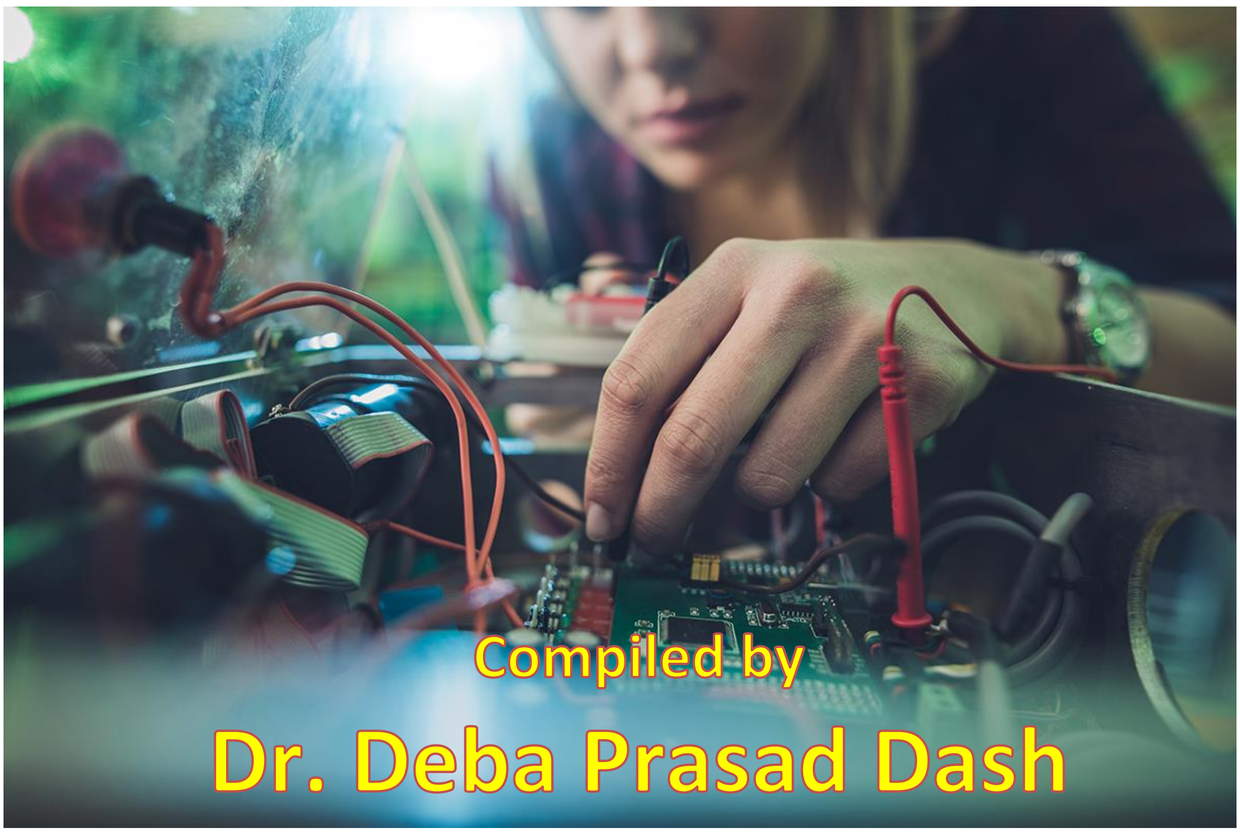
GOVERNMENT COLLEGE OF ENGINEERING, KALAHANDI

Lecture notes

on

BASIC ELECTRICAL ENGINEERING
(Module III)



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MODULE-III

Magnetic Circuits:

The closed path followed by the flux lines is called a magnetic circuit.

Magnetomotive force (MMF): Flux is produced around any current carrying coil to produce flux density and the coil should have correct number of turns, so the product of current and the number of turns is called magnetomotive force (mmf).

Mmf =IN amp

N is dimensionless.

