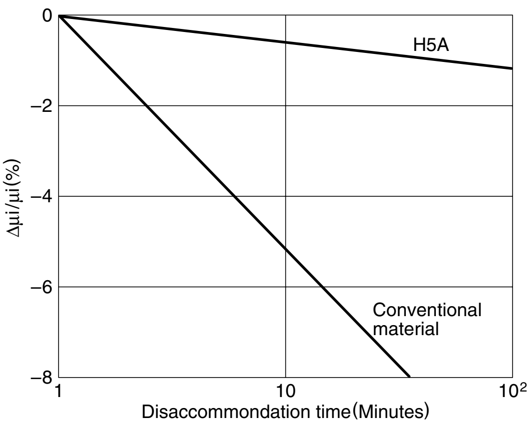

Fig. 6

5.3 DISACCOMMODATION FACTOR, DF

For cores with air gap, the disaccommodation of the material in the circuit is nearly proportional to its effective permeability. The value of disaccommodation per unit permeability is designated as the disaccommodation factor(DF)-one of the characteristics-and is determined for each material.

$$DF=\frac{\mu 1-\mu 2}{\log_{10}\frac{t_2}{t_1}}\cdot\frac{1}{\mu 1^{2}}(t_2>t_1)$$

where, $\mu 1$ = initial permeability noted at time t_1 after the material is AC demagnetized.
$\mu 2$ = initial permeability noted at time t_2 after the material is AC demagnetized.

Normally t_1, is 1 minute, and t_2 is 10 minutes; but up to 10 and 100 minutes, respectively, are occasionally used.
For a practical magnetic core, the following formula is used to determine its disaccommodation:

$$D=DF\times\mu e$$

6. INDUCTANCE COEFFICIENT, A_L

Inductance coefficient is defined as the self-inductance per unit turn of a coil of a given shape and dimensions wound on a magnetic core, and is determined by the following formula:

$$A_L = \frac{L}{N^2}$$

where, L = self-inductance of coil with core(H)
N = number of turns

This coefficient is normally expressed in units of 10^{-9}H(1nH).
Shapes and dimensions are separately prescribed for test coils to be used in the measurement for A_L.

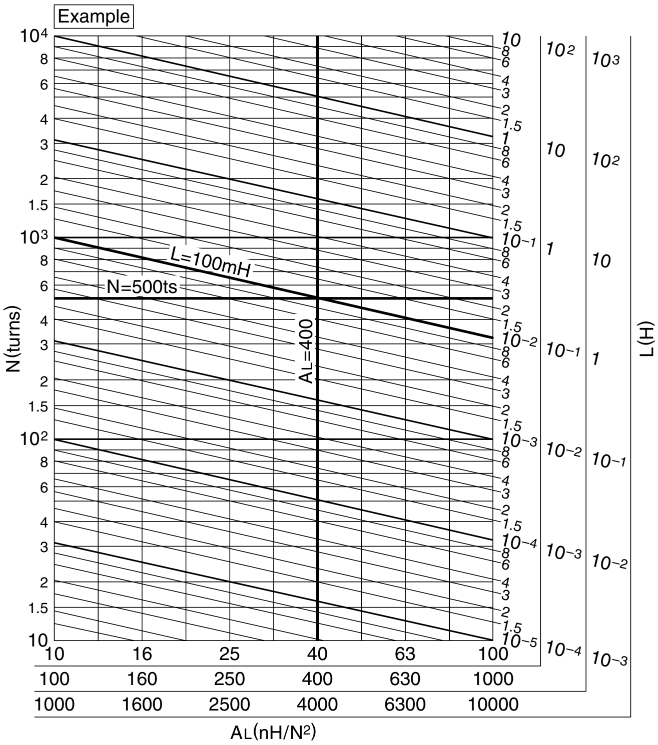

Fig. 7

7. WINDING COEFFICIENT, α

Winding coefficient is defined as the number of coil turns required for producing unit self-inductance in a coil of a given shape and dimensions wound on a core, and is determined by the following formula:

$$\alpha = \frac{N}{\sqrt{L}}$$

where, L = self-inductance of coil with core(H)
N = number of turnsl

Normally 1mH is taken for the L in this case.

8. ELECTRICAL RESISTIVITY, ρ_v

Electrical resistivity is the resistance measured by means of direct voltage of a body of ferromagnetic material having a constant cross-sectional area.

9. DENSITY, d_b

Specific gravity of a magnetic core is calculated from its volume and mass, as shown in below.

$$d_b = W/V(kg/m^3)$$

where, W = mass of the magnetic core
V = volume of the magnetic core

Note: The symbol and the catalog of this data are in accordance with IEC Publication 60401-3.