Magnetic Measurements

Magnetic measurement:

The principle objective of magnetic measurement are:

a. The measurement of magnetic field strength.
b. Determination of B-H curve and hysteresis loop for soft ferro - magnetic materials.
c. Testing of permanent magnet.
d. Determination of eddy current and hysteresis losses for soft ferro - magnetic materials when they are subjected to A.C. magnetic fields.

Types of Test:

1. **Ballistic test:** These tests involves sudden changes in magnetization and usually include measurements of corresponding changes in magnetizing force H and flux density B. The change in magnetic flux density is measured by a flux meter or a ballistic galvanometer. These tests are generally employed for the determination of B-H curves and hysteresis loop of ferro-magnetic materials.
2. **A.C. test:** These may be carried out at power audio or radio frequencies and are usually intended to give information about power loss in the material.
3. **Steady-state test:** These are performed to obtain the steady value of flux density existing in the air gap of the magnetic circuit.

Measurement of flux density:

The measurement of flux density inside a specimen can be done by winding a search coil over the specimen. The search coil is connected to a ballistic galvanometer or to a flux meter. The ring specimen is wound with a magnetizing winding which carries a current I. A search coil of convenient number of turns is wound on the specimen and connected through a resistance and a calibrating coil, to a ballistic galvanometer. The current through the magnetizing coil is reversed and therefore the flux linkage of the search coil changes inducing an emf in it. This emf drives current through the ballistic galvanometer causing it to deflect.

Let Φ = flux linking the search coil
R = resistance of the ballistic galvanometer circuit
N = number of turns in the search coil
t = time taken to reverse the flux
K_q = galvanometer constant

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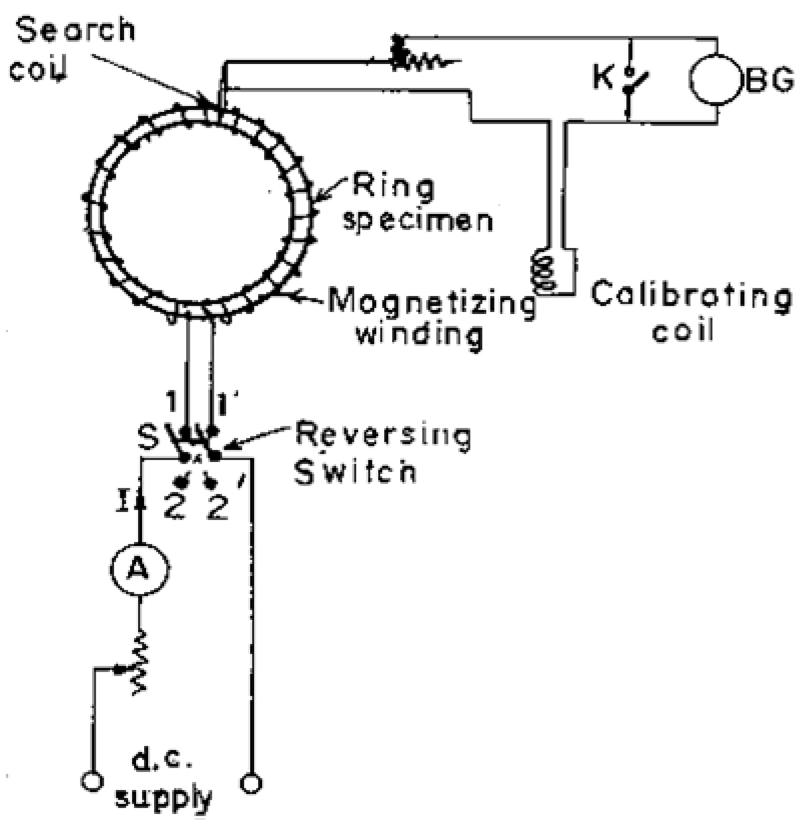


Fig.1. measurement of Flux density in ring specimen

Average emf induced in the search coil: $e = N\dfrac{d\phi}{dt} = 2N\dfrac{\phi}{t}$

Average current through the ballistic galvanometer is, $i = 2N\dfrac{\phi}{Rt}$

Charge passing through galvanometer coil: $Q = it = 2N\dfrac{\phi}{R}$

θ_1= Throw of the galvanometer due to flow of charge
Charge indicated by ballistic galvanometer = $K_q\theta_1$

$\therefore \dfrac{2N\phi}{R} = K_q\theta_1$ or flux density $\phi = \dfrac{RK_q\theta_1}{2N}$

In a uniform field and with search coil turns at right angles to the flux density, the flux density:
$B = \dfrac{flux}{area} = \dfrac{\phi}{A_s} = \dfrac{RK_q\theta_1}{2NA_s}$, where A_s = cross sectional area of specimen.

In above calculation, it has been assumed that the flux is uniform throughout the specimen, and that the effective area of cross section of the search coil is equal to the cross sectional area of the specimen. However, the search coil is usually of larger area that the specimen and

thus flux linking with the coil is the sum of the flux existing in the specimen and the flux which is present in the air space between the specimen and the search coil.
Observed value of flux =True value of flux in specimen + flux in the air space between specimen and search coil

or, $B'A_s = BA_s + \mu_o H(A_c - A_s)$

Hence, true value of flux density: $B = B' - \mu_o H(\frac{A_c}{A_s} - 1)$

Where B' = observed value of flux density (Wb/m^2)
B = true value of flux density in specimen (Wb/m^2)
A_s = area of cross section of specimen (m^2)
A_c = area of cross section of coil (m^2)

Measurement of value of magnetizing force (H):

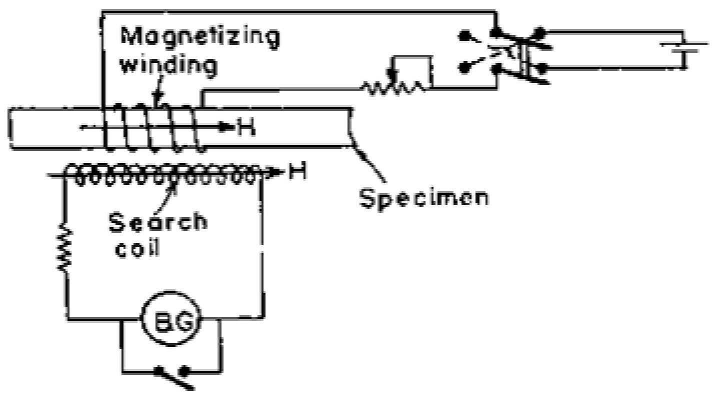


Fig.2. Determination of Magnetising Force H

The magnetizing force of a constant magnetic field may be measured by a ballistic galvanometer and a search coil. The value of H inside a specimen can either be inferred from calculations involving data of magnetizing coil and the specimen or from measurement made outside the specimen. It cannot be measured directly. If the magnetizing force is to be determined in the air gap, the search coil is placed in the air gap itself. While testing ferro-magnetic materials, the magnetizing force, within the specimen may be determined by measuring the magnetizing force on its surface, since the tangential components of the field are of equal in magnitude for both sides of the interface. The search coil measures the value of flux density in air. The search coil is called an H coil. Since the H-coil links the flux crossing through the air, the sensitivity is much less than that in the search coil, which is wound over the specimen. The flux density encountered in H-coil is also much less due to the fact that permeability of the air is thousand times less than that of iron. The value of flux density in air through H-coli is measured by ballistic galvanometer method. Thus the magnetizing force: $H = \frac{B_o}{\mu_o}$ A/m, where B_o is the flux density in air and μ_o is the permeability of air

Magnetic potentiometer:

The device is used for measurement of magnetic potential difference between two points in magnetic circuit. The integral of the magnetizing force H produced by a coil of N turns carrying a current I around a closed path linking the coil is: $\int Hdl = NI$

