UNIT – V

Magnetic Measurements

Introduction:

The measurements of various _of a magnetic material are called magnetic Measurements. The magnetic materials play a very important role in the operation of electrical machines hence measurement of various characteristics of a magnetic Materials is important from the point of view of designing and manufacturing of Electrical machines,

The magnetic measurements include,

1. Measurement of flux density B in a specimen of Ferro magnetic material.
2. Measurement of magnetizing forces H, producing the flux density B, in air.
3. Determination of BH curve and the hysteresis loop.
4, Determination of eddy current and the hysteresis losses,
5. Testing of permanent magnets.

Ballistic Galvanometer

The ballistic galvanometer and the flux meter are the necessary instruments for various types of magnetic measurements.

The ballistic galvanometer is used to measure a quantity of electricity passed through it. The ballistic galvanometer has a search coil connected to its terminals. When there is change in the flux linked with the search coil, an emf. is induced in the search coil. The Electricity proportional to this emf is measured by the ballistic galvanometer.

The ballistic galvanometer is usually of D'Arsonval type. The electricity passing through the ballistic galvanometer is in the form of transient current which is instantaneous in nature. It exists only till the change of flux is associated with the search coil- Thus the ballistic galvanometer gives a ‘throw‘ proportional to the quantity of current instantaneously passing through it. It does not give steady deflection. The scale of the ballistic galvanometer is calibrated in such a way that from its throw, the quantity of electricity and the change in the flux producing it can be measured.

The throw of the ballistic galvanometer is proportional to the electrical only if the discharge of electricity through it gets completed before any appreciable change in position of the moving system, Hence the moving system of the galvanometer is mad lo have large moment of inertia and due to this, it keeps on vibrating for long time for about 10-15 seconds. The large moment of inertia is achieved by the addition at weights to the moving system. Thus the oscillations of the galvanometer moving system are damped with large time period and damping ratio, The damping erasures the first deflection (throw) is high and large in amplitude The throw or deflection is measured at the extreme point of the first throw using a lamp and scale,

The dead beat galvanometer is best- It has to have Electromagnetic damping such that it mo be determined horn the constants of the instrument Air damping should not be present as it is indeterminate. To bring the moving system back rapidly, a key is provided with which galvanometer terminals are short circuited,

The special construction of the ballistic galvanometer also includes

1. The moving coil is free from magnetic material.

2. The terminals coil and all the Connections are made up of copper to avoid thermoelectric e.m.fs at the starting junctions.

3. The suspension strip is selected carefully and mounted precisely.

4. In precision instrument, the suspension is non-conducting and current is led in and out of the coil with the help of delicate spirals of very thin strip of copper.

Theory of Ballistic Galvanometer

1. The quantity of Electricity through the galvanometer is instantaneous and for very short period of time while discharged it gives energy to the moving system which is dissipated gradually in friction and damping.

   θ = deflection in radians

   b = damping meant

a = moment of inertia

c = controlling constant

During the actual motion, Electricity is not present once gets discharged hence the equation of motion becomes,

$$a \frac{d^2\theta}{dt^2} + b \frac{d^2\theta}{dt^2} + c\theta = 0 \qquad \text{------(i)}$$

The solution of the differential equation is

$$\theta = Ae^{m_1 t} + B\, e^{m_2 t} \qquad \text{----(ii)}$$

A, B = constants.

m_1, m_2 = roots of quadratic.

As damping is very small, b is very small hence (b^2 - 4ac) term is negative and the roots are imaginary in nature.

