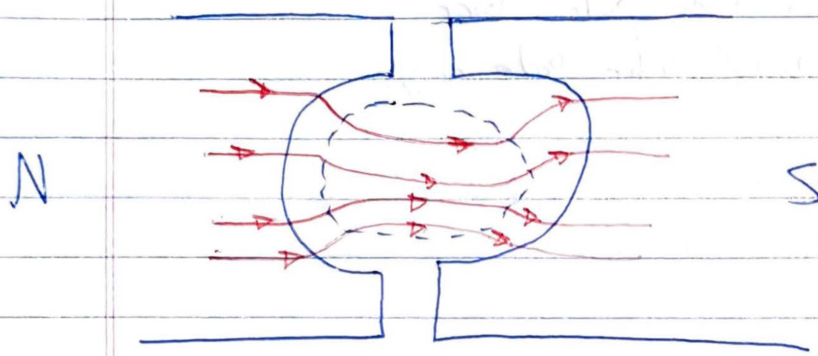
CH7: Fundamentals of DC Machine

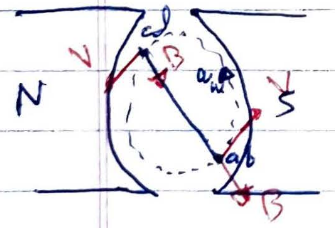
Simple DC machine:

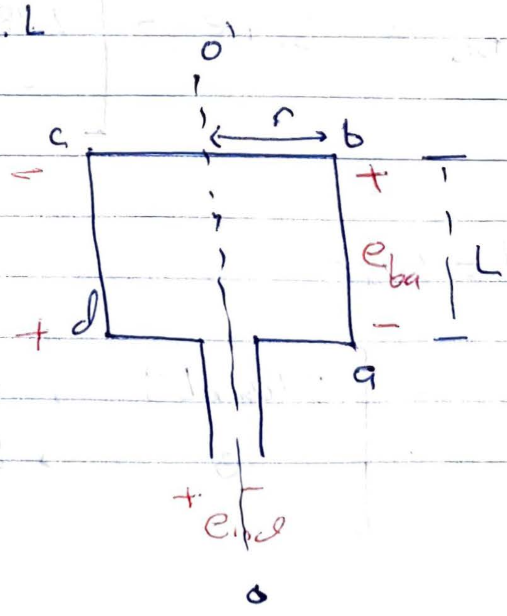
- It consists of a simple loop of wire rotating around a fixed o, o' axsis.
- The stationary part is called stator and the rotating part is called rotor.
- The magnetic field is supplied by a magnet north pole & magnet south pole.



⊛ Induced Voltage (Generators Mode)

Induced voltage $= (\vec{V} \times \vec{B}) . L$





W_m: speed of rotation

⊗ المرتكز Ac هو ابقاء الزاوية ٩٠ بين
الحركة والمجال

① Segment ab

$$e_{ba} = \begin{cases} VBL & , \text{ under the pole face} \\ 0 & , \text{ beyond the pole edge.} \end{cases}$$

angle between $\vec{V}$ & $\vec{B}$ is $90°$
〃 〃 $(\vec{V} \times \vec{B})$ & L is zero

② Segment cd

$$e_{cd} = \begin{cases} VBL & , \text{ under the pole face} \\ 0 & , \text{ beyond the pole edge.} \end{cases}$$

angle between $\vec{V}$ & $\vec{B}$ is $90°$
〃 〃 $(\vec{V} \times \vec{B})$ & L is $0°$

③ Segment bc & da

$e_{bc} = e_{dc} = 0$ since $(\vec{V} \times \vec{B})$ is $\perp$ to $\vec{L}_{bc}$ & $\vec{L}_{da}$

the Total Induced Voltage is given by:

$$e_{total} = e_{ba} + e_{dc} = \begin{cases} 2VBL & , \text{ under the pole face} \\ 0 & , \text{ beyond the pole edge.} \end{cases}$$

$$V = \omega_m r$$

$$e_{total} = \begin{cases} 2\omega_m r L B & , \text{ under the pole face} \\ 0 & , \text{ beyond the pole edge} \end{cases}$$

