LECTURE NOTES

ON

ENERGY CONVERSION-1 (TH-1)

DIPLOMA COURSES

4TH SEMESTER

ELECTRICAL ENGINNERING

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DEPT. OF ELECTRICAL ENGINEERING

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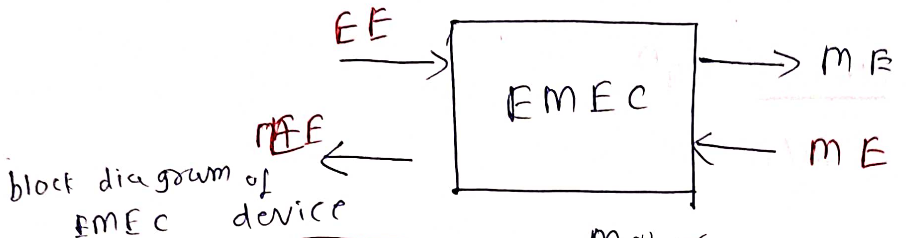
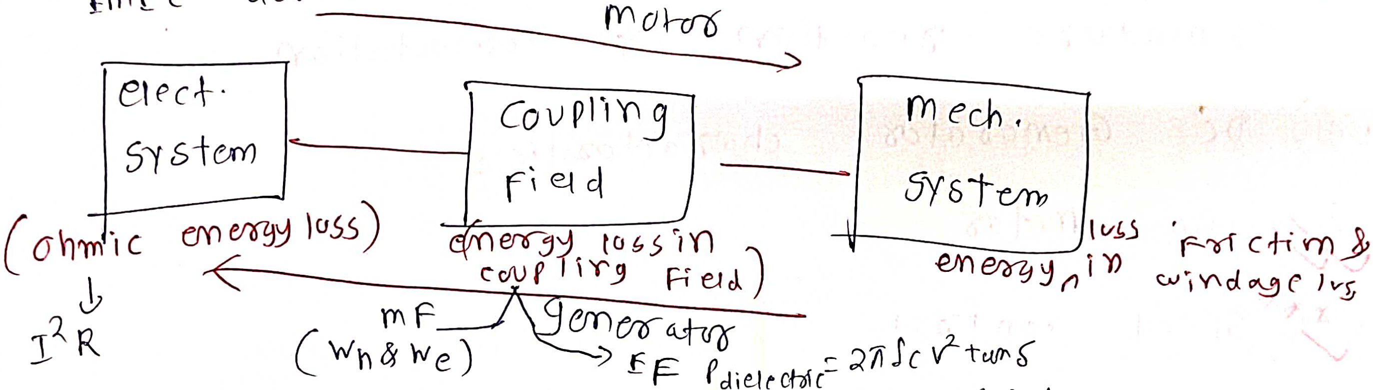
Electro-mechanical energy conversion principles

The basic principle of EMEC device is law of conservation of energy, i.e. energy can neither be created nor be destroyed but it can be changed from one form to another form.





i) motor is an EMEC device which converts EE into ME. Generator is an EMEC device which converts ME into EE.

ii) main blocks of EMEC device are Elect. system, mech. system & coupling field system

coupling field acts as a coupling medium b/w elect. & mechanical systems.

iii) coupling field may be a elect. field or magnetic field. The energy storing capacity of magnetic field is about 30000 times more than that of in the elect. field

That's why magnetic field is used as a coupling field in most of the EMEC devices.

In electrostatic voltmeter coupling field is elect. field.

	MF	EF
energy density	$\frac{B^2}{2\mu_0}$	$\frac{1}{2}\epsilon_0 E^2$
	$= \frac{1.6^2}{2 \times 4\pi \times 10^{-7}}$	$\frac{1}{2} \times 8.854 \times 10^{-12} \times (1 \times 10^6)^2$ V/m
	$= 1.01 \times 10^6$	4.427

energy balance eqn

motor

$\frac{1}{2} L I^2$

[elect. energy i/p] − [ohmic energy losses] = [energy loss in coupling field due to (W_h & W_e) + energy stored in the coupling field] + [energy loss in mechanical system + energy stored in the rotating body + mech. energy o/p]

$\frac{1}{2} J \omega^2$

$W_{elect} = W_{Fld} + W_{mech}.$

under steady state condn

under s.s. condn energy stored in the coupling field & the mechanical systems are constants, po.

Power balance eq^n (differentiation of energy balance eq^n w.r.t time under s.s. condn)

P_{in} = i^2R loss + $(W_h + W_e)$ + 0 + F & W losses + 0 + P_m

$$P_{in} = \underset{o/p}{P_{mech}} + losses$$

$P_{in} = VI$

$P_{mech} = E_b I$

$E_b \propto \phi N$

if $N = 0$, $E_b = 0$, $P_{mech} = 0$

→ For small changes the energy balance eq^n becomes $dW_{elect} = dW_{Fld} + dW_{mech}$

→ The analysis of EMEC device is based on the energy balance eq^n is conjuction with Faraday's laws of electromagnetic induction

→ In Generator, the coupling field system interacts with mechanical system & absorbs mechanical energy from it. coupling field supplies elect. energy to the elect. system after converting mechanical energy into EE.

