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FUNDAMENTALS OF ELELCTRICAL ENGINEERING(FEE) [22212]

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CH.4 MAGNETIC CIRCUITS

Contents:CH.4 Magnetic Circuits (14/70)

- Magnetic lines of force, flux, flux density, magnetic flux intensity.
- Magneto-Motive-Forces (MMF), AmpereTurns (AT), Reluctance, Permeance, reluctivity.
- Electric and Magnetic circuit: Series Magnetic and Parallel Magnetic Circuit.
- Magnetization Curve (B - H Curve)
- Magnetic Hysteresis, Hysteresis Loop., Applications.

- **Magnetic field:** The area around a magnet where effects of the magnetism present is called the magnetic field

- **Magnetic flux(Φ):** The total number of lines of force in a magnetic field is called as magnetic flux. Unit :Weber (Wb).

- **Characteristics of magnetic field / flux :**

✓ Forming a closing loop

✓ Did not crossed against each other

✓ Has a certain direction

✓ Repel between one another

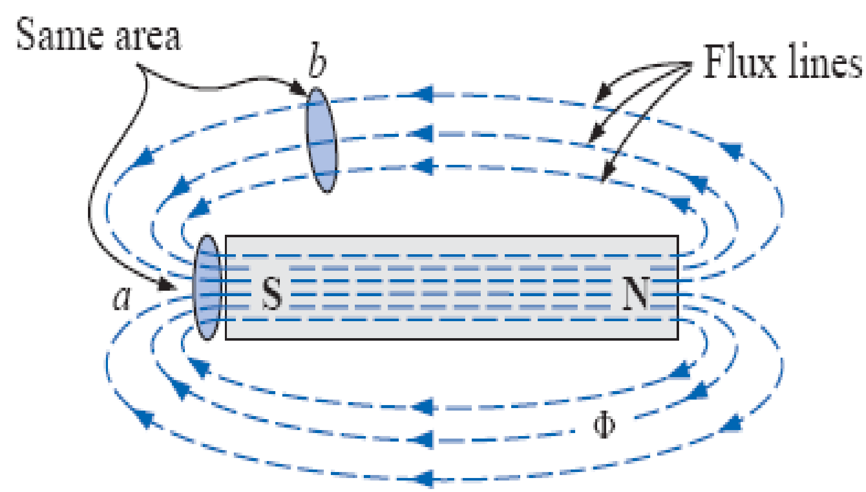


FIG. 11.1

Flux distribution for a permanent magnet.

- **Magnetic flux density(B):** The Magnetic flux per unit area measured in plane perpendicular to the flux is called as Magnetic flux density.
  Unit: Wb/m^2 or Tesla (T).

- **Magnetic field strength(H):** It is force experienced by a unit North Pole placed in magnetic field or The magneto-motive force per unit length is called the magnetic field strength. Unit: At/m

$$H = \frac{F}{L} = \frac{NI}{L}$$

- **Applications of Permanent magnet:**

✓ 1) Field of DC motors. 2) Tacho-generators. 3) In stepper motors. 4) Field of two wheeler and car dynamo. 5) In magnetic therapy. 6) In magnetic compass. 7) Speedometers. 8) Telephones. 9) Microphones. 10) Earphones.

- **Applications of electromagnet:**

✓ 1) As Field and armature in DC Machine. 2) In cores of solenoid valves. 3) In cores of electromechanical relays. 4) In electromagnetic circuits of all AC Machines 5) Electrical measuring instruments 6) Cores of transformers.

- **Permeability:** Ability of material to carry magnetic flux is called as permeability

- **Absolute Permeability (μ):** The ratio of magnetic flux density(B) to magnetic field strength(H).

  $\mu = B/H$ $\mu = \mu_0 \mu_r$ Unit: Henry/meter

- **Permeability of free space(μ_0):** The ratio of magnetic flux density(B) in air or vacuum to magnetic field strength(H) in air or vacuum.

$\mu_0 = B_0/H_0$ $\mu_0 = 4\pi * 10^{-7}$ Unit: henry/meter

- **Relative Permeability (μ_r):** The ratio of magnetic flux density(B) in any medium to magnetic flux density in air or vacuum(B_0).

$\mu_r = B/B_0$ Unit less quantity

the value of relative permeability of air or vacuum is =1

- **Magneto Motive Force (MMF/F_m):** Magneto Motive Force is defined as the force responsible for the generation of flux.

MMF (F_m) = N.I Unit: Ampere turns (AT)

Where N=Number of turns of magnetizing coil.

I= Current through the coil.

- **Reluctance (S):** Reluctance is defined as the opposition to the flux in a material. $S = \frac{Kl}{a}$ Unit: AT/Wb.

Where K =Constant of proportionality.

l= length of magnetic circuit in meter

A= cross sectional area in m^2

$K = \frac{1}{\mu}$ $S = \frac{l}{\mu a}$ $\mu = \mu_0 . \mu_r$ $\boldsymbol{S = \frac{l}{\mu_0 \mu_r a}}$

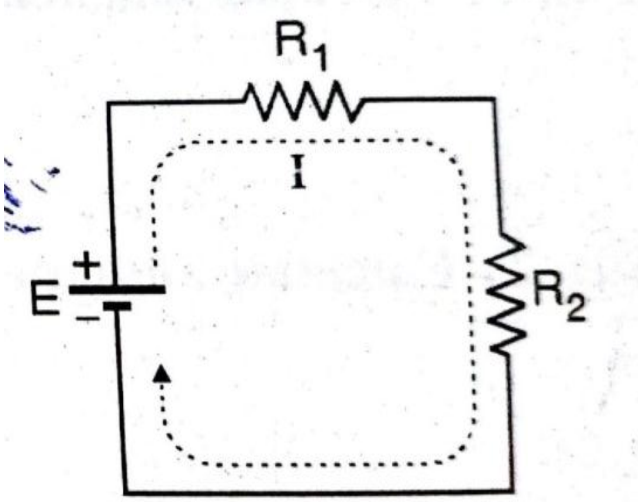
Reluctance can also be defined as the ratio of magneto motive force (MMF) to the flux(Ø).

$S = \frac{MMF}{Ø}$ $\boldsymbol{S = \frac{N.I}{Ø}}$ [similar to ohms law: Resistance=EMF/current]

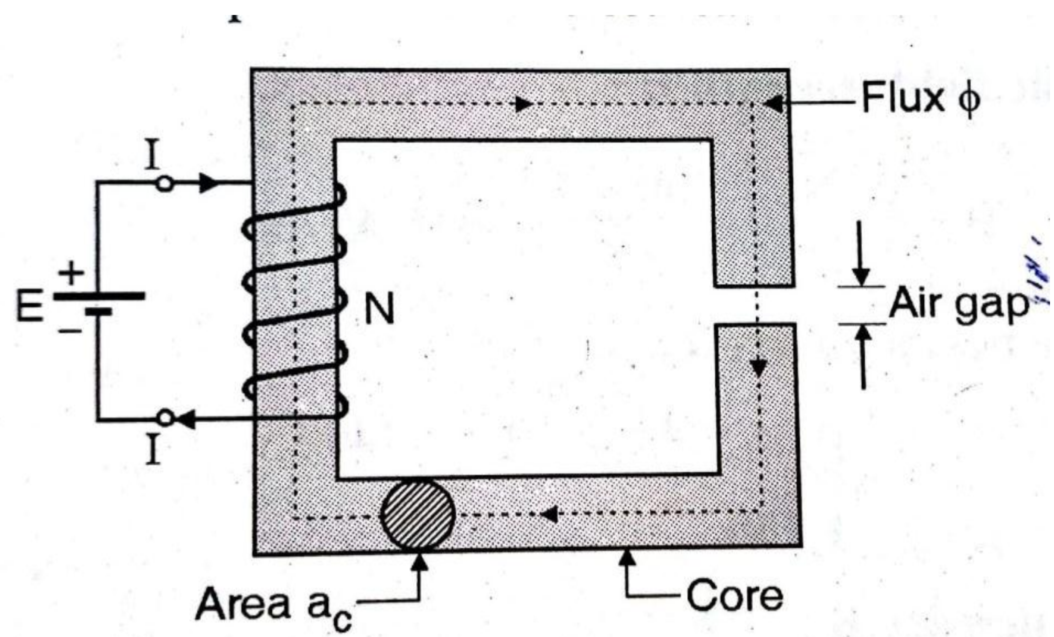
Permeance: It is the reciprocal of reluctance. It is measured in Wb/AT.

