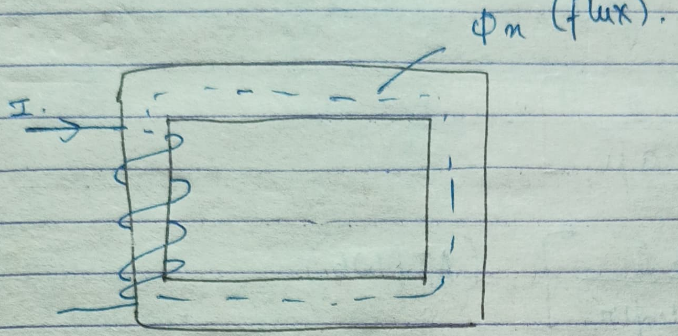
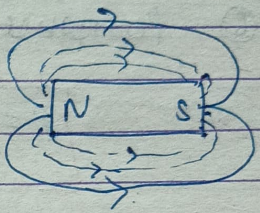
Date
12 may 2020

Module - 4

Intro. of Magnetic Circuits



Terms Used -



① Magnetic flux → (ϕ) Unit → Webers.

flux of 1 weber — 10^8 line of forces.

② magnetic flux density → $\boxed{B = \frac{\phi}{a}}$ (flux) (area)

Unit → web/m^2 or Tesla.

③ Magnetic field Intensity → $\boxed{H = \frac{NI}{l}}$

N = No. of turns of conductor winding
I → Supply Current (in A)
l → length of conductor (in m).

Unit → (AT/m)

$\left[\begin{array}{l} B \propto H \\ B = \mu H \end{array}\right]$

④ Permeability → $\boxed{\mu = \mu_0 \mu_r}$

μ_0 → absolute permeability ($4\pi \times 10^{-7}$)
μ_r → relative permeability of medium

μ_r value = 1. (only for air or vacuum).

⑤ Reluctance → opposition offered to the flow of mag^n flux.

$$\left[\underset{\text{Reluctance.}}{S} = \frac{l}{a\mu}\right]$$

$$\left[S = \frac{l}{a\mu_0\mu_r}\right] \quad (AT/Wb)$$

⑥ Permeance → Reciprocal of resistance.

$$\left[P = \frac{1}{S}\right] = \frac{\mu_0\mu_r a}{l} \quad (Wb/AT)$$

⑦ Magneto-motive force (MMF) → Driving force required for magnetic flux to be transferred in the circuit

$$\boxed{MMF = \phi S} \quad [\text{Unit} \rightarrow AT]$$

$$MMF = Hl$$

$$mmf = NI.$$

Derivation →

$$MMF = \phi S.$$

$$= \frac{\phi l}{a\mu_0\mu_r}.$$

$$MMF = \frac{Bl}{\mu} = \frac{\cancel{\mu}Hl}{\cancel{\mu}}$$

$$[mmf = Hl] \Rightarrow \left[mmf = \frac{NI\cancel{l}}{\cancel{l}}\right]$$

Magnetic flux Leakage

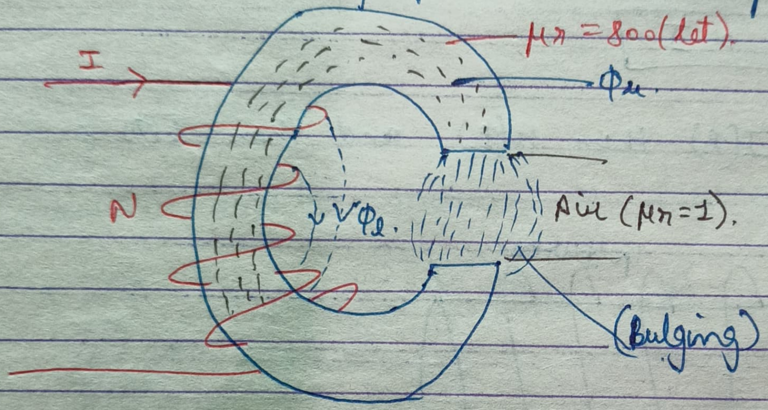
$\phi_T = \phi_e + \phi_u$

ϕ_T → Total flux

ϕ_e → Leakage flux

ϕ_u → Useful flux

Magnetic fringing (Mag^n Bulging) collection of various line of forces in a specific area.



μ_r(iron) > μ_r (air)

800 > 1.

If. Magnetic line of forces when travel from one medium to another having different relative permeability then, area having lower μ_r experiences mag^n fringing.

Effect of mag^n fringing →

→ Increased cross-section area.

