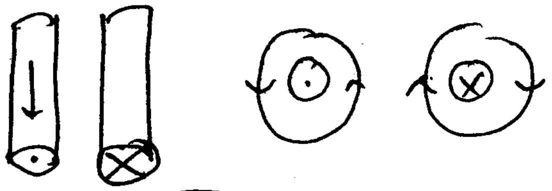
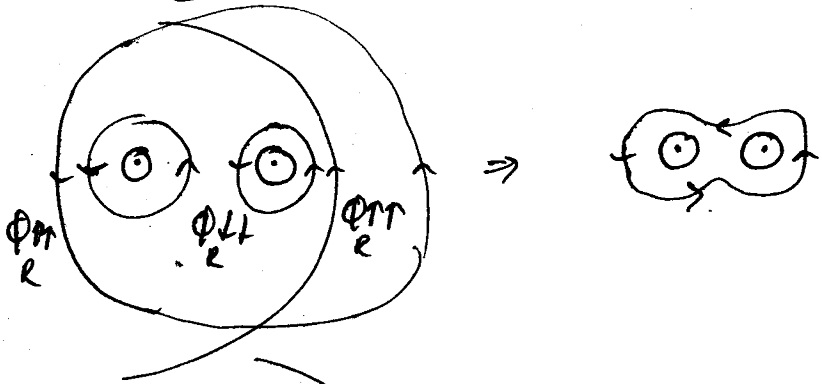
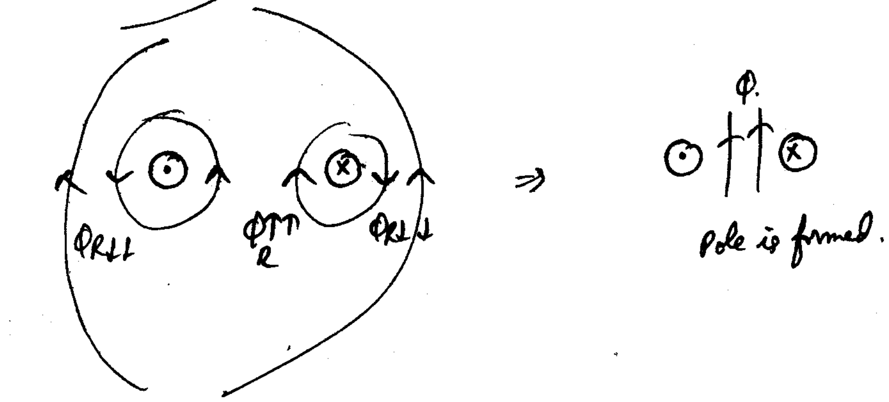
D.C machines & Induction motors

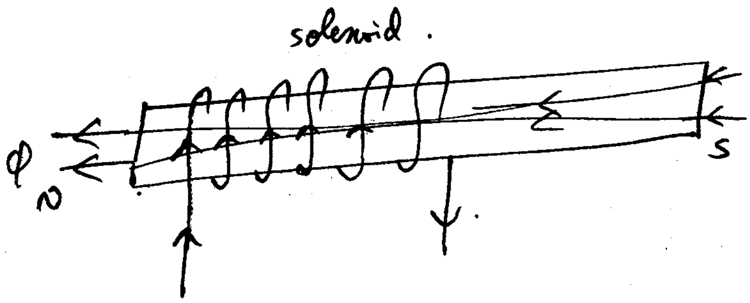
D.C Machines

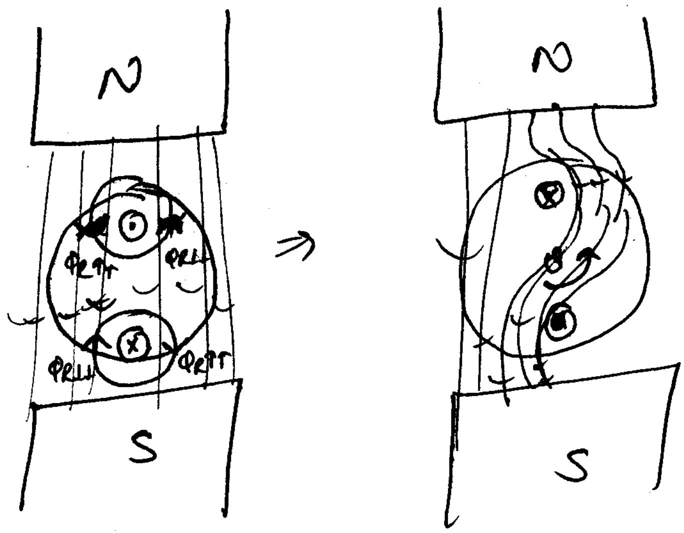
Basics











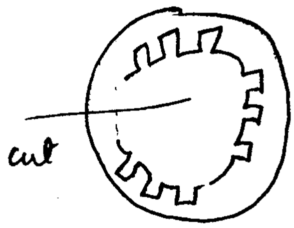
Flemings left hand rule

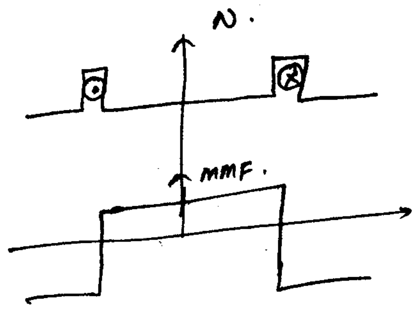
$$F \propto \bar{I} \times \bar{B}$$

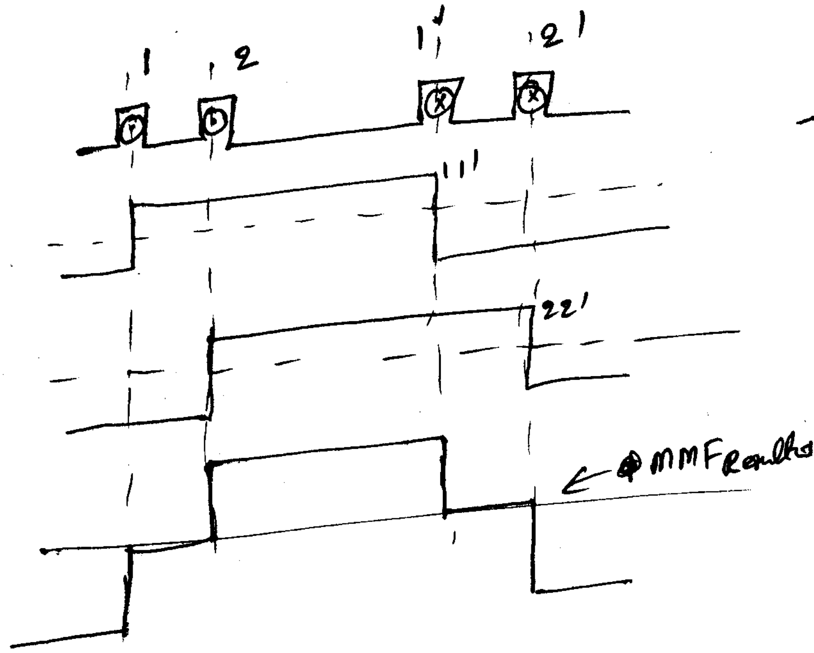
$$F = B I l_e \sin\theta$$

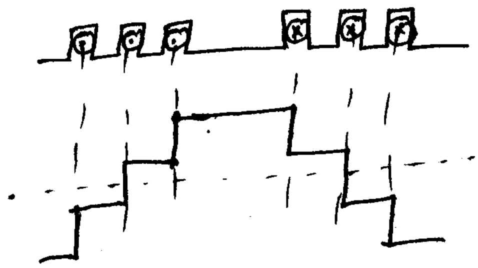
l_e — effective length of conduct

$\theta = \angle I \& B$.

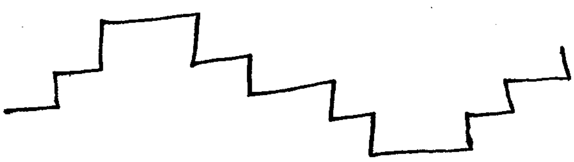








If conductors are increased



If conductors are increased → it becomes sinusoidal.

For d.c machines → we need flat topped wave.

Faradays laws of Electromagnetic induction:-

Basic requirements:- (1) magnetic field.

(2) set of conductors

(3) Relative space variation (or) time variation b/w set of conductors & magnetic field.

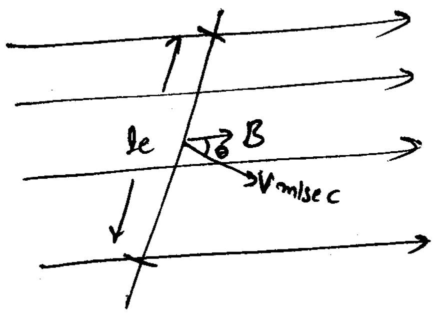
method 1:-

M.F is time varying, conductors are stationary $\}$ statically induced emf. → T/F

method 2:-

MF is stationary, conductors are being moved $\}$ dynamically induced emf (or) motionally induced emf $\}$ Rotating machines.

The magnitude of dynamically induced emf is given by "flux cutting law".

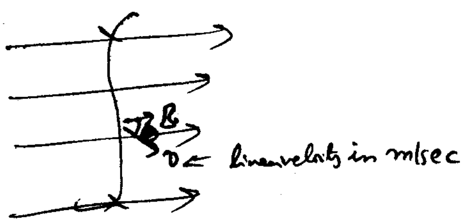


$\theta = \angle B \& v$

$\varepsilon_d \propto v \times B.$

$$\boxed{\varepsilon_d = B l_e v \sin\theta.}$$

l_e = effective length of conductor falling in the magnetic field.