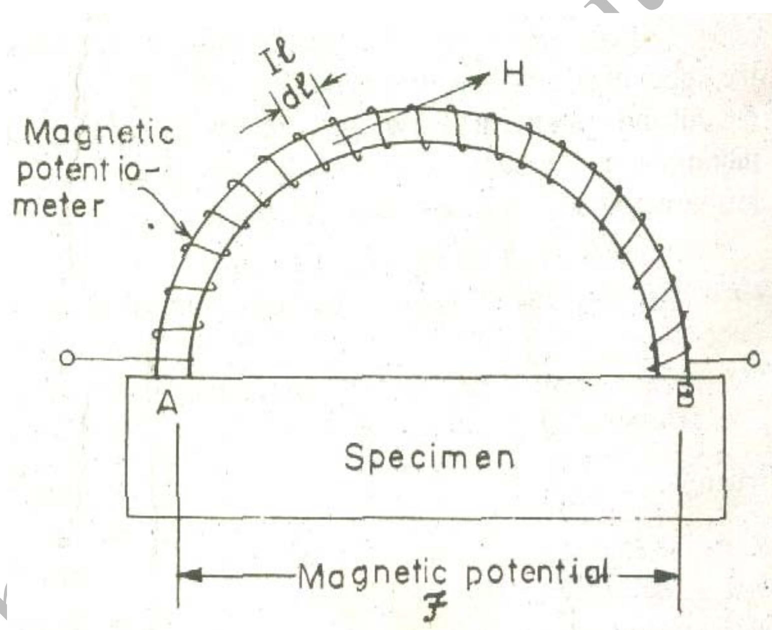


Fig.3. Magnetic Potentiometer

A magnetic potentiometer measures the mmf around a closed path, or the magnetic potential difference between two points in a magnetic circuit. The potentiometer consists of a one metre long flat and uniform coil made of two or four layers of thin wire wound unidirectional on a strip of flexible non-magnetic material. The coil ends are brought out at the middle of the strip and connected to a ballistic galvanometer. The magnetic potential difference between points A and B of the field is measured by placing the ends of the strip at these points and observing the throw of the ballistic galvanometer when the flux through the specimen is changed. The flux is changed by reversing the field.

Let A = area of the strip (m^2)

n = number of turns per unit length of the strip

H_1 = tangential component of the magnetizing force A/m and

R = resistance of the ballistic galvanometer circuit

Flux linkage of a small infinitesimal part of strip of length dl are:

Flux X turns = $(\mu_o H_1 A)ndl = \mu_o H_1 Andl$

Total flux linkage of the strip: $\int \mu_o H_1 Andl = \mu_o An \int H_1 dl$

When the current in the magnetizing winding is reversed, change in flux linkages: $2\mu_o An \int H_1 dl$

But $\int H_1 dl = M$ = magnetic potential difference between A and B

Change in flux linkages: $2\mu_o AnM$

Charge: $Q = it = \dfrac{e}{R}t = \dfrac{2\mu_o AnM}{Rt}t = \dfrac{2\mu_o AnM}{R}$

Charge indicated by the deflection of galvanometer: $Q = K_q \theta_1$

Magnetic potential difference $M = \dfrac{RK_q \theta_1}{2\mu_o An}$

The value of constant of galvanometer can be found with the help of a calibrating circuit.

Determination of B-H curve:

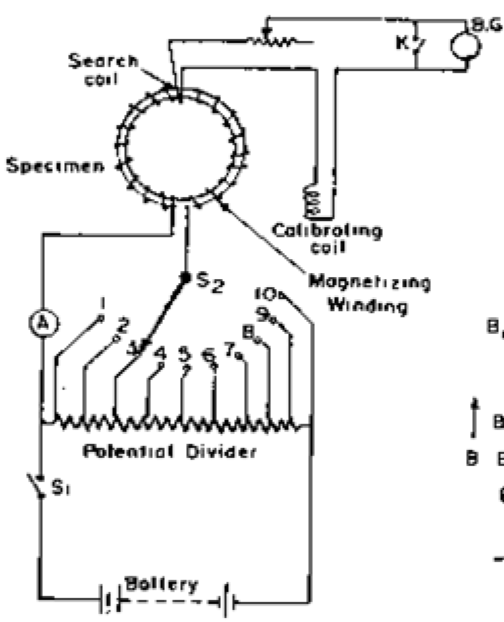
There are two methods available for determination of B-H curve of a magnetic specimen as i) Method of reversals ii) Step by step method

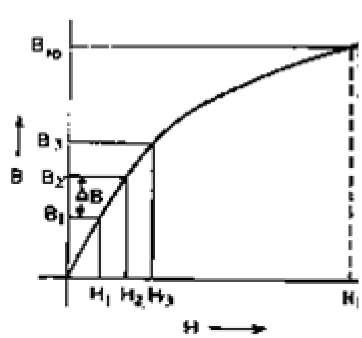
i) Method of reversals:

A magnetizing winding is uniformly distributed over the ring specimen and a layer of tape made of paraffined wax is coated over the search coil 1. The search coil is wound over this layer. The search coil is connected to either ballistic galvanometer via series rheostat and a calibrating coil. After demagnetizing the specimen, the test is started by setting the magnetizing current to its lowest test value. With galvanometer key K closed, the iron specimen is brought into a reproducible cyclic magnetic state by throwing the reversing switch S backward and forward about twenty times. Key K is now opened and the value of flux corresponding to this value of H is measured by reversing the switch S and observing the throw of galvanometer. The value of flux density corresponding to this H can be calculated by dividing the flux by area of the specimen. The above procedure is repeated for various values of H upto the maximum testing point. The B-H curve may be plotted from the measured values of B corresponding to the various values of H.

ii) Step by step method:

In this method, the magnetizing winding is supplied through a potential divider having a large number of tapings. The tapings are arranged so that the magnetizing force H may be increased in a number of suitable steps, upto the desired maximum value. The specimen before being tested is demagnetized. The tapping switch S_2 is set on tapping 1 and the switch S_1 is closed the throw of the galvanometer corresponding to this increase in flux density in the specimen, from zero to some value of B_1 is observed. The value of I can be calculated from the throw of the galvanometer. The value of corresponding magnetizing force H_1 may be calculated from the value of current flowing in the magnetizing winding at tapping 1. The magnetizing force is then increased to H_2 by switching S_2 suddenly to tapping 2, and the corresponding increase in flux density ΔB is determined from the throw of galvanometer. Then flux density B_2 corresponding to magnetizing force H_2 is given by $B_1 + \Delta B$. This process is repeated for other values of H upto the maximum point and the complete B-H curve is thus obtained.