Electric and magnetic circuit similarities

Electric Circuit



Magnetic Circuit



Similarities:

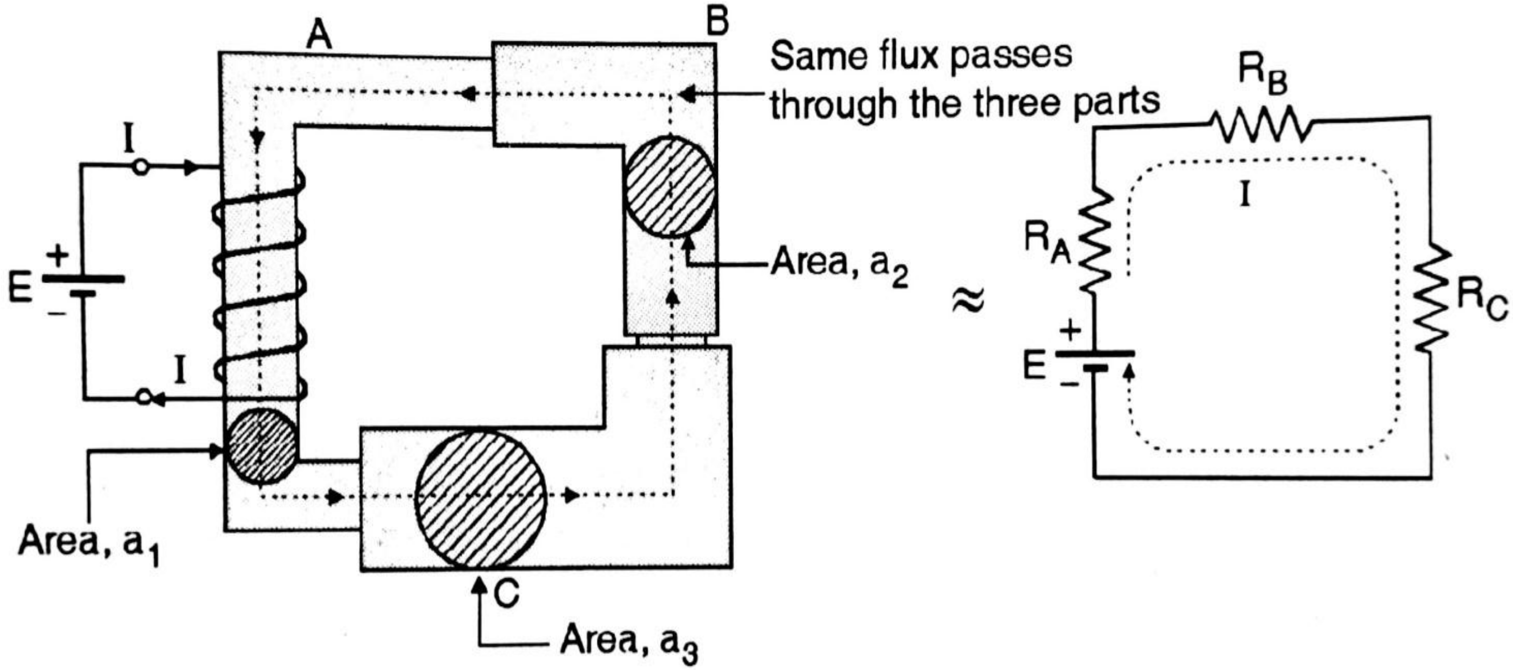
Sr no.	Electric Circuit	Magnetic Circuit
1.	Current- Flow of Electrons through conductor is current, it is measured in Amperes.	Flux- Lines of force through a medium from N pole to S pole form flux. It is measured in Weber.
2.	EMF- It is driving force for current, measured in volts.	MMF- It is driving force for flux, measured in Amp- turn.
3.	Resistance- It is opposition of to current measured in Ohms.	Reluctance- It is opposition offered to flux measured in AT/Wb.
4.	Resistance is directly proportional to length of conductor.	Reluctance is directly proportional to length of magnetic path.
5.	Resistance is inversely proportional to cross sectional area of conductor.	Reluctance is inversely proportional to cross sectional area of magnetic path.
6.	Resistance depends upon nature of conductor material (l)	Reluctance varies inversely according to permeability of medium 1/μ.

Dissimilarities:

Sr no.	Electric Circuit	Magnetic Circuit
1.	Current is actual flow of electrons.	Flux is direction of force- Nothing flows between N pole and S pole.
2.	Energy is required to produce current and to maintain it.	Energy is required to produce flux but not for its maintanence.
3.	Current does not pass through air.	Flux can pass through air also.
4.	Resistance is almost constant. It can vary slightly due to change in temperature.	Reluctance depends on permeability. Hence it can vary to a great extent due to the variations in the flux density, but reluctance does not change much with temperature.
5.	We can use insulation to define the path of the current.	There is no insulator for magnetic flux. Hence its path cannot be defined.

Series Magnetic Circuit

- Figure shows the series magnetic circuit. This is because it consists of three parts A,B and C which are connected one after the other to form a chain.
- The length of these parts are l_1,l_2, $and\ l_3$ respectively where as the cross sectional areas are a_1 ,a_2 and a_3 respectively relative permeability's of the three parts are μ_{r1}, μ_{r2} and μ_{r3} respectively.



Expression for the total reluctance:

- Let a coil of N number of turns be wound on any one of parts and let the current through the coil be I amperes. Hence the total m.m.f. is given by

m.m.f.=F=N.I (AT)

this m.m.f establishes a flux which is same for al the three parts of the magnetic circuits. as the flux is same in series circuits

- Let S_1 ,S_2 and S_3 are the individual reluctances of A,B and C respectively

$$S_1 \frac{l_1}{\mu_0 . \mu_{r1} . a_1} , \qquad S_2 \frac{l_2}{\mu_0 . \mu_{r2} . a_2} , \qquad S_3 \frac{l_3}{\mu_0 . \mu_{r3} . a_3}$$

- And if F_1 ,F_2 and F_3 are m.m.f of three parts then total m.m.f can expressed as

$$F = F_1 + F_2 + F_3$$

$$F = \emptyset . S_1 + \emptyset . S_2 + \emptyset . S_3$$

$$F = \emptyset (S_1 + S_2 + S_3)$$

$$F = \emptyset . S$$

Where S is equivalent reluctance of the series magnetic circuit.

$$S = S_1 + S_2 + S_3$$

$$S = \frac{l_1}{\mu_0 . \mu_{r1} . a_1} + \frac{l_2}{\mu_0 . \mu_{r2} . a_2} + \frac{l_3}{\mu_0 . \mu_{r3} . a_3}$$

- Thus the total reluctance of a series circuit is equal to the sum of the reluctance of the individual parts of the series magnetic circuit.
- Expression for total Ampere turns MMF of the series magnetic circuits as below