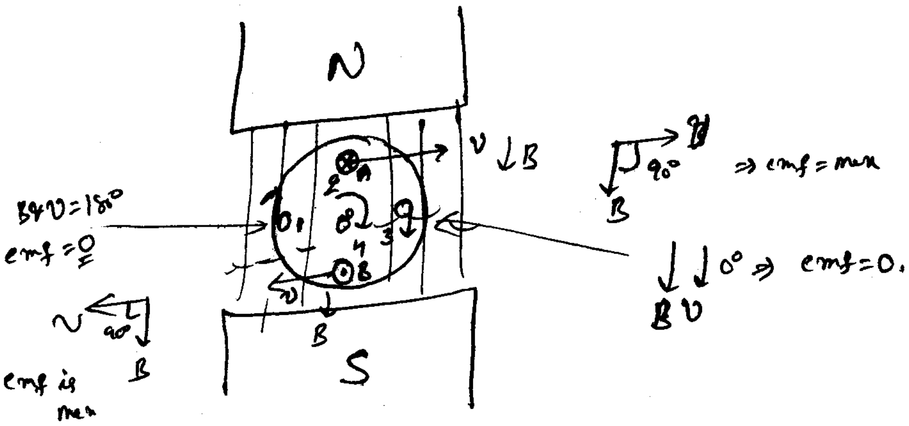


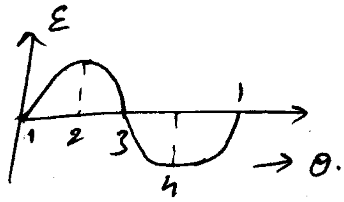
$d\varepsilon_d = B v \sin\theta \, dl.$

$\varepsilon_d = \int_l B v \sin\theta \, dl.$

$= \int_l (\bar{v} \times \bar{B}) \cdot \bar{dl}.$

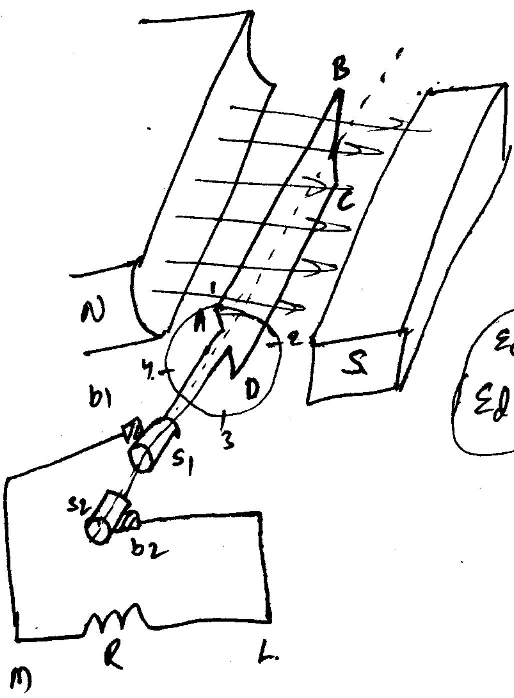
direction of emf is found by flemings right hand rule.





~~Basic~~ Elementary D.C Generator:-

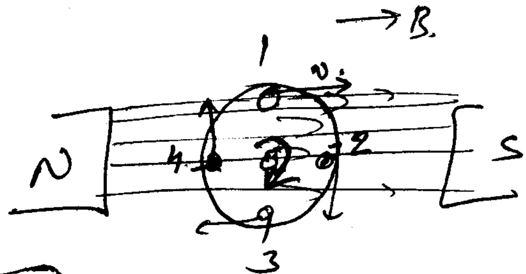
(1) simple loop generator

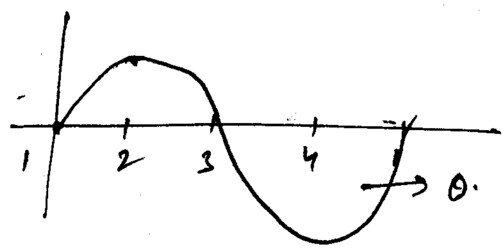


$$\varepsilon_d = \int_1^2 (\bar{v} \times \bar{B}) \cdot d\bar{l}$$

$$\varepsilon_d = Blv \sin\theta$$

$$\theta = \angle B\,\&\,v$$





north pole ⇒ ⊗

south pole → ⊙

$A \rightarrow S_1 \rightarrow b_1 \rightarrow M$

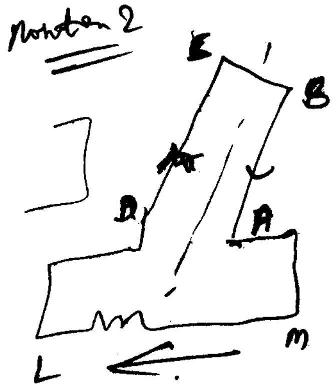
$D \rightarrow S_2 \rightarrow b_2 \rightarrow L$

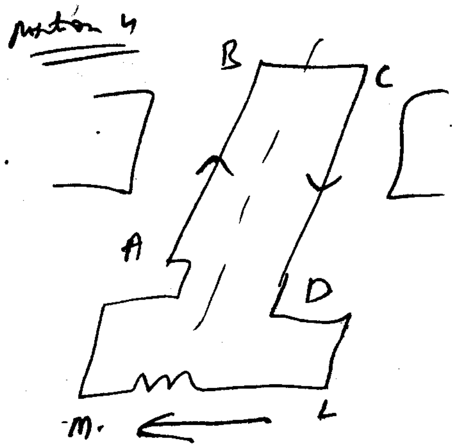
at position 1 ⇒ $I = 0$

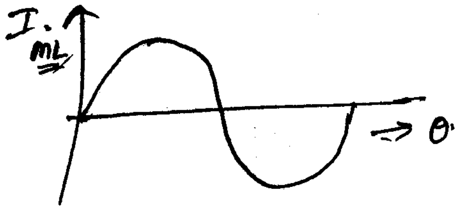
2 ⇒ $I \rightarrow$ $A \rightarrow S_1 \rightarrow b_1 \rightarrow M \rightarrow L \rightarrow b_2 \rightarrow S_2 \rightarrow D$.

3 → $I = 0$

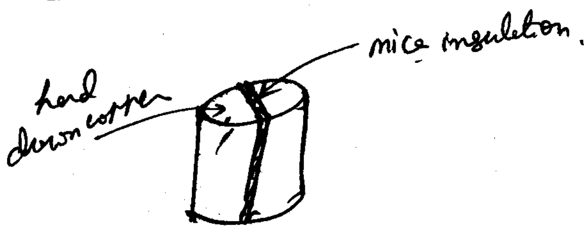
4 → $I \rightarrow$ $D \rightarrow S_2 \rightarrow b_2 \rightarrow L \rightarrow M \rightarrow b_1 \rightarrow S_1 \rightarrow A$

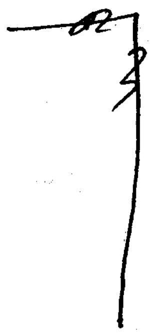


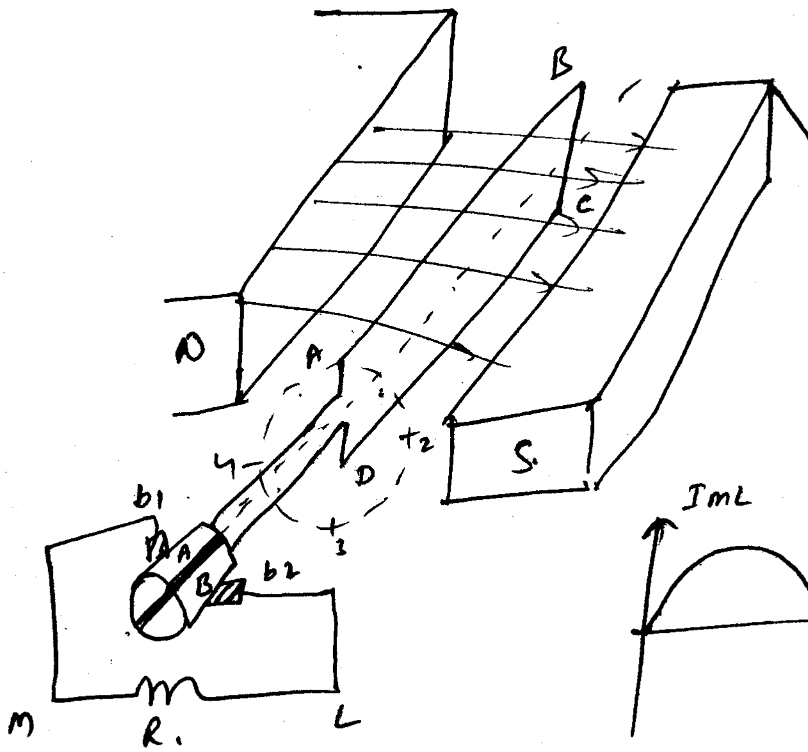


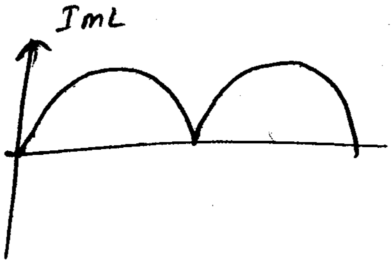


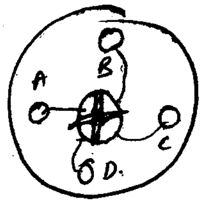
we go for device called as split ring.



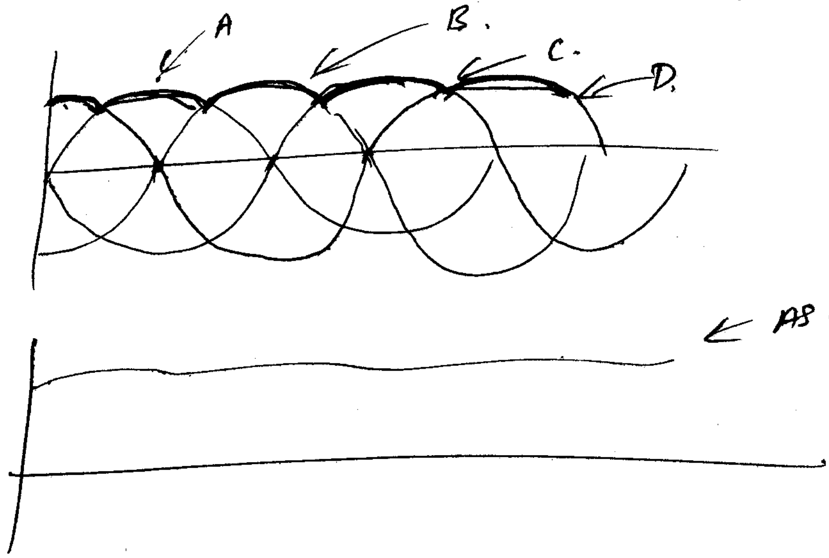








each split ring will be contact with brush for $\frac{360^\circ}{4} = 90^\circ$.



← As of conductors ↑.

Basic D.C motor:-

Lorentz's Force law.

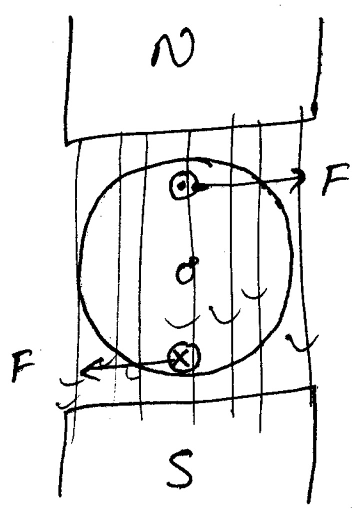
$F \propto I\bar{dl} \times \bar{B}$

$F = BIl_e \sin\theta$

↑ effective length of conduct

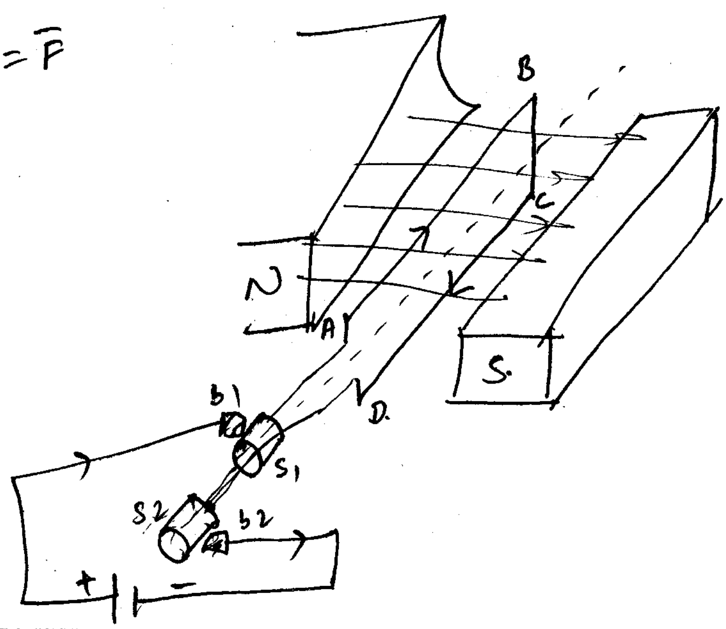
$\theta = \bar{dl} \& B.$

direction → Flemings left hand rule.