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Determination of Hysteresis loop of B-H curve:

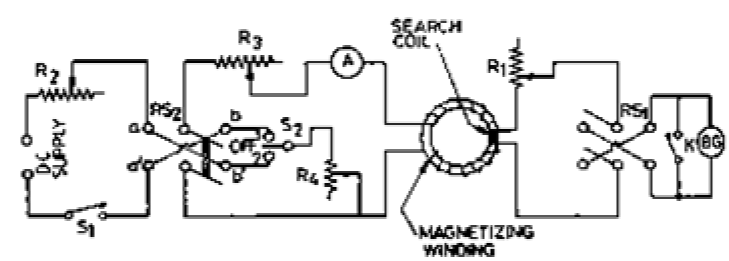
i) Step-by step method :

In the test circuit, the magnetizing winding is supplied through a potential divider having a number of tappings. The tappings are arranged so that the magnetizing force may be increased in a no. of suitable steps, upto desired maximum value. The specimen before test should be magnetized. The specimen after being wound with insulation tape, search coil then with insulation tape and magnetizing windings is then energized by setting switch position to 1. The galvanometer throw indicates the increase in flux density in the specimen from zero to some value B_1 due to H_1. The magnetizing force is then increased to H_2 by setting switch position to tapping 2 and the corresponding increase in flux density is determine from the throw of galvanometer. The flux density B_2 corresponding to the magnetizing force H_2 is then given by: . The process is repeated for other values of H upto the maximum value of H. With all the set values of H and corresponding values of B the B-H curve is plotted. For determination hysteresis loop formed by the B-H curve, the magnetizing force should also be decreased after reaching the B at its maximum value.

ii) Method of reversal

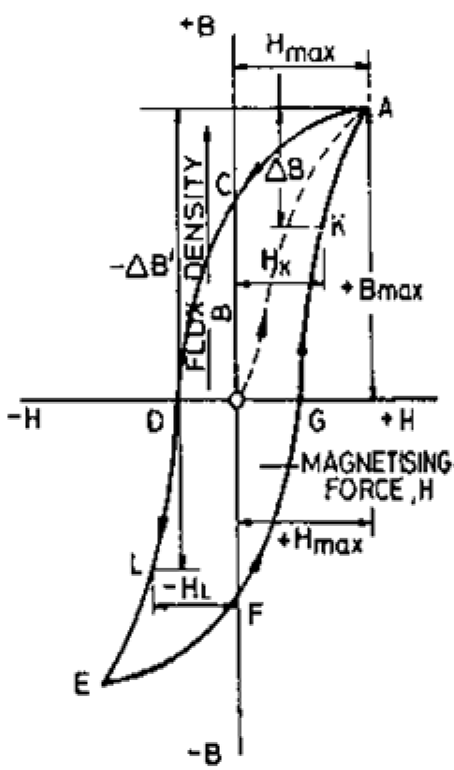
The test is done by means of a number of steps, but the change in flux density measured at each step is the change from maximum value $+B_m$ down to some lower value. But before the next step is commenced the iron specimen is passed through the remainder of the cycle of magnetization back to the flux density $+B_m$. Thus the cycle state of magnetization is preserved.

In the test circuit diagram, R_1,R_2 and R_3 are the variable resistances for adjusting the resistances in the ballistic galvanometer across the magnetizing coil by means of switch S_2 thus reducing the magnetizing current from its maximum value down to any desired value depending upon the value of R_4.



Connection Diagram For Determination of Hysteresis Loop By Method of Reversal

The reversing switch RS_2 is placed on contacts aa' and ballistic galvanometer is connected to the test circuit by opening key K. The value of B_{max} is determined corresponding to magnetizing force H_{max} from the deflection of the galvanometer observed on reversing switch RS_2 and point a on the hysteresis loop is obtained. The switch S_2 is then thrown down off position to contact 2 in order to connect resistance R_4 across the magnetizing winding and reduce the magnetizing force to H_k. The corresponding reduction in flux density B is obtained from the galvanometer throw and thus point K is obtained on the loop. The galvanometer is then short-circuited by closing the key and reversing switch RS_2 is reversed to contact bb'. Switch S_2 is then moved to the off position and reversing switch RS_2 is moved back to contact aa'. Thus specimen is passed through the cycle of magnetization and brought back to point A again. The section AC of the loop is obtained by adjusting the shunting resistance R_4 to give different reduced values of H and determining corresponding reduction in B. To obtain the section CDE of the loop, the galvanometer is short-circuited, switch S_2 is put in the off position reversing switch RS_2 is thrown to contacts aa'. Now switch S_2 is put on contact 1, key K is opened and reversing switch RS_2 is reversed to position bb' and corresponding galvanometer throw is observed. the galvanometer throws gives the change in flux density B since the switching process explained changes H from + H_{max} to value H_L depending upon the value of shunting resistance R_4 . The specimen magnetization is brought back to position A by closing key K, opening switch S_2 and throwing reversing switch RS_2 to contacts aa'. Similarly other points on the CDE of the loop are obtained after drawing portion AKCDLE of the loop, the rest portion is completed by drawing section EFGA in the reverse of ACDE as two halves are identical. The determination of hysteresis loop enables the hysteresis loss per cycle of magnetization to be calculated. Allowing the scales of B and H, the loop area gives the loss per unit volume per cycle for the specimen.



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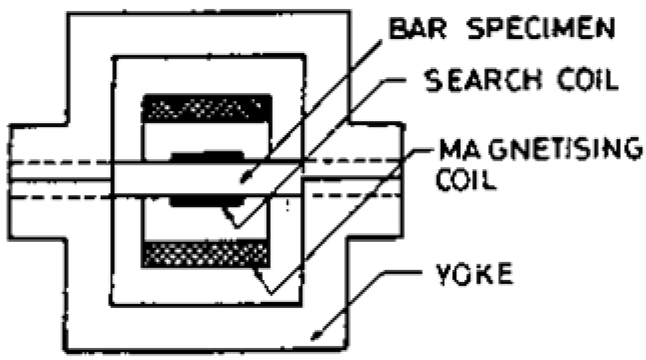
Permeameter:

This device measures the magnetizing force or field intensity inside a specimen of bar shape. The testing of magnetic specimen is done with the help of permeameters, which makes use of straight bar specimens and also provides are turn path of low reluctance and thus reduce or in some cases entirely remove the effects of self demagnetisation.

a) Hopkinson permeameter (Bar and Yoke method):

The bar specimen is clamped between two halves of a massive iron yoke, whose reluctance is low compared to that of the bar specimen. This yoke provides a return path for the flux. The bar specimen is wound with a magnetizing winding, which is energized with flow of direct current. A test coil is wound upon the central part of the bar



Bar and Yoke Method

Let N = number of turns on the magnetizing winding

I = current in the magnetizing winding

l = length of the bar specimen between two halves of the yoke

A_s = area of cross section of the specimen

μ_s = permeability of the specimen when the magnetizing current is I.

R_y = reluctance of the yoke

R_j = reluctance of the joints between the bar specimen and the yoke

ϕ = flux in the magnetic circuit

Reluctance of the specimen $R_s = \dfrac{l}{\mu_s A_s}$

$\therefore$ Flux $= \phi = \dfrac{mmf}{\text{reluctance of magnetic circuit}} = \dfrac{NI}{R_y + R_j + (l/\mu_s A_s)}$

Flux density in the specimen: $B = \dfrac{\phi}{A_s} = \dfrac{NI}{A_s(R_y + R_j + l/\mu_s A_s)}$

Magnetizing force $H = \dfrac{B}{\mu_s} = \dfrac{NI}{\mu_s A_s(R_y + R_j + l/\mu_s A_s)}$

Let $m = \dfrac{\text{reluctance of (yoke + joints)}}{\text{reluctance of specimen}} = \dfrac{R_y + R_j}{l/\mu_s A_s} = \dfrac{\mu_s A_s}{l}(R_y + R_j)$

$\therefore H = \dfrac{NI}{l(1+m)}$

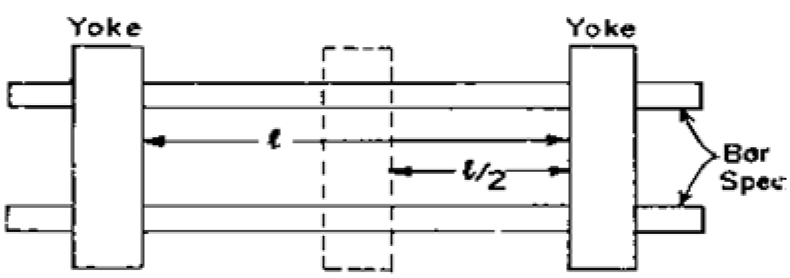
The value of m is made small by keeping the reluctance of yoke and that joint to a small value. This can be done by carefully fitting the specimen into the yoke so that air gap between bar and yoke is negligible) and making the yoke of a large cross section.