The solution of second order differential equation having complex conjugate roots is damped sinusoidal oscillations given by

$$\theta = e^{\frac{-bt}{2a}}\ b \sin\left(\frac{\sqrt{4ac-b^2}}{2a} t + a\right) \qquad \text{------(iii)}$$

But as b is very small hence $4ac-b^2 = 4ac$

$$\theta = e^{\frac{-bt}{2a}}\ b \sin\left(\frac{\sqrt{c}}{\sqrt{a}} t + a\right) \qquad \text{-----(iv)}$$

From the initial conditions when t=0, θ = 0, hence α = 0

$$\theta = e^{\frac{-bt}{2a}}\ b \sin\left(\frac{\sqrt{c}}{\sqrt{a}} t\right) \qquad \text{-----(v)}$$

During the discharge of the electricity through the instrument for the short period of timeτ, the deflecting torque proportional to instantaneous current 'i' exists given by Gi. Where 'G' is displacement constant.

Hence the torque produced by G_i is represented as

$$Gi = a\,\frac{d^2\theta}{dt^2} \qquad \text{-------(vi)}$$

$$\int_0^T Gi\,dt = \int_0^T a\frac{d^2\theta}{dt^2}\,dt = a\,\frac{d\theta}{dt} \quad \text{-----(vii)}$$

But $\int_0^T i\,dt$ represents the charge Q coulombs.

$$QG = a\,\frac{d\theta}{dt} \qquad \text{----(viii)}$$

Where $\frac{d\theta}{dt}$ is the angular velocity of the system at the end of the period τ i.e at the beginning of the first deflection.

$$\frac{d\theta}{dt} = \frac{G}{a}\,Q \qquad \text{---(ix)}$$

Now differentiating above equation

$$\frac{d\theta}{dt} = \frac{-b}{2a}\,e^{\frac{-bt}{2a}}b\,\sin\left(\sqrt{\frac{c}{a}}t\right) + e^{\frac{-bt}{2a}}\,b\,\cos\left(\sqrt{\frac{c}{a}}t\right)\sqrt{\frac{c}{a}} \qquad \text{-----(x)}$$

As the period of discharge is small, at the end of discharge, t=0, using above,

$$\frac{d\theta}{dt} = b\sqrt{\frac{c}{a}} \qquad \text{----(xi)}$$

From the equations (ix) and (xi)

$$\frac{G}{a}\,Q = b\sqrt{\frac{c}{a}}$$

$$b = \frac{G}{a}\sqrt{\frac{a}{c}}\,Q$$

Substituting the value of b in (V)

$$\theta = e^{\frac{-bt}{2a}}\left[\frac{G}{a}\sqrt{\frac{a}{c}}Q\right]\sin\left(\sqrt{\frac{c}{a}}t\right).$$

Flux meter:

A special ballistic galvanometer with very small controlling torque and high electromagnetic damping is used as flux meter.

It consists of a small cross-section carrying a coil C. the cross-section is suspended in the narrow airgap of permanent magnet. The cross-section is suspended with the help of spring support and a single thread of silk. The current is injected to the coil through very thin, annealed silver springs as shown in fig.

The pointer is fitted to the moving system of the flux meter and the scale is calibrated in terms of flux turns. Such a flux meter is designed by grassot and hence it is called grassot flux meter. The spirals of silver of silver springs keep the controlling torque to minimum.

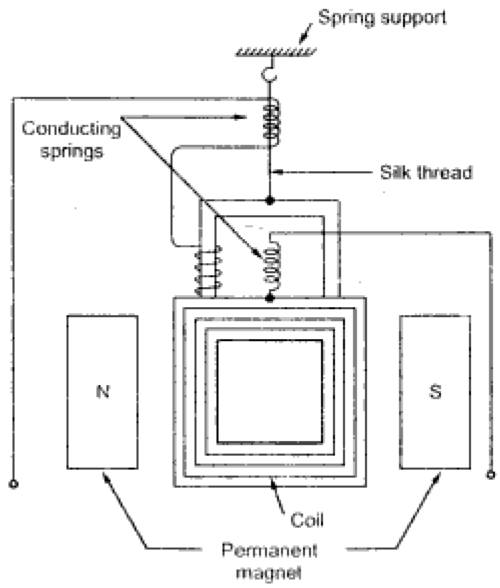

Fig: Flux meter

As controlling torque is minimum, pointer takes time to come back to the zero position. But readings may be taken by observing the difference in deflections at the beginning and end of the change in flux, without waiting for pointer to restore its zero position.