$\bar{x} \times \bar{y} = \bar{z}$

$\bar{I} \times \bar{B} = \bar{F}$

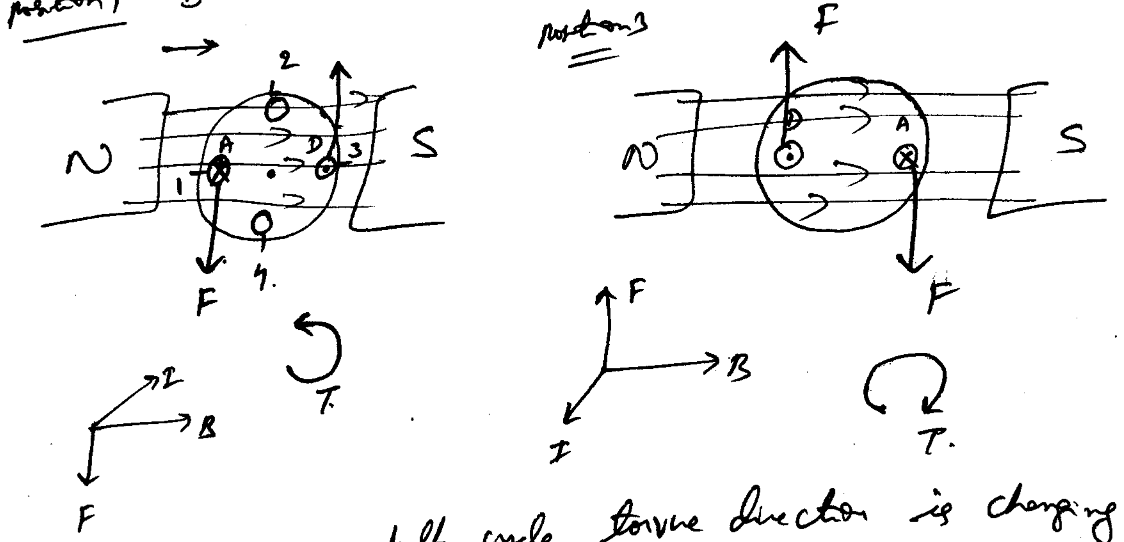


(A) → $S_1 \rightarrow b_1 \rightarrow$ (+ve.)

(D) → $S_2 \rightarrow b_2 \rightarrow$ (-ve)

AB → ⊗

CD → ⊙



Every half cycle torque direction is changing.

∴ motor stops rotating due to inertia.

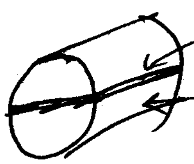
→ To make the motor rotate, direction of torque should be unidirectional.

→ conductor under north should have ⊗ & S → ⊙

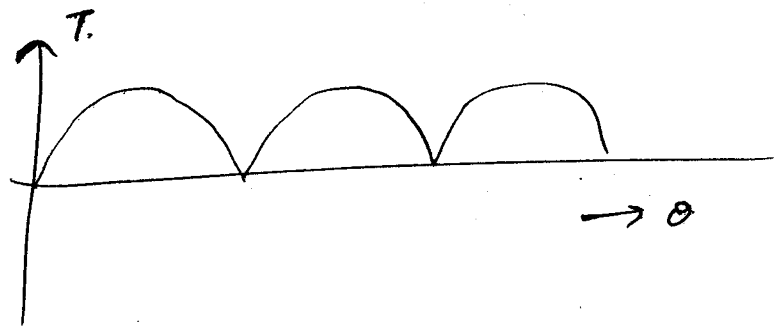
then motor rotates is counterclockwise.

(or) vice versa.

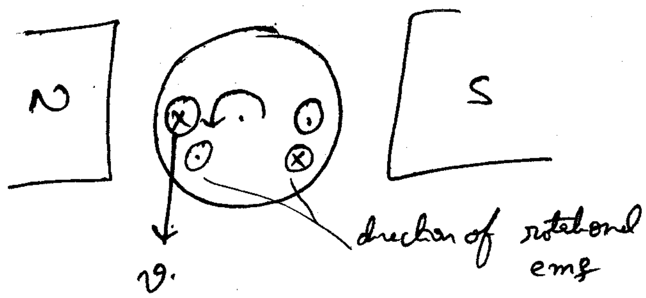
→ split ring is used for this purpose.



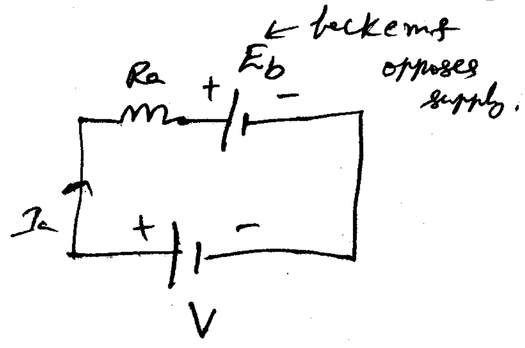
with commutator (or) split ring torque becomes unidirectional.



increase conductors & make flux as flat topped wave to get unidirectional torque.



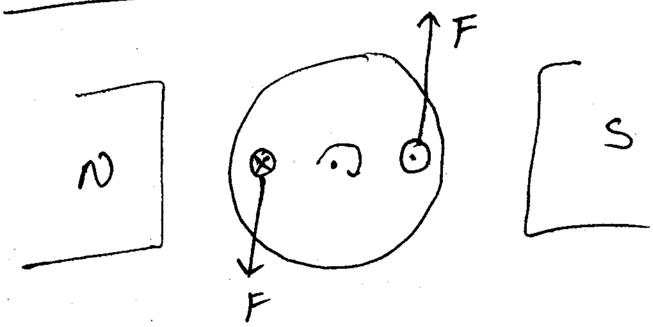
$\Rightarrow$



$$I_a = \frac{V - E_b}{R_a}.$$

$E_b I_a$ = net mechanical energy produced.

For generator:-

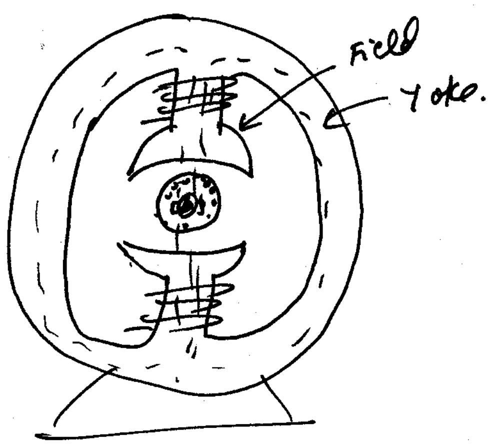


generator → opposition is due to magnetic drag which opposes the supply. ie mech input.

$E_g I_a$ → electrical energy produced.

constructional details:-

1, magnetic frame (or) Yoke
2, Field pole
3, Armature core
4, Brushes
5, Armature winding
6, commutator.



magnetic frame (or) Yoke:-

made up of cast iron ← small m/c's
cast steel ← large m/c's.

Functions — 1, It acts a protecting cover for entire m/c
2, mechanical support for field poles
3, It provides return path for magnetic flux
4,

Field pole core & pole shoe:-

silicon steel

pole core → houses field winding.
produce the required flux.

$$\phi = \frac{MMF}{R} = \frac{NI}{R}$$

pole shoe → laminated si steel →

⇒ gives more average value of emf

1, mech support for field winding

2, Reduces Reluctance of magnetic path

3, Distributes the flux uniformly in the air gap.

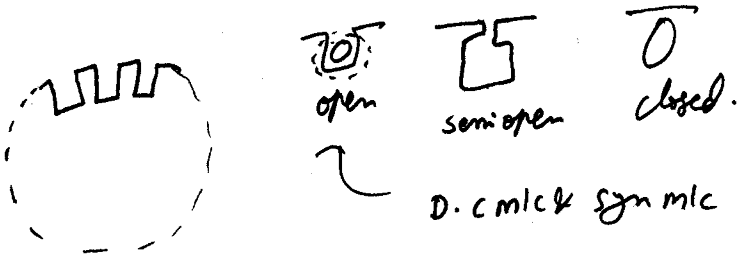
pole arc = 70% of pole pitch.

Armature core:-
↳ si steel lamination

skewed → decrease vibrations due to harmonic torques due to slot harmonics.

1, It houses armature winding

2, provides less reluctance path for main field flux.



D.c m/c & syn m/c → open type

$$\phi_e \downarrow \Rightarrow L\downarrow. \Rightarrow \tau = \frac{L\downarrow}{R} \Rightarrow \tau\downarrow\downarrow.$$

commutation process improves.

Brushes:-

→ To lead current from stator to rotor.

→ Replacing commutator is difficult. ∴ brush should erode first

high thermal stability.

and should withstand high temp ←

→ $\tau = \dfrac{L}{R\uparrow} \Rightarrow \tau\downarrow$ ⇒ commutation improves
→ sparking at brushes ↓ ?

∴ carbon (or) graphite is used.

① → brushes/c/s
② → wave wdg
P → lap wdg

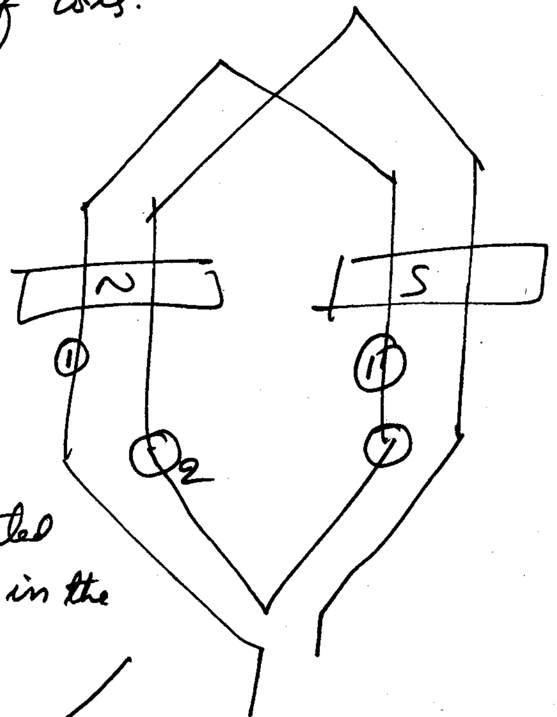
commutator :-

Acts as rectifier → generator

inverter → motor

Hard drawn copper is used.