The area of one pole surface is given by

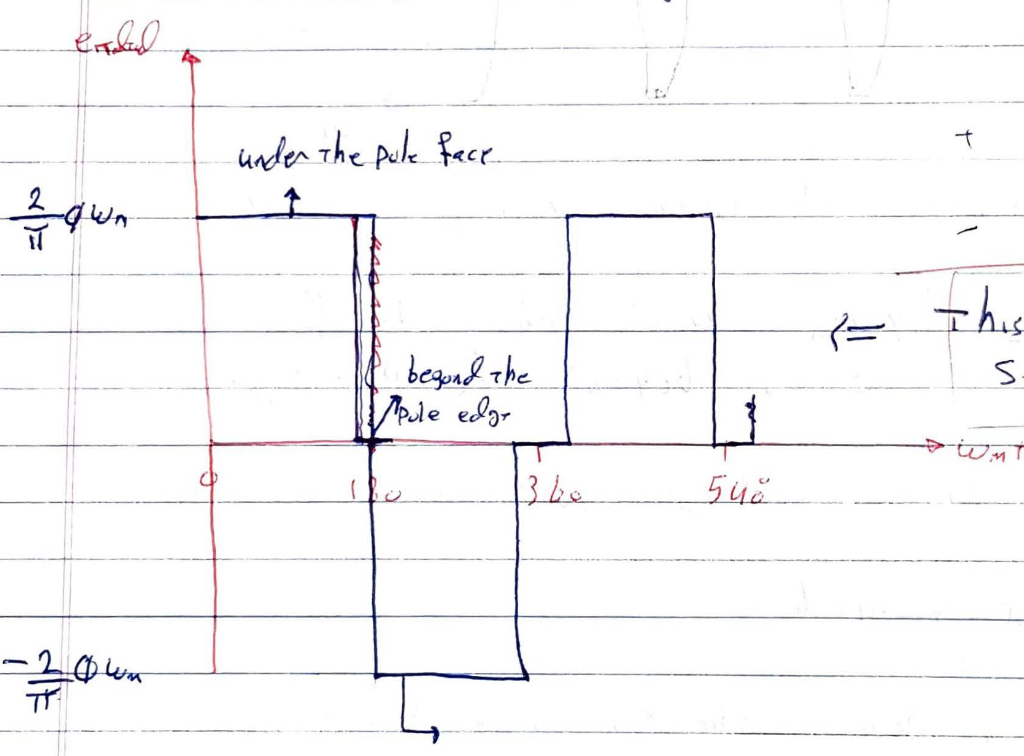
$$A_p = \pi r L \Rightarrow rL = \frac{A_p}{\pi}$$

الحالات الخاصه للاطوالة

معروضه كا؟

$$e_{Total} = \begin{cases} \frac{2}{\pi} \underbrace{A_p B}_{\phi} \omega_m = \frac{2}{\pi}\phi\omega_m, & \text{under the pole face} \\ 0, & \text{beyond the pole edge} \end{cases}$$

Note: when the loop is rotating through 180°, the segment ab will become under the north pole instead of the south pole $\Rightarrow$ the direction of the induced voltage will be reversed, but the magnitude is constant.