→ Reduced mag^n flux density

$$\text{Leakage factor} = \frac{\text{Total flux}}{\text{Useful flux}}$$

or

$$" = \frac{\text{Flux in Iron path}}{\text{Flux in air gap}}$$

B-H Curve

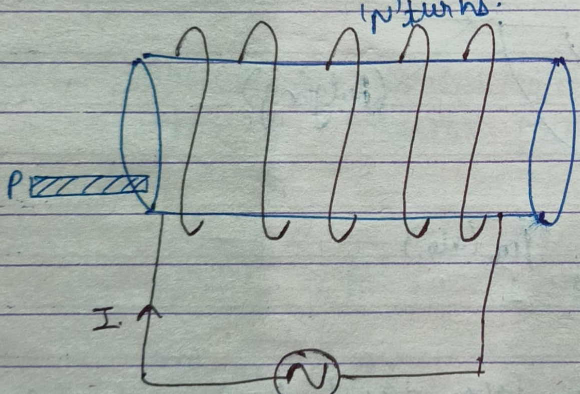
$B \propto H$.

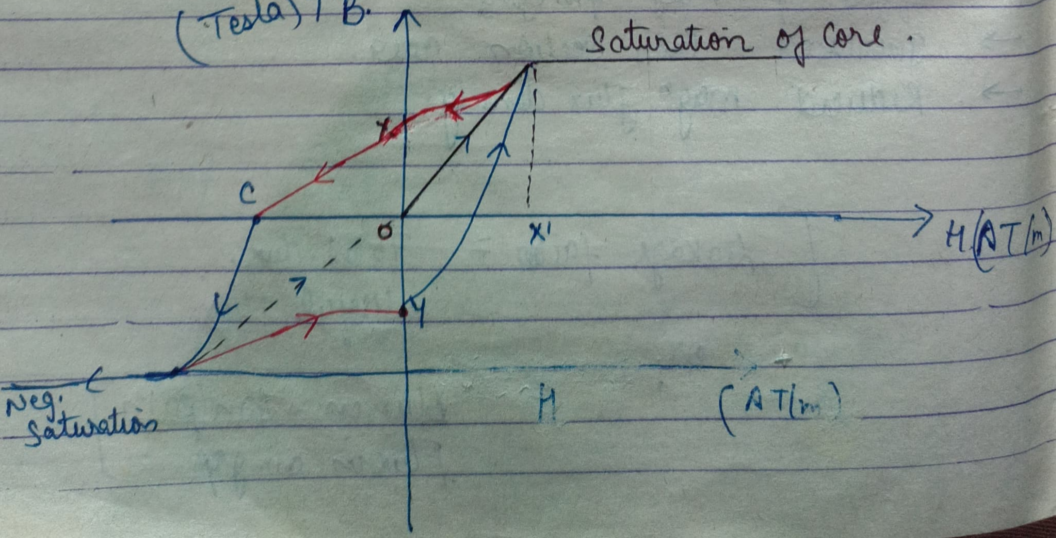
$B = \frac{\phi}{a}$ (Tesla). $H = \frac{NI}{l}$ (AT/m)

$\boxed{B = \mu H.}$ $\boxed{\mu = \mu_0 \mu_r}$

If N & l are constant, then
$\boxed{H \propto I}$

means, If I(↑) then H(↑) and then B(↑).





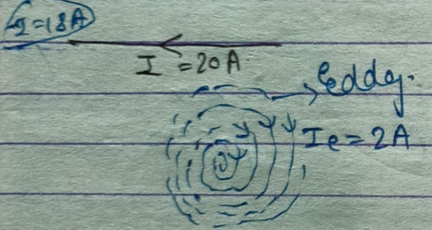
Retentivity → Prop. of magnetic material to store the residual magnetism.

Hysterisis Loss (B lags behind H)

Hysterien (Greek)
↳ Means Lagging Behind.

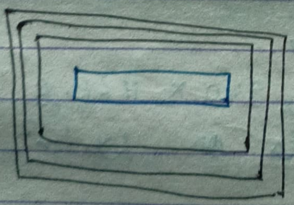
Coercive force → Amt of force in the negative dirⁿ, to eliminate residual magⁿ field.

Eddy Currents :-
↓
Continuous circular motion of Current.



(Inet = 18A)

1) It is a Leakage Current.
2) It is opposing in nature from the actual supply current. (Lenz's law).
3) Available on the surface of the system.



Surface (↓) eddy current (↓).

Numericals (JB Gupta).

eg 1 $B = 1.3\ Wb/m^2$ $AT = ?$

$l_g = 4mm.$

$B = \mu H.$

$\mu_r(Air) = 1$

$1.3 = \mu_0 \mu_r . H.$

$H = \frac{1.3}{4\pi \times 10^{-7} \times 1} = 1.035 \times 10^6\ AT/m.$

$AT = H_g l_g$

$AT. = 1.035 \times 10^6 \times 4 \times 10^{-3} = 4140.$

eg 2

$l = 18cm.$ $A = 15mm \times 20mm.$

$N = 300.$ $I = 0.7A.$ $\mu_r = 940$

$A = 3 \times 10^{-4} m^2$ $l = .18m.$

(i) Magnetising force, $H = \frac{NI}{l}$

$H. = \frac{300 \times 0.7}{.18} = 1166.6\ AT/m$

(ii) flux density, $B = \mu_0 \mu_r H.$

$= 4\pi \times 10^{-7} \times 940 \times 1166.6$

$= 1.377$ Tesla or Wb/m^2.