The resistance R_s of the search coil connected to the flux meter must be small. The inductance of search coil may be large.

Let $\varnothing_1$and $\varnothing_2$are the interlinking fluxes at the beginning and the end of the change in flux to be measured respectively. Then,

$d\theta$ = change in deflection = $\theta_2 - \theta_1$

$d\varnothing$ = change in flux = $\varnothing_2 - \varnothing_1$

And it can be proved that,

$G\ d\theta = N\ d\varnothing$

G = constant of flux meter called displacement constant

N = number of turns on search coil.

$d\theta = \frac{N}{G}\ d\varnothing.$

In modern flux meters, the coil is supported with pivots and mounted in jeweled bearings. The current is passed to the coil through fine ligaments.

The flux meter has an advantage over ballistic galvanometer as the deflection is same irrespective of the time taken for the corresponding change in flux, interlinking with the search coil. Another advantage of flux meter is it is portable.

Determination of B-H Curve

There are two methods, by which B-H curve can be obtained for the magnetic material specimen,

I. Method of reversals 2. Step by step method

Method of reversals

A ring specimen with known dimensions is taken for the test. A thin tape is wound on the ring. The search coil insulated by the paraffined wax is wound over the tape. Another layer of tap Ls wound on the search coil. Then the magnetizing winding is wound uniformly on the specimen. The overall circuit used is as shown in the Fig.

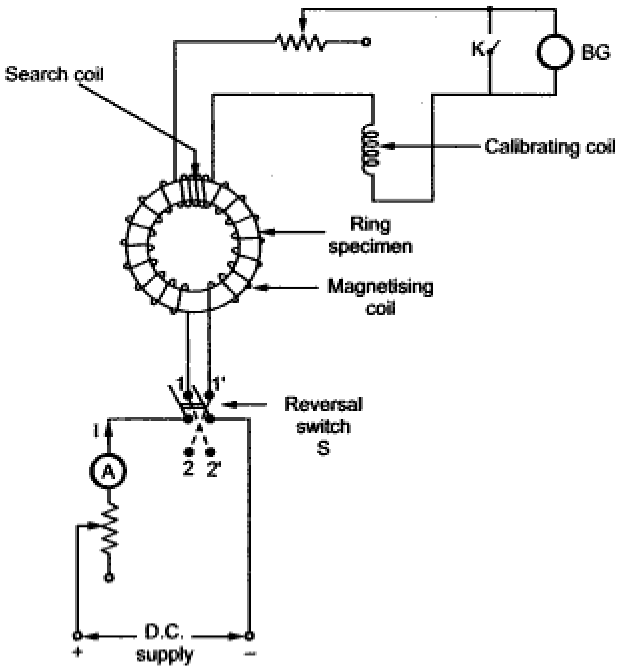

Fig: Method of reversals.

The complete specimen is demagnetized before the test. Using the variable resistance, the magnetizing current is adjusted to its lower value, at the beginning of the test The ballistic galvanometer switch K is closed and reversing switch S is thrown backward and forward for about twenty times. This brings the iron specimen into a reproducible cyclic magnetic state. The galvanometer key K is now opened and the flux in the specimen corresponding to this value of H is measured from the deflection of the ballistic galvanometer, by reversing the switch S. The change in flux, measured by the galvanometer, when the reversing switch S is quickly reversed, will be twice the aux in the specimen, corresponding to the value of H applied. This value of H can be obtained as

$$H=\frac{¿_1}{l}$$

N = number of turns on the magnetizing winding.

I_1= corresponding magnetizing current.

$l=¿$Mean circumference length of specimen in m.

While the flux density B is obtained by dividing the flux measured by the area of cross-section of the specimen

The procedure is repeated for the different values of H by increasing H upto the maximum testing point value. The graph of B against H gives the required B-H curve for the specimen.

Magnetic testing under ac conditions:

Whenever a piece of magnetic material is subjected to alternating current, it goes under a cycle of magnetizing and demagnetization.