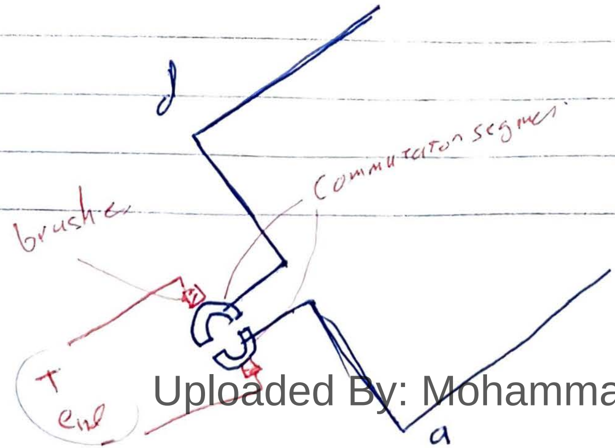


$\Leftarrow$ This an AC Signal

Solution: The DC voltage is obtained using commutator segment & brushes

* هنا ثبتت الـ e_{ind} نأخذ اتجاها لكن فيبقى عندنا الجهد لنا اما موجب او سالب

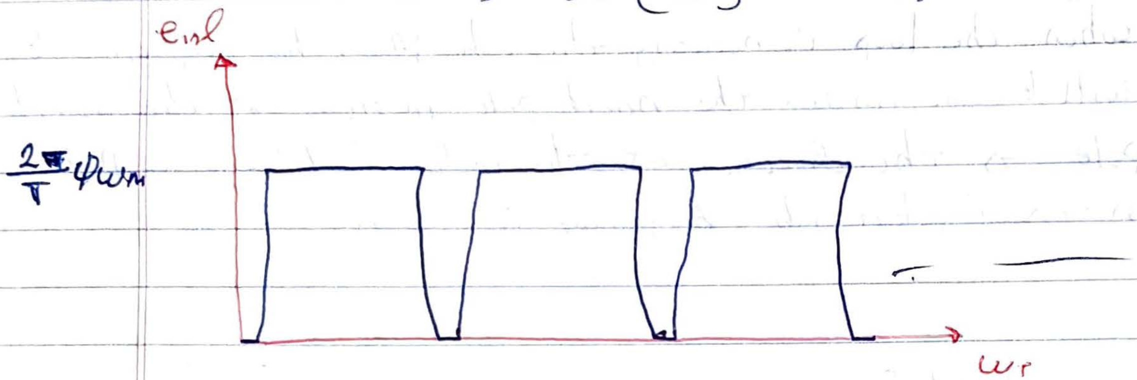
* ثم دخلنا الـ Brush عن كل الـ short عند الأطراف للاطراف ...



Commutation Segment :-

Two semi-circul conducting segments added to the end of the loop

Brushes :- Fixed contacts that are set up at angle such that they will make a short circuit with the two segment when the induced voltage is zero (beyond the pole edge).



In general, the induced voltage is given by :-

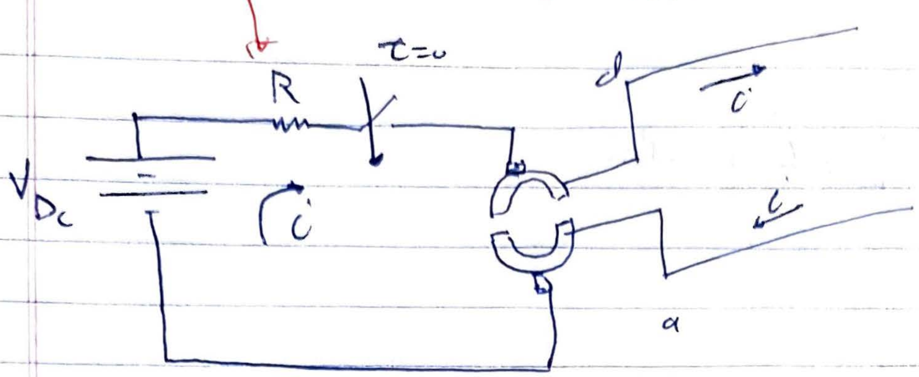
$$e_{ind} = \begin{cases} K\phi\omega_m , & \text{under the pole face} \\ 0 , & \text{beyond the pole edge} \end{cases}$$

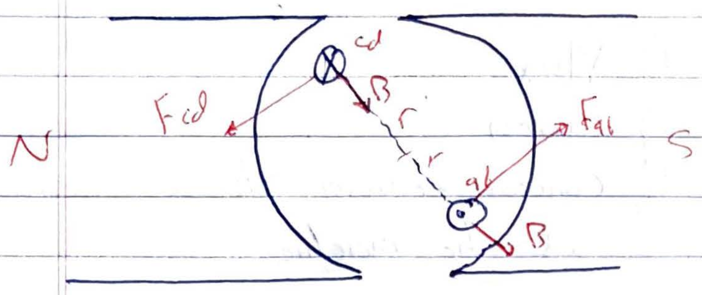
The induced voltage depends on :

- Flux of machine
- speed
- constant represent the construction of machine.