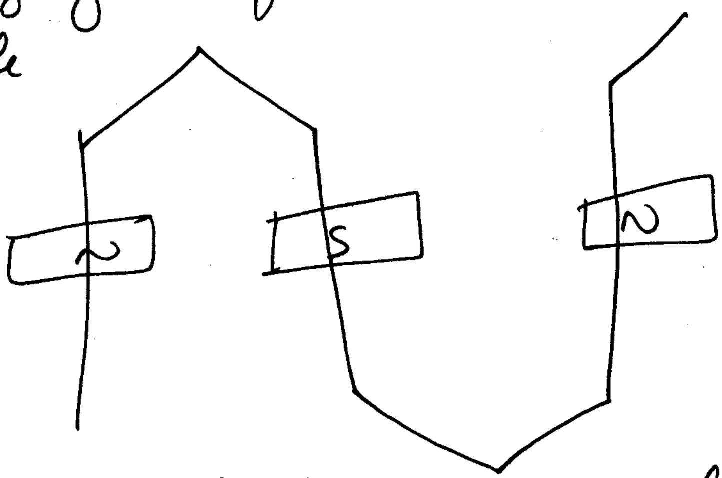
no of commutator segments = no of coils.



Armature winding :-

- Lap winding
- wave winding

Finishing end of one coil is connected to the beginning end of another coil in the same pole



Finishing end of one coil is connected to beginning end of another coil which is at different pole.

$Z = 100$, $P = 4$.

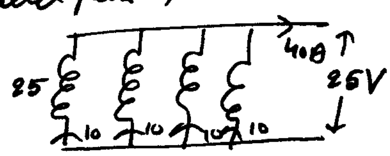
Lap winding ⇒ no of parallel paths = no of poles.

$A = P$.

$\therefore$ $\frac{100}{4} = 25$ / parallel path , $A = P = 4$.

~~volt/turn = 1V~~

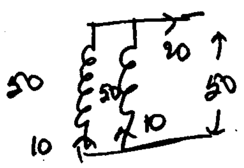
Let Voltage/turn = 1V



$P = 25 \times 40 = 1000\,W$

wave winding :-

$A = 2$



$P = 50 \times 20 = 1000\,V$.

→ Lap winding → I↑ V↓
wave winding → I↓ V↑.

→ Lap winding is called complete winding

→ wave winding is called incomplete winding
↳ dummy coils are used.

→ due to non uniform air gap, emf induced in conductors under different poles is not same.

as no of parallel paths = P.

each parallel path will have different parallel paths which leads to circulating currents
↓
heat ↑, sparking at brushes ↑.

equalizer rings are used to bypass currents from entering commutator

$$\text{max. no of equalizer rings} = \frac{\text{no of conductors}}{\text{Pair of poles.}}$$

$$= \frac{Z}{(P/2)} = \frac{2Z}{P}.$$

Emf equation:-

ϕ = flux per pole (Wb) $\qquad \phi = \frac{MMF}{R} = \frac{NI}{R}$

Z = total no of armature conductors

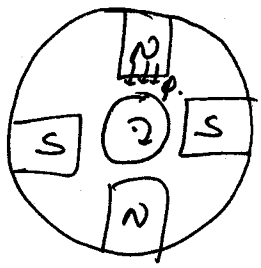
P = number of poles

A = no of parallel paths = 2 ← wave winding
= P ← lap winding.

N = speed of rotor in rpm

E_g : emf of generator = emf / parallel path.

flux cut by conductor in one rev = $P\phi$ wb



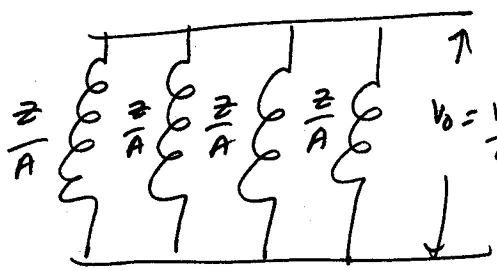
speed = N rpm.

$= \frac{N}{60}$ rps

time taken for one revolution = $\frac{60}{N}$ sec.

emf generated / conductor $= \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{P\phi N}{60}.$

conductors / parallel path $= \frac{Z}{A}$



$V_0 = \frac{\text{voltage}}{\text{conductor}} * \frac{\text{no conductors}}{\text{parallel path}}$

emf / parallel path $= \frac{P\phi N}{60} \times \frac{Z}{A}.$

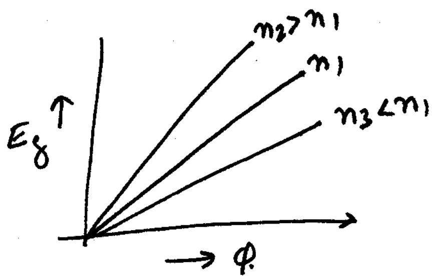
$$\boxed{E_g = \frac{\phi Z N}{60} \times \left[\frac{P}{A}\right]}$$

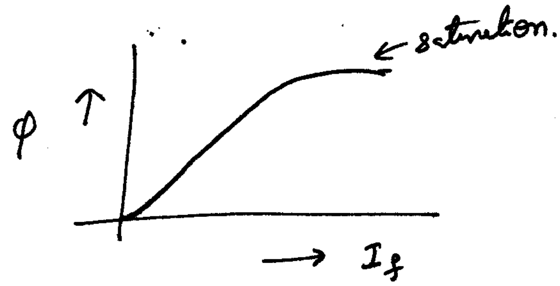
$A = 2 \leftarrow$ wave

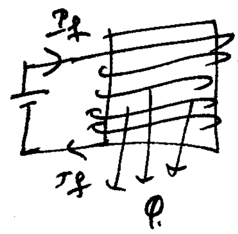
$A = P \leftarrow$ lap wdg.

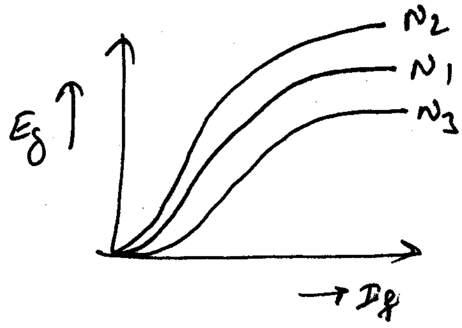
once the machine is designed

Z, P, A are const. $\Rightarrow E_g \propto N.$ $\propto \phi.$









$N_2 > N_1 > N_3.$

ex: The armature of a dc generator has 80 slots and has 240 ~~segments~~ commutator segments. It is lap wound with 1 turn/coil. If the flux per pole is 30 mwb. Calculate the generated emf at a speed of 1200 rpm. No of poles = 6.

Sol: no of coils = no of commutator segments = 240.

$$Z = 240 \times 2 = 480, \qquad \phi = 30\times10^{-3} = 0.03\,wb.$$

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{A} = \frac{0.03 \times 480 \times 1200}{60} \times \frac{6}{6}.$$

$$= \underline{\underline{288V}}.$$

Types of D.C machines:-

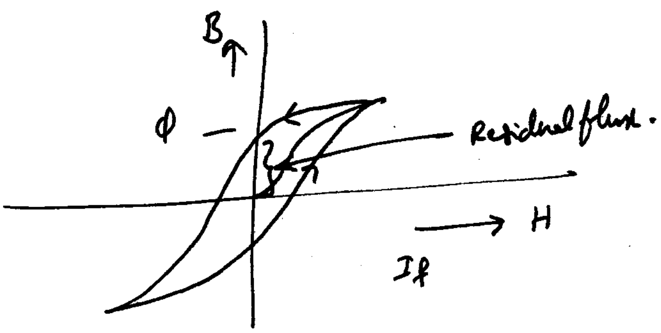
(i) methods of Excitation

(a) seperately excited

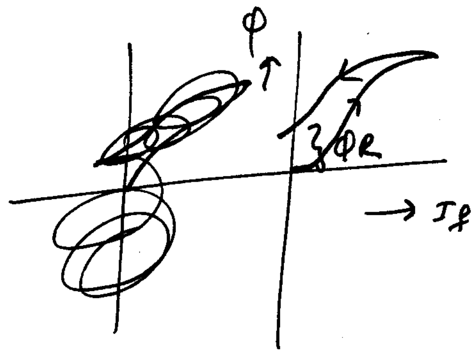
(b) self excited — series / shunt / compound.

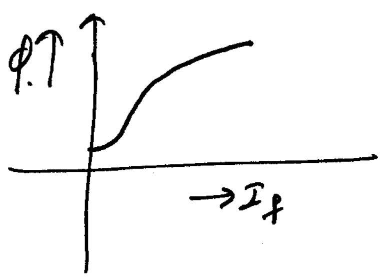
$$E = \frac{\phi Z N}{60} \times \frac{P}{A} \Rightarrow E \propto \phi N$$

$\phi \to I_f$



⇒





$P_m = E_b I_a = V I_a - I_a^2 R_a$ (neglecting brush losses).

$$\frac{dP_m}{dI_a} = V - 2 I_a R_a = 0 \Rightarrow \boxed{I_a = \frac{V}{2R_a}}$$

$$\Rightarrow E_b = V - I_a R_a = V - \left(\frac{V}{2R_a}\right) R_a = \frac{V}{2}.$$

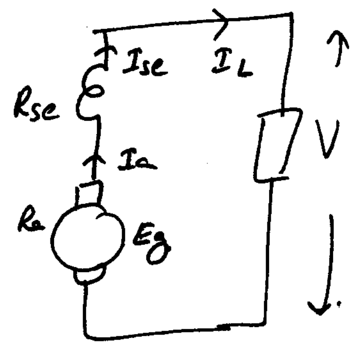
condition for max power developed $\Rightarrow E_b = \frac{V}{2}$

$I_a = \frac{V}{2R_a}.$

$$\eta_{\text{max mech power}} = \frac{\text{mech power developed}}{\text{electrical power i/p}} = \frac{E_b I_a}{V I_a.} = \frac{\left(\frac{V}{2}\right) I_a}{V I_a}$$

$$= \frac{1}{2} = 50\%$$

<u>Series machine</u>:-

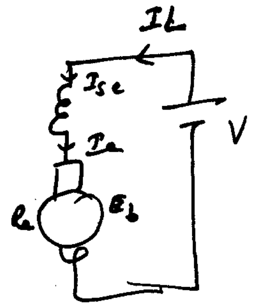


$I_L = I_{se} = I_a$

$E_g = V + I_a (R_a + R_{se}) + B.D.$

$E_b = V - I_a (R_a + R_{se}) + B.D$

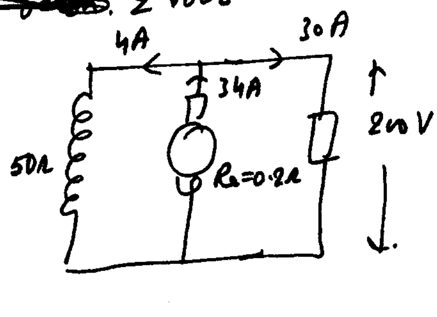
$I_a = I_L = I_{se}$



ex:-

A 4 pole shunt m/c with lap connected armature has armature and field resistances of $0.2\,\Omega$ & $50\,\Omega$ respectively. It supplies power to 100 lamps each of 60W, 200V.

