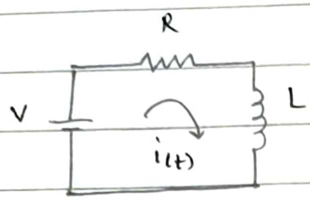
ELECTRICAL MACHINES - I

★ 

$$V = i_{(t)} R + L\frac{di_{(t)}}{dt}$$

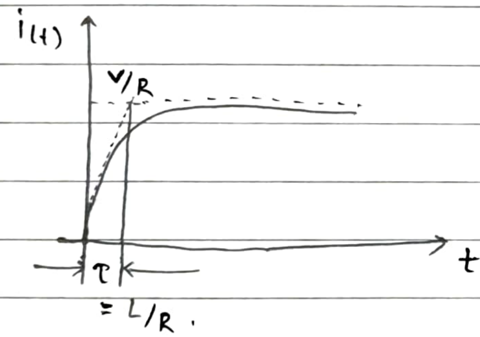
Taking Laplace -

$$\Rightarrow V/s = R\,I_{(s)} + Ls\,I_{(s)} \Rightarrow I_{(s)} = \frac{V}{s(R+Ls)}$$

$$\Rightarrow I_{(s)} = \frac{V}{Ls(s+R/L)} = \frac{L\times V}{R\;L}\left[\frac{(s+R/L)-s}{s(s+R/L)}\right]$$

$$\Rightarrow I_{(s)} = \frac{V}{R}\left[\frac{1}{s} - \frac{1}{s+R/L}\right]$$

Taking Inverse L.T., $i_{(t)} = \frac{V}{R}\left[1 - e^{-R/L\,t}\right]$



$\tau = L/R$.

★ Electrical materials should have following properties - High conductivity, Least temp. coeff. of resistance, Adequate mechanical strength, absence of brittleness, rollability and drawability (can be drawn to thin wires), good weldability and solderability, adequate resistance to corrosion.

★ Copper :

1) Highest electrical conductivity with resistance to oxidation and corrosion.

ii) Highly malleable & ductility.

iii) Most electrical machines employ winding of annealed highly conducting copper.

iv) Hard drawn copper wires are used in electrical machine as hard drawing increases mechanical strain but resistivity also increases.

v) Temp. coeff. of Cu is 0.00393 / °C.

★ Aluminium :

i) Cu is getting depleted and Al is available in abundance.

ii) Al can be rolled into thin sheets but not in wires.

iii) Al is cheaper and can be used for bars of squirrel cage induction motor (SCIM).

iv) It can be used for foil type winding in transformer because it cannot be drawn into ~~foi~~ thin wires.

v) It can be used to construct transformer ~~bands~~ banks.

★ Electrical carbon :

i) They are made of graphite and other forms of carbon.

ii) Conductivity is less than Cu and therefore it is used to make brushes in electrical machines.

iii) Brush carbon are heat treated to increase size of crystal & increase conductivity & reduce hardness.

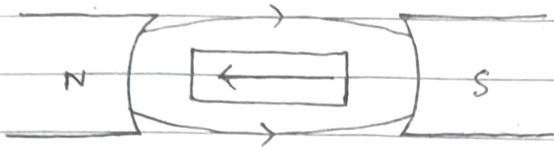
iv) It has negative temp. coeff. of resistance.

★ Materials for magnetic circuits -

i) Diamagnetic material.

→ It has weak form of magnetism only when magnetic field is applied.

→ Induced magnetisation is small and is opposite to the applied magnetic field.



E.g. → Cu, Ge, Au, Si, Diamond, etc.

→ Field lines move away from each other while passing through diamagnetic material.

M → opposite to H.

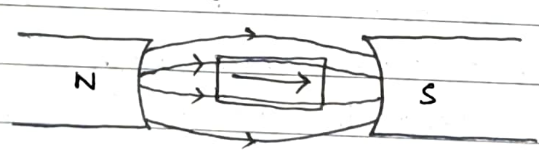
$H = \frac{NI}{l}$ → mmf. , $\chi_m < 0$.

So, $\mu_r = 1 + \chi_m < 1$. $\{\mu_r \approx 1\}$.

ii) Paramagnetic material.

→ Here weak form of magnetism exists when magnetic field is applied.

→ Induced magnetisation is small & is in same direction as the applied magnetic field.



E.g. → K, W, Al, rare earth metals, etc.

M → same direction as H.

$M = \chi_m H$.