The Magnetic Field:

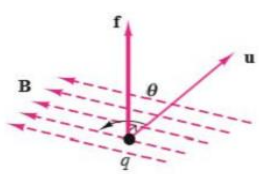
Magnetic fields are generated by electric charge in motion, and their effect is measured by the force they exert on a moving charge. As you may recall from previous physics courses, the vector force f exerted on a charge of q moving at velocity u in the presence of a magnetic field with flux density B is given by $f = qu \times B$

Where the symbol × denotes the (vector) cross product. If the charge q is moving at a velocity u in a direction that makes an angle θ with the magnetic field, then the magnitude of the force is given by

$f = q\,u\,B \sin\theta$

and the direction of this force is at right angles with the plane formed by the

vectors B and u.



The magnetic flux ϕ is then defined as the integral of the flux density over some

surface area. $\phi = \int B\,dA$ in webers = $\phi \Rightarrow B\,A$

Permeability: Every substance possesses a certain power of conducting magnetic lines of force (iron is better conductor for magnetic lines of force than air). Permeability of a material is its conducting power for magnetic lines of force. It is the ratio of flux density (B) produced in a material to the magnetic field strength i.e

$$\mu = B/H$$

Relative Permeability: For measuring relative permeability, vaccum or free space is chosen as the reference medium. Absolute permeability $\mu_0 = 4\pi \times 10^{-7}$ H/m

If its relative permeability as compared to vaccum is μ_r, then $\boldsymbol{\mu=\mu_0\mu_r}$

Reluctance: (S) is a measure of the opposition offered by a magnetic circuit to the setting up of flux is called reluction of magnetic circuits. S= L/A

Magnetic Field Intensity (H): It is the magnetomotive force per unit length of the magnetic flux path. H=F/L=IN/L =A/m Unit

Faraday's law states that a time-varying flux causes an induced electromotive force $e = -\frac{d\phi}{dt}$

In practical applications, the size of the voltages induced by the changing magnetic field can be significantly increased if the conducting wire is coiled many times around, so as to multiply the area crossed by the magnetic flux lines many times over. For an N-turn coil with cross-sectional area A, for example, we have the emf

$$e = N \frac{d\phi}{dt}$$

When N-turn coil linking a certain amount of magnetic flux, then the flux linkage

$$\lambda = N\phi$$

$$\Rightarrow e = \frac{d\lambda}{dt}$$

The relation between flux linkage and current is gven by $\lambda = Li$

so that the effect of a time-varying current was to induce a transformer voltage across an inductor coil, according to the expression $v = L\frac{di}{dt}$

L is the self-inductance which measures the voltage induced in a circuit by magnetic field generated by a current flowing in the same circuit.

Ampere's Law:

Ampere's law forms a counterpart to Faraday's law. Both the laws explain the relationship between electricity and magnetism. Ampere's law states that the magnetic field intensity H in the vicinity of a conductor is related to the current carried by the conductor; thus Ampère's law establishes a dual relationship with Faraday's law.

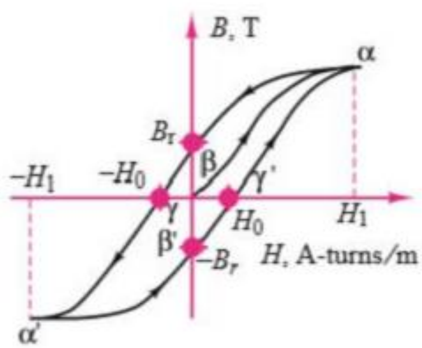
In the previous section, we described the magnetic field in terms of its flux density Band flux ϕ. To explain Ampère's law and the behaviour of magnetic materials, we need to define a relationship between the magnetic field intensity H and the flux density B. These quantities are related by

$$B = \mu H = \mu_r \mu_0 H \text{Wb/m}^2 \text{ or T}$$

where the parameter μ is a scalar constant for a particular physical medium which is the permeability of the medium. The permeability of a material can be factored as the product of the permeability of freespaceμ0 = 4π×10−7 H/m, and the relative permeability μr, which varies greatly according to the medium.7 H/m, and the relative permeability μr which varies greatly according to the medium. For example, for air and for most electrical conductors and insulators, μr is equal to 1. For ferromagnetic materials, μr can take values in the hundreds or thousands. The size of μr represents a measure of the magnetic properties of the material.