Calculate the total armature current, current per path and generated emf. Allow a total brush drop of ~~...~~ 2 volts.

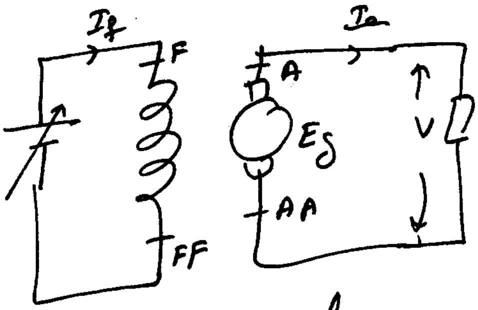


Sol

$P = 4, \quad A = P.$

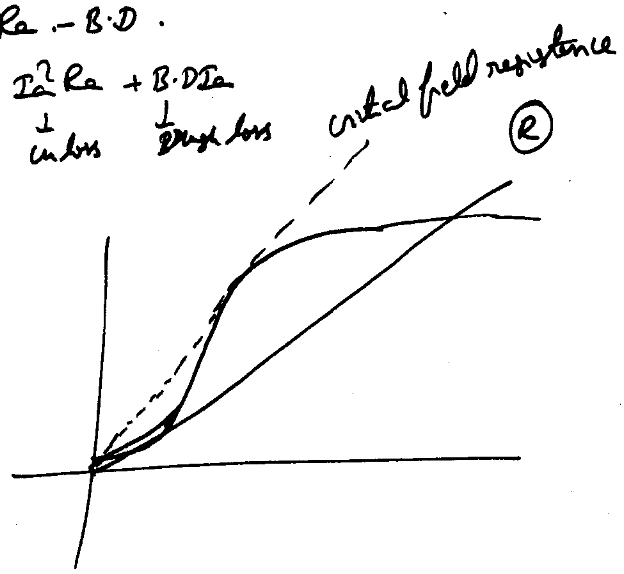
$100 \times 60 = 6000\,W$

$$I_a = I_L + I_{sh} = \frac{P}{V} + \frac{V}{50} = 34A.$$

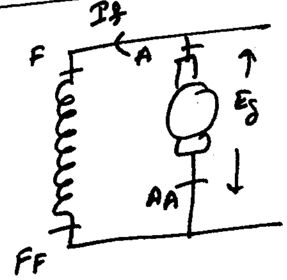


$$V = E_g - I_a R_a - B.D.$$

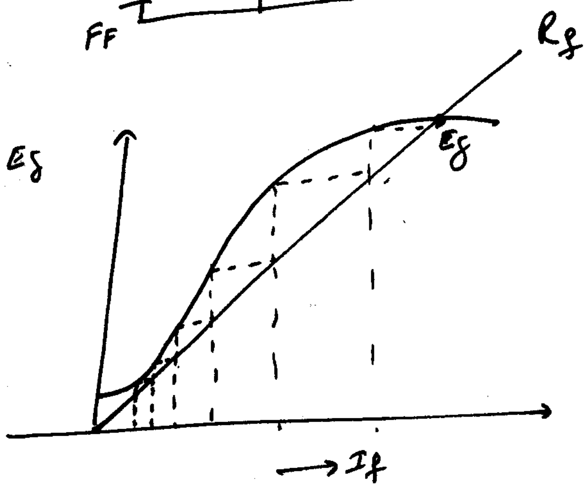
$$\underset{\text{gross power developed}}{E_g I_a} = \underset{\text{net power o/p}}{V I_a} + \underset{\text{cu loss}}{I_a^2 R_a} + \underset{\text{brush loss}}{B.D I_a}$$



self excited generator:-

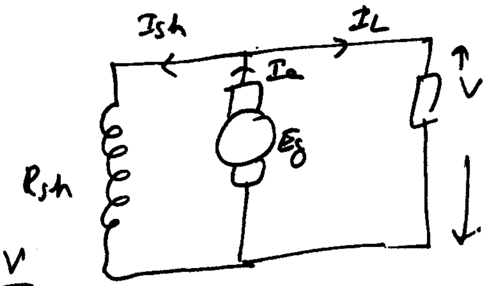


$$\frac{E_g}{I_f} = R.$$



1) shunt machine:-

(i) generator mode



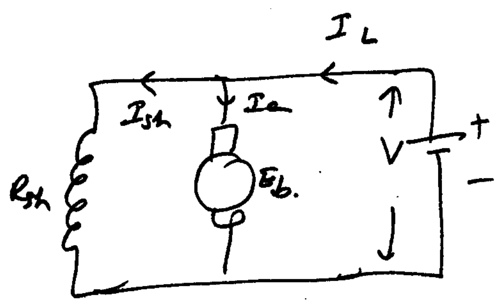
$$E_g = V + I_a R_a + B.D$$

$$I_a = I_L + I_{sh} \ ; \quad I_{sh} = \frac{V}{R_{sh}}.$$

$$E_g I_a = V I_a + I_a^2 R_a + B.D\, I_a$$

gross power developed = net power o/p + cu loss + brush loss.

(ii) motor mode



$$E_b = V - I_a R_a - BD$$

$$\underset{\text{mech power developed}}{E_b I_a} = \underset{\text{electrical power I/p}}{V I_a} - \underset{\text{cu loss}}{I_a^2 R_a} - \underset{\text{brush loss.}}{B.D\, I_a}$$

$$\text{current/path} = \frac{I_a}{A} = \frac{34}{4} = 8.5A$$

$$E_g = V + I_a R_a + \text{Brush drop.}$$
$$= 200 + (34 \times 0.2) + 2 = 208.8 \text{ volts.}$$

3, **Compound machine:-**

- cumulative → $\phi_{se} + \phi_{sh}$
- differential → $\phi_{se} - \phi_{sh}$.

Based on level of compounding

- over compound → $N_{se} I_{se} > N_{sh} I_{sh}$
- flat compound → $N_{se} I_{se} = N_{sh} I_{sh}$
- under compound → $N_{se} I_{se} < I_{sh} N_{sh}$.

Based on connection

- long shunt compound
- short shunt compound.

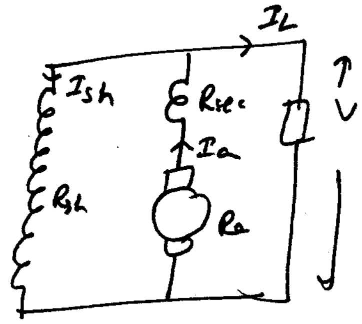
Long shunt:-

generator

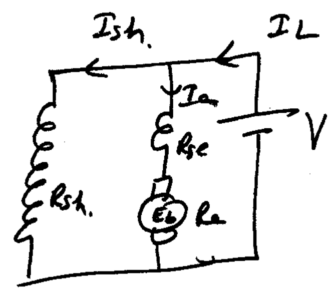
$I_a = I_L + I_{sh}$; $I_{se} = I_a$

$E_g = V + I_a (R_a + R_{se}) + B.D$

$I_{sh} = \frac{V}{R_{sh}}$



motor

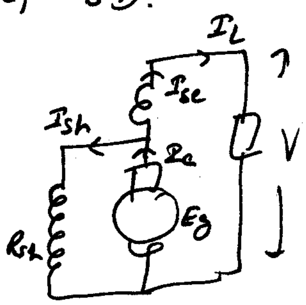


$I_a = I_L - I_{sh}$

$I_{se} = I_a$

$E_b = V - I_a (R_a + R_{se}) - B.D.$

Short shunt:



$I_a = I_L + I_{sh}$.

$$I_{sh} = \frac{E_g - I_a R_a - B.D}{R_{sh}}.$$

$E_g = V + I_L R_{se} + I_a R_a + B.D.$

Losses in a D.C machine:-

- copper losses (30 to 80%.)
  - Armature cu loss ← (30-40%.)
  - shunt field cu loss, series field cu loss } (20-40%.)
- Iron losses (20-30%.)
  - Hysteresis loss
  - eddy current loss
- mech losses (10-20%.)
  - Friction
  - windage.

(1) **copper losses:-**

Armature cu loss $= I_a^2 R_a$

shunt field cu loss $= I_{sh}^2 R_{sh}$

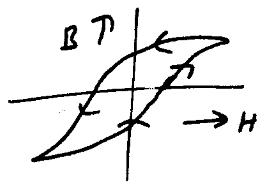
series field cu loss $= I_{se}^2 R_{se}$

*→ Brush losses are included in armature cu losses

(2) **Iron (or) core losses:-**

(i) **Hysteresis loss:-**

occurs in armature of d.c m/c since it undergoes magnetic reversal as it passes through various poles.



$$P_h = \eta B_m^{1.6} f V$$

V ← volume of armature m^3

f ← frev of magnetic reversals $= \frac{NP}{120}$

B_m ← max flux density

η ← steinmetz coefficient

area under hysteresis loop gives hysteresis loss per cycle per unit volume.

To decrease hysteresis loss si steel is used.

(ii) **eddy current loss:-**

As armature rotates in magnetic field of the poles. emf is induced in armature core and leads to eddy currents and hence eddy current loss.

→ Armature core laminated to decrease the losses.

$$P_e = K_e B_m^2 f^2 t^2 v \text{ watts.}$$

t ← thickness of laminations.

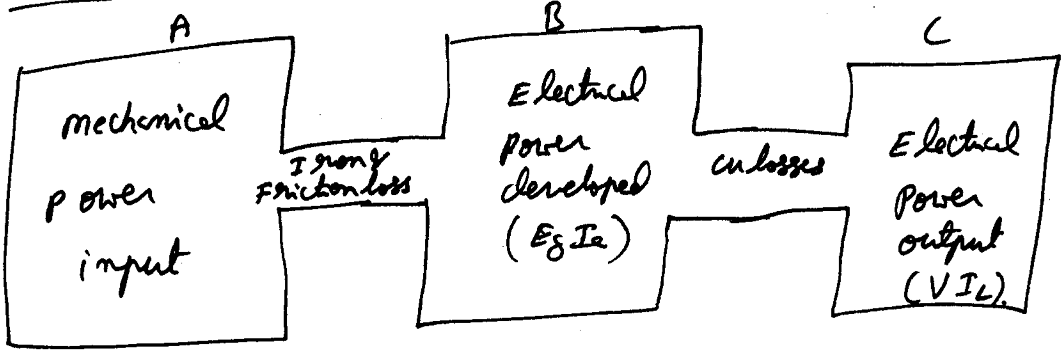
(3) mech losses:-

(1) friction losses → due to bearing friction, brush friction etc

(2) windage losses → air friction of rotating armature.
↳ depends on speed.

