CHAPTER III

LOSSES IN MAGNETIC CORE

The losses that occur in the material arise from two cases:-

1. The tendency of material to retain magnetism or to oppose a change in magnetism, often referred to as magnetic hysteresis and it was called "hysteresis loss".

2. The I^2R heating which appears in the material as a result of the voltage and consequent circulatory current induced in it by the time variation of flux which was called "Eddy current loss".

1. Hysteresis loss.

Hysteresis loss is the result of the tendency for the B, H characteristic of the material to involve a loop when the material is subjected to a cyclic magnetizing force: The hysteresis loss is the energy converted into heat because of the hysteresis phenomenon.

Considering the magnetization of a ring specimen of iron by means of a magnetizing wiring as shown

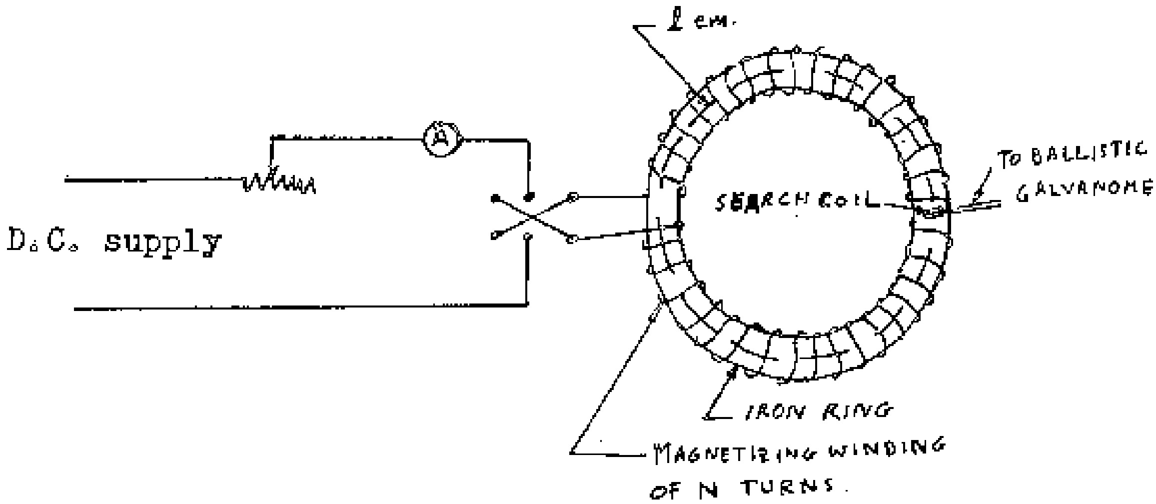

Fig. 2 Connection of equipments for flux measuring

If the length of magnetic path = l cm.

cross section area of iron ring = a cm^2

the magnetizating wiring = N turns

the current in wiring = i cgs unit

the induced emf at any instant = e

$$\therefore \quad e = \frac{N(d\ Ba)}{dt}$$

where B = flux density

the power supplied

$$ei = i\ N \frac{d\ Ba}{dt}$$

The energy supplied in order to build up the magnetic field in time t second is

$$\int_0^t eidt = \int_0^t ei\ N\ \frac{dB}{dt} \cdot dt = a \int_{B_1}^{B_2} iN\ dB.$$

