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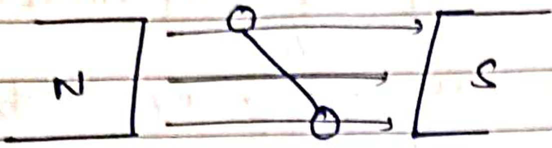
YOUVA

DC MACHINES



$\boxed{E = (2Bl V)\cos\theta}$

EMF induced $= (\vec{V} \times \vec{B}) \cdot \vec{l}$

INTRO TO ROTATING MACHINES

$e = \frac{d\lambda}{dt}$ change in flux-linkage 'λ' result from mechanical motion $\Rightarrow$ EMF is induced.

$\Rightarrow$ Rotating Machine → generate voltage by rotating windings mechanically through a M.F. or rotate M.F. through stationary windings.

↳ set of such windings connected together $\Rightarrow$ $\boxed{\text{Armature winding}}$

↓ windings which carry A.C. current.

→ Induction or synchronous machines $\Rightarrow$ armature winding on the stationary part of the circuit.

$\boxed{\text{stator windings}}$ ⇐ (STATOR)

→ DC machine → armature is on the rotating part (ROTOR)

→ Second winding → carry DC current $\Rightarrow$ field windings

produce main operating flux

↓

Permanent magnets can be used instead.

LORENTZ FORCE LAW

$$\vec{F} = q(\vec{E} + \vec{V} \times \vec{B})$$

$\vec{E}$ ↓ V/m, $\vec{V}$ ↓ m/s, $\vec{B}$ ↓ T

in a pure electric-field system, $\vec{F} = q\vec{E}$

in a pure magnetic system, $\vec{F} = q(\vec{V} \times \vec{B})$

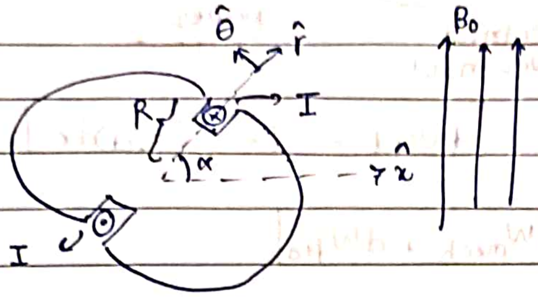
Force density, $F_v = \rho(\vec{E} + \vec{V} \times \vec{B})$ current density, $J = \rho V$ (A/m^2)

$$\boxed{\vec{F_V} = \vec{J} \times \vec{B}}$$

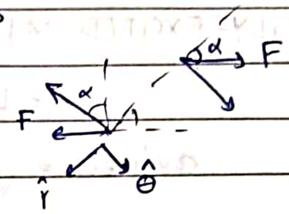
magnetic system force density

$\vec{J} = \rho \vec{V}$ $\quad \vec{F_V} = \rho(\vec{E} + \vec{V} \times \vec{B})$.

e.g.-



Force per unit length on wire $= \vec{I} \times \vec{B}$



wire-① $\quad \vec{F_\theta} = -IB_0 l \sin\alpha \, \hat{\theta}$

wire-② $\quad \vec{F_\theta} = -IB_0 l \sin\alpha \, \hat{\theta}$

so,

$$F_{\theta\text{-dirn}} = -2IB_0 l \sin\alpha.$$

so, $\quad T_{net} = (-2IB_0 l \sin\alpha)(R) = (-2IRB_0 l \sin\alpha)$

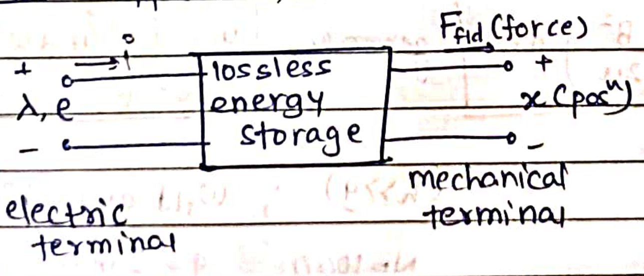
(force per unit length $= (\vec{J}A) \times \vec{B} = \vec{I} \times \vec{B}$)

rotor $\rightarrow$ M.F. and stator $\rightarrow$ M.F.