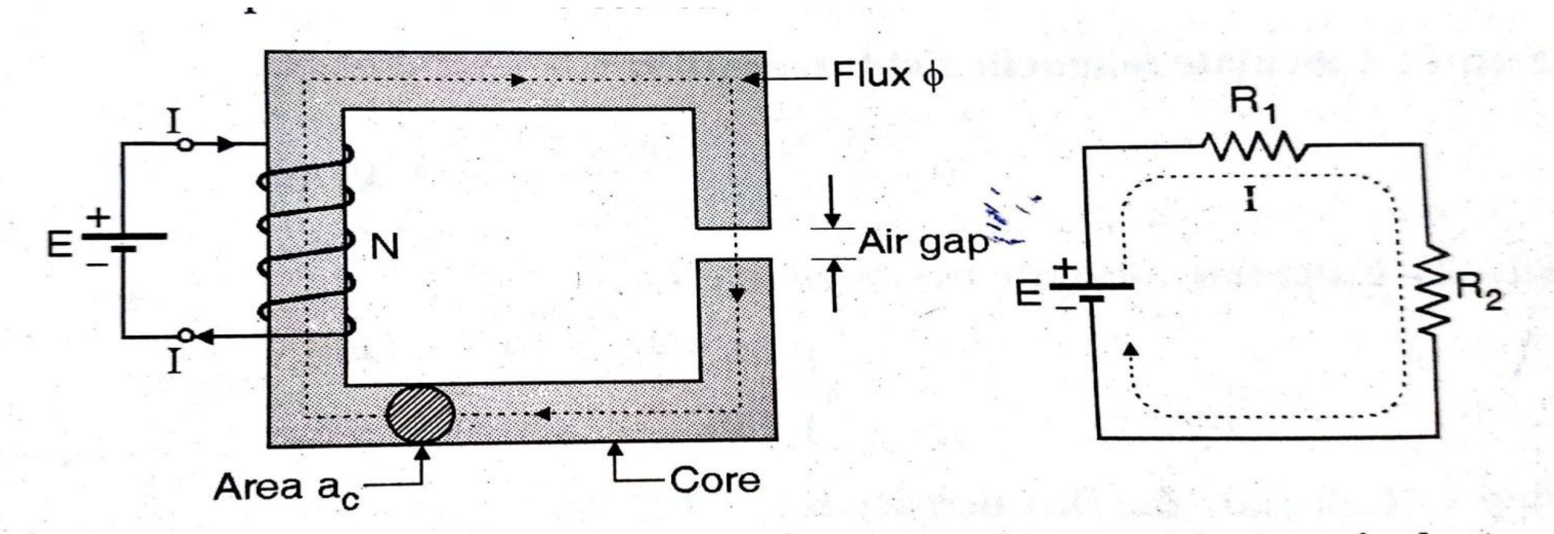
$$F = F_1 + F_2 + F_3$$

$$F = H_1 . l_1 + H_2 . l_2 + H_3 . l_3$$

- Where H_1 ,H_2 and H_3 Re the magnetic field strength of the three parts A,B and C respectively.

Series Magnetic circuit with air gap

- Fig shows magnetic core with a small air gap. We can use the principle of series magnetic circuit here. Note that even with the presence of small air gap. the magnetic circuit gets complete because flux can pass through air. This would not have been possible for electrical circuit.
- Let the mean length of the ion core be l_c and that of the air gap l_g let S_c be the reluctance of the core and let S_g be the reluctance of the air gap



The total reluctance $S = S_c + S_g$

$$S_c = \frac{l_c}{\mu_0 . \mu_{rc} . a_c} \quad \text{and } S_g = \frac{l_g}{\mu_0 . a_c}$$

- The expression for S_g has been written by assuming that the cross sectional area of the air gap is equal to that of the core and the absolute permeability of air.

$$\mu = \mu_0$$

- Hence the total reluctance is given by

$$S_c = \frac{l_c}{\mu_0 . \mu_{rc} . a_c} + \frac{l_g}{\mu_0 . a_c}$$

- Total MMF = F= mmf of the core + mmf of the air gap

$$F = F_e + F_g = \emptyset\, s_c + \emptyset\, s_g = \emptyset\, (s_c + s_g)$$

- An iron ring of mean circumference 80 cm is uniformly wound with 500 turns of wire and carries 0.8A. Find the magnetic field strength.

Soution: Magnetic field strength H = NI /*l* ⍰= 500 x 0.8 / 80 x10-2 = 500 AT/m

When a voltage of 220 V is applied to a coil with resistance of 50Ω, produces 5mWb of flux. If the coil has 1000 turns, find inductance of coil and energy stored in the magnetic field.

Ans:

Current in the coil I= V/R = 220/50 = 4.4 A

Inductance of coil $L = \frac{N\emptyset}{I} = \frac{1000 \times 5 \times 10^{-3}}{4.4} = 1.136H$

Energy stored in the magnetic field

$E = \frac{1}{2} L\, I^2 = \frac{1}{2} \times 1.136 \times 4.4^2 = 10.996\, J \cong 11$ joules

- An iron ring of mean circumference 100 cm is uniformly wound with 500 turns of wire. Calculate the value of flux density to produce a current of 1.1 Amp in the ring. Assume μr = 1200.

Ans: Given: Length of magnetic circuit l =100cm = 100×10^{-2}m , N=500 Turns, I=1.1A & μ_r = 1200 Assume $\mu_0 = 4\pi 10^{-7}$

Magnetic Field Strength: H = NI / l = = 550 AT/m

Flux Density: = $4\pi 10^{-7} \times 1200 \times 550$ = 0.8293 T or Wb/ m^2

An iron ring of mean circumference 0.8 m is uniformly wound with 400 turns of wire. It carries 1.6A and produces a flux density of 1.1 T. Find permeability of the material.

Ans:

Given data: l = 0.8 m, N =400 turns, I = 1.6 A, B = 1.1 tesla

H =NI/ l = 400×1.6 /0.8 = 800 AT/m

$B = \mu_0 \mu_r H$ therefore $\mu_r = B/(\mu_0 H)$, $\mu_0 = 4 \pi \times 10^{-7}$

Relative permebility of iron ring:

$\mu_r = 1.1/(4 \pi \times 10^{-7} \times 800) =$ **1094.19**

$\mu = \mu_0 \times \mu_r = 4 \pi \times 10^{-7} \times 1094.19 = \mathbf{1.375 \times 10^{-3}\ H/m}$

Parallel Magnetic Circuit

Value of reluctance for series magnetic circuit:

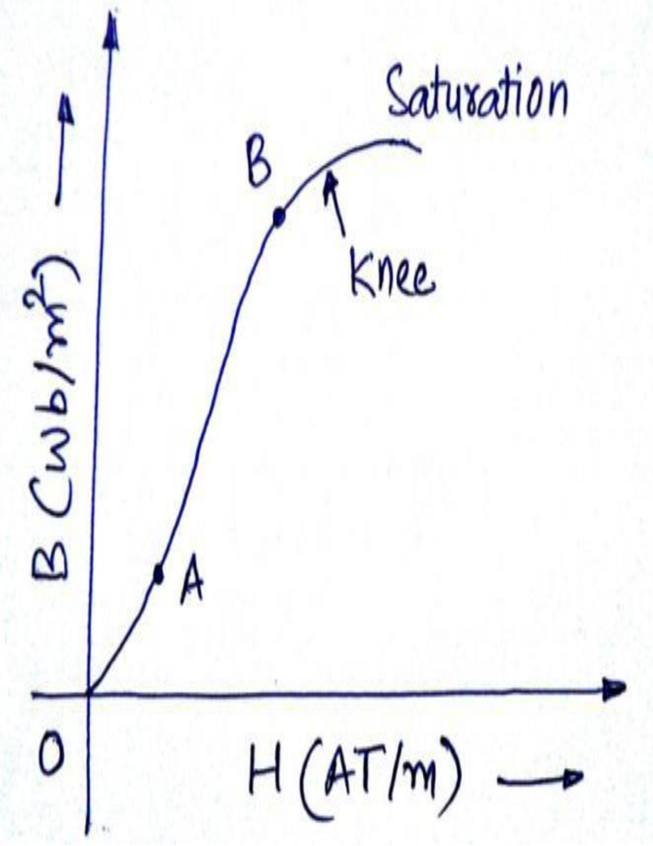
$$S=S_1+S_2+S_3$$

Value of reluctance for parallel magnetic circuit:

$$\frac{1}{S}=\frac{1}{S_1}+\frac{1}{S_2}+\frac{1}{S_3}$$

B-H curve

- The B-H curve is the graphical representation of relation between magnetic flux density (B) and magnetic field strength (H), with H plotted on the x-axis and B plotted on the y-axis.
- The B-H curve can be described by dividing it into 3 regions.
- **Region OA:** For zero current, H = 0 and B is also zero. The flux density B then increases gradually as the value of H is increased. However B changes slowly in this region.
- **Region AB:** In this region, for small change in H, there is large change in B.
  The B-H curve is almost linear in this region.
- **Region beyond B:** After point B, the change in B is small even for a large change in H. Finally, the B-H curve will tend to be parallel to X axis. This region is called as saturation region.

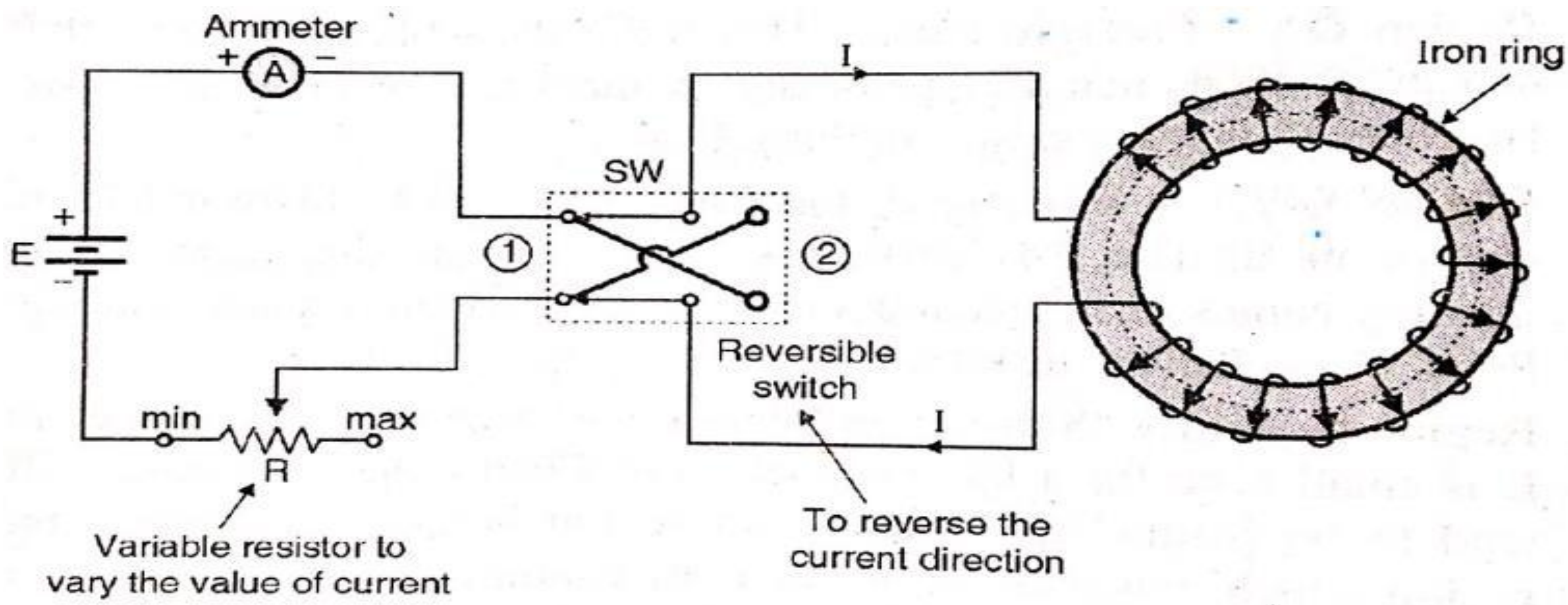


Concept of leakage flux, useful flux and fringing

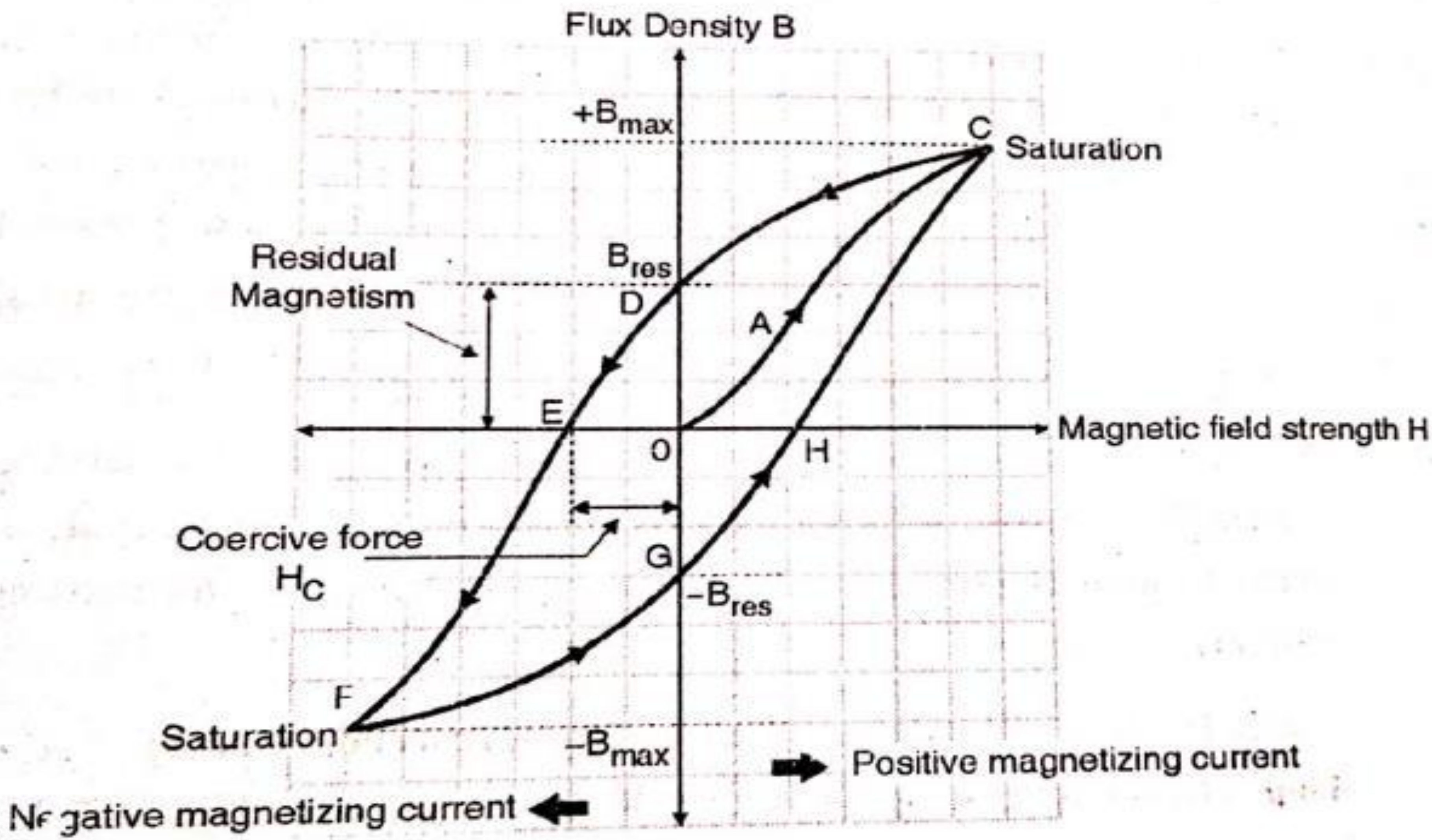
- **Leakage flux:** Some flux while passing through the magnetic circuit, leaks through the air surrounding the core. This flux is called as leakage flux.
- **Useful flux:-** The flux in the air gap which is actually utilized for various purposes depending upon the application is called as useful flux
- **Fringing:** When the magnetic flux passing or crossing an air gap tends to bulge outwards the iron ring, this effect is called as "Fringing".