Iron losses + mech losses = stray load losses.

power stages of D.C Generator:-



(i) mech efficiency (η_m) $= \dfrac{B}{A} = \dfrac{E_g I_a}{\text{mech power input}}$

(ii) Electrical efficiency (η_e) $= \dfrac{C}{B} = \dfrac{V I_L}{E_g I_a}$.

~~(iii) commercial~~

(iii) commercial or overall efficiency:-

$$\eta_c = \frac{C}{A} = \frac{V I_L}{\text{mech power input}} = \eta_m * \eta_e$$

$$\therefore \quad \eta = \eta_c = \frac{C}{A} = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output} + \text{losses}}.$$

condition for maximum efficiency:-

ex:- shunt machine:-

$$\eta = \frac{V I_L}{V I_L + I_a^2 R_a + W_c} = \frac{V I_L}{V I_L + (I_L + I_{sh})^2 R_a + W_c}$$

$$\simeq \frac{V I_L}{V I_L + I_L^2 R_a + W_c} \qquad (\because \; I_{sh} \ll I_a)$$

$$\Rightarrow \eta = \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{W_c}{V I_L}\right)} \rightarrow ①$$

The efficiency will be maximum when the denominator of eq ① is minimum.

$$\frac{d}{dI_L}\left(\frac{I_L R_a}{V} + \frac{W_c}{V I_L}\right) = 0 \Rightarrow \frac{R_a}{V} - \frac{W_c}{V I_L^2} = 0$$

$$\Rightarrow I_L^2 R_a = W_c$$

$$\boxed{\text{Variable losses} = \text{constant losses.}} \quad (\because I_L \simeq I_a)$$

The load current corresponding to max efficiency

$$I_L = \sqrt{\frac{W_c}{R_a}}.$$

eg:- A 100 KW shunt generator is operated at 200 V. The stray losses are 1800 W and shunt field draws 5.0 A. The armature circuit has a resistance of 0.035 Ω and brush drop is 2.2 V. Calculate (i) total losses (ii) input of prime mover (iii) efficiency at rated load.

Sol: (i) $I_L = \frac{100 \times 10^3}{200} = 500\,A$

$I_a = I_L + I_{sh} = 500 + 5.0 = 505\,A$

Armature cu loss $= I_a^2 R_a = (505)^2 \times 0.035 = 8925.875$

shunt cu loss $= V I_{sh} = 200 \times 5 = 1000\,W.$

Brush power loss $= 2.2 \times 505 = 1111\,W.$

Total losses $= 8925.875 + 1000 + 1111 + 1800$

$= 12836.875\,W.$

(ii) input = o/p + losses = $100 \times 10^3 + 12836.875$

$= 112.837$ kW.

(iii) $\eta = \frac{100}{112.837} \times 100 = 88.62\ \%$

constant losses = shunt cu loss + stray load loss.

$= 1000 + 1800 = 2800$ W.

Variable losses = armature cu loss + Brush power loss

$= 8925.875 + 1111$

$= 10036.875$ W.

condition for max efficiency ⇒ variable loss = constant losses

$= 2800$ W.

$$\eta_{max} = \frac{o/p}{o/p + \text{variable loss} + \text{constant losses}}$$

$$= \frac{100 \times 10^3}{100 \times 10^3 + 2 * 2800} \times 100 = 94.7\%$$

D.C Generator characteristics:-

→ The prime mover is equipped with a speed governer so that speed can be maintained constant.

As $N =$ const.

only variables are ϕ, I_a (load)

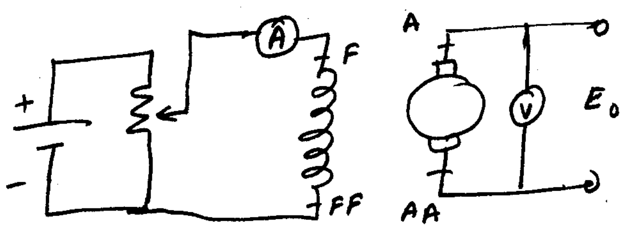
The knows the behaviour of generator under different conditions the characteristic curves are plotted.

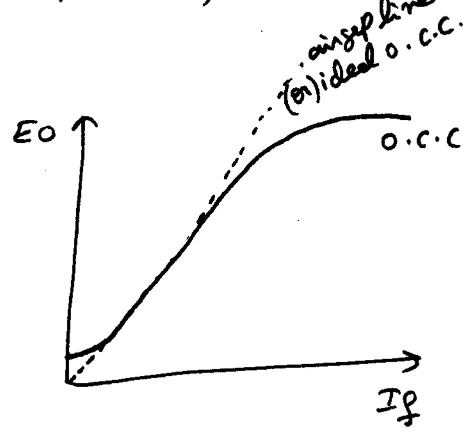
(1) open circuit characteristic (O.C.C) (or) magnetisation characteristics E_0 vs $I_f \,|_{N=\text{const}}$

(2) Internal characteristics (E vs $I_a \,|_{N=\text{const}}$)

(3) External characteristics (V vs $I_L \,|_{N=\text{const}}$)

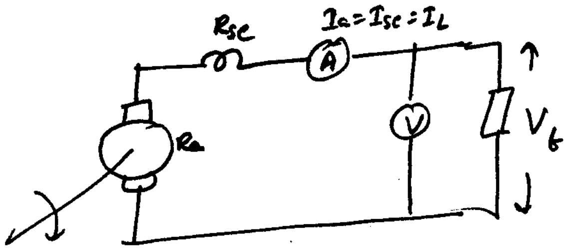
(1) O.C.C :-

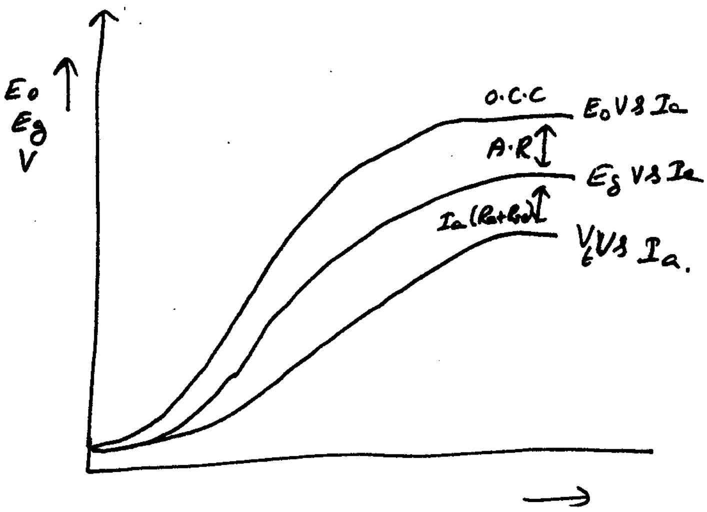




(2) Internal & external characteristics ($N=$const).

(i) Series generator :-





$$E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$$

$\propto \phi$

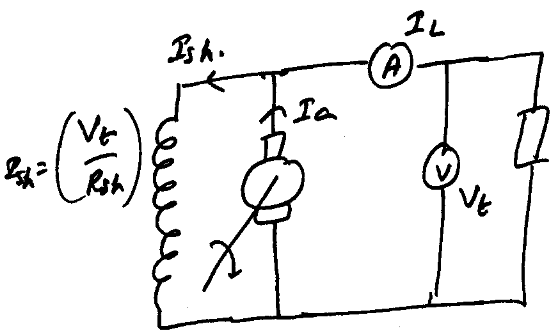
$\propto I_f$

$\propto I_a$

→ Series generator has rising characteristics

→ It is used as voltage booster.

(ii) Shunt generator:-



$V_t = E_g - I_a R_a$

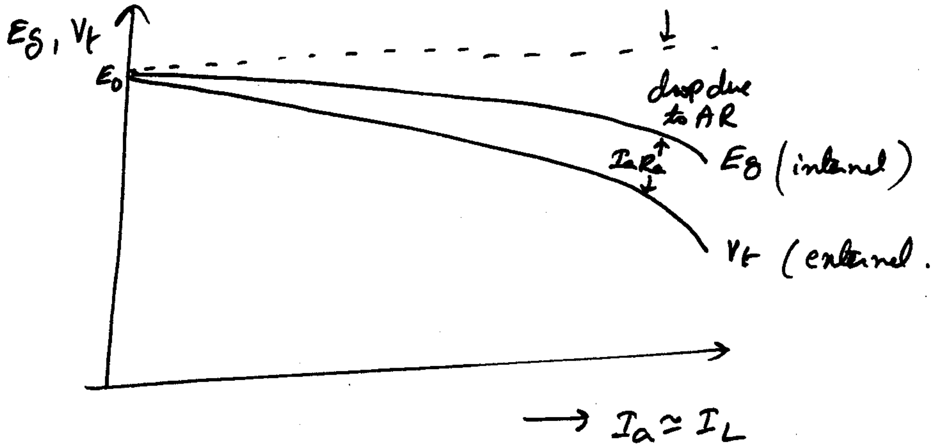
$I_{sh} = \frac{V_t}{R_{sh}}$

$I_a = I_L + I_{sh}$
$\simeq I_L$

(1) Armature Reaction
$\hookrightarrow \phi_f \downarrow \rightarrow E_g \downarrow$.

(2) $I_a R_a$ drop $\rightarrow V_t \downarrow$.

due to ① & ② V_t drops further extent due to $\downarrow I_f$



$E_0 = V_t + I_a R_a +$ drop due to A.R.

$E_g = V_t + I_a R_a$.

→ The characteristics of shunt generator are "drooping characteristics"

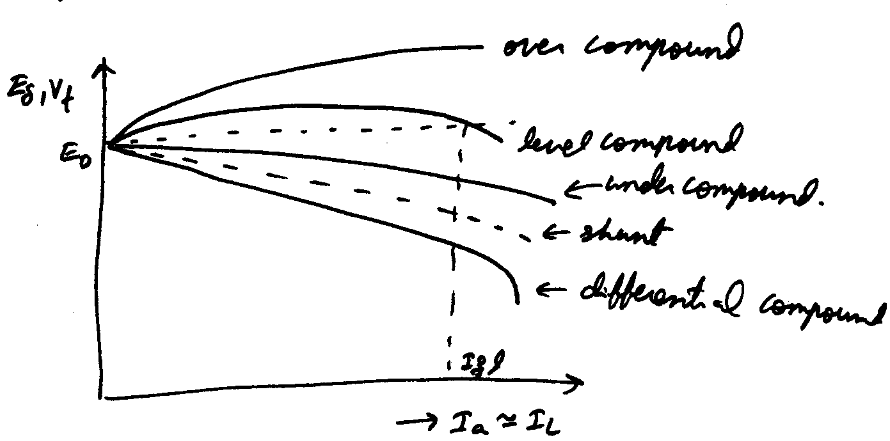
→ shunt generator can be considered as const flux & constant voltage m/c.