If m is made small, then $H = \dfrac{NI}{l}(1-m)$

Thus actual value of magnetizing force differs from the calculated value of magnetizing force ($\dfrac{NI}{l}$) by the amount $= mNI/l$

b) Ewing double bar permeameter:

This permeameter consists of two exactly similar bars made up of magnetic materials under test. There are two pairs of magnetizing coils. One pair of coils is exactly half the length of the other pair. Each bar is wound with two coils, one of full and the other of half length.



Let

n = number of turns per unit length of magnetizing coil,

I_1 = current in the coils when the specimen length is l

I_2 = current in the coils when the specimen length is l/2

H_1 = apparent magnetizing force for sample of length
H_2 = apparent magnetizing force for sample of length
M = mmf required for yokes and the joints
B = flux density in specimen

Then $H_1 = \frac{nlI_1}{l} = nI_1$ and $H_2 = \frac{nl/2I_2}{l/2} = nI_2$

If H is the magnetizing force in the iron for a flux density B, then $H_2 l/2 = Hl/2 + M$, $H_1 l = Hl + M$

[$\because$ Total applied mmf=mmf required for iron + mmf required for yoke and joints]

Thus true magnetizing force $H = 2H_1 - H_2$

The disadvantages of this method are:

i. The reluctance of yokes and joints are not exactly same for the two positions of the yoke
ii. Two exactly similar bars are needed
iii. The test is time consuming.

c) The National Physical laboratory permeameter:

This permeameter is one of the most accurate and easy to use in practice. In this arrangement, specimen consisting of bundle of strips or in rod form of circular cross section can be tested. The specimen is clammed between two similar rectangular iron yokes Y_1 and Y_2. To keep the flux path of low reluctance, cross sectional area of these yoke are taken large. A search coil S is wound in middle part of the specimen for measurement of flux density in the specimen. Two similar auxiliary search coils A_1 and A_2, each having half the number of turns of than in search coil S, are wound at either side of the specimen. Coils A_1 and A_2 are used to check the uniformity in flux in the specimen. The main measuring winding M is wound such that it surrounds the specimen. Both ends of the main winding M is provided with compensating windings M_1 and M_2, which supply necessary mmfs to reluctance of the joints. Now series combination of windings A_1 and A_2 is connected in series opposition with search coil S and then connected with ballistic galvanometer. Current in the main magnetizing winding is set for the required value of H. Current in the compensating windings is so adjusted that there is no throw in the ballistic galvanometer during simultaneous reversal of current in these windings M_1 and M_2 and main winding M. This connection shows the uniform distribution of flux density in the specimen. Now this flux density is measured with the help of ballistic galvanometer by connecting it to search coil S. H coils are provided in this permeameter for the measurement of value of H in the specimen. Measurement of H is done by connecting the H coils to the ballistic

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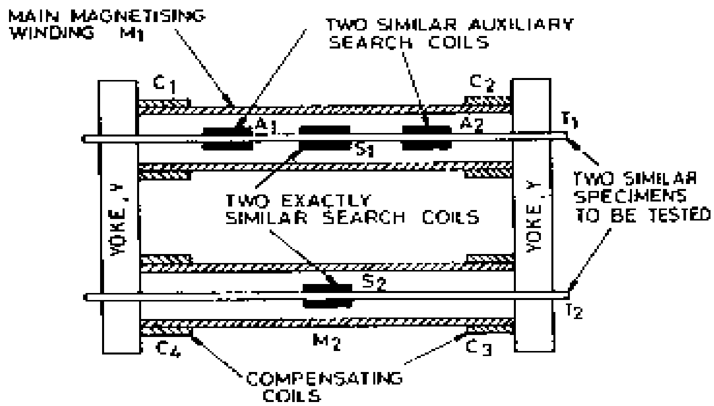
galvanometer. With this permeameter, accurate results can be obtained for the value of H from 10AT/m to 30,000 AT/m.



Burrow's Double Bar and Yoke Permeater

Testing of Bar specimen:

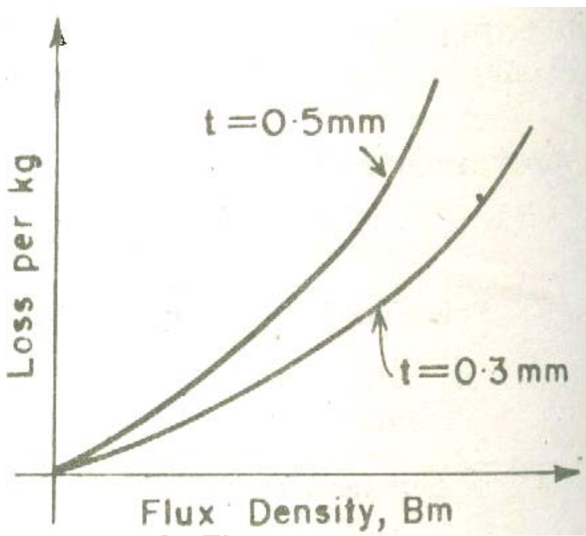
It is very difficult to prepare the ring specimen while the bar specimen is much easier to construct. But bar specimen suffers one major inaccuracies arising in testing. When the bar specimen is magnetized the flux produced inside it get the return path through air having very high reluctance, at the corners or ends Also, poles are produced at its ends, and these poles produce, inside it, will create magnetizing field acing in opposition to the applied magnetizing force. This is called self –demagnetization or end effects. Thus the value of H of the magnetizing force which is effective is producing the flux in the specimen is less than the applied magnetizing force as calculated from the mmf of the magnetizing winding.

The true magnetizing force, $H = H' - H_d$, where H' = applied magnetizing force= NI/l for a long solenoid and $NI/\sqrt{l^2 + d^2}$ for a short solenoid of length l and diameter d, H_d = magnetizing force due to self – demagnetization.

In order to obtain accuracy in measurement, a correction factor must be needed for the demagnetizing force or reduce the end effect. However, the self demagnetization force H_d is somewhat an uncertain quantity. Since the effect of demagnetization force is small when the ratio of length to diameter of bar is large, the dimensions of the specimen should be so chosen that the effect of demagnetization is negligible. It has been found that if the ratio of length to diameter of bar specimen is 25 or more, the demagnetizing effect h becomes negligibly small.

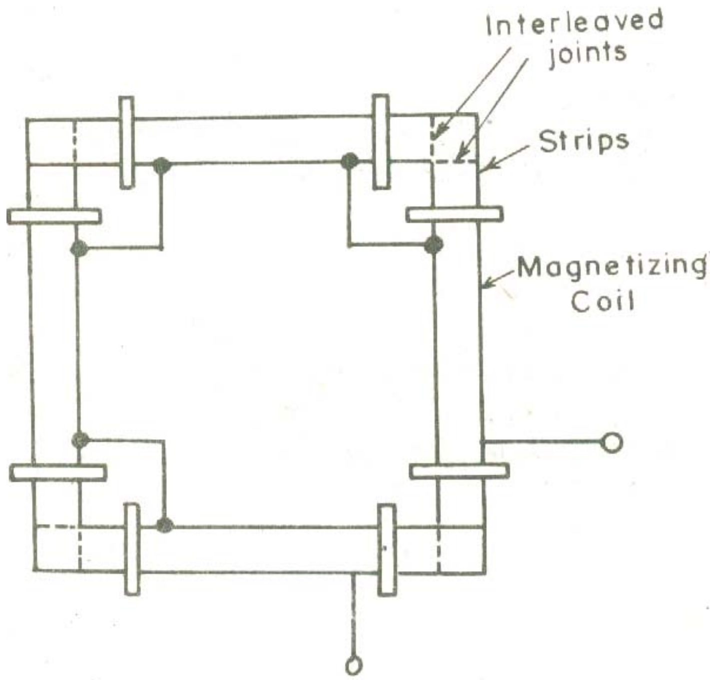
A.C. Magnetic testing:

When a magnetic material is subjected to an a.c. magnetic field, loss in power occurs owing to hysteresis & eddy currents. This loss is called iron or core loss. The hysteresis loss may be computed from the hysteresis loop test carried out & D.C. connection, but this loss will be different under actual working a.c. magnetization condition. The eddy current loss can be measured only under a.c. condition. Sometimes specific iron loss i.e. loss/kg or loss/unit value are also referred. The iron loss in ferromagnetic material depends on the maximum operating flux density, freq. of a.c. magnetization, geometrical thickness of the material. A typical iron loss/kg vs. flux density for different thickness is shown below:



Epstein Square:-

The ferromagnetic materials are shaped into this rectangular sheet. Four stacks are formed by these thin sheets. The individual sheets are insulated from each other & are slipped into from magnetizing coils of equal no. of turns. The ends of the four stacks are interleaved & clamped corners so that a square specimen is formed. The magnetizing coils are connected in series & finally two end terminals are drawn out.

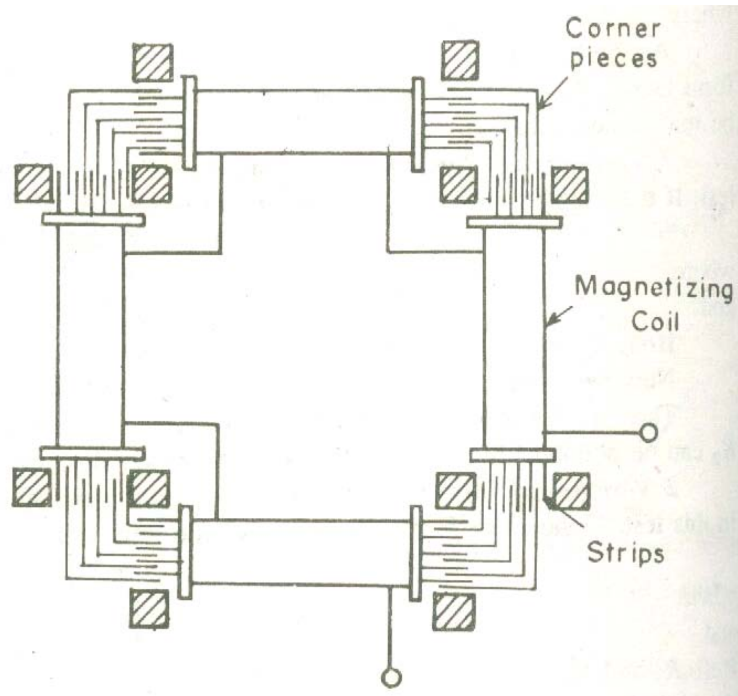


Lloyd-Fisher Square:-

The ferromagnetic materials are shaped into strips of usually 25cm long & 5-6cm wide. These strips are built up into 4 stacks. Each stack is made up of two types of strips – one cut in the direction of rolling & the other cut perpendicular to the direction of rolling.

The stacks of strips are placed inside four magnetizing coil of large cross-section. These 4 coils are connected in series to form the one primary coil distributed over the iron core. Each magnetizing coils have two similar single layer coils underneath it. They are called secondary coils. Thus in a magnetic square there are eight secondary coils. These secondary coils are connected in series in groups of 4, one from each core, to form two separate secondary windings.

The strips are stacked together in such a manner that the plane of each strip is perpendicular to the plane of the square. The magnetic circuits completed by bringing the 4 stacks together in the form of a square and joining them at the corners. The corner joints one made by a set of standard right angled corners pieces. The corner pieces one of the same materials as strips. There is an overlapping of corner piece and strips at the corners due to which cross-section of iron is doubled at the corners. Therefore, as correction must be applied for this.



Test Setup: - The test specimen is weighed before assembly & its effecting cross-section is determined. The primary coil or winding is connected to a.c. voltage supply through an isolation transformer or autotransformer and ammeter and current coil of a wattmeter. The potential coil of the wattmeter is separately connected to one of the secondary windings. The wattmeter used should be of low p.f. range (≈ 0.2). The other secondary winding should be connected to an electrostatic voltmeter (or an voltmeter of very high input impedance). The frequency of supply is adjusted to the correct value at which the iron loss is to be determined. The voltage of primary winding is adjusted, preferably to the value till the magnetizing current will produce the required value of flux density (B_m). The wattmeter and voltmeter reading are observed.

The induced secondary voltage is

$E = 4\, k_f\, \phi_m\, f\, N_2 = 4\, K_f\, B_m\, A_s\, f\, N_2$

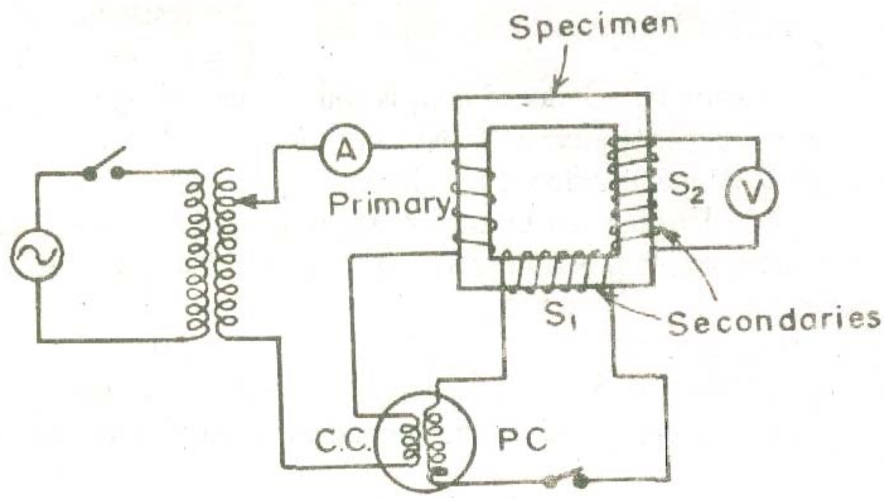
Where K_f = form factor

ϕ_m = Maximum flux linking the secondary coils.

A_s = Effective cross-section of the specimen.

N_2 = No. of turns of secondary winding.

∴ Maximum flux density $B_m = \frac{E}{4\, K_f\, A_s\, f\, N_2}$ wb/m^2



The above value of B_m gives the apparent value of flux density since the coil S_2 encloses. The flux in the air space between specimen & the coil in addition to the flux in the specimen.

The actual value of flux density in the specimen is given by

$$B'_m = B_m - \mu H_m \left(\frac{A_c}{A_s} - 1\right)$$

Where A_c = cross-section area of coil.

H_m = magnetizing force corresponding to maximum density which can be obtained from B-H curve of the specimen.

The wattmeter reading includes both the iron loss in the specimen & the copper loss in the secondary circuit.

Let P_i = total iron loss occurring in the specimen.
P = wattmeter reading.
V = voltage applied to wattmeter pressure coil.
E = voltmeter reading = Voltage induced in coil S_2.
r_p = resistance of wattmeter pressure coil.
r_s = resistance of coil S_1.
I_p = current in the pressure coil circuit.

Since, the voltage induced in S_1 is equal to the voltage induced in S_2 since both of them have equal no. of turn and they link with the same flux.

∴ Voltage induced in S_1 coil = E

The leakage reactance of winding S_1 & that of pressure coil are very small as compared with resistance of the pressure coil circuit.