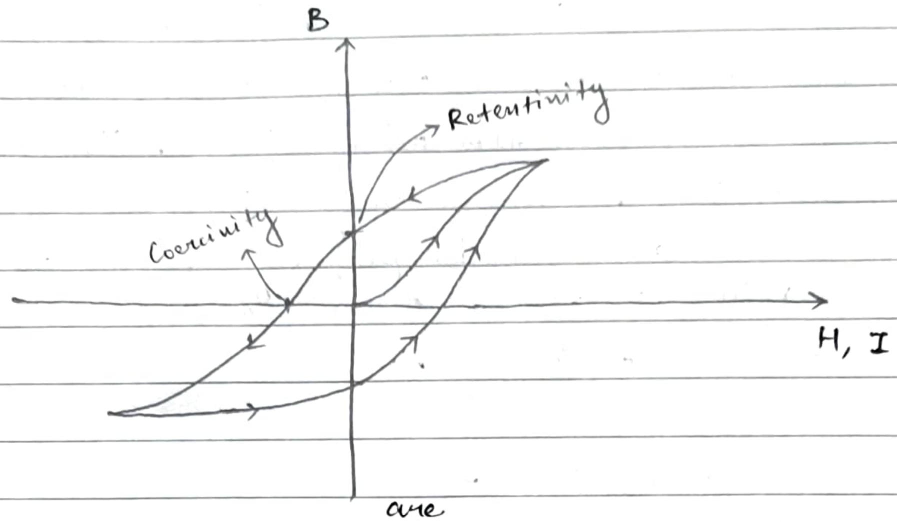
$\chi_m > 0$, $\mu_r = 1 + \chi_m > 1$.

→ Mag. field lines come closer to each other.

iii) Ferromagnetic material.

→ characterised by presence of permanent alignment of magnetic dipoles due to spin of unpaired e^-.

→ Examples are Fe, Co, Ni, Gd, Dy.

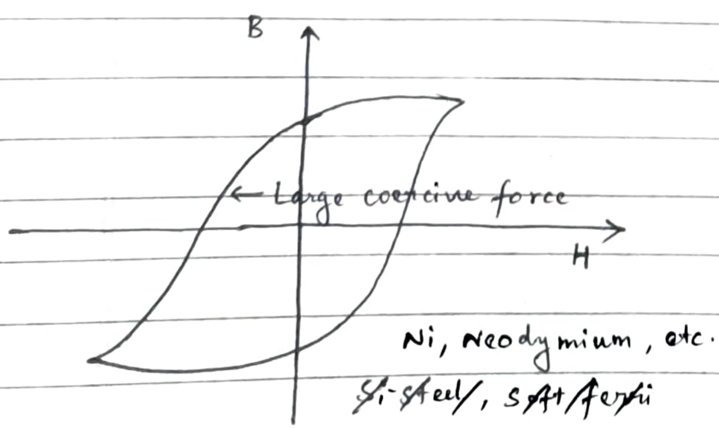


→ The salient features ~~is~~ are ~~Re~~ Residual Flux density and coercive force.

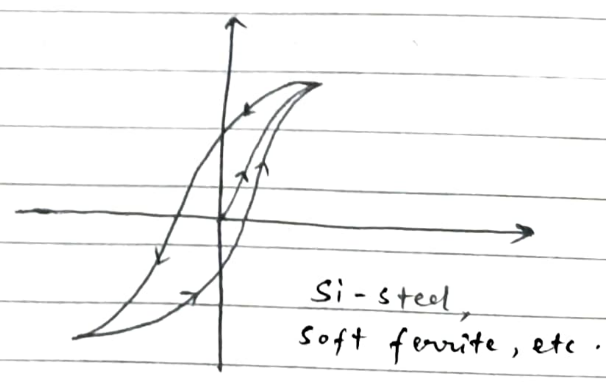
- Magnetostriction.

This is the change in material dimensions when mag. field is applied. So, when alternating field is applied, material expands & contracts in alternate half cycles. This is observed in transformers because it produces humming sound in transformers.
To mitigate this, transformer should be mounted on a soft surface such as mud, rubber mat, etc. to damp out mechanical oscillations.

Hard and soft magnetic materials



Hard mag. materials



Soft mag. materials.
(Used for building machines).

- CRGO Steel (Cold Rolled Grain Oriented Steel)

In hot rolled steel, crystals are oriented in a random manner, so, it has low permeability. The rolling direction of material is magnetically superior to other directions in sheet and this ~~for~~ property leads to CRGO steel. Cold rolled materials have highest permeability in the direction of rolling.

- Insulating materials -

i) ~~The~~ It possesses high dielectric strength.
ii) High resistivity.
iii) Low dielectric loss.
iv) Good thermal conductivity.
v) High thermal stability.
vi) Non hygroscopic (not absorb moisture)
vii) Unaffected by vibration, abbration & bending & should withstand chemical attack.