Hysteresis loop

- The arrangement for plotting the hysteresis loop is shown in figure.
- The electromagnetic part consists of a coil wound on the iron ring. The current direction can be reversed using reversible switch as shown. The magnitude of current is changed by varying the resistance.
- Magnetic ring is subjected to a cycle of magnetization and demagnetization for both the directions of the current



- When the magnetic material is subjected to magnetization and demagnetization then flux density B in magnetic material lags behind the applied magnetizing force H. This phenomenon is known as **magnetic hysteresis**.



- During demagnetization of core (ring) it is seen that even if the magnetizing force has reduced to zero, the flux density does not become zero. Some flux remains in the core. This flux is called “**Remanent or residual flux**” and
- the corresponding flux density is called “**Residual magnetism**”.
- This property of magnetic material is referred as “**Retentivity**”.
- To wipe out the residual flux in the core, the magnetizing force in the opposite direction is required. This force is called “**Coercive force** Hc”.
- At large magnetizing force values, it is seen that there is no appreciable change in flux densities. The flux density remains constant in spite of change in magnetizing force. This is called “**Magnetic saturation**”.
- **Hysteresis loss:** due to presence of magnetic hysteresis a fraction of the applied power to the magnetic circuit is lost in the form of heat.
- This energy loss is given by the area under the hysteresis loop.

The factors affecting the hysteresis loss are:

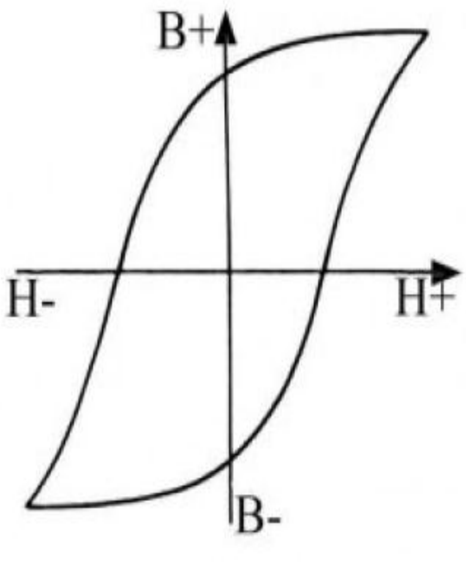
- **Frequency of magnetization:** The frequency here corresponds to the number of cycles of magnetization per second. The hysteresis loss is directly proportional to the frequency.
- **Volume of the material:** The hysteresis loss is proportional to the volume of the material. In fact the hysteresis loss per unit volume in one cycle is equal to the area under the hysteresis loop.

  Hysteresis Loss/ volume= Area under hysteresis loop
- **Area enclosed by the hysteresis loop:** The hysteresis loss is directly proportional to the area under the hysteresis loop .For the low loss materials the hysteresis loop is narrow.

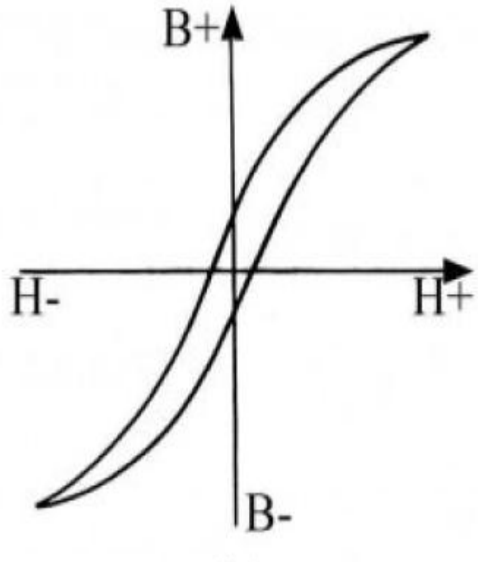
- **Methods to minimize the hysteresis loss:**

1. By reducing the operating frequency,
2. By reducing the volume of the material and
3. By selecting a material which has a narrow hysteresis loop.

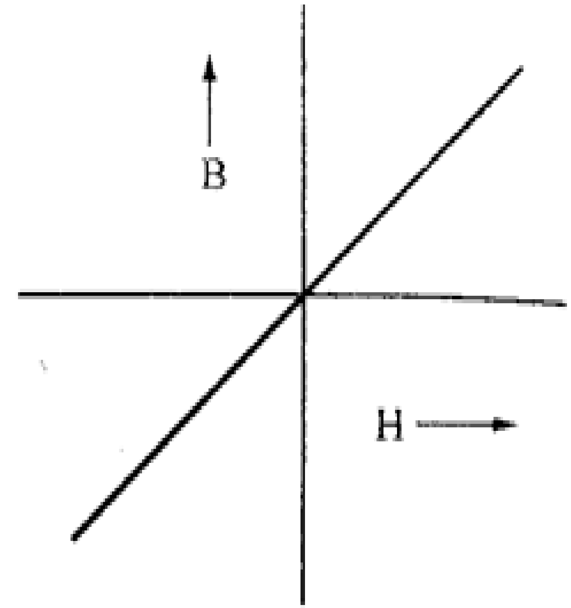
Hysteresis loop for Different materials



(a)



(b)



Hysteresis loop for **hard steel** materials are used for **permanent magnets.**

Hysteresis loop for **cast steel, Steel alloy** material can be used for **electromagnets**

plastic

Ex. 4.12.1 : An iron ring of mean circumference of 80 cm is uniformly wound with 500 turns wire.

Calculate the value of flux density that a current of 1A would produce in the ring. Assume relative permeability 1400.

S-02, 8 Marks

Soln. :

Given : $l = 80$ cm $= 0.8$ m, $N = 500$, $I = 1$ A, $\mu_r = 1400$

To find : Flux density B

Step 1 : Calculate magnetic field strength H :

$$H = \frac{NI}{l} = \frac{500 \times 1}{0.8} = 625 \text{ AT/m}$$

Step 2 : Calculate absolute permeability μ :

$$\mu = \mu_0 \mu_r = 4 \pi \times 10^{-7} \times 1400$$

$$\mu = 1.759 \times 10^{-3}$$

Step 3 : Calculate the flux density B :

$$\mu = \frac{B}{H}$$

$$\therefore B = \mu \times H = 1.759 \times 10^{-3} \times 625$$

$$\therefore B = 1.0995 \approx 1.1 \text{ Tesla}$$

...Ans.