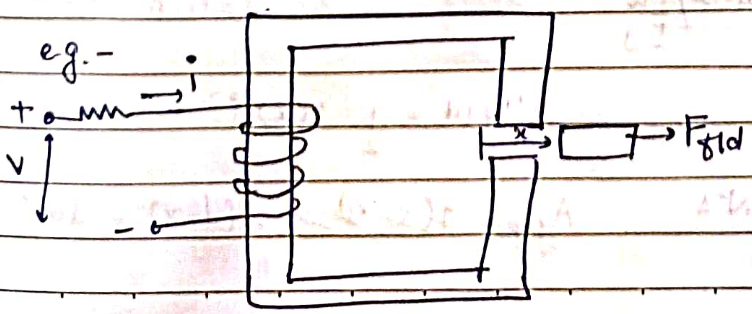
These two sets attempt to align $\rightarrow$ Torque associated with their displacement from alignment.

⇒ Motor :- stator MF pulls the rotor MF, and performs work.

Generator:- opposite ; rotor does work on the stator.



e.g.-



Energy conservation :⟶

$$\frac{dW_{fld}}{dt} = ei - f_{fld}\left(\frac{dx}{dt}\right)$$

rate of change of energy stored in M.F.

electrical power input

mechanical power output

$$e = \frac{d\lambda}{dt}, \qquad \boxed{dW_{fld} = d\lambda - (f_{fld})dx}$$

$$\boxed{dW_{elec} = ei\,dt = dW_{mech} + dW_{fld}}$$

SINGLY-EXCITED M.F. systeme

$$\lambda = L(x)\, i$$

$$dW_{mech} = f_{fld} \cdot dx \qquad dW_{elec} = i\,d\lambda$$

$$dW_{fld} = i\,d\lambda - f_{fld} \cdot dx$$

$$\boxed{\Delta W_{fld} = i(\Delta\lambda) - F_{fld}(\Delta x)}$$

(energy stored in the magnetic field)

if $dx = 0$

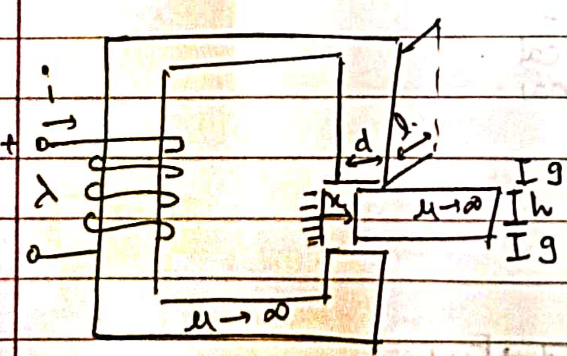
$$dW_{fld} = i\,d\lambda$$

$$W_{fld} = \int i \cdot d\lambda = \int \frac{\lambda}{L(x)} \cdot d\lambda = \frac{1}{2}\frac{\lambda^2}{L(x)}$$

$$\boxed{W_{fld} = \frac{1}{2} \cdot \frac{\lambda^2}{L(x)}}$$

also, $\boxed{W_{fld} = \int_v \left(\frac{B^2}{2\mu}\right) dv}$ generally, $\boxed{w = \int_v \left(\int_0^B (H \cdot dB')\right) dV}$

e.g.-



$(h \gg g)$; W_{fld} as a f^nc of x.

$N = 1000 \qquad g = 2\,mm \qquad d = 0.15\,m$

$i = 10\,A \qquad l = 0.1\,m$

$$w_{fld} = \frac{1}{2} L(x)\, i^2$$

$$L(x) = \frac{\mu_0 N^2 A}{2g} \qquad A_{gap} = \cancel{d(l-x)} \; l(d-x) = ld\left(1 - \frac{x}{d}\right)$$

$$L(x) = \frac{\mu_0 N^2 l d\,(1 - x/d)}{2g}$$

$$\boxed{W_{fld} = \frac{1}{2} \frac{N^2 \mu_0 l d\,(1 - x/d)}{2g}\, i^2}$$

MAGNETIC FORCE AND TORQUE FROM ENERGY

$$dW_{fld}(\lambda, x) = i\,d\lambda - f_{fld}\,dx$$

mechanical ~~magnetic~~ force

$$dW_{fld}(\lambda, x) = \left.\frac{\partial W}{\partial \lambda}\right|_x d\lambda + \left.\frac{\partial W}{\partial x}\right|_\lambda dx$$