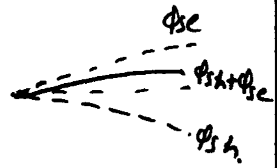
→ used as voltage source for lighting, as exciter in alternator etc.

(iii) compound generator:-

(1) cumulative compound $\Rightarrow \phi = \phi_{sh} + \phi_{se}$

(2) differential compound $\Rightarrow \phi = \phi_{sh} - \phi_{se}$

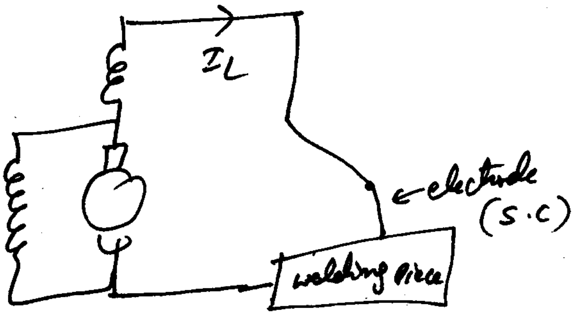




→ over compound → voltage source for lighting purpose and long transmission.

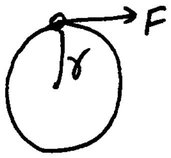
→ Flat (or) level compound → exciting field of alternator (exciter)

→ differential compound → welding



load ↑ ⇒ V↓ ⇒ E_g↓
→ P_L↓

Torque & mechanical energy produced in D.C motor:-

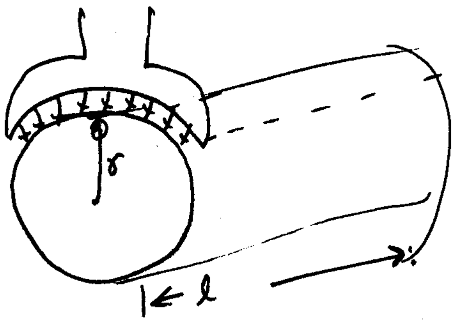


$\bar{F} \propto \bar{I} \times \bar{B}$

$F = BIl\sin\theta$

$\angle\theta = \angle \bar{I}dl \,\&\, \bar{B}$

$\theta = 90° \Rightarrow F = BIl.$

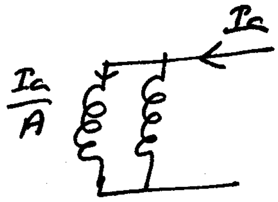


r = average radius of armature 'm'

l = effective length of conductor

Z = Total no of conductors

A = no of parallel paths



i = current in each conductor $= \frac{I_a}{A}$

B = average flux density wb/m² $= \frac{\text{flux/pole}}{\text{area under each pole}} = \frac{\phi}{\left(\frac{2\pi r l}{P}\right)}$

ϕ = flux per pole

P = no of poles.

Force on each conductor $= F = Bil$ newtons

Torque due to one conductor $= F \times r$ N-m.

Total armature torque $= Z F r$

$= Z\, B i l\, r$.

$\because\ i = \frac{I_a}{A},\quad B = \frac{\phi}{a} = \frac{\phi}{(2\pi r l/P)}$

$$T_a = Z \cdot \frac{\phi}{(2\pi r l/P)} \cdot \frac{I_a}{A}\, l\, r = \frac{Z \phi I_a P}{2\pi A} \text{ N-m.}$$

$$\boxed{T_a = 0.159\ \phi Z I_a \left(\frac{P}{A}\right) \text{ N-m.}} \rightarrow (1)$$

$T_a \propto \phi I_a$.

shunt $\rightarrow \phi =$ const $\Rightarrow T_a \propto I_a$

series $\rightarrow \phi \propto I_a \Rightarrow T_a \propto I_a^2$

$(1) \Rightarrow\ T_a = 0.159 \left(\frac{P\phi Z}{A}\right) I_a. \Rightarrow \left(\frac{P\phi Z}{A}\right) = \frac{T_a}{0.159 I_a} \rightarrow (2)$

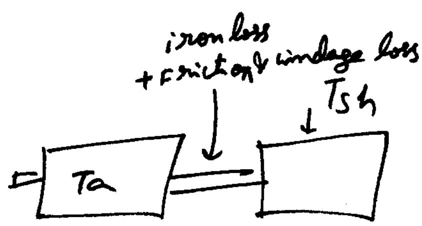
<u>Relation between T & E_b</u>:-

$E_b = \frac{\phi Z N}{60} \times \frac{P}{A} \Rightarrow \frac{60 E_b}{N} = \frac{\phi Z P}{A} \rightarrow (3)$

fm eq (2) & (3).

$$T_a = 0.159\, I_a \cdot \left(\frac{60 E_b}{N}\right)$$

$$\boxed{T_a = 9.55 \frac{E_b I_a}{N}}$$



$T_a - T_{sh} = \frac{9.55}{N}$ (Iron loss + friction windage loss) work done / revolution = force × distance moved in one revolution

$$= F \times 2\pi r$$

$$= 2\pi T_{sh} \text{ Joules.}$$

work done / min $= 2\pi T_{sh} \cdot N$ Joules/min.

W.D / sec $= 2\pi T_{sh} \dfrac{N}{60}$ J/sec (or) watts

$$\boxed{\text{output power} = \frac{2\pi N T_{sh}}{60} \text{ watts}}$$

1 hP = 746 W

$$\boxed{\text{output power} = \frac{2\pi N T_{sh}}{60 \times 746} \text{ hP}}$$

characteristics & applications of D.C ~~series~~ motors:-

(1) N vs I_a characteristics } Electrical characteristics ~~[illegible]~~

(2) T vs I_a characteristics }

(3) N vs T characteristics → mechanical characteristics

$T_a = 0.159\, \phi Z I_a \dfrac{P}{A}$; $E_b = \dfrac{\phi Z N}{60} \cdot \dfrac{P}{A}$

$\Rightarrow N = \dfrac{E_b\, 60 A}{\phi Z P}$.

$E_b = V - I_a R_a$.

$P = \dfrac{2\pi N T}{60}$

D.C series motor:-

$T_a \propto \phi I_a$; $N \propto \dfrac{E_b}{\phi}$

$\propto I_a^2$

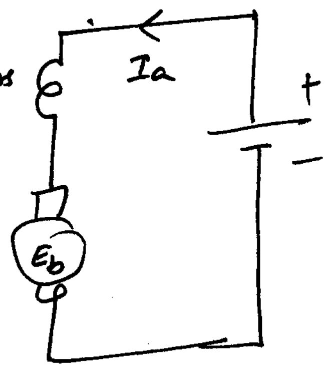
$\downarrow E_b = V - \uparrow I_a R_a$

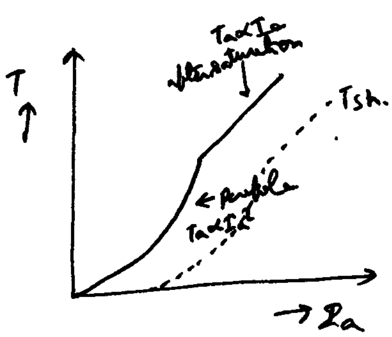
↓

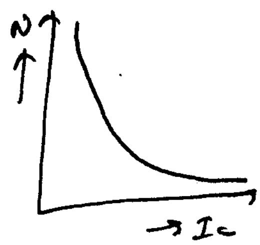
change is very less can be taken as const

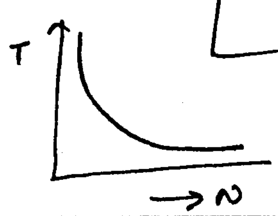
$\Rightarrow N \propto \dfrac{1}{\phi}$

$\propto \dfrac{1}{I_a}$.









$T \propto I_a^2$

$N \propto \dfrac{1}{I_a}$

$\Rightarrow T \propto \dfrac{1}{N^2}$

1, when the load is less, speed is very high so should not be started on no load.

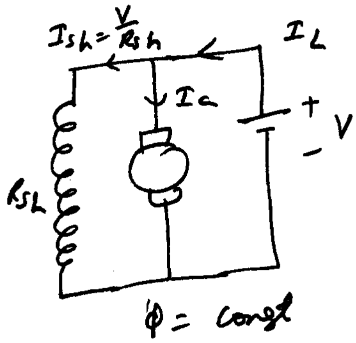
2, $T \propto I_a^2$; $N \propto \frac{1}{I_a}$ as torque $\propto I_a^2$ $\Rightarrow$ less current is required to produce more torque

$\uparrow P \propto \downarrow N T \uparrow$. $\rightarrow$ extra power required to drive load is less.
less.

$\rightarrow$ high starting torque so m/c can accelerate fast.

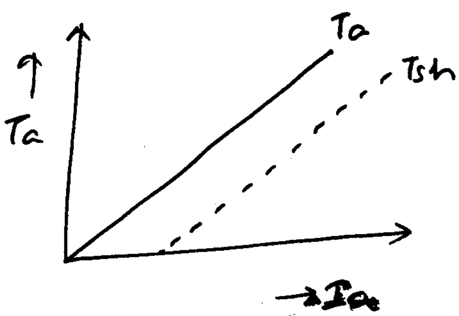
Applications :- hoists, electric trains, cranes etc.

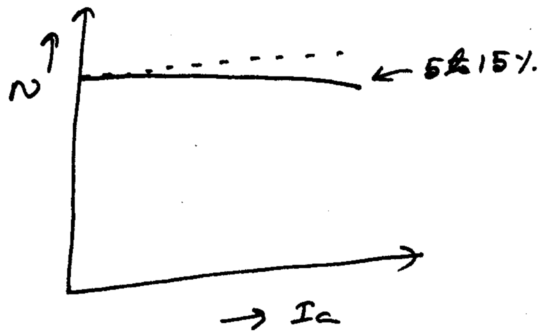
Shunt motor :-

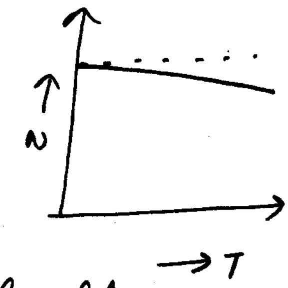


$T_a \propto \phi I_a \Rightarrow T_a \propto I_a$

$N \propto \frac{E_b}{\phi \leftarrow \text{const}} \Rightarrow N \propto (V - I_a R_a)$







speed regulation $\downarrow\downarrow$

applications :-
fans, machine tools, lathes, wood-working machines etc.