(iii) Reluctance, $S = \frac{l}{a \mu_0 \mu_r} = \frac{.18}{3\times 10^{-4} \times 4\pi \times 10^{-7} \times 940}$

$= 50.79 \times 10^4\ AT/Wb$

(iv) flux, $\phi = B \times a$

$= 1.377 \times 3 \times 10^{-4} = 4.13 \times 10^{-4}$

eg3. $N = 500$ $R = 4\Omega$

$D = .25m$ $a = 700 mm^2$

$\mu_r = 550$

$\phi = ?$ $V = 6V$

$l = \pi D$

$= 3.14(.25) = .785m$

$a = 7 \times 10^{-4} m^2$

$V = IR$

$I = \frac{6}{4} = 1.5 A$

$\phi = \frac{NI}{S} = \frac{NI}{l / a\mu_0\mu_r}$

flux, $\phi = \frac{500 \times 1.5 \times 7 \times 10^{-4} \times 4\pi \times 10^{-7} \times 550}{.785}$

$\phi = \cancel{3.826 \times 10^{-4} Wb}$ 4.62×10^{-4}

eg4. $l = 0.3m$ $D = 0.2m$

$N = 500$ $\phi = 0.5 mWb$

$l_g = 1mm$ $\mu_r = 4000$ $I = ?$

$\phi = 0.5 \times 10^{-3} Wb$

$\cancel{H = \frac{NI}{l}}$ $\phi S = Hl = NI$

$D = 0.02\,m.$ $\qquad a = \pi\left(\frac{0.2}{2}\right)^2.$

$$0.5\times10^{-3} \times \frac{l}{a\mu_0\mu_r} = NI.$$

$$0.5\times10^{-3}\times \frac{0.3}{\pi(0.1)^2\times4\pi\times10^{-7}\times4000} = I.$$

$NI = AT.$

$$B = \frac{\phi}{a} = \frac{0.5\times10^{-3}}{\pi(0.01)^2}$$

$B = 1.59\,T.$

$$AT = H_g l_g + Hl.$$

$$= \frac{B l_g}{\mu_0} + \frac{Bl}{\mu_0\mu_r}$$

$$= \frac{1.59}{4\pi(10^{-7})}\left(0.001 + \frac{.3}{4000}\right)$$

$AT = 1360.86$

$$I = \frac{1360.86}{500} = 2.72\,A.$$

eg 5. $D = 0.2\,m.$ $\qquad l_g = 1\times10^{-3}\,m.$

$a = 3.6\,cm^2$

$N = 1000$ $\qquad \phi = 0.5\times10^{-3}\,Wb.$ $\qquad \mu_r = 650.$

$I = ?$

$$B = \frac{\phi}{a} = \frac{0.5\times10^{-3}}{3.6\times10^{-4}} = 1.389\,T.$$

length of iron path $= \pi D - l_g.$

$= 0.627\,m.$

$AT = Hl + H_g l_g.$

$$= \frac{B}{\mu_0 \mu_r} l_i + \frac{B l_g}{\mu_0}$$

$$= \frac{B}{\mu_0} \left(\frac{l_i}{\mu_r} + l_g \right).$$

$$AT = \frac{1.389}{4\pi 10^{-7}} \left(\frac{.627}{650} + 10^{-3} \right) = 2172.65.$$

$AT = NI.$

$$I = \frac{2172.65}{1000} = 2.172A.$$

eg. 6. $D_i = 7.4$ inch $= .177m$

$D_o = 9$ inch. $= .228$ m

thickness $= 0.8$ inch.

$N = 600$ $\quad I = 2.5A$ $\quad \phi = 1.2 \times 10^{-3} Wb.$

(i) $B = ?$ (ii) $S = ?$ (iii) $\mu = ?$

mean length. $= \frac{\pi (D_i + D_o)}{2} = .654$ m.

$\pi \frac{(.228 + .177)}{2}$ $\quad a = 0.8 (9 - 7.4)$ inch^2.

$= 1.28$ inch^2.

$a = 8.25 \times 10^{-4} m^2.$

mg flux density $B = \frac{\phi}{a} = \frac{1.2 \times 10^{-3}}{8.25 \times 10^{-4}} = 1.45$ AT.

$\phi S = NI.$

$$S = \frac{600 \times 2.5}{1.2 \times 10^{-3}} = 1250 \times 10^{3} \ AT/wb$$

$\mu = \frac{l}{Sa}$

$\mu = \frac{.654}{1250\times10^3 \times 8.25\times10^{-4}} = 6.34\times10^{-4}$

eg 7. $l_g = 3\times10^{-3}$ m $\quad l_i = 0.4$ m.

AT = ? $\quad B = 0.7$ Wb/m^2 in gap.

AT in gap = 70% of Total.

$\left[AT_g = \frac{70}{100} \times AT = 0.7 AT \right]$

$\left[AT = \frac{AT_g}{0.7} \right]$ —— ①

$AT_g = H_g l_g$

$= \frac{0.7}{4\pi(10^{-7})} \times 3\times10^{-3} = 1671.9$

$AT = \frac{1671.9}{0.7} \quad 2388.5$

eg 8. $D = .25$ m $\quad l_g = 1.5\times10^{-3}$ m.

cross-sec diam = .03m.