$$i = \left.\frac{\partial W_{fld}}{\partial \lambda}\right|_x \qquad f_{fld} = -\left.\frac{\partial W_{fld}}{\partial x}\right|_\lambda$$

$$f_{fld} = -\frac{\partial}{\partial x}\left(\frac{1}{2} L(x) i^2\right) = \frac{-\partial}{\partial x}\left(\frac{1}{2}\frac{\lambda^2}{L(x)}\right)$$

$$= \frac{\lambda^2}{2(L(x))^2}\,(L'(x))$$

$$\boxed{F_{fld} = \frac{\lambda^2}{2(L(x))^2}\frac{dL(x)}{dx} = \frac{i^2}{2}\left(\frac{dL(x)}{dx}\right)}$$

rotating terminal $\Rightarrow$

$$dW_{fld}(\lambda, \theta) = i\,d\lambda - (T_{fld})\,d\theta$$

$$T_{fld} = -\left.\frac{\partial W_{fld}}{\partial \theta}\right|_\lambda$$

if $\lambda = L(\theta)\, i \Rightarrow T_{fld} = \frac{1}{2}\frac{\lambda^2}{(L(\theta))^2}\left(\frac{dL(\theta)}{d\theta}\right)$

$$\boxed{T_{fld} = \frac{i^2}{2}\frac{d(L(\theta))}{d\theta}}$$

COENERGY

$$W'_{fld} = i\lambda - W_{fld}$$

$$W'_{fld}(i, x) = i\lambda - W_{fld}(\lambda, x)$$

$$d(i\lambda) = \lambda\,di + i\,d\lambda$$

$$dW_{fld}(\lambda, x) = i\,d\lambda - f_{fld}\,dx$$

so, $\boxed{dW'_{fld}(i, x) = i\,d\lambda + f_{fld}\,dx}$

$$\lambda = \left.\frac{\partial W'}{\partial i}\right|_x \qquad f_{fld} = \left.\frac{\partial W'}{\partial x}\right|_i$$

$$W'_{fld}(i,x) = \int_0^{i} \lambda(i',x)\,di' = \int_0^{i} L(x)\, i\, di = \frac{1}{2} L(x) i^2$$

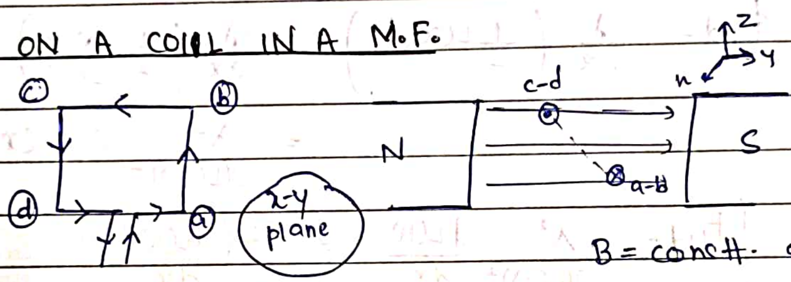
$$f_{fld} = \left.\frac{dW'}{dx}\right|_i = \boxed{\frac{i^2}{2}\left(\frac{dL(x)}{dx}\right)}$$

and similarly,

$$T_{fld} = \left.\frac{dW'}{d\theta}\right|_i = \frac{i^2}{2}\left(\frac{d(L(\theta))}{d\theta}\right)$$

$$W'_{fld} = \int_V \left(\int_0^{H_0} B\cdot dH\right) dV \qquad W'_{fld} = \int_V \left(\frac{\mu H^2}{2}\right)\cdot dV$$

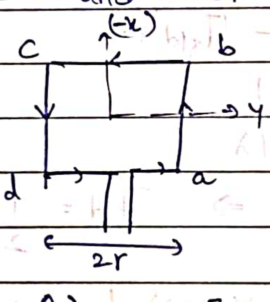
FORCE ON A COIL IN A M.F.