Magnetic materials and B-H curves:

The relationship between the magnetic flux density B and the associated field intensity H is expressed by B Hμ= ,where μ = permeability of magnetic material. From the above expression flux density increases in proportion to field intensity upto a saturation point reaches. But in general all magnetic material shows a nonlinear B-H curve, depending upon the value of permeability, which can be better explained by eddy currents and hysteresis. Eddy current caused by any time-varying flux in the core material. It will induce a voltage , and therefore current. The induced voltage will cause eddy current, which depends on the resistivity of the core. It shows a complex behavior related to the magnetization properties of the material which can be shown as



Here the core has been energized for some time ,with a field intensity of H1 A-turns/m. as the current decreases curve follow from the point α to the point β. At this point mmf is zero to bring the flux density to zero ,mmf is further deceased until the field intensity reaches to –H0. As mmf value is made more negative , the curve eventually reaches to the point α'. The excitation current is now increased, the magnetization curve will follow the path α' = β' = γ'= α, and finally returns to the original point of B-H curve.

Hysteresis loss:- During the complete cycle, the magnets within the magnetic material try to align first in one way and then in reverse way. The tendency to turn around of elementary magnets give rise to mechanical stresses in the magnetic material, which in turn produces heat which is a waste form of energy. The dissipitated heat energy during the cycle of magnetization is given by the area within the hysteresis loop and is called hysteresis loss.

Hysteresis power loss = $$P_h = KfB_{max}^{x}V$$

Where, K= Hysteresis coefficient

f= frequency of magnetization

V= volume of the material (m^3)

B_{max} = Maximum flux density (wb/m^2)

x = 1.5-2.5

- **Steinmetz law:-** $$P_h = \eta\ fB_{max}^{1.6}V$$

Where, η= Steinmetz constant or hysteresis coefficient

f= frequency of magnetization

V= volume of the material (m^3)

B_{max} = Maximum flux density (wb/m^2)

B_m lies between 0.1 to 1.2 wb/m^2 , when B is not between 0.1

Eddy current loss: During the cycle of magnetization, the change in flux density induces an emf in the core of an electromagnet. The effect sets up small locally circulating currents called eddy currents. These currents are of no practical significance but produce heat which means some loss of energy. This loss of energy is called eddy current loss.

$$P_e = K_e t^2 f^2 V$$

Where, Ke= Eddy current constant B= Flux density , F= Frequency, V= Volume of iron

t= thickness of the lamination of the pole core and armature

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Law Governing magnetic ckt :→

It is convenient to compare magnetic ckt. with dc electric ckt for calculation of magnetic ckt.

According to ohm's law

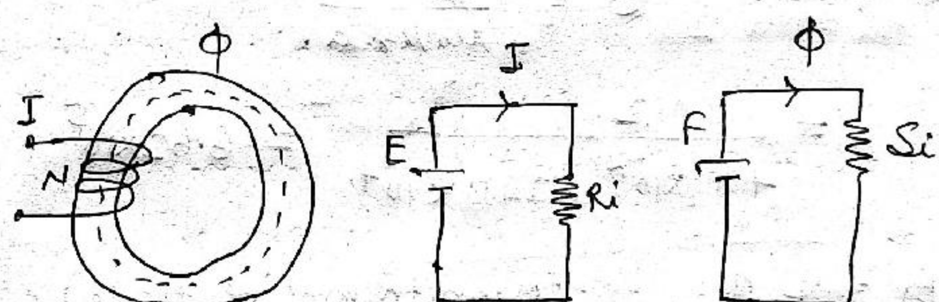
$$\text{current } (I) = \frac{\text{emf}}{\text{resistance}} = \frac{V}{R} \text{ or } \frac{E}{R}$$

In magnetic ckt. —

$$\text{flux } (\Phi) = \frac{\text{mmf}}{\text{reluctance}} = \frac{F}{S}$$

But we know $S = \frac{l}{\mu_0 \mu_r a}$

so $F = S\Phi$ and $S = \frac{l}{\mu_0 \mu_r a}$



In electric ckt. $E = I R_i$

In magnetic ckt. $F = S_i \Phi = H \cdot l$

$$E = (R_i + R_g) I$$

$$F = (S_i + S_g)\Phi \Rightarrow F_i + F_g$$

$$= H_i l_i + H_g l_g$$

Q. A magnetic core, in the form of closed ring, has a mean length of 20 cm and a cross-section of 1 cm^2. The relative permeability of iron is 2400. What ~~dc~~ direct current will be needed in a coil of 2000 turns uniformly wound around the ring to creat ~~a~~ a flux of 0.2 mwb in the iron?