$N = 750 \quad I = 2.1$ A.

(i) mmf = ?

mmf = NI. = 1575. = AT

$AT_g = \frac{65}{100}(AT) = .65 \times 1575$

$= \cancel{1181.25}$ 1023.75

$a = \pi\left(\frac{.03}{2}\right)^2 = .0007\ m^2.$

$$AT_g = \left(\frac{B_g}{\mu_0\mu_r}\right) \times l_g$$

$$B_g = \frac{\cancel{1189.205}\ 1023.75 \times 4\pi \times 10^{-7}}{1.5 \times 10^{-3}} = \cancel{.989}\ 0.857\ T.$$

(iii) $\Phi = B \times a = .857 \times .0007$

$= 5.99 \times 10^{-4} \approx 0.6\ mWb.$

~~Assu.~~ negligible Leakage →

$B_l = B_g = .857.$

Length of Iron path $= \pi D - l_g$

$= (3.14 \times .25) - 1.5 \times 10^{-3}$

$= .784\ m.$

$$AT_l = \frac{B_l\, l}{\mu_0 \mu_r}$$

$$551 \times 4\pi \times 10^{-7} = \frac{(.784) \times .857}{\mu_r}. \quad \cancel{=970}$$

$$\boxed{\mu_r = 970}$$

eg 8. $l = 0.5\ m$ $\quad \mu_r = 300$ $\quad l_g = 10^{-3}\ m$

$N = 200$ $\quad I = 1A$ $\quad B_g = ?$

$AT = NI = 200.$

$200 = AT_l + AT_g.$

$$200 = \left(\frac{B_l}{\mu_0 \times 300} \times 0.5 + \frac{B_g \times 10^{-3}}{\mu_0}\right).$$

$$200 = \frac{B}{4\pi 10^{-7}}\left(\frac{0.5}{300} + .001\right)$$

$$B = \frac{2.512\times10^{-4}}{2.66\times10^{-3}} = .0942\ T.$$

eg10.

$l_1 = 10\ cm.$ $A_1 = 8\ cm^2$

$l_2 = 8\ cm$ $A_2 = 3\ cm^2$

$l_3 = 6\ cm$ $A_3 = 2.5\ cm^2.$

$\mu_1 = 2670$ $I = ?$

$\mu_2 = 1050$ $\phi = 0.4\times10^{-3}\ Wb.$

$\mu_3 = 600.$ $N = 250$

$$NI = \phi S$$

$$S = \frac{1}{4\pi 10^{-7}}\left(\frac{.1}{.08\times2670} + \frac{.08}{.03\times1050} + \frac{0.06}{.025\times600}\right)$$

$$\frac{(4.68\times10^{-4} + 2.53\times10^{-3} + 4\times10^{-3})}{4\pi 10^{-7}}$$

$$S = \frac{53.33}{4\pi}\times10^{-3+7} = 4.246\times10^{4}$$

$$I = \frac{4.246\times10^{4}\times0.4\times10^{-3}}{250} = .067\ A$$

$$S = \frac{1}{4\pi 10^{-7}} \left[\frac{0.1}{8\times10^{-4} \times 2670} + \frac{.08}{3\times10^{-4}\times 1050} + \frac{.06}{2.5\times10^{-4}\times 60} \right]$$

$$\frac{1}{4\pi(10^{-11})} \left[4.68\times10^{-6} + 2.53\times10^{-5} + 4\times10^{-5} \right].$$

$$S = \frac{6.998}{4\pi} \times 10^{-5+11} = .557\times10^{6}$$

$$I = \frac{.557\times10^{6} \times 0.4\times10^{-3}}{250} = 0.8912\,A$$

egy. $a = 16\times10^{-4}\,m^2$ $N = 1000.$

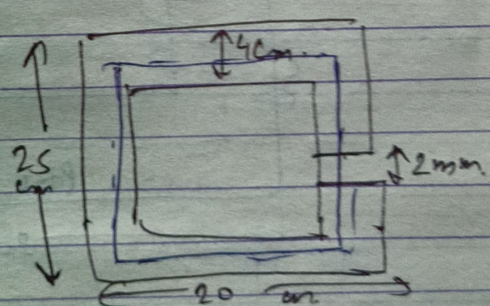
$\phi = 4\times10^{-3}$ Wb.