The magnetizing force acting upon the ring is

$$H = 4\pi \frac{Ni}{l}$$

$$Ni = \frac{1}{4\pi} H$$

and the energy supplied $= \frac{la}{4\pi} \int_{B_1}^{B_2} H\,dB$

la = volume of ring

therefore the energy supplied per unit volume

$$= \frac{1}{4\pi} \int_{B_1}^{B_2} H\,dB \qquad \text{ergs.}$$

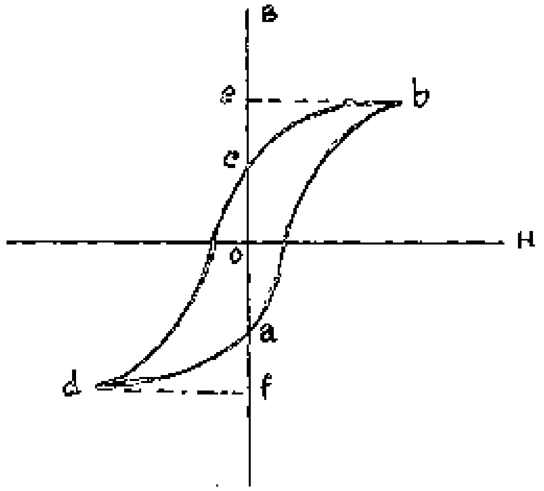

Fig. 3

oe is + B max

of is − B max

oc is + B_1

oa is − B_1

During the part of the cycle ab the energy absorbed by the core per unit volume is

$$w_1 = \frac{1}{4\pi} \int_{B_1}^{B\,max} H\, dB$$

$$= \frac{1}{4\pi} \text{ (area of a b e c)}$$

The part of the cycle b c the energy absorbed by the core per unit volume is

$$w_2 = \frac{1}{4\pi} \text{ area of (c b e)}$$

The same for cycle c d a and d a we have

$$w_3 = \frac{1}{4\pi} \text{ (area of d f a c)}$$

and
$$w_4 = \frac{1}{4\pi} \text{ (area of d f a)}$$

The net energy w_h absorbed by magnetic core per unit volume in a cycle is

$$w_h = w_1 + w_2 + w_3 + w_4$$

$$= \frac{1}{4\pi} \text{ (area of a b c d a) ergs per c.c.}$$

Steinmetz Hysteresis law

The empirical law which proposed by Steinmetz is

$$w_h = k\, B_{max}^{1.6}$$

This equation gives the hysteresis loss with sufficient accuracy for most practical purposes, provided the maximum flux density B_{max} lies between 1,000 and 12,000 lines per sq.cm.

Wh = energy loss in ergs per cu.cm.per cycle

k = hysteresis coefficient of the material, and is constant for any given material

The magnitude of k varies with the material. Its value for annealed sheet steel lies between 0.001 to 0.002 and for silicon steel is about 0.00084.

Nowadays for the sufficient degree of accuracy the formular is given by

$$W_h = \eta \; B^n_{max}$$

Where n is between 1.5 to 2.5 depending on the kind of material.

$$\text{then } \log W_h = n \log B_{max} + \log \eta$$

The straight line relationship between log W_h and log B_{max} can be obtained by plotting log W_h as ordinates and log B_{max} as abscissas. The points should line in a straight line having a slop equal to the exponent n and having an intercept on the vertical axis equal to log η.

2. The eddy current

The eddy current or secondary current is the electric current which circulate with in the mass of the conducting material when the latter is situated in a varying magnetic field. The conducting material may be considered as consisting of a large number of closed conducting paths, each of which behaves like the short circuit winding of a transformer of which the varying magnetic field is the working flux.

The secondary emf. is induced in these elemental paths by the varying magnetic field, giving rise to the eddy current. The figure below shows the induction of the eddy emf, with their accompanying currents.