Sol^n.

$l = 20\,cm = 20 \times 10^{-2}\,m = 0.2\,m$

$a = 1\,cm^2 = 1 \times 10^{-4}\,m^2$

$\mu_r = 2400$, $N = 2000$

$\phi = 0.2\,mwb = 0.2 \times 10^{-3}\,wb$

Reluctance, $S = \frac{l}{\mu_0 \mu_r a}$

$= \frac{0.2}{4\pi \times 10^{-7} \times 2400 \times 10^{-4}} = 6.63 \times 10^{5}$

$F = S\phi$ (Magneto motive force)

But $IN = S\phi$

$\Rightarrow I = \frac{S\phi}{N}$

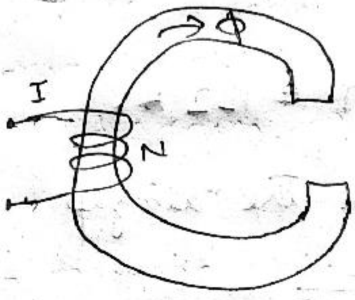
$\Rightarrow I = \frac{6.63 \times 10^{5} \times 0.2 \times 10^{-3}}{2000}$

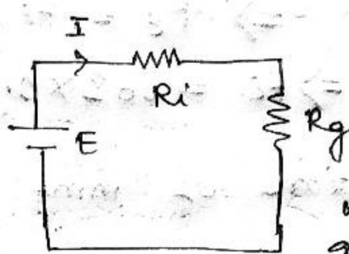
$\Rightarrow I = 66.3 \times 10^{-3}\,A$

$\Rightarrow \boxed{I = 66.3\,mA}$

Ring with airgap :-

The ring with airgap is shown in fig ⓐ





where i & g are iron and gap.

Fig ⓐ Fig ⓑ

Magnetic ckt ⇒ electric ckt.

By applying KVL, $E = (R_i + R_g) I$

by analogy, $F = (S_i + S_g)\phi$

$\Rightarrow F = S_i\phi + S_g\phi = F_i + F_g$

$\Rightarrow H_i l_i + H_g l_g$.

Calculation of mmf for iron-path :→

l_i = original circumference − air gap length

$l_i = 0.20 - 0.001 \Rightarrow 0.199\ m$

Flux density, $B_i = \frac{\phi}{a_i} = \frac{0.2 \times 10^{-3}}{10^{-4}} = 2T$

$\boxed{B_i = 2\ T}$

$H_i = \frac{B_i}{\mu_0 \mu_{ri}} = \frac{2}{4\pi \times 10^{-7} \times 2400} = 663\ A/m$

$\boxed{H_i = 663\ A/m}$

mmf for iron path

$\Rightarrow F_i = H_i l_i$

$\Rightarrow F_i = 663 \times 0.199 = 132$ A.