Doubt $l_g = 2\times10^{-3}\,m$ $\mu_r = 2000.$

$I = ?$

$\cancel{\phi = \frac{B}{a}} \Rightarrow \cancel{B = \phi a.}$

$\cancel{B = 4\times10^{-3}\times16\times10^{-4} = 64\times10^{-7}}$



$NI = AT = \cancel{\phi}\ Hl.$

$\cancel{Hl = B}$

$$B = \frac{\phi}{a} = \frac{4\times10^{-3}}{16\times10^{-4}} = 2.5\,T$$

$$\frac{2.5}{4\pi\times10^{-7}\times2000}$$

Length of iron path =

$$2\left(25 - 2\left(\frac{4}{2}\right) + 20 - 2\left(\frac{4}{2}\right)\right) - 0.2$$

$$2(21+16) - 0.2 = \cancel{30}$$

$l_i = 74 - 0.2 = 73.8\,cm = .738\,m$

$$AT = \left(\frac{B\,l_g}{\mu_0} + \frac{B\,l_i}{\mu_0\mu_r}\right)$$

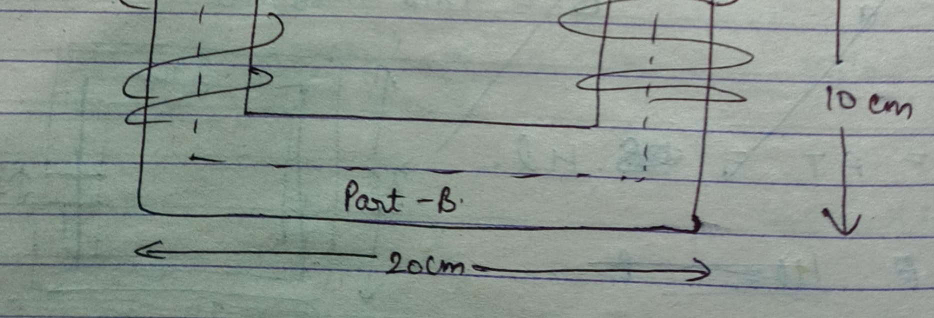
$$\frac{2.5}{4\pi 10^{-7}}\left(.002 + \frac{.738}{2000}\right)$$

$$AT = \frac{2.5}{4\pi 10^{-7}}\left(2.369\times10^{-3}\right) = 4715.36$$

$NI = AT.$

$$I = \frac{4715.36}{1000} = 4.715A.$$

eg12.



$\mu_r(A) = 1000$
$\mu_r(B) = 1200$
$N = 1000.$
$I = 1A$

$a = (.03)^2 = 9\times10^{-4}\,m^2$

(l_A) Mean length in Part A = $20 - (1.5 + 1.5) = 17\,cm$
$= .17\,m.$

(l_B) Mean length in Par B = $[10 - (1.5)]\times 2 + [20 - (1.5 + 1.5)]$
$= 34\,cm = 0.34\,m.$

(a) $S_A = \frac{l}{a \mu_0 \mu_r}$

$= \frac{.17}{4\pi \times 10^{-7} \times 1000 \times 9 \times 10^{-4}} = 150389.24 \, AT/Wb$

$S_B = \frac{.34}{4\pi \times 10^{-7} \times 1200 \times 9 \times 10^{-4}} = 250648.23 \, AT/Wb$

(b) $S_g = \frac{l_g}{a \mu_0} = \frac{2(2 \times 10^{-3})}{4\pi \times 10^{-7} \times 9 \times 10^{-4}} = 3538570$

(c) Total reluctance $= S_A + S_B + S_g$
$= 3939608.388 \, AT/Wb$

(d) $mmf = NI$
$= 2(1000 \times 1) = 2000 \, AT$.

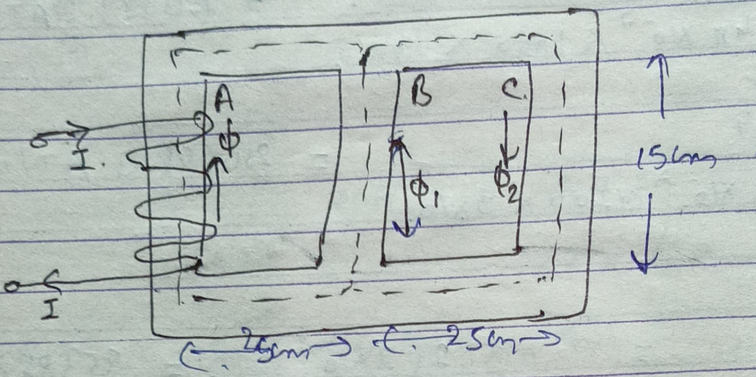
(e) $\phi = ?$
$\phi S = MMF$
$\phi = \frac{2000}{3939608.388} = 5.0766 \times 10^{-4} \, Wb$.

(f) $B = \frac{\phi}{a} = \frac{5.0766 \times 10^{-4}}{9 \times 10^{-4}} = .564 \; T$

eg 13. Cross section = 2cm x 2cm.

$N = 500$ $\mu_r = 600$

Soln. $\phi = 2 \times 10^{-3}$ Wb.



$S_B = \frac{l}{\mu_0 \mu_r \times a} = .15$

Magnetically induced emfs (or Voltages)

$\left[\text{induced emf, } e = -N\frac{d\phi}{dt}\right]$ Volts.

eg 14. $N = 400$ turns $t = 0.2$ sec.

$d\phi = (0.2 \text{ to } 1)$ mWb.