★ Mechanical properties of Electric materials :

Newton's Law of Rotation -

$F = ma$, and for ~~f~~ rotation, $\tau = J\alpha$

$J \rightarrow$ moment of inertia $\Rightarrow$ $kg\,m^2$.

$\alpha \rightarrow$ angular acc^n

$\tau \rightarrow$ Torque in Nm.

Work

For linear motion, $W = \int F\,dr$

For rotational motion, $W = \int \tau\,d\theta$.

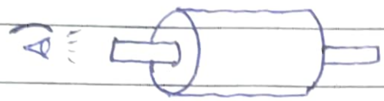
Power

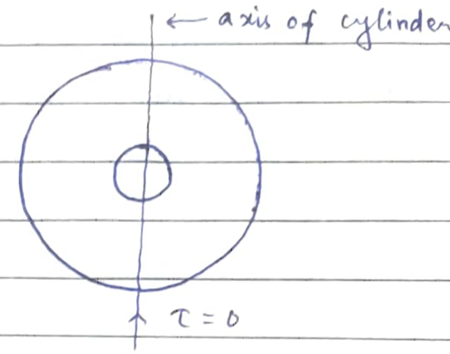
Important for rotating machines.

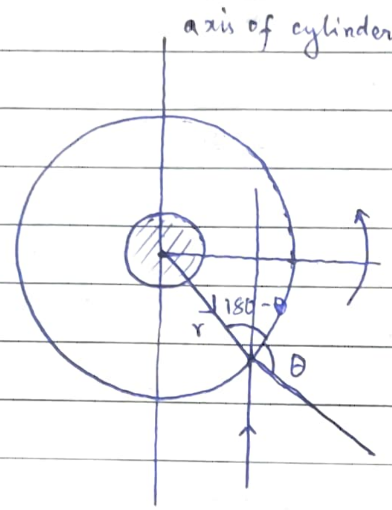
$$P = \frac{dW}{dt} = \frac{d}{dt}(\tau\theta) = \tau\frac{d\theta}{dt} = \boxed{\tau\omega = P}$$

Torque

→ twisting force in rotational motion.







Torque (τ) = $F \times r \sin\theta$

$= rF\sin\theta$.

★ Magnetic Circuit

↳ MMF → $F = NI$ (Ampere Turns)

→ Magnetic field intensity – The avg. magnitude of the field intensity in a homogeneous section of a magnetic circuit is equal to the MMF across the section divided by effective length of the mag. circuit.

$$H = \frac{NI}{l} \quad (AT/m).$$

In the composite magnetic circuits (having diff. materials & cross sections), magnetic field ~~ei~~ intensity will differ from section to section.

Magnetic flux density : Measure of concn of magnetic flux ~~field~~ lines in a particular area of a homogeneous mag. circuit.

$$B = \phi / A \rightarrow Wb/m^2 \text{ or Tesla}.$$

Reluctance : Measure of opposition produced by mag. circuits to the flow of flux. It is analogous to resistance in electrical circuits.

$$\cancel{R=}\ \phi = \frac{MMF}{Reluctance}$$

$$Reluctance = \frac{MMF}{flux} = \frac{NI}{\phi} = \frac{NI/l}{\phi/l}$$

$$= \frac{H}{BA/l} = \frac{l}{(B/H)A} = \frac{l}{\mu A}$$

μ → Permeability of magnetic circuits.

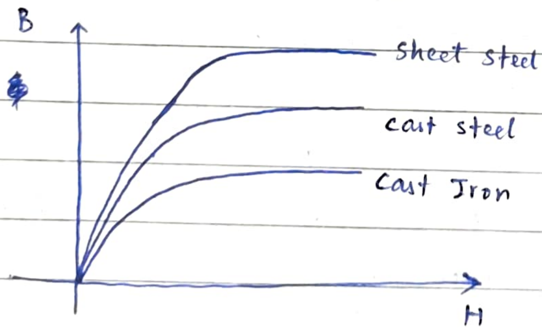
$$R = \frac{l}{\mu A}$$ → applicable for a homogeneous mag. circuit of uniform cross section.

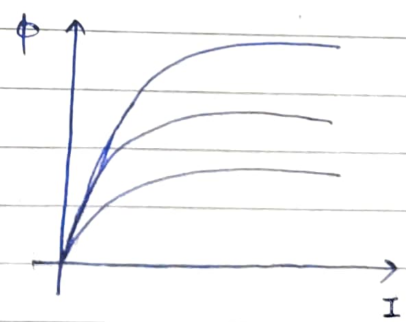
Relative permeability : It is the ratio of permeability of a material ~~by~~ to the permeability of free ~~spac~~ space.