If the leakage reactance of coil S_1 & pressure coils are neglected then $E = I_p (r_p + r_s)$

∴ Total iron loss in specimen + total copper loss in the secondary circuit $= P.\frac{E}{V}$.

Total copper loss in the secondary circuit $= \frac{E^2}{r_p + r_s}$

∴ Total iron loss in the specimen $P_i = P.\frac{E}{V} - \frac{E^2}{r_p + r_s} = P\left(1 + \frac{r_s}{r_p}\right) - \frac{E^2}{r_p + r_s}$

If the weight of the iron specimen in W kg.

∴ iron loss/mass = P_i/W (W/kg).

Separation of Iron Losses:

It is sometime necessary to separate the total iron loss in ferromagnetic material in to hysteresis and eddy current loss components,

The hysteresis loss per unit volume

$P_h = \eta f B_m k$ watt

When η = hysteresis co-efficient.

K = Steinmets co-efficient, the value of which varies from 1.6 to 2.

Eddy current loss per unit volume $P_e = \frac{4{K_f}^2 f^2 {B_m}^2 t^2}{3\rho}$ watt

where K_f = form factor of a.c. voltage

t = thickness of specimen

ρ = resistivity of material

∴ Total iron loss per unit volume

$P_i = P_h + P_e$

Total iron loss in a specimen $P_i = (A_s \times l) \times (P_h + P_e)$

When l = mean length of the magnetic circuit formed by the specimen.

A_s = cross section of the specimen

Or, $P_i = (A_s \times l)(\eta f {B_m}^2 + \frac{4{k_f}^2 f^2 {B_m}^2 t^2}{3\rho})$

$= K_h f {B_m}^k + K_e {K_f}^2 f^2 {B_m}^2$

When $K_h = A_s \times l \times \eta$, $K_e = \left(\frac{A_s \times l \times 4t^2}{3\rho}\right)$

As the hysteresis and eddy current losses have different law of variation with both frequency and form factor K_f; it is possible to separate the losses by variation of frequency of form factor if B_m can be maintained constant.

a) Variation of frequency:

The form factor K_f & maximum flux density B_m should remain constant in this test. Now if the frequency is varied the total iron loss is given by:-

$P_i = K_1 f + K_2 f^2$

where $K_1 = K_h {B_m}^k$ & $K_2 = K_e {K_f}^2 {B_m}^2$ are constants.

Also $\frac{P_i}{f} = K_1 + K_2 f$. The total iron loss ($P_i$) is measured at different frequency (f) ranging from minimum to maximum value (e.g. 25 Hz to 1000 Hz).

On plotting $\left(\frac{P_i}{f}\right)$ vs. f, a straight line is obtained which intercepts the Y-axis at (0, K_1) point with a slope (K_2). The value of K_1, K_2 can be obtained from the plot respectively. At a given frequency (f_1) the total hysteresis loss & eddy current loss can be determined.

$\therefore$ $P_h = K_1f_1$, $P_e = K_2f_1^2$

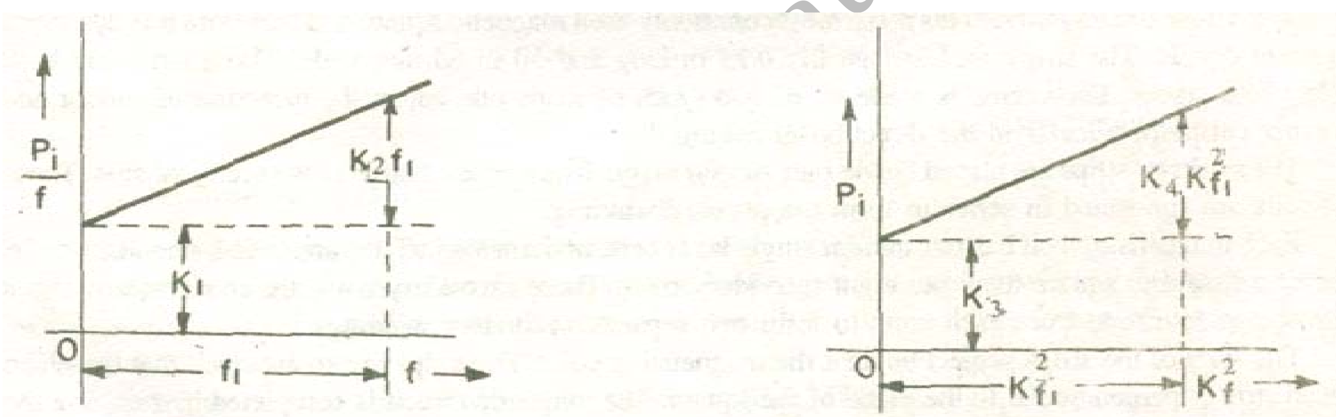
b) Variation of Form factor:

In this method, the value of B_m & f are kept constant. The form factor K_f is varied. The total iron loss P_i is expressed as

$P_i = K_3 + K_4K_f^2$

when $K_3 = K_nfB_m^k$, $K_4 = K_ef^2B_m^2$ are plotting P_i vs. K_f^2, a straight line is obtained which intercepts the Y-axis at (0, K_3) point with a slope (K_4). The values of K_3 & K_4 can be obtained from the plot respectively. At a given form factor (say, K_{f1}), the total hysteresis loss & eddy current loss can be determined.

$\therefore$ $P_h = K_3$ & $P_e = K_4K_{f1}^2$



Bridge Method:-

The coil is wound on the ring specimen made by ferromagnetic material, which is placed in the arm of unknown element of Maxwell inductance bridge.
Let the effective resistance & inductance of the coil are be R_s & L_s to be measured by the bridge.
From the balance condition, we obtain

$$R_s = \frac{R_3}{R_4}(R_2 + R_S)$$

Let I_1 have the current flowing through the coil at balance condition & R_w be the resistance of the coil. Also effective resistance of unknown arm is given by,

R_s = (Iron Loss in the specimen + Copper loss in winding) ÷ (current)^2

= $(P_i + I_1^2R_w)/I_1^2$

Total Iron Loss $P_i = I_1^2 (R_s - R_w)$
At balance voltage drop between bc & dc are equal.

$\therefore$ $I_1R_3 = I_2R_4 = (I - I_1) R_4$; where I = total current supplied by the bridge.

$\therefore \quad I_1 = \left(\frac{R_4}{R_3 + R_4}\right) I$

$\therefore$ Total iron loss = $I^2 \left(\frac{R_4}{R_4 + R_4}\right)^2 (R_s - R_w)$

The value of iron loss may be calculated by measuring I, R_s & R_w (i.e. D.C. resistance of the coil).