$d\phi = (1 - 0.2)$ mWb

$= 0.8 \times 10^{-3}$ Wb $= 8 \times 10^{-4}$ Wb

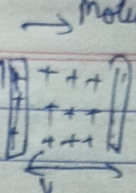
Rate of change of flux, $\frac{d\phi}{dt} = \frac{\cancel{8} \times 10^{-4} \times 10}{0.\cancel{2}}$

$= 4 \times 10^{-3}$ Wb/s

induced voltage, $e = N\frac{d\phi}{dt}$

$= 400 \times 4 \times 10^{-3}$

$\boxed{e = 1.6 \text{ V}}$



Dynamically induced emf :-

Area swept per second by cond = $l \times v$

Flux cut per second = Flux density $\times$ area swept per sec

$= B l v$

Induced emf $= \frac{d\phi}{dt} = Blv$ volts

$\boxed{e = Blv \sin\theta \text{ volts}}$ → angle b/w B & v.

eg 15. $l = 150$ cm $\quad \theta = 30°$ $\quad B = 1.2 \, W/m^2$

$v = 60$ m/s.

$e = Blv \sin\theta$

$= 1.2 \times 1.5 \times 60 \sin 30°$

$e = 54V$

eg 16. $l = 30$ cm. $\quad I = 100A$ $\quad \theta = 90°$

$B = 0.4 \, wb/m^2$. $\quad F = ?$

$F = IBl = 100 \times 0.4 \times 0.3 = 12N$

$e = Blv \sin\theta$. $\quad v = 10$ m/s.

$e = 0.4 \times .3 \times 10 = 1.2V$

$P = F \times V = 12 \times 10 = 120W$.

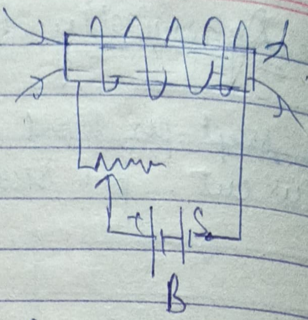
Statically induced emf → (a) Self Induced
(b) Mutually induced

Self induced emf →

Consider solenoid of N turns, length l. area of x-section $a \, m^2$, relative permeability μ_r, current i.

$\phi = \frac{Ni}{l / \mu_0 \mu_r a}$ $\quad (\phi S = Ni)$

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



$$= -N\frac{d}{dt}\left(\frac{Ni}{l/\mu_0\mu_r a}\right)$$

$$= \frac{-N^2}{l}\mu_0\mu_r a \frac{di}{dt}$$

self inductance

$$\boxed{e = -L\frac{di}{dt}}$$

$$L = \frac{N^2\mu_0\mu_r a}{l} \text{ Henry}$$

or $\boxed{L = \frac{e}{di/dt}}$

$$\boxed{L = \frac{N\phi}{i}}$$

Mutually induced emf :-

Consider coil of turns N_1 wound on core of length l m, area of cross-section a sq m. relative permeability μ_r. When current i_1 flow through it, $\Phi = \frac{N_1 i}{l/(\mu_0\mu_r a)}$ is set up around the coil.

e.m. (mutually induced emf) = − rate of change of flux of linkage of coil B

$$= -N_2 \times \text{rate of change of flux in A}$$

$$= -N_2\frac{d}{dt}\left(\frac{N_1 i}{l/\mu_0\mu_r a}\right)$$

$$= -\frac{N_1 N_2 a \mu_0 \mu_r}{l} \frac{di_1}{dt}$$

$M = \frac{N_1 N_2 a \mu_0 \mu_r}{l}$ Henry.

$$\boxed{e_m = -M \frac{di_1}{dt}}$$

or

$$\boxed{M = \frac{e_m}{di_1/dt}}$$

$$\boxed{M = N_2 \frac{\Phi_2}{i_1}}$$

eg 17. $N = 300$ $L = 10 mH.$ $I = 5A$

(i) $\Phi = ?$

$L = \frac{N\Phi}{I} = \frac{300 \times \Phi}{5}$

$\Phi = \frac{10 \times 10^{-3} \times 5}{300} = 1.66 \times 10^{-4}$ Wb.

$\frac{di}{dt} = \frac{5-(-5)}{8 \times 10^{-3}} = \frac{10 \times 10^{3}}{8} = 1250$ A/s.

$e = \frac{L di}{dt} = \cancel{10 \times 10^{-3} (1250) = 125V}$

$e = 10 \times 10^{-3} (1250) = 12.5V$

eg18. $N = 1000$ $a = 5 \times 10^{-4} m^2$ $l_g = 2 \times 10^{-3} m$
$\theta = 90^\circ$ $i = ?$ $B = 0.5 T.$ $L = ?$
$\mu_r = \infty$.

$AT = Ni$ —①.