Calculation of mmf for the airgap

$$H_a = \frac{B_0}{\mu_0} = \frac{2}{4\pi \times 10^{-7}}$$

$$\boxed{H_a = 0.1591 \times 10^7}$$

$l_a = 1$ mm $= 1 \times 10^{-3}$ m

So mmf for airgap is $= F_a$

~~Ha = Ha la~~ $F_a = H_a l_a$

$F_a = 0.1591 \times 10^7 \times 10^{-3} = 1591$ A

$$\boxed{F_a = 1591 \text{ A}}$$

Total mmf for whole magnetic ckt. is =

$F = F_i + F_a \Rightarrow F = 132 + 1591$

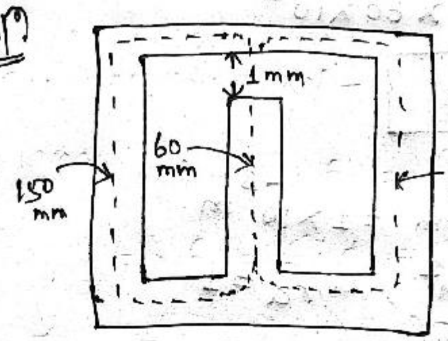
$$\boxed{F = 1723 \text{ A}}$$

But $F = IN \Rightarrow I = F/N = 1723/2000$

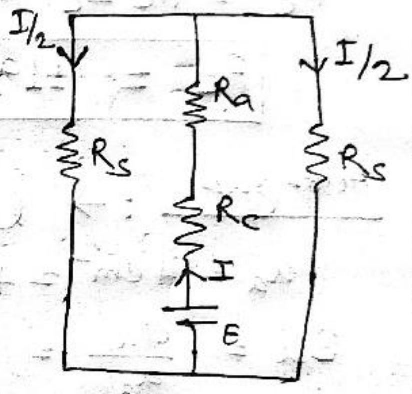
$$\boxed{I = 0.862 \text{ A} = 862 \text{ mA}}$$

Q. An inductor has a core built up stamping of the shape shown in fig. The coil being on the centre limb. There is a 1 mm airgap in the centre limb which has cross-sectional area of 4 cm^2. All the other paths in the core have a cross-sectional area 2 cm^2. The mean length of a magnetic flux in each portion are shown in fig. The μ_r of iron is 800. Find the current needed in coil 500 turns to produce total flux in the air-gap of 0.8 m wb.

Sol



$\Rightarrow$



R_s = resistance of side limb.

R_c = resistance of centre limb.

R_a = resistance of air-gap.

Apply KVL to equivalent ckt.

$$E = R_c I + R_a I + R_s I/_2$$

By analogy in magnetic ckt.

$$F = S_c \Phi + S_a \Phi + \frac{1}{2} S_s \Phi$$

$$\boxed{F = H_c l_c + H_a l_a + \frac{1}{2} H_s l_s}$$

Centre limb :-

$$l_c = 60\ mm = 60 \times 10^{-3}\ m$$

$$a_c = 4\ cm^2 = 4 \times 10^{-4}\ m^2 \quad \mu_{rc} = 800$$

$$B_c = \frac{\phi_c}{a_c} = \frac{0.8 \times 10^{-3}}{4 \times 10^{-4}} = 2\ T$$

$$H_c = \frac{B_c}{\mu_0 \mu_{rc}} = \frac{2}{4\pi \times 10^{-7} \times 800} = 1989$$

$$F_c = H_c l_c = 1989 \times 60 \times 10^{-3}$$

$$\boxed{F_c = 119.4\ A}$$

Air-gap :→ $l_a = 1mm = 1 \times 10^{-3}\ m$

$$a_a = 4\ cm^2 = 4 \times 10^{-4}\ m^2, \ \mu_{ra} = 1$$

$$B_a = \frac{\phi_a}{a_a} = \frac{0.8 \times 10^{-3}}{4 \times 10^{-4}} = 2\ T$$

$$H_a = \frac{B_a}{\mu_0 \mu_{ra}} = \frac{2}{4\pi \times 10^{-7} \times 1} = 0.159 \times 10^{7}$$

$$F_a = H_a l_a = 0.159 \times 10^{7} \times 10^{-3} = 1590\ A$$

Side limb :- $l_s = 150\ mm = 150 \times 10^{-3}\ m$

$$a_s = 2\ cm^2 = 2 \times 10^{-4}\ m^2, \ \mu_{rs} = 800$$

$$B_s = \frac{\phi_s}{a_s} = \frac{0.8 \times 10^{-3}}{2 \times 10^{-4}} = 4\ T$$

$$H_s = \frac{B_s}{\mu_0 \mu_{rs}} = \frac{4}{4\pi \times 10^{-7} \times 800} = 3978\ A.$$

$$\frac{1}{2} H_s l_s = \frac{1}{2} \times 3978 \times 150 \times 10^{-3} = 298.4\ A.$$

So total mmf of the magnetic ckt

$$F = H_c I_c + H_a I_a + \frac{1}{2} H_s I_s$$

$$= 119.4 + 1590 + 298.4$$

$$F = 2007.8$$

$$\text{Current } (I) = \frac{F}{N} = \frac{2007.8}{500}$$

$$\boxed{I = 4.02 \text{ A}}$$

End