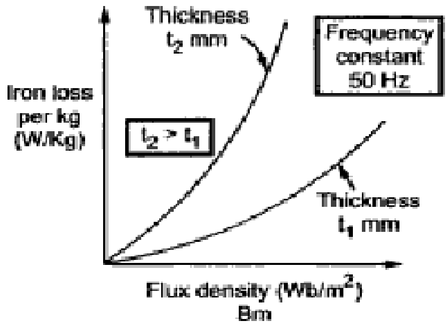

Fig. typical iron loss curves

There exists a hysteresis, due to which power loss occurs in the form of hysteresis loss and eddy current loss. This loss is called iron loss. The knowledge of iron loss in Ferro-magnetic materials plays an important role for the designers. The iron loss depends on,

(i) Frequency of alternating field to which it is subjected.

(ii) Maximum value of flux density Bm.

In practice, for various materials, the curves are obtained at typical frequency giving the variation between iron loss per kg against the maximum flux density. Such curves are called iron loss curves. The curves help the designers to select proper materials for the proper application. the fig shows typical iron loss curves at a frequency of 50Hz.

The total iron loss has two components

(i) Hysteresis loss

(ii) Eddy current loss.

(i) Hysteresis loss:

For a given volume and thickness of laminations, these losses depend on the operating frequency and maximum flux density in the core. Basically hysteresis lodd per unit volume is the area of the hysteresis loop of that material.

Practically steinmetz has given the formula for the hysteresis loss per unit volume as,

$P_h = \eta\ f\ B_m^k$ watts/m^3

η= hysteresis coefficient

F= frequency

B_m = maximum flux density

K = steinmetz coefficient varies between 1.6 to 2

Practically k Is taken as 1.67

For a given specimen of thickness t and certain volume, it is given by

$P_h = K_h f B_m^{1.67}$ watts

(ii) <u>Eddy current loss:</u>

The eddy current loss per unit volume for given lamination is given by,

$$P_e = \frac{4 k_f^2 f^2 B_m^2 t^2}{3 \rho} \text{ watts/m}^3$$

Where K_f = form factor of alternating supply used

T= thickness of lamination

ρ = resistivity of the material in ohm-meter

$P_e = k_e k_f^2 f^2 B_m^2$ watts

$p_i = p_h + p_e$ = total iron loss

Core loss measurements by bridges:

The Maxwell Bridge used for testing ring specimen is shown in fig.

The arm a-b consists of the specimen.

Thus $R_{ab} = R_s$

$L_{ab} = L_s$

At the bridge balance, detector current is zero hence,

$I_1 R_3 = I_2 R_4$ ------------(i)

$I_1 (R¿¿s + j\omega L_s) ¿ = I_1 (R¿¿2 + r + j\omega L_2) ¿$ -----------(ii)

Dividing the two equations

$$\frac{(R¿¿s + j\omega L_s)}{R_3} = \frac{(R¿¿2 + r + j\omega L_2)}{R_4} ¿¿$$

Equating real and imaginary parts,

$$R_s = \frac{R_3}{R_4}(R_2 + r ¿$$

And $L_s = \frac{R_3}{R_4} L_2$ -----------------------(iii)

R_s= effective resistance of a-b including winding resistance

$I_1^2 R_s$= iron loss+ copper loss in winding

P_i= I_1^2¿¿- R_w] --------------(iv)

$I = I_1 + I_2$

From equation 1

$$I_1 R_3 = (I_1 - I_2) R_4$$

$$I_1 = I\left[\frac{R_4}{R_3 + R_4}\right] \quad \text{---------(v)}$$

P_i= $I_1^2\left[\frac{R_4}{R_3+R_4}\right]^2$¿¿- R_w] -----------(vi)

The current I is measure on ammeter and R_s, R_w can be measured. Thus iron loss can be obtained.

Maxwell's inductance capacitance bridge:

Instead of Maxwell's bridge, Maxwell's inductance capacitance bridge can be used as shown in fig.