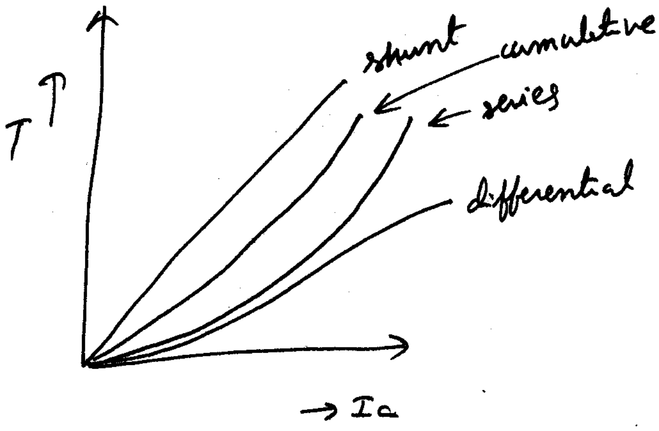
Compound motor :-

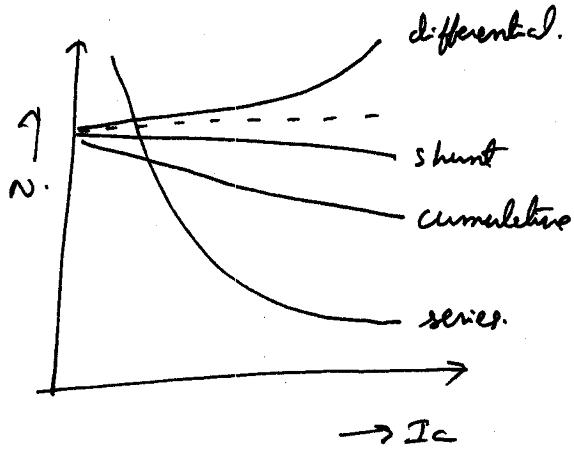
shunt $T \propto I_a$ series $T \propto I_a^2$

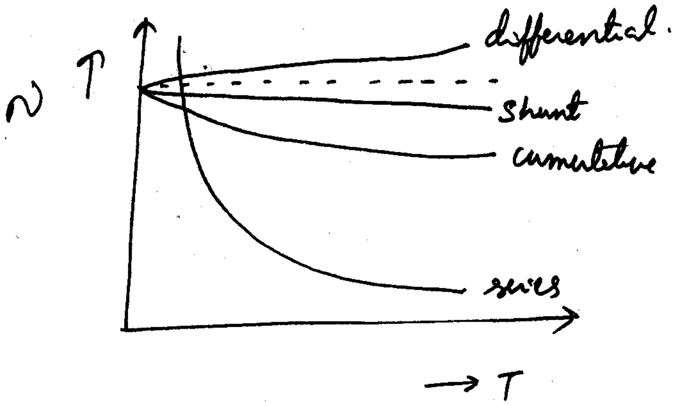
- cumulative $\leftarrow \phi_{se} + \phi_{sh}$
- differential $\leftarrow \phi_{sh} - \phi_{se}$

$\rightarrow$ No load $\longrightarrow$ $\phi_{se} \simeq 0$; $\phi_{sh} \neq 0$ $\leftarrow$ shunt motor

FL $\longrightarrow$ $\phi_{se} \neq 0$; $\phi_{sh} \neq 0$ $\leftarrow$ series motor + shunt motor.



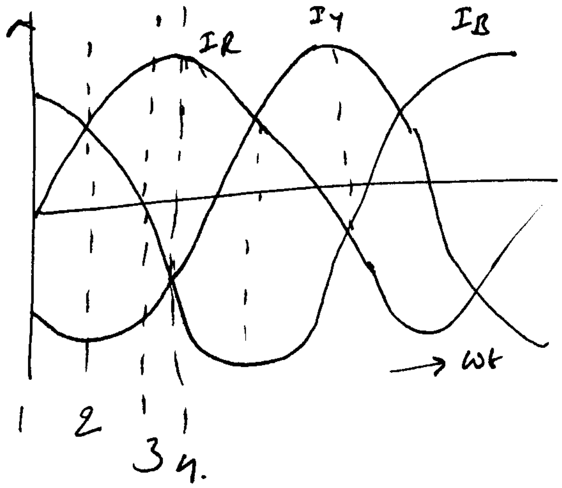


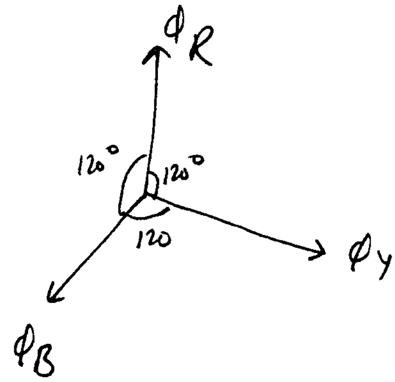


→ used where intermittently high starting torques are required
Rolling mills, shears, elevators, ~~etc~~. Ice machines, air compressor, printing press etc.

differential compound → experimental purpose in labs to get const speed drive

Three phase rotating magnetic field:-

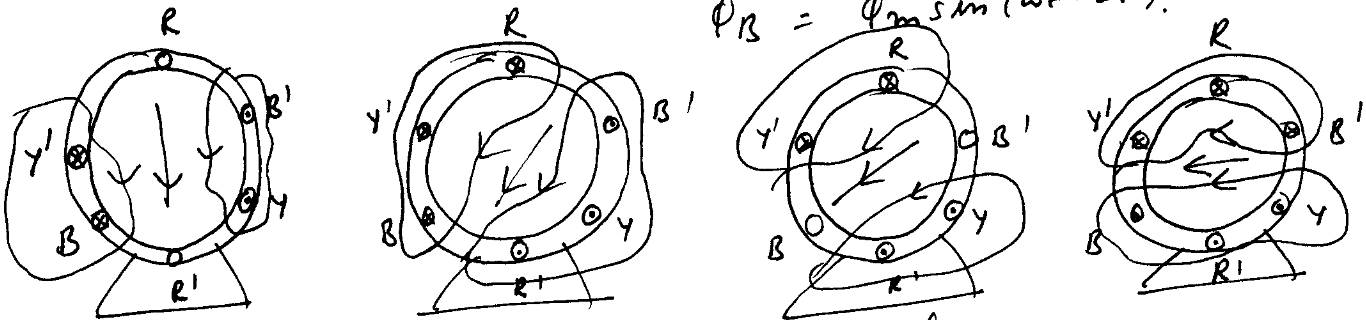




$$\phi_R = \phi_m \sin \omega t$$

$$\phi_Y = \phi_m \sin(\omega t - 120)$$

$$\phi_B = \phi_m \sin(\omega t - 240).$$



position 1 position 2 position 3

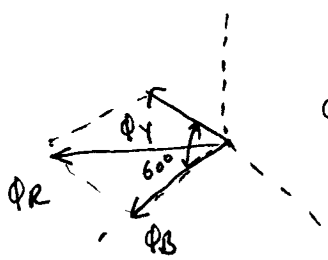
①

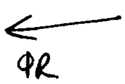
$$\phi_R = \phi_m \sin(0) = 0$$

$$\phi_Y = \phi_m \sin(0-120) = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_B = \phi_m \sin(-240) = \frac{\sqrt{3}}{2}\phi_m.$$

$$\phi_R = 1.5\phi_m.$$



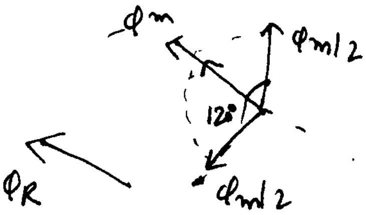


②

$$\phi_R = \phi_m \sin 30° = \frac{\phi_m}{2}$$

$$\phi_Y = \phi_m \sin(30-120) = -\phi_m$$

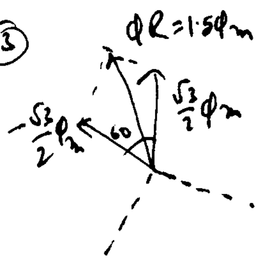
$$\phi_B = \phi_m \sin(30-240) = \frac{\phi_m}{2}$$



$$\phi_R = \phi_m + \frac{\phi_m}{2}$$

$$= 1.5\phi_m.$$

③



$$\phi_R = \phi_m \sin 60 = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_Y = \phi_m \sin(60-120) = -\frac{\sqrt{3}}{2}\phi_m$$

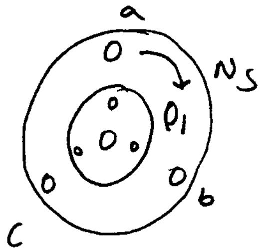
$$\phi_B = \phi_m \sin(\underbrace{60-240}_{-180°}) = 0$$

④

~~$\phi_R = \phi_m \sin 90$~~

working of 3-ϕ Induction motor:-

(i) wound rotor I.M



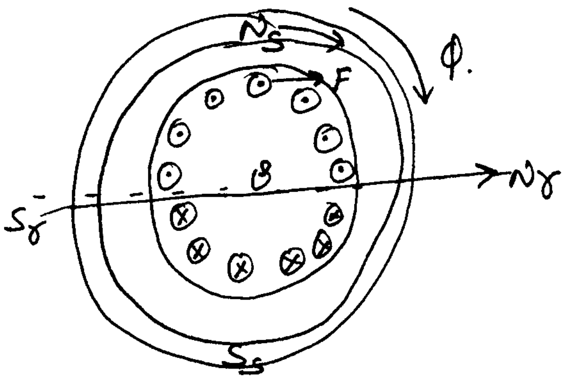
$$F_R = 1.5 F_m \cos(\theta - \omega t)$$

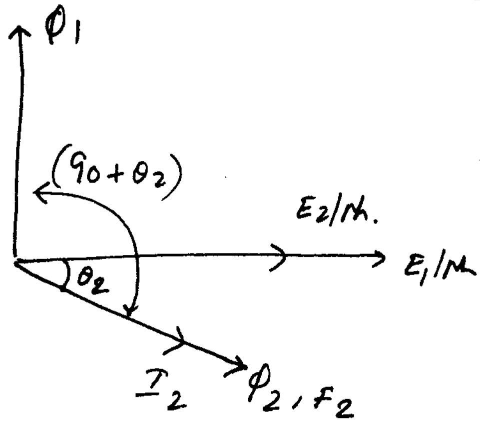
$$N_s = \frac{120 f}{P}.$$

$$\omega_e = \frac{P}{2} \omega_m$$

$$2\pi f = \frac{P}{2} \frac{2\pi N}{60}$$

$$\Rightarrow \quad \underline{N. = \frac{120 f}{P}}$$



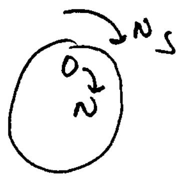


$$T \propto \phi_1 \phi_2 \sin(90+\theta_2)$$

$$\propto \phi_1 \phi_2 \cos(\theta_2)$$

$$E_r = 4.44\, N_{ph\,r}\, \phi_1\, f_r\, K_{wr}$$

K_{wr} ← winding fact of rotor



$N_s - N =$ slip speed.

$$s = \frac{N_s - N}{N_s} = \text{p.u slip}$$

$$N = N_s(1-s).$$

$$f_2 = \frac{N_s P}{120} = f$$

$$f_r = \frac{(N_s - N)P}{120} = \left(\frac{N_s - N}{N_s}\right) \frac{N_s P}{120} = \underline{sf}$$

$$\boxed{f_r = sf}$$

$S_{fl} \longrightarrow$ 2 to 8%.

$f = 50\,Hz$, $\quad f_r =$ 1 to 4 Hz