Ex. 4.12.2 : An iron ring with cross-sectional area 6 cm^2 carries a flux of 0.1 mWb.

It is wound with a wire of 100 turns and has a saw cut of 2 mm.

If the mean length of magnetic path is 30 cm, relative permeability of iron is 500. Calculate –

1. Flux density
2. Ampere turns for iron
3. Ampere turns for air
4. Magnetising current.

W-02, 8 Marks

Soln. :

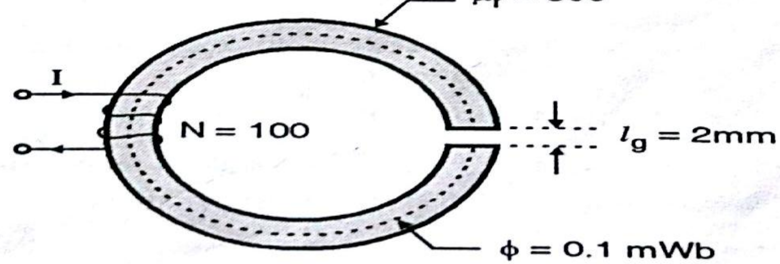
Given : $a = 6\ cm^2 = 6 \times 10^{-4}\ m^2$, $\phi = 0.1\ mWb = 1 \times 10^{-4}\ Wb$, $N = 100$ turns, $l_g = 2\ mm = 2 \times 10^{-3}\ m$, $l_r = 30\ cm = 0.3\ m$, $\mu_r = 500$

To find :
1. Flux density B
2. Ampere turns F_i (for iron)
3. Ampere turns F_a (for air)
4. Current I

Step 1 : Flux density B :

$$\text{Flux density } B = \frac{\phi}{a}$$

$$\therefore B = \frac{1 \times 10^{-4}}{6 \times 10^{-4}} = 0.167\ Wb/m^2 \quad \text{...Ans.}$$



(A-2905) **Fig. P. 4.12.2**

Step 2 : Ampere turns for iron (F_i) :

$$\text{Reluctance of iron} \quad S_i = \frac{l_r}{\mu_0 \mu_r a} = \frac{0.3}{4 \pi \times 10^{-7} \times 500 \times 6 \times 10^{-4}}$$

$$\therefore \; S_i = 795.774 \times 10^3 \text{ AT/Wb}$$

$$\therefore \text{ Ampere turns for iron, } F_i = \phi \times S_i$$

$$= 1 \times 10^{-4} \times 795.774 \times 10^3$$

$$= 79.58 \text{ AT} \qquad \text{...Ans.}$$

Step 3 : Ampere turns for air (F_a) :

$$\text{Reluctance of air gap } S_a = \frac{l_g}{\mu_0 \mu_r a} = \frac{2 \times 10^{-3}}{4 \pi \times 10^{-7} \times 1 \times 6 \times 10^{-4}}$$

$$\therefore \; S_a = 2.6525 \times 10^6$$

$$\therefore \text{ Ampere turns for air gap, } F_a = \phi \times S_a$$

$$= 1 \times 10^{-4} \times 2.6525 \times 10^6$$

$$\therefore \; F_a = 265.26 \text{ AT} \qquad \text{...Ans.}$$

Step 4 : Magnetizing current (I) :

$$\text{Total ampere turns } F = F_i + F_a$$

$$\therefore \; F = 79.58 + 265.26$$

$$\therefore \; F = 344.84 \text{ AT}$$

$$\text{But } \; F = N \times I$$

$$\therefore \; 344.84 = 100 \times I$$

$$\therefore \; I = \frac{344.84}{100} = 3.4484 \text{ Amp.} \qquad \text{...Ans.}$$

Ex. 4.12.3 : An iron ring has a cross section of 3 cm^2 and a mean diameter of 25 cm. An air gap of 0.4 mm has been cut across the section of the ring. The ring is wound with a coil of 200 turns through which a current of 2 Amp. is passed. If the total magnetic flux is 0.245 mWb, find the relative permeability of the material assuming no magnetic-leakage.

S-05, 4 Marks

Soln. :

Given : $a = 3 \text{ cm}^2 = 3 \times 10^{-4} \text{ m}^2$, diameter $d = 25 \text{ cm} = 0.25 \text{ m}$

Air gap $l_g = 0.4 \text{ mm} = 4 \times 10^{-4} \text{ m}$, $N = 200$ turns, $I = 2$ A,

$\phi = 0.245 \text{ mWb} = 0.245 \times 10^{-3} \text{ Wb}$

To find : μ_r

Step 1 : Calculate total m.m.f. F :

$$F = N \times I = 200 \times 2$$

$$\therefore F = 400 \text{ AT}$$

Step 2 : Calculate total reluctance :

$$S = \frac{F}{\phi} = \frac{400}{0.245 \times 10^{-3}}$$

$$\therefore S = 1.6327 \times 10^{6} \text{ AT/Wb}$$

Step 3 : Calculate μ_r :

Total reluctance S = Reluctance of iron S_i + Reluctance of air S_a

$$\therefore S = S_i + S_a$$

$$\therefore 1.6327 \times 10^{6} = \frac{l_i}{\mu_0 \mu_r a} + \frac{l_g}{\mu_0 a}$$

$$= \frac{1}{\mu_0 a}\left[\frac{l_i}{\mu_r} + l_g\right]$$

But $l_i = \pi \times d = \pi \times 0.25 = 0.7854$ m

$$\therefore 1.6327 \times 10^{6} = \frac{1}{4\pi \times 10^{-7} \times 3 \times 10^{-4}}\left[\frac{0.7854}{\mu_r} + 4 \times 10^{-4}\right]$$

$$\therefore \mu_r = 3644.32$$

...Ans.

Ex. 4.12.4 : A coil of 500 turns and resistance of 20 ohm is wound uniformly on an iron ring of mean circumference 50 cm and cross sectional area 4 cm^2. It is connected to 24 V d.c. supply. Relative permeability of the material = 800. Find

1. MMF
2. Magnetising force
3. Total flux
4. Reluctance

S-07, S-10, 4 Marks

Soln. :

Given : $N = 500$, $R = 20\ \Omega$, $l = 50$ cm $= 0.5$ m, $a = 4\ cm^2 = 4 \times 10^{-4}\ m^2$, $V = 24$ V, $\mu_r = 800$

To find : 1. MMF 2. Magnetizing force H 3. Flux ϕ 4. Reluctance S

Step 1 : Find current and MMF :

$$I = \frac{V}{R} = \frac{24}{20} = 1.2 \text{ Amp.}$$

$$MMF = N \times I = 500 \times 1.2 = 600 \text{ AT} \quad \text{...Ans.}$$

Step 2 : Find H :

$$H = \frac{N \times I}{l} = \frac{600}{0.5} = 1200 \text{ AT/m} \quad \text{...Ans.}$$

Step 3 : Find reluctance S :

$$S = \frac{l}{\mu_0 \mu_r a} = \frac{0.5}{(4\pi \times 10^{-7} \times 800 \times 4 \times 10^{-4})}$$

$$\therefore S = 1.2433 \times 10^6 \text{ AT/Wb} \quad \text{...Ans.}$$

Step 4 : Find total flux ϕ :

$$\phi = \frac{MMF}{S} = \frac{600}{1.2433 \times 10^6}$$

$$\therefore \phi = 4.825 \times 10^{-4} \text{ Wb} \quad \text{...Ans.}$$

Ex. 4.12.5 : A mild steel material having a cross-sectional area of 10 cm^2 and a mean circumference of 40 cm has a coil of 180 turns wound around it. Find Ampere-turns and current required to produce a flux of 800 μWb in the ring. [Assume μ_r = 380]

S-09, 4 Marks

Soln. :

Given : $a = 10 \text{ cm}^2 = 10 \times 10^{-4} \text{ m}^2$, $l = 40 \text{ cm} = 0.4 \text{ m}$, $N = 180$, $\phi = 800 \ \mu\text{Wb}$, $\mu_r = 380$.