The arm a-b consists of a specimen hence

R_{ab}= R_s

L_{ab}= L_s

From general bridge balance equation

$Z_1' Z_4 = Z_2' Z_3$

Now $\acute{Y}_4 = \frac{1}{\acute{Z}_4}$

$\acute{Z}_2$= R_2 and $\acute{Z}_3$= R_3

$\acute{Z}_1$= $R_s + j L_s$

$\acute{Y}_4 = \frac{1}{\acute{R}_4} + j\omega C_4$

As $\acute{Z}_4 = R_4 \left\| \frac{-j}{\omega C_4} \right.$ and $\frac{1}{j}$ = -1

Using the expression of $\acute{Z}_1$,

$$R_s + j\omega L_s = R_2 R_3 \left[\frac{1}{\acute{R}_4} + j\omega C_4 \right]$$

$$R_s + j\omega L_s = \frac{R_2 R_3}{R_4} + j\omega\, R_2 R_3 C_4$$

Equating real and imaginary parts

$$R_s = \frac{R_2 R_3}{R_4} \text{ ohm}\ ,\ L_s = R_2 R_3 C_4$$

Calculating I at balance, iron loss can be obtained.

A.C potentiometer method:

The fig shows a.c co-ordinate type of potentiometer used for the measurement of iron loss at low flux densities.

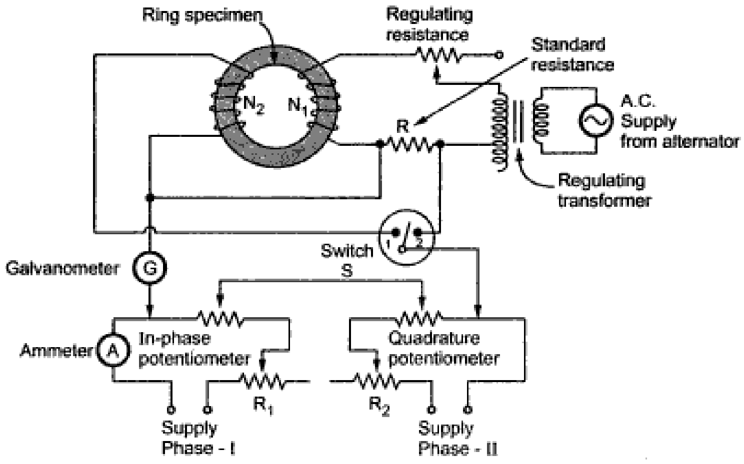

Fig: measurement of iron loss using a.c potentiometer method

The ring specimen has two windings, primary with N_1 turns and secondary with N_2turns. The primary is supplied from a.c supply, through a regulating transformer. This also supplies the two slide wire circuits of the two potentiometers.

The primary winding has a regulating resistance. Another standard resistance r is also connected in the primary circuit. By measuring drop across R, current through primary can be obtained. The alternator a.c supply must have sinusoidal waveform.

When supply is given to the primary, the voltage E_2 is induced in the secondary.

According to transformer equation, it is given by,

$$E_2 = 4.44\ \varnothing_m f N_2 = 4.44\ B_m A\ f\ N_2$$

$$B_m = \frac{E_2}{4.44\, A\, f\, N_2}$$

For sinusoidal waveform K_f= 1.11

Then put the switch to position 2 and adjust both the potentiometers till galvanometer shows zero deflection.

The total current has two parts as core loss component I_c and magnetizing component I_m

The in-phase potentiometer reading gives the drop I_cR while the quadrature potentiometer reading gives the drop I_mR.

$$I_c = \frac{reading\, of \in - phase\ potentiometer}{R}$$

$$I_m = \frac{reading\, of\ quadrature\ potentiometer}{R}$$

$$P_i = ¿\ \text{Iron loss} = I_c E_2 \left(\frac{N_2}{N_1} \right)$$

This method is very effective as both core loss and magnetizing components of currents are obtained.