→ In motors, coupling field system interacts with elect. system & absorbs elect. energy from it. & the coupling field supplies mech. energy to the mechanical system.

→ Coupling ~~ter~~ terms are E_b & torque in motor, E_g & torque in generator.

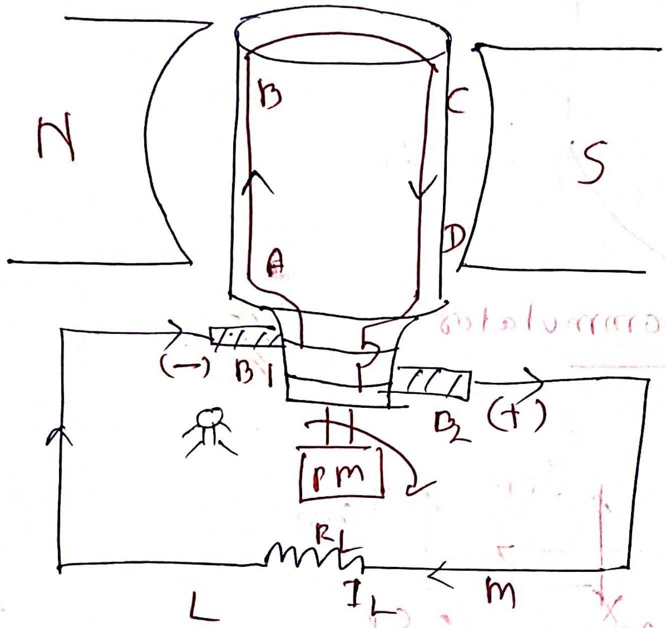
② Working principle of DC Generator

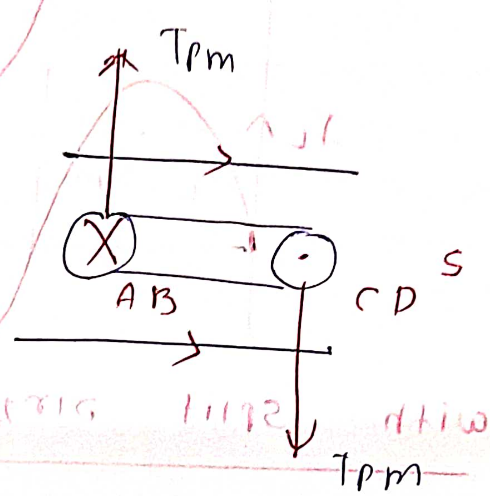
(Rotating armature & stationary Field)

DC Generator = S.G + commutator

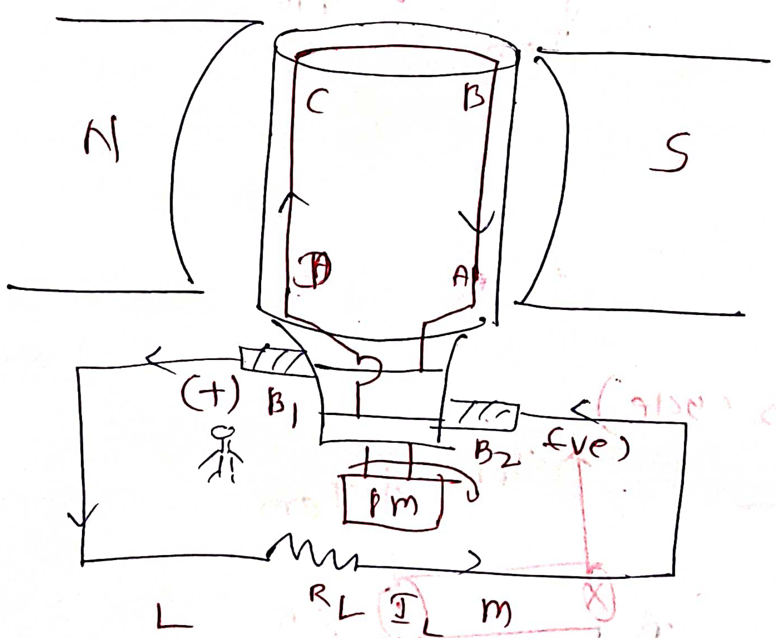
<u>with slip rings</u>

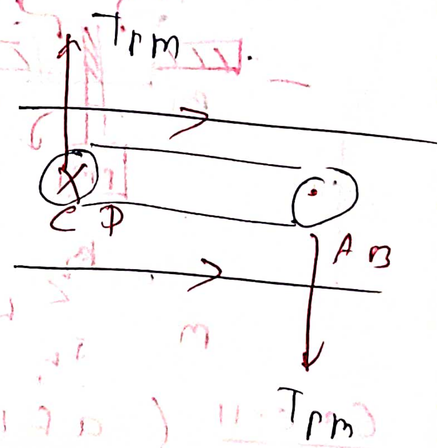
<u>case-1 (0-180°)</u> $\theta = \omega t$ $\theta \propto t$