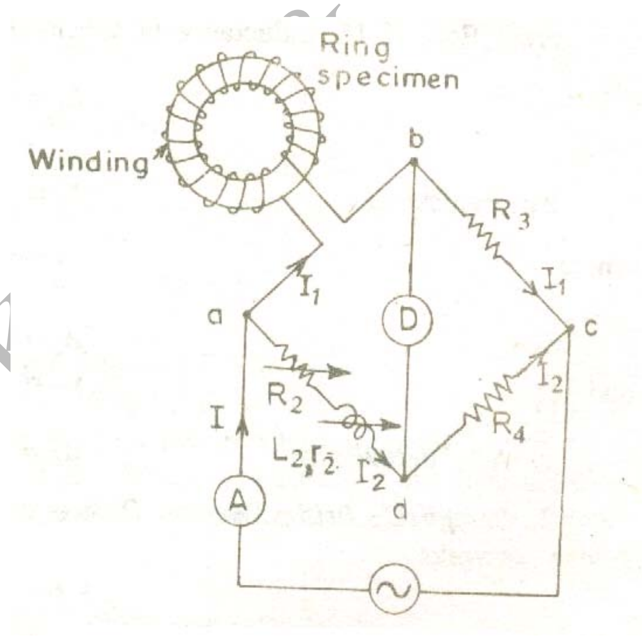
The inductance of specimen is given by

$$L_s = \left(\frac{R_3}{R_4}\right) L_2$$

But inductance $L_s = \frac{N^2}{\frac{l_s}{\mu_s A_s}}$

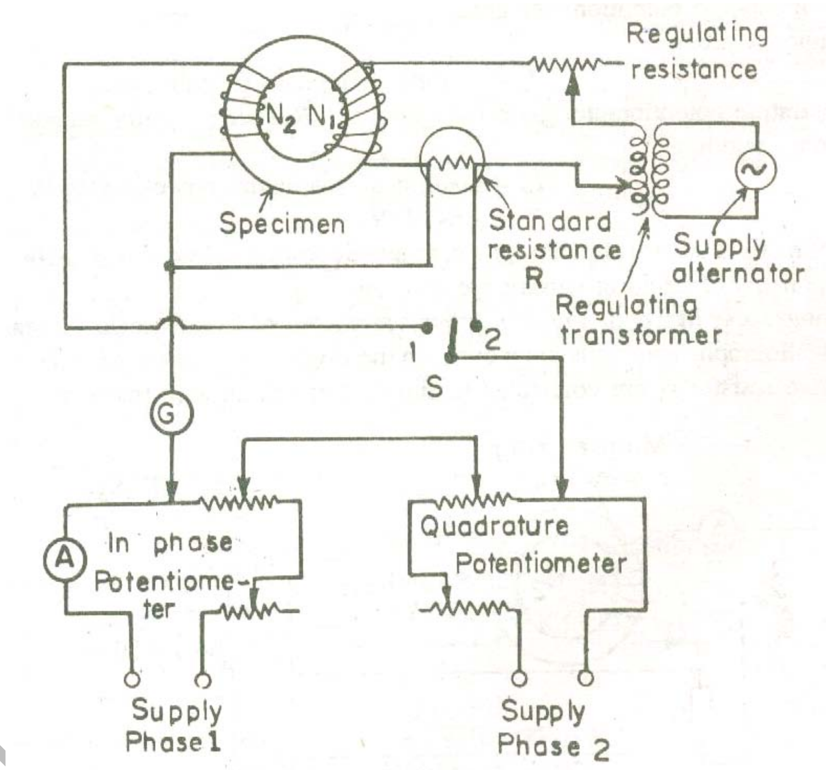
Where N = no. of turns of the coil.
l_s = length of mean flux path in specimen.
A_s = cross-section of specimen.
μ_s = a.c. permeability of specimen.

$\therefore$ A.C. permeability $\mu_s = \frac{l_s L_s}{N^2 A_s} = \frac{l_s R_3 L_2}{N^2 A_s R_4}$



Iron Loss Measurement using A.C. Potentiometer:-

The co-ordinate type a.c. potentiometer can be used for determination of iron loss & a.c. permeability of Ferro-magnetic materials working at lone flux density.
The test set up consists of ring type Ferro-magnetic specimen which carries two windings. The primary winding has N_1 turns & the secondary N_2 turns. The primary winding is energized from a.c. source through a regulating transformer. The same a.c. also energizes the in-phase & quadrature slide wire circuits of a.c. potentiometer. The magnetizing current in the primary winding is controlled by a rheostat. A standard resistor R is connected in series with the primary winding for sensing the voltage drop proportional to magnetizing current. The test circuit is shown below:-



The potentiometer is standardized first. The supply is given to the primary winding of the specimen. A voltage E_2 is induced in the secondary winding, which is measured by putting the switch S on contact 1, & setting the quadrature potentiometer slide wire. Contact is adjusted till balanced is obtained. The setting of in phase potentiometer give the value of E_2 directly. Switch S is then set to position (2). At this position, the p.d. in the standard resistor R is applied to quadrature potentiometer gives the value of I_mR, where I_m is the magnetizing component of current in the primary winding.

$$\therefore \; I_m = \frac{E_r}{R}$$

The reading of in phase potentiometer gives the value of I_eR where I_e is the loss component of the current in the primary winding.

$\therefore \quad I_e = \frac{E_x}{R}$

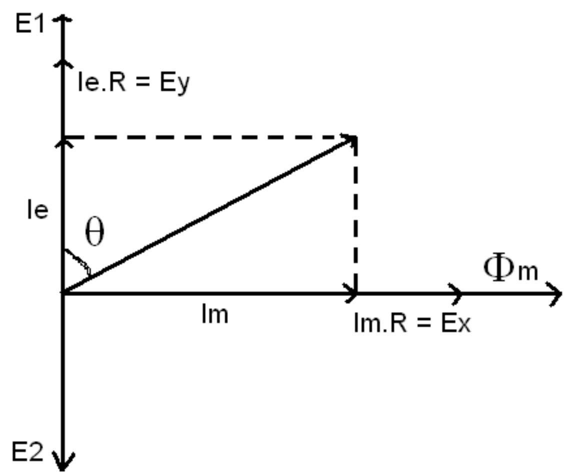
The total iron-loss in the ring specimen is given by $P_i = I\, E_1 \cos\theta$

Where $I = \sqrt{{I_m}^2 + {I_e}^2}$ & $\theta = \tan^{-1}(\frac{I_m}{I_e}) = \tan^{-1}(\frac{E_y}{E_x})$

= current through primary winding

θ = phase angle between primary winding voltage & current.

The phasor diagram under balance condition is shown below.



$E_2 = E_y = 4k_f f\phi_m N_2 = 4\, k_f f B_m A_s\, N_2$

Where k_f = form factor = 1.11 for sinusoidal a.c. supply.

B_m = maximum flux density.

A_s = cross-section of ring specimen.

N_2 = no. of turns in the secondary winding.

$E_1 = E_2\left(\frac{N_1}{N_2}\right) = E_y\left(\frac{N_1}{N_2}\right)$

$\therefore \quad B_m = \frac{E_y}{4k_f f A_s N_2} = \frac{E_y}{4.44 f A_s N_2}$

Potentiometer method is very suitable for a.c. magnetic testing at low flux density. Since magnetizing current are measured separately.

Magnetic Measurements

Grassot Flux meter:

The instrument is actually a special type of ballistic galvanometer provided with heavy electromagnetic damping and very small controlling torque. The construction is shown below:
It consists of a moving coil of small cross section suspended by mean of a single silk thread from a spring support a hanging with its parallel sides in the narrow air gaps of a permanent magnet system. This annealed silver strip spirals are used to lead the current in and out of the coil. As a result of this construction the controlling torque is reduced to a minimum. The instrument is usually provided with a pointer attached to the moving system and a scale graduated in Wb-turns. For laboratory use the coil may have a silk fibre suspension and a mirror, the deflection being observed by means of a light beam. When the instrument terminals are connected to a search coil and the flux linking with the search coil is changed , the moving system of the flux meter is deflected and rotates through an angle which depends upon the change o in flux –turns . The instrument coil rotates during the whole period of the flux change but stops as soon as the flux change ceases because of its high electromagnetic damping. The high damping is obtained by reducing the resistance of the coil comprising the flux meter coil and search coil to the minimum possible. Though the Grassot flux meter, although not so sensitive and accurate as ballistic galvanometer, But possesses the flowing advantages:

i. The instrument is very portable and has a scale calibrated directly in Weber-turns.
ii. The deflection is independent of the length of time taken for the change in flux producing the deflection. The deflection obtained for a given change of flux linking with the search coil connected to the flux meter will be same whether the time taken for the change be a fraction of a second or as much as 30 seconds. This advantage I of considerable importance in highly inductive circuits where the flux changes may be relatively slow.