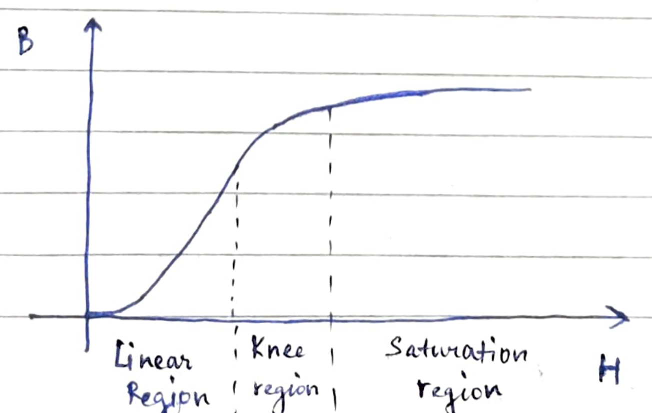
$$\mu_r = \frac{\mu}{\mu_0}$$

μ_r → dimensionless constant

μ_0 → $4\pi \times 10^{-7}$ H/m.







$$\frac{0.1 \times 0.1}{\frac{10}{100 \times 100}} \qquad \frac{0.1}{0.100} \quad 0.001$$

Reluctance $\leftarrow R = \dfrac{l}{\mu_0 \mu_r A}$

$\mu_r \hookrightarrow$ depends upon magnetisation..

★ Electromagnetic induction :

$$e_{induced} = -N\frac{d\phi}{dt}$$

Q: A steel ring having a mean circumference of 50 cm and 10 cm^2 ~~squar~~ ~~squared~~ cross sectional area has a coil of 300 turns wound uniformly around it. Determine the Reluctance of the ring and current required to produce a flux of 1 mWb in the ring, given $\mu_r = 300$.

Sol^n: Reluctance $= \dfrac{l}{\mu A} \neq \cancel{\dfrac{50}{300\, \mu_0 \times 10}} = \cancel{\dfrac{1}{60\,\mu_0}}$

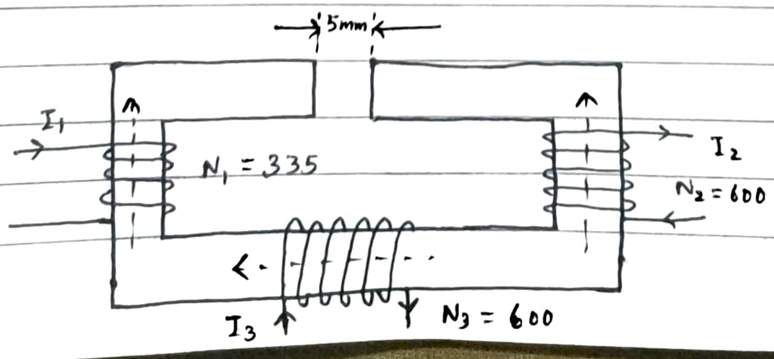
$$\cancel{= \frac{1}{60 \times 4\pi \times 10^{-7}}} = \cancel{\frac{10^7}{240}}$$

$$= \frac{0.5}{300 \times \mu_0 \times 0.001} = 1326963.91 \text{ AT.}$$

$$\text{Current} = \frac{\phi R}{N} = \frac{0.001 \times 1326963.91}{300}$$

$$= 4.42 \text{ A.}$$

Q:



A rectangular iron core is shown. It has mean length of mag. path of 100 cm, cross section of (2 cm × 2 cm), Relative permeability of 1400 ~~at~~ and ~~and~~ air gap of 5 mm is cut in the core. The 3 coils carried by the core have $N_1 = 335$, $N_2 = 600$, $N_3 = 600$, and $I_1 = 1.6$ A, $I_2 = 4$ A, $I_3 = 3$ A. The directions of currents are as shown. Calculate – (1) flux in the air gap.

~~A~~ $\phi = \dfrac{mmf}{Reluctance}$

Net mmf $= N_1 I_1 + N_3 I_3 - N_2 I_2$.

$= -335 \times 1.6 - 3 \times 600 + 4 \times 600$

$= +64$ AT

So, $\phi = \dfrac{mmf}{Reluctance}$.

mmf $= \phi \times$ Reluctance.

mmf $= \phi \left[\dfrac{l_{iron}}{\mu_0 \mu_r A} + \dfrac{l_{air}}{\mu_0 A} \right]$.

mmf $= \phi \left[\dfrac{1}{1400 \times 4\pi \times 10^{-7} \times 4 \times 10^{-4}} + \dfrac{5 \times 10^{-3}}{4\pi \times 10^{-7} \times 4 \times 10^{-4}} \right]$

mmf $= \phi \left[1.41 + 9.95 \right] \times 10^{6}$.

$\phi = 5.63 \times 10^{-6}$ wb.