Step 1 : Calculate reluctance S :

$$S = \frac{l}{\mu_o \mu_r a} = \frac{0.4}{4\pi \times 10^{-7} \times 380 \times 10 \times 10^{-4}}$$

$$= 837657.6 \text{ AT/Wb}$$

Step 2 : Calculate ampere turns :

$$\text{mmf (Amp Turns)} = S \times \phi = 837657.6 \times 800 \times 10^{-6}$$

$$= 670.13 \text{ AT} \quad \text{...Ans.}$$

Ex. 4.12.6 : An iron ring has a cross sectional area of $400mm^2$ and a mean diameter of 25cm. It is wound with 500 turns. If the relative permeability is 250, find the total flux set up in the ring. The coil resistance is 474Ω and supply voltage across the coil is 20V. **W-10, 4 Marks**

Soln. :

Given : Iron ring $a = 400\ mm^2$, $d = 25\ cm$, $\mu_r = 250$, $N = 500$, $R = 474\Omega$ and $V = 20$ Volts.

Find : Total flux set up in the ring.

Step 1 : Find current I and MMF :

$$I = \frac{V}{R} = \frac{20}{474} = 0.042 \text{ Amps. or } 42 \text{ mA}$$

$$MMF = N \times I = 0.042 \times 500 = 21 \text{ AT}$$

Step 2 : Find reluctance S :

$$S = \frac{l}{\mu_o\ \mu_r \times a}$$

But $l = \pi d = 25\pi = 78.58$ cm

$\therefore\ l = 0.7854$ m

$$\text{Area } a = 400\ mm^2 = 400 \times 10^{-6} \text{ meters}$$

$$\therefore S = \frac{0.7854}{4\pi \times 10^{-7} \times 250 \times 400 \times 10^{-6}}$$

$$= \frac{0.7854}{1.2566 \times 10^{-7}} = 6250014.6$$

$$= 6.25 \times 10^6 \text{ Siemence}$$

$$\therefore \text{flux} = \frac{MMF}{S} = \frac{21}{6.25 \times 10^6} = 3.36\ \mu Wb \quad \textbf{...Ans.}$$

Ex. 4.12.7: An iron ring 15 cm in diameter and $10cm^2$ in cross sectional area is wound with 200 turns. For a flux density of $1Wb/m^2$ and permeability of 500 find :

1. Reluctance of the iron ring
2. Flux in the ring
3. M.M.F. required for iron ring.
4. Exciting current.

W-11, 4 Marks

Soln. :

Given : $d = 15\ cm = 0.15\ m,\ a = 10\ cm^2 = 10 \times 10^{-4}\ m^2,$
$N = 200,\ B = 1\ Wb/m^2,\ \mu_r = 500$

To find : 1. S 2. ϕ 3. mmf 4. I

1. Reluctance (S) :

$$S = \frac{l}{\mu_o\ \mu_r\ a}$$

But $l = \pi \times d = 0.15\ \pi\ m$

$$\therefore S = \frac{0.15\ \pi}{4\pi \times 10^{-7} \times 500 \times 10 \times 10^{-4}} = 7.5 \times 10^{+5}\ \text{Siemence} \quad \text{...Ans.}$$

2. Flux ϕ :

$$B = \frac{\phi}{a} \quad \therefore \phi = B \times a = 1 \times 10 \times 10^{-4} = 1\ mWb \quad \text{...Ans.}$$

3. MMF F :

$$F = \phi \times S = 1 \times 10^{-3} \times 7.5 \times 10^{+5} = 750\ AT \quad \text{...Ans.}$$

4. Current I :

$$F = N \times I \quad \therefore 750 = 200 \times I$$

$$\therefore I = 3.75\ \text{Amp} \quad \text{...Ans.}$$

Ex. 4.12.8 : A solenoid 50 cm long and 10 cm in diameter is wound with 1500 turns find :

1. Inductance
2. Energy stored in the magnetic field, when a current of 4A flows. **W-11, 4 Marks**

Soln. :

Given : Solenoid, $d = 10\ cm = 0.1\ m.,\ N = 1500,\ l = 50\ cm = 0.5\ m$

To find : 1. L 2. Energy E if $I = 4\ A$.

1. Inductance L :

Cross sectional area of the solenoid $a = \pi\ r^2 = \frac{\pi d^2}{4}$

$$a = \frac{\pi \times (0.1)^2}{4} = 7.85 \times 10^{-3}\ m^2$$

$$\text{Reluctance } S = \frac{l}{\mu_o\ \mu_r\ a} = \frac{0.5}{4\pi \times 10^{-7} \times 1 \times 7.85 \times 10^{-3}}$$

$$\therefore S = 50686287.61\ \text{Siemence.}$$

A mild steel ring of 30 cm circumference has cross sectional area of 6 cm^2 and winding of 500 turns. Air gap is cut of 1 mm in magnetic circuit. A current of 4 A produces a flux density of 1 Tesla in air gap. Find

i) Total ampere turns

ii) Relative permeability of steel

Ans:

Given data: $l = 30cm = 0.3m$, $a = 6\ cm^2 = 6 \times 10^{-4}\ m^2$, N =500 turns,

I = 4 A, B =1 tesla air gap =1mm = 1×10^{-3} m

(i) Amp-turns = $N \times I = 500 \times 4 =$ **2000 AT**

(ii) $H = NI/l = 500 \times 4/0.3 = 6666.66$ AT/m

$B = \mu_0 \mu_r H$ therefore $\mu_r = B/(\mu_0 H)$, $\mu_0 = 4\pi \times 10^{-7}$

Relative permebility of steel

$\mu_r = 1/(4\pi \times 10^{-7} \times 6666.66) =$ **119.366**

Calculate the inductance and energy stored in magnetic field of air cored coil of 250 cm long, 50 cm diameter and wound with 4000 turns and carrying current of 10 A.

Ans:

Given: l = 250 cm = 2.5 m, d = 50 cm = 0.5 m, N = 4000 turns, I = 10A

i) Inductance:

Magnetizing force $H = \frac{NI}{l} = \frac{4000 \times 10}{2.5} = 16000$ AT/m.

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

Now $\mu_0 = 4\pi \times 10^{-7} H/m$ $\mu_r = 1$, $a = \pi r^2 = \pi \frac{d^2}{2} = \pi \frac{0.5^2}{2} = 0.196\ m^2$

$$S = \frac{2.5}{4\pi \times 10^{-7} \times 1 \times 0.196} = 1.01502 \times 10^7 \text{ AT/wb}$$

$$\therefore \text{Inductance } L = \frac{N^2}{S} = \frac{4000^2}{1.01502 \times 10^7} = 1.576\ H$$

ii) Energy stored in magnetic field:

$E = ½\ L\ I^2 = ½ \times 1.576 \times 10^2 = 78.8$ joules.

Air core coil has 500 turns and diameter of 30 cm and cross sectional area 3 cm^2. Calculate:

i) Inductance of coil

ii) Emf induced in coil if current of 2A is reversed in 0.04 sec.