$AT = Hl$.
$$AT = \frac{B l_i}{\mu_0 \mu_r} + \frac{B l_g}{\mu_0}$$

$$AT = 0 + \frac{0.5 \times 2 \times 10^{-3}}{4\pi 10^{-7}} = 796.$$

$\cancel{L = \frac{N\phi}{i}}$ — ① $796 = 1000\, i$.
$$\boxed{i = 0.796 A}$$

$$L = \frac{N\phi}{i} = \frac{1000 \times 0.5 \times 5 \times 10^{-4}}{.796}$$
$L = .314 H.$

eg19. $a = 2500 mm^2$. $D = 250 mm$.
$\mu_r = 1000$. $N = ?$ $L = 1H$.

length $= \pi D$.
$= \pi(.25) = .785$.

$$L = \frac{N^2 \mu_0 \mu_r a}{l}$$

$$N = \sqrt{\frac{1 \times .785}{4\pi \times 10^{-7} \times 1000 \times 2500 \times 10^{-6}}}$$

$N = 500$

eg 20. $l = .4m$ $a = 4\times10^{-4} m^2$ $\mu_r = 1000$

$l_g = 10^{-3} m$ $N = 1000$ $L = ?$

$l_i = 0.4 - 10^{-3} = .399m$

$$AT = \frac{B\, l_i}{\mu_0 \mu_r} + \frac{B\, l_g}{\mu_0}$$

$$= B\left(\frac{.399}{4\pi 10^{-7}(1000)} + \frac{10^{-3}}{4\pi 10^{-7}}\right)$$

$$= B(317.67 + 796.17)$$

$NI = AT = 1113.84B$

$NI = (1113.84)B$

$$I = \frac{(1113.84)B}{1000}$$

$$\boxed{I = 1.113B}$$

$\phi = B\times a$

$\phi = B\times 4\times10^{-4}$

$$L = \frac{N\phi}{I}$$

$$\left[L = \frac{1000\times \cancel{B}\times4\times10^{-4}}{1.113\cancel{B}} = 0.359H\right]$$

eg 21) $L = ?$ $\quad i = 0.2\,A$ $\quad \frac{di}{dt} = 0.4\,A$ per second

$P = 0.4\,W$

$P = e\,i$

$e = \frac{0.4}{0.2} = 2\,V.$

$L = \frac{e}{di/dt} = \frac{2}{0.4} = 5\,H.$

eg 22. $N_1 = 100$ $\quad N_2 = 50.$ $\quad M = ?$

$\mu = 4000\,\mu_0.$ $\quad l = 0.6\,m$ $\quad a = 9\times10^{-4}\,m^2$

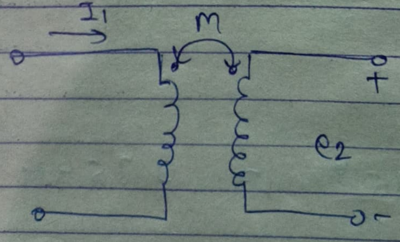
$M = \frac{N_1 N_2 \mu_r \mu_0 a}{l}$

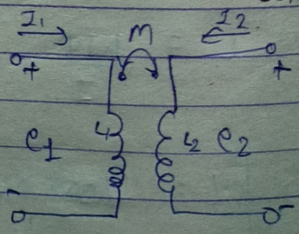
$M = \cancel{\frac{100\times50\times4000\,(4\pi\times10^{-7})^2\,9\times10^{-4}}{0.6}}$

$M = \frac{N_1 N_2 \mu a}{l} = \frac{100\times50\times9\times10^{-4}\times4000\times4\pi10^{-7}}{0.6}$

$M = .0376\,H$ or $37.6\,mH.$

Mutual coupling in simple mag. circuit





$e_1 = \frac{L_1 di_1}{dt} + \frac{M di_2}{dt}$

$$e_2 = L_2 \frac{di_2}{dt} + \frac{M di_1}{dt}$$

Coefficient of coupling, (k).

$$\Phi_1 = \frac{N_1 i_1}{l/\mu_0 \mu_r a}$$

$$\Phi_2 = K \Phi_1$$

$$= \frac{K N_1 i_1}{l/\mu_0 \mu_r a}$$

$$M = \frac{N_2 \Phi_2}{i_1} = \frac{N_2 K \Phi_1}{i_1}$$

$$\boxed{M = \frac{K N_1 N_2}{l/\mu_0 \mu_r a}}$$

$$L_1 = \frac{N_1 \Phi_1}{i_1} = \frac{N_1^2}{l/\mu_0 \mu_r a}$$

$$L_2 = \frac{N_2 \Phi_2}{i_2} = \frac{N_2^2}{l/\mu_0 \mu_r a}$$

$$\sqrt{L_1 L_2} = \frac{N_1 N_2}{l/\mu_0 \mu_r a}$$

$$M = K \sqrt{L_1 L_2}$$

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

☆ $(k = 1)$ [when coils are tightly coupled)

☆ when flux is zero then, $k = 0$.

eg23. $N_1 = 1200$ $N_2 = 800$.

In (A) $i_1 = 5A$ $\Phi_1 = 0.25 \times 10^{-3} Wb$.

In (B) $i_2 = 5A$. $\Phi_2 = 0.15 \times 10^{-3} wb$.