Induced Torque " Motor Mode "

R, to limit the starting current





Induced Force $= i\vec{L} \times \vec{B}$

$\quad\;\;$ " $\quad$ Torque $= \vec{r} \times \vec{F}$

Segment ab

$$F_{ab} = iLB \quad , \quad T_{ab} = riLB \Rightarrow T_{ab} = \begin{cases} rilB & \text{, under the pole faces} \\ 0 & \text{, beyond pole edges} \end{cases}$$

Segment cd

$$F_{cd} = iLB \quad , \quad T_{ab} = rilB \Rightarrow T_{cd} = \begin{cases} rilB & \text{, under} \\ 0 & \text{, beyond} \end{cases} \qquad \underline{\underline{CCW}}$$

Segment bc & da

$$F_{bc} = F_{da} = 0 \quad \text{since } \vec{L} \times \vec{B} = 0 \quad , \quad \boxed{\vec{T} = 0}$$

The Total Induced Torque

$$T_{ind} = \begin{cases} 2rilB & \text{, under the pole fac-} \\ 0 & \text{, beyond the pole edges} \end{cases}$$

→ Area of one pole surface

$A_p = \pi r^2$

$T_{ind} = \begin{cases} \frac{2}{\pi}\phi i & , \text{under --} \\ 0 & , \text{--} \end{cases}$

In general

$T_{ind} = K\phi i$

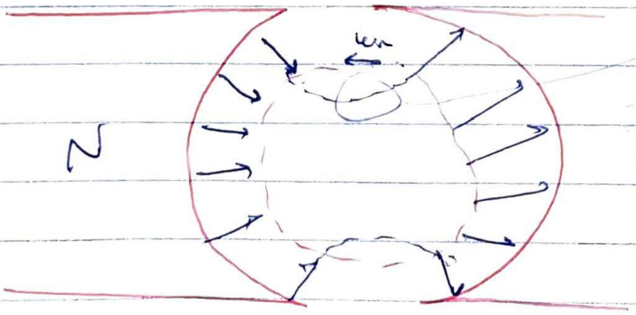
which depend on
1) flux
2) current
3) Constant represent the construction of the machine

(*) Induced Voltages

$e_{ind} = \begin{cases} K\phi w_m & , \text{under the pole face} \\ 0 & , \text{beyond " " edge.} \end{cases}$

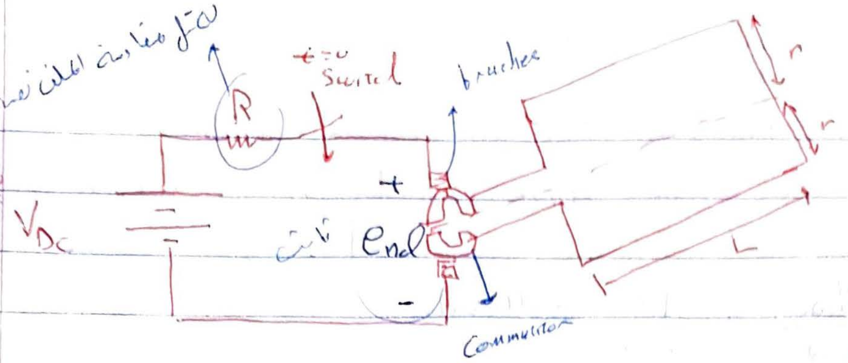
* Induced Torque

$T_{ind} = \begin{cases} K\phi i & \text{under the pole faces} \\ 0 & , \text{beyond the pole edges} \end{cases}$



هنا الحقل متوازي
مع الحركة لذلك
$V \times B = 0$

Example



$r = 0.5\ m$

$L = 1\ m$

$B = 0.25\ T$

$V_{DC} = 120\ V$

$R = 0.3\ \Omega$

A simple rotating loop lies between curved pole faces connected to a battery and a resistor through a switch
The resistor model, the total resistance of the battery and the wire in the machine

a) what happens when the switch is closed?