Ans:

Given:- d = 30cm = 0.3m, N = 500 turns, air cored coil $\therefore \mu_r = 1$

a = $3cm^2 = 3 \times 10^{-4} m^2$

Inductance of coil $L = \dfrac{N^2}{S}$ But $S = \dfrac{l}{\mu_0 \times \mu_r \times a}$

$$\therefore L = \frac{N^2 \times \mu_0 \times \mu_r \times a}{l} = \frac{(500)^2 \times 4\pi \times 10^{-7} \times 1 \times 3 \times 10^{-4}}{\pi \times 0.3} = 0.1 \times 10^{-3} \text{ H}$$

Induced emf

di= 2 - (-2) = 4A, dt = 0.04sec

$$\therefore e = L\frac{di}{dt} = 0.1 \times 10^{-3} \times \frac{4}{0.04} = 0.01 \text{ Volt}$$

A coil consisting of 120 turns is placed in magnetic field of 0.8 ~~mub~~ **mWb**. Calculate the average emf induced in the coil when it is moved in 0.08 sec from the given field ~~of~~ **to** 0.3 ~~mub~~ **mWb**. If the resistance of the coil is 200Ω, find the induced current in the coil.

Ans:

Given: No. of turns N = 120

Initial magnetic field $\phi_I = 0.8$ mWb

Final magnetic field $\phi_F = 0.3$ mWb

Time of movement dt = 0.08 sec

Resistance of coil R= 200Ω

Average induced emf is given by,

$$E = -N\frac{d\emptyset}{dt} = -N\frac{\emptyset_F - \emptyset_I}{dt} = -120 \times \frac{(0.3 - 0.8)10^{-3}}{0.08} = 0.75V$$

Current induced in the coil $I = \frac{E}{R} = \frac{0.75}{200} = 3.75\ mA$

An iron ring with mean circumference of 80cm and cross sectional area 10 cm^2 is uniformly wound with 500 turns of wire. Determine the current required to set up a flux density of 1.2 T in the ring. Assume $\mu_r = 1000$ for iron.

Ans:

Given: $l = 80 \text{ cm} = 80\times10^{-2}$ m

$a = 10 \text{ cm}^2 = 10\times10^{-4} \text{ m}^2$

$N = 500$

$B = 1.2$ T

$\mu_r = 1000 \qquad \mu_0 = 4\pi\times10^{-7}$

The relationship between flux density and magnetizing force (field strength) is given by,

$$B = \mu_0\mu_r H$$

$$\therefore H = \frac{B}{\mu_0\mu_r} = \frac{1.2}{4\pi\times10^{-7}\times1000} = 3000\ AT/m$$

But $H = \frac{NI}{l}$

$$\therefore I = \frac{Hl}{N} = \frac{3000\times80\times10^{-2}}{500} = 4.8\ amp.$$

An iron ring of mean length 60 cm is uniformly wound with 250 turns of wire. Calculate the value of flux density if current of 2 A flows the wire. Assume $\mu_r = 500$ for iron.

Ans:

N= 250 turns, I = 2 A, l = 60 cm = 0.6 m, $\mu_r = 500$.

$H = NI/l$

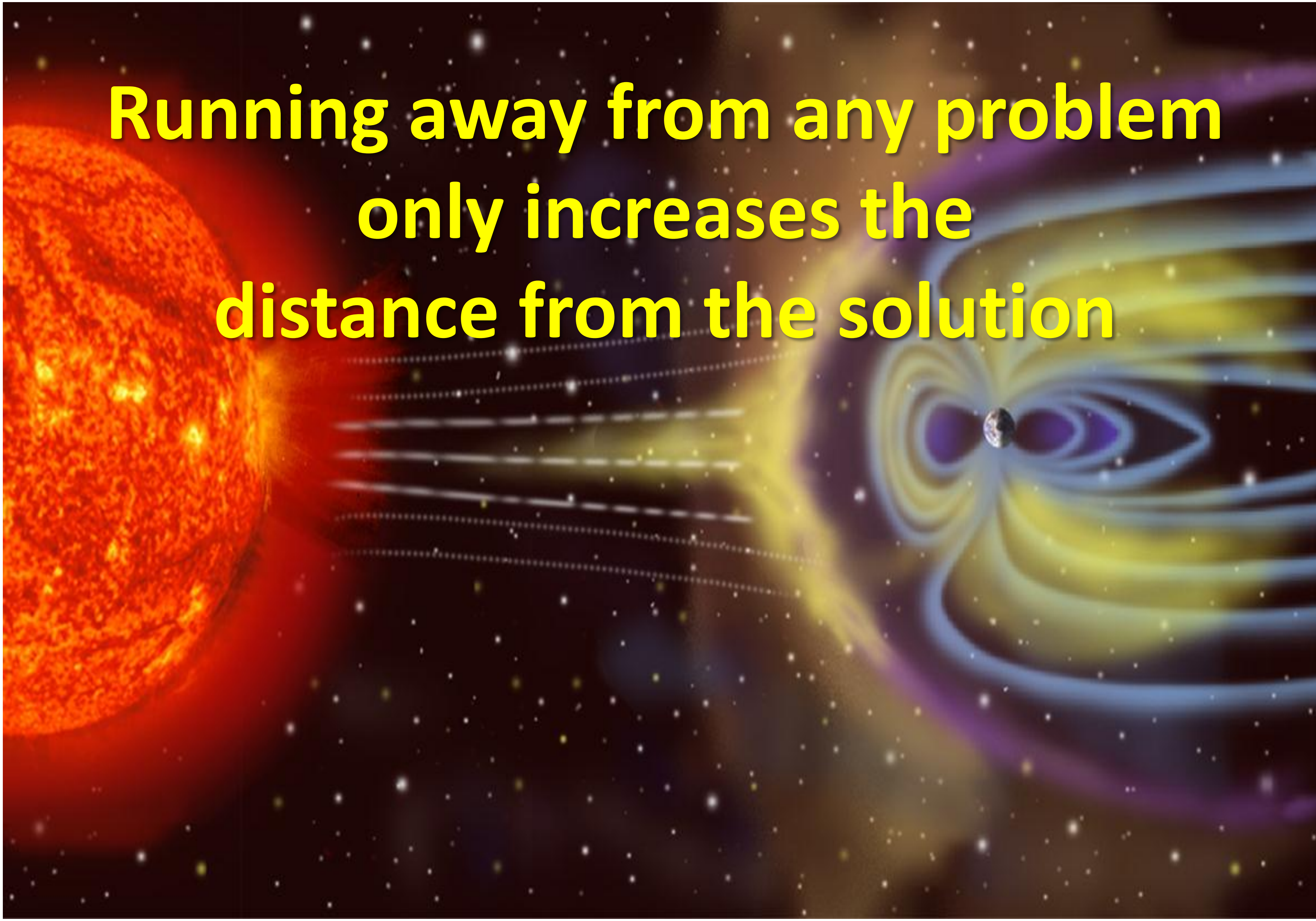
$= (250 \times 2)/(0.6) = 833.33$ A/m.

$B = \mu_o \mu_r H$

$= 4\pi \times 10^{-7} \times 500 \times 833.33 = 0.5235$ T

ASSIGNMENTS-4

1) Draw simple magnetic circuit.
2) State the relationship between permeability of free space and relative permeability of air.
3) Compare electric circuit and magnetic circuit on any four points.
4) Explain B-H curve for magnetic material. With the help of diagram, explain the concept of leakage flux, useful flux and fringing.
5) Define the following terms: i) Magnetic flux density, ii) Reluctance, iii) Magneto-motive force, iv) Permeance.
6) Explain Hysteresis loop of magnetic material with neat diagram
7) Give any two similarities and dissimilarities between electric and magnetic circuits.
8) State the values for permeability of free space and relative permeability of air.
9) Define (i) Magnetic field strength (ii) Magnetic flux density (iii) Permeability, give relation between them.


Running away from any problem
only increases the
distance from the solution