$M = ?$; $k = ?$

$$L_1 = \frac{N_1 \Phi_1}{i_1} = \frac{1200 \times .25 \times 10^{-3}}{5} = .06H.$$

$$L_2 = \frac{N_2 \Phi_2}{i_2} = \frac{800 \times .15 \times 10^{-3}}{5} = .024H.$$

$$M = \frac{N_2 \Phi_2}{i_1} = \frac{800 \times .15 \times 10^{-3}}{5} = .024H.$$

$$k = \frac{.024}{\sqrt{.06 \times .024}} = 0.6332.$$

$$\because K = \frac{M}{\sqrt{L_1 L_2}}$$

eg24 $L_1 = 60 \times 10^{-3} H$ $L_2 = 80 \times 10^{-3} H$
$M = 40 \times 10^{-3}$

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

$$K = \frac{40 \times 10^{-3}}{\sqrt{60 \times 10^{-3} \times 80 \times 10^{-3}}} = \frac{.04}{.069}$$

$\boxed{K = .579}$

AC Excitation in magnetic circuits

Consider an iron cored excited by a winding having N turns, carrying current of i A. Magn. flux ϕ produced by exciting current i.

$$\phi = \phi_{max} \sin \omega t.$$

$$e = N\frac{d\phi}{dt} = N\phi_{max}\frac{d}{dt}\left(\sin(2\pi f t)\right)$$

$$e = 2\pi f N \phi_{max} \cos(2\pi f t)$$

$$\therefore \left[e_{rms} = \frac{2\pi}{\sqrt{2}} f N \phi_{max} = 4.44 f N \phi_{max} \right]$$

eg 25. $\phi = 0.6 \sin 314$ mWb. $N = 500$.

$a = 3 \times 3 \times 10^{-4} = 9 \times 10^{-4}\ m^2$.

$$B = \frac{\phi_{max}}{a} = \frac{0.6 \times 10^{-3}}{9 \times 10^{-4}} = 0.666\,T$$

$l_g = 1.5 \times 10^{-3}$ m. $l_i = 2\left[35 - \frac{2 \times 3}{2} + 25 - \frac{2 \times 3}{2}\right] - \frac{1.5}{10}$

$l_i = 107.85$ cm

$$AT_{max} = \frac{B_{max} l_g}{\mu_0} + \frac{B_{max} l_i}{\mu_0 \mu_r}$$

$$= \frac{.667}{4\pi 10^{-7}}\left(1.5 \times 10^{-3} + \frac{1.0785}{3775}\right)$$

$AT_{max} = 948.29 = N I_{max}$.

$$I_{max} = \frac{948.29}{500} = 1.896\ A$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{1.896}{\sqrt{2}} = 1.34A$$

$$E_{rms} = 4.44 N f \phi_{max}.$$

$$= 4.44 \times 500 \times \frac{314}{2\pi} \cdot .66 \times 10^{-3}$$

$$= 66.6V$$

Eddy Current Loss

$$P_e = K_e (B_{max})^2 f^2 t^2 v$$

t → thickness of lamination

K_e → Eddy Current coefficient

v → volume of material

<u>eg 26:</u> $B = 1.2\ wb/m^2$ $f = 50Hz$ $P = 1600W$.

If $B = 1.5\ wb/m^2$ freq $60Hz$, eddy current loss?

$P_{e1} = 1600$

$B_{max1} = 1.2$

$f_1 = 50Hz$.

$B_{max2} = 1.5$.

$f_2 = 60H$.

$$P_e \propto B_{max}^2 \propto f^2$$

$$\frac{P_{e2}}{P_{e1}} = \frac{(B_{max2})^2 f_2^2}{(B_{max1})^2 (f_1)^2}.$$

$$P_{e2} = 1600 \times \frac{(1.5)^2 (60)^2}{(1.2)^2 (50)^2} = 3600W$$

eg 27 Hysteris loss $P_h = 80W$

eddy current loss. $P_e = 50W$

Calculte above ets when freq = increased by 20%

$P'_h = P_h \times \frac{f_2}{f_1}$

$P'_h = 80 \times \frac{\left(f_1 + \frac{20 f_1}{100}\right)}{f_1} = 80 \times \frac{\frac{120 f_1}{100}}{f_1} = 96$

$P'_e = \cancel{80 \times 4.0}\ P_e \times \left(\frac{f_2}{f_1}\right)^2 = 50 \times (1.2)^2 = 72W$

eg 28. Total core loss (hysteresis + eddy) = 1800W

freq = 60Hz.

If freq increased 50%, total core loss = 3000W

$P_h \propto f$, $P_e \propto f^2$

P_i = $P_h + P_e$ = $Af + Bf^2$

Total core loss

$1800 = 60A + (60)^2 B$ — (1)

$3000 = 90A + (90)^2 B$ — (2).

$A = 23.334$ $B = 0.1111$

P_h at 60 Hz = 60 A = 1400W.

" 90Hz = 90 A = 2100W

P_e at 60Hz = $60^2 B$ = 400W

" 90Hz = $90^2 B$ = 900W