when the switch is closed a current will flow throw the wire at starting

$$i = \frac{V_{DC} - e_{ind}}{R}$$

At starting $\Rightarrow \omega_m = 0 \Rightarrow e_{ind} = 0 \Rightarrow \boxed{i_{start} = \frac{V_{DC}}{R}}$

$$\Rightarrow T_{ind,start} = K\phi i = \frac{K\phi V_{DC}}{R}$$

Newtons 2^{nd} law

$$T_{ind} - T_{load} = J\frac{d\omega_m}{dt} \Rightarrow \frac{d\omega_m}{dt} > 0 \Rightarrow \omega_m \uparrow$$

$$\omega_m \uparrow \Rightarrow (e_{ind} = K\phi\omega_m)\uparrow \Rightarrow i = \frac{V_{DC} - e_{ind}}{R} \downarrow$$

$\Rightarrow (T_{ind} = K\phi i) \downarrow$ until it reache zero

under steady state condition so

$T_{ind} = 0 \Rightarrow i = 0$

$\Rightarrow e_{ind} = V_{DC} = K\phi\,\omega_{m\,ss}$.

where $\omega_{m,ss}$ is the steady state speed of unloaded machine.

$K = \frac{2}{\pi}$ (one loop)

a) what is the machine Maximum starting current?

b) what is the steady state angular velocity at No Load?

$i_{start} = \frac{V_{DC}}{R} = \frac{120}{0.3} = 400A$

$i = 0 \Rightarrow V_{DC} = e_{ind} \Rightarrow 120 = K\phi\omega_{m,s}$

$120 = \frac{2}{\pi}\phi\omega_{m,s}$

$\phi = BA = (\pi r L)(B) \Rightarrow 120 = \left(\frac{2}{\pi}\right)(\pi r L)(B)\omega_{m,s}$

$\omega_m = 480$ rad/s

c) Suppose a load is attached to the loop, and the Resulting Load Torque is 10 N.m, what would the new steady state speed? How much power supplied to the shaft of the machine? How much power is being supplied by the battery? Is this machine a motor or generator?

$\underset{0}{T_{ind}} - T_{Load} = J\frac{d\omega_m}{dt} \Rightarrow \omega_m \downarrow \Rightarrow e_{ind} = K\phi\omega_m \downarrow$

$\Rightarrow i \uparrow$

$\Rightarrow T_{ind} = K\phi i \uparrow$ until it reach $T_{Load} = J\frac{d\omega_m}{dt} = 0$

$\omega_m = \omega_{m,ss}' < \omega_{m,s,s}$

$T_{ind} = 10 = (2rLB)i \Rightarrow \boxed{i = 40A}$

$e_{ind} = V_{DC} - Ri \Rightarrow e_{ind} = 108$

$108 = (2rLB)\omega_{m,ss}' \Rightarrow \omega_{m,ss}' = 432$ rad/s

$P_m = T_{Load}\omega_{m,ss}' = (10)(432) = 4320W$

$P_{battery} = (120)(40) = 4800$

Motor, since the speed Decreases

d) Suppose the machine is again unloaded and a torque of 7.5 N.m is applied to the shaft in the direction of rotation, what is the steady ss speed? Is this machine motor or generator

$\cancel{T}_{ind} - T_{load} = J\frac{d\omega_m}{dt} > 0 \Rightarrow \omega_m \uparrow \Rightarrow e_{ind} \uparrow > V_{DC}$

$T_{load} < 0$

$|i| \uparrow \Rightarrow |T_{ind}| \uparrow$ until it Reaches $T_{applied}$

$\Rightarrow J\frac{d\omega_m}{dt} = 0 \Rightarrow \omega_m = \omega_{m,ss}' > \omega_{m,ss}$

$T_{ind} = 7.5 = 2rlBi \Rightarrow \boxed{i = 30\ A}$ in opposite direction

$e_{ind} = V_{DC} + Ri \Rightarrow \boxed{e_{ind} = 129\ V}$

$129 = 2rLB\,\omega_{m,ss}' \Rightarrow \omega_{m,ss}' = 516$ rad/s

"generator."