In the complete absence of controlling toque, the coil would remain in its deflected position indefinitely but actually, in practice, it comes back to zero very slowly. The readings may be obtained by observing the difference in deflections at the beginning and at the end of change of flux without waiting for the pointer to return to zero.
Let R and L are the total resistance and inductance respectively of the circuit comprising of the meter coil and search coil, N is the no. of turns of the search coil, is the flux linking the search coil and I is the instantaneous current flowing in the search coil.

The emf induced in search coil due to the change in linking flux at any instant, $e = N\dfrac{d\phi}{dt}$

The emf induced in flux meter coil is given by: $e_b = K\dfrac{d\theta}{dt}$

Where K is a constant, which depends on the dimensions o the coil, number of urns of the coil and flux density in air gap and angular velocity of the coil

The voltage equation in the coil circuit: $e = e_b + L\dfrac{di}{dt} + Ri$

Since the resistance of the circuit as well as current flowing the circuits are small so the potential drop term may be neglected, thus: $e = e_b + L\dfrac{di}{dt}$

Substituting $e = N\dfrac{d\phi}{dt}$ and $e_b = K\dfrac{d\theta}{dt}$ in the voltage equation: $N\dfrac{d\phi}{dt} = K\dfrac{d\theta}{dt} + L\dfrac{di}{dt}$

Integrating the above expression over a time interval 0 to T, where T is the time taken for flux change:

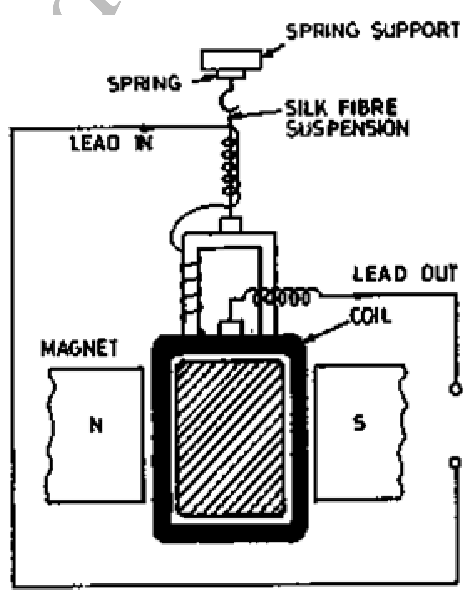
$$\int_0^T N\frac{d\phi}{dt}dt = \int_0^T K\frac{d\theta}{dt}dt + \int_0^T L\frac{di}{dt}di$$

Assuming ϕ_1 and ϕ_2 be the fluxes linking with the search coil θ_1 and θ_2, the deflections of the flux meter and i_1, i_2 the currents flowing through the search coil circuit at the beginning and at the end of the flux change respectively then the expression may be given as:

$$\int_{\phi_1}^{\phi_2} Nd\phi = \int_{\theta_1}^{\theta_2} Kd\theta + \int_{i_1}^{i_2} Ldi$$, Since $i_1 = i_2 = 0$,

$\therefore \int_{i_1}^{i_2} Ldi = 0$ and $N(\phi_2 - \phi_1) = K(\theta_2 - \theta_1)$ or $(\theta_2 - \theta_1) = \dfrac{N}{K}(\phi_2 - \phi_1)$

Thus deflection $(\theta_2 - \theta_1)$ is proportional to the change in flux –turns. The flux meter will therefore have a uniform scale.



Grassot Flux Meter

Use of shunts with flux meter:

For very high value of flux, the deflection of a flux meter, even when a single turn search coil is used, may exceed the scale length. In these cases, the range may be increased by employing a low resistance, non-inductive shunt. Such a circuit is shown below: in which Rc and Lc are respectively resistance an inductance of search coil, Rf and Lf are respectively resistance and inductance of flux meter coil and Rs is the resistance of the shunt.
Let the current flowing through the search coil, flux meter coil and shunt be respectively. Since search coil, flux meter coil and shunt are connected in parallel, therefore, voltage acting across each of them is same.

Thus voltage across shunt = voltage across flux meter coil = voltage across search coil

or $i_s R_s = K\frac{d\theta}{dt} + R_f i_f + L_f \frac{di_f}{dt} = N\frac{d\phi}{dt} - L_c \frac{di_c}{dt} - i_c R_c$

or $N\frac{d\phi}{dt} - K\frac{d\theta}{dt} = R_f i_f + R_c i_c$

or $N\frac{d\phi}{dt} - K\frac{d\theta}{dt} = R_f i_f + R_c(i_s + i_f) = i_f(R_c + R_f) + i_s R_c = i_f(R + R) + R\frac{Ri + K\frac{d\theta}{dt}}{R_s}$

or $N\frac{d\phi}{dt} - K\frac{d\theta}{dt} - \frac{R_c}{R_s}K\frac{d\theta}{dt} = i_f(R_c + R_f) + i_f\frac{R_c R_f}{R_s}$

Since the currents are small so potential drops across the resistances may be neglected and the above expression may be given as:

$$N\frac{d\phi}{dt} - K\frac{d\theta}{dt}(1 + \frac{R_c}{R_s}) = 0$$

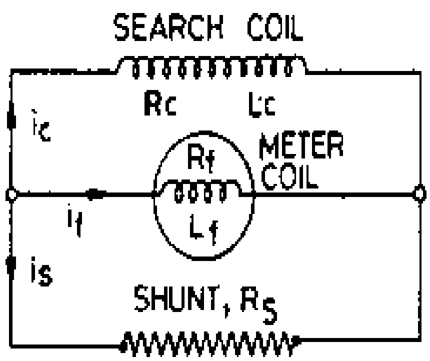
$$N\frac{d\phi}{dt} = (\frac{R_s + R_c}{R_s})K\frac{d\theta}{dt}$$

Integrating above expression over a time interval 0 to T corresponding to a change in flux from to and deflection from to is expressed as:

$$\int_0^T N\frac{d\phi}{dt}dt = (\frac{R_s + R_c}{R_s})K\int_0^T \frac{d\theta}{dt}dt$$

or $N(\phi_2-\phi_1)=(\frac{R_s+R_c}{R_s})K(\theta_2-\theta_1)$ or $(\phi_2-\phi_1)=\frac{K}{N}(\frac{R_s+R_c}{R_s})(\theta_2-\theta_1)$

Comparing expression for $(\phi_2-\phi_1)$ with shunt and without shunt, the multiplying factor is found as $\frac{R_s+R_c}{R_s}$.



Problem:-

#1. A test was conducted on a sample of short steel gave the following result at a maximum flux density of 1.0 Wb/m^2 with flux wave form purely sinusoidal.

Frequency (Hz) - 25 75

Iron Loss, P_i (W/kg) - 2.32 10.9

Determine i) Hysteresis & eddy current loss in W/kg at 50Hz & 1.0 Wb/m^2

ii) Hysteresis & eddy current loss at maximum flux density of 1.2 Wb/m^2 & at frequency 60Hz & form factor of 1.2.

[Assume Steinmetry index as 1.6].

#2. The resistance & inductance of a test coil 4, R_1 were determined at a frequency of 4000/2π Hz with a Maxwell's bridge shown below. The results were as follows:-

a) With air core the balance was obtained with R_2=550Ω, R_3=18 Ω, R_4=1250 Ω, C_4=3.85μF.

b) With iron core, balance was obtained with R_1=550 Ω, R_3=18 Ω, R_4=1125 Ω, C_4=3.85μF.

Determine the iron loss in the core at the test frequency the voltage applied to the bridge is 50V.