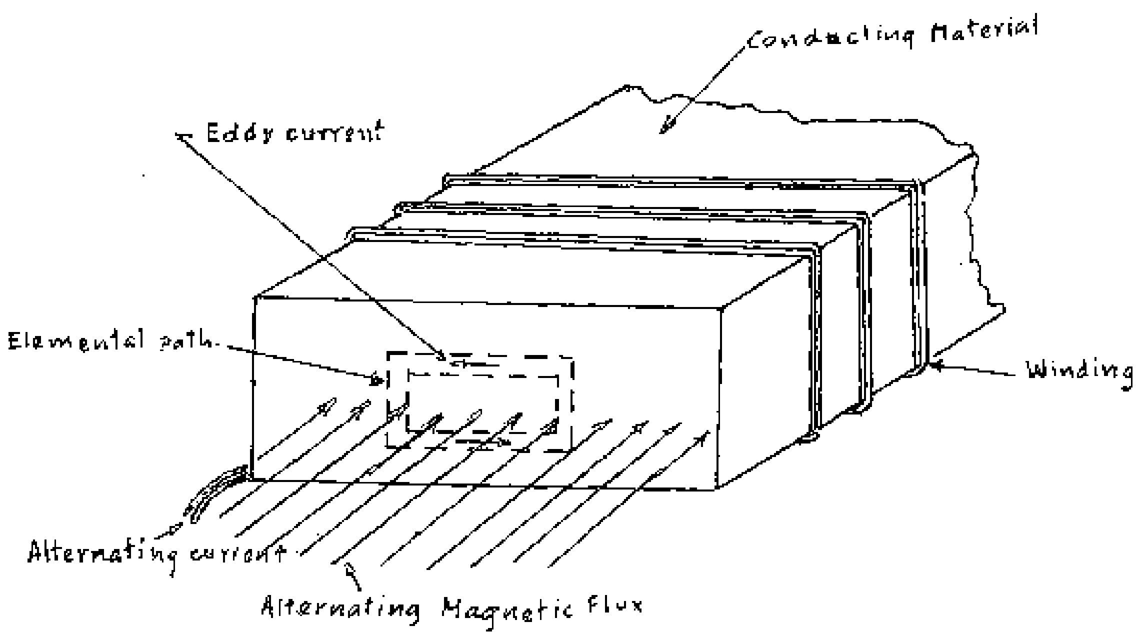

Fig. 4 Induction of eddy current

When the magnetic flux in a medium is changing, an electric field appears with in the medium as a result of the time variation of the flux. The line integral of the electric field E taken around any closed path that bounds the flux is given by the Faraday induction law.

$$\oint E dl = \frac{-d}{dt} \int B.n.ds$$

The average eddy current power loss per unit volume when the flux density is varying sinusoidally at a frequency f is.-

$$W_e = \frac{\pi^2 f^2 t^2 B^2_{max}}{6\rho}$$

Where t is the thickness of the individual lamination . In a magnetic circuit containing volume V of laminate core material. The average eddy current power loss is.-

$$W_e = V p_e = \frac{\pi^2 f^2 t^2 B^2 max. V}{6\rho}$$

$$\text{or } W_e = k_e f^2 t^2 B^2 max. V$$

$$\text{Where } k_e = \frac{\pi^2}{6\rho}$$

The total core loss.

The total power loss in iron cores subjected to an alternating magnetizing force is the sum of the hysteresis and the eddy current loss. If W_{fe} is the total core loss per unit volume. Therefore

$$W_{fe} = k_h f B^n_{max} + k_e f^2 \; {}^2B^2_{max}$$

The determination of n, k_h and k_e

Let the total core loss be measured (1) at frequency f_1 and flux density B_1; (2) at frequency f_2 and flux density B_2; (3) at frequency f_1 and flux density B_2. If the corresponding measured values of total core loss are respectively, P_1, P_2, and P_3,

$$P_1 = k_h \cdot f_1 B_1^n + k_e \cdot f_1^2 \cdot B_1^2$$

$$P_2 = k_h \cdot f_2 B_2^n + k_e \cdot f_2^2 \cdot B_2^2$$

$$P_3 = k_h \cdot f_1 B_2^n + k_e \cdot f_1^2 \cdot B_2^2$$

which, when aolved as simultaneous equations, yield the results:

$$n = \frac{\log \dfrac{B_2^2(P_2 - a^2P_3)}{(P_2 - aP_3)B_1^2 - a(a-1)P_1B_2^2}}{\log (B_2/B_1)}$$

$$k_h = \frac{P_2 - a^2P_3}{f_2(1-a)B_2^n}$$

$$k_e = \frac{P_2 - aP_3}{f_2^2B_2^2} \cdot \frac{a}{a-1}$$