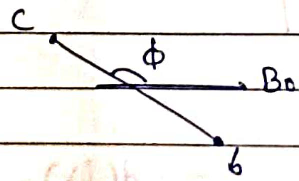
B = const. along y-axis

~~Fab = I(l × B) = I(dl × B ĵ) = ILB~~ $\hat{k}$

~~Fab = Fcd = 0 and Fcd = ILB~~ $\hat{k}$



$F_{ab} = BIl\,(-\hat{z})$ $\qquad F_{cd} = BIl\,(\hat{z})$

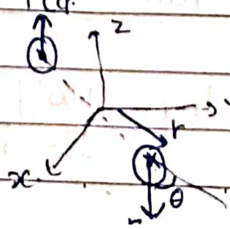


$F_{bc} = BI(2r)\sin\phi\,(-\hat{x})$

$F_{ad} = BI\,2r\,\sin\phi\,(+\hat{x})$

F_{bc} and F_{da} try to stretch the loop

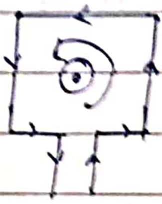
Torque $\rightarrow$ F_{ab} and F_{cd}

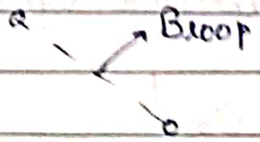


$$\tau = 2rF\sin\theta$$
$$= 2r(IBl)\sin\theta$$

$$\tau_{net} = (2r)(I l B)\sin\theta = I(2rl)B\sin\theta$$
$$= (IA)(B)\sin\theta$$
$$\tau = (I\vec{A}) \times (\vec{B}) \qquad \boxed{\tau = \vec{M} \times \vec{B}}$$

The loop also creates a M.F., B_{loop}



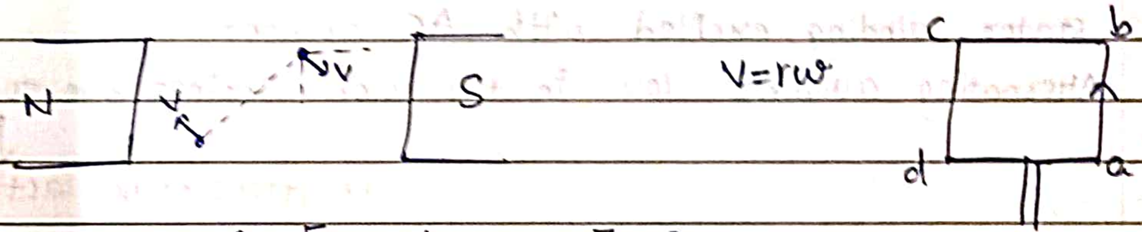


$$\tau_{net} = \underbrace{[(2rl) I]}_{K \, B_{loop}} B\sin\theta$$

$$\boxed{\tau = K' \hat{B}_{loop} \times \hat{B}_{ext}}$$

EMF

$$\boxed{\mathcal{E} = (\vec{V} \times \vec{B}) \cdot \vec{l}}$$



$$E_{a\to b} = l(-\hat{x}) \cdot [(r\omega)(B_0)\sin\theta](-\hat{x})$$
$$\boxed{E_{a\to b} = l r\omega B_0 \sin\theta}$$

variable

$$E_{b\to c} = (l\cos\theta(-\hat{y}) + l\sin\theta(-\hat{z}))\,((r\omega)(B_0)\sin\theta\,(\hat{x}))$$
$$= 0$$
$$E_{c\to d} = l(\hat{x})[(r\omega)(B_0)\sin\theta](+\hat{x})$$
$$\boxed{E_{c\to d} = +l r\omega B_0 \sin\theta}$$

and $E_{d\to a} = 0$

$(lr\omega B_0\sin\theta)$ $(lr\omega B_0\sin\theta)$

ⓑ +   − ⓒ

ⓐ − (0)   + ⓓ $(2lr\omega B_0\sin\theta)$

$$\boxed{E_{net} = 2l\omega r B_0 \sin\theta}$$

$$E = (2rl)\,\omega B\sin\theta$$
$$= A\omega B\sin\theta$$

$\theta = 180 - \phi$ angle made by normal.

$$E = \omega AB\sin\theta$$
$$\boxed{EMF = \omega AB \sin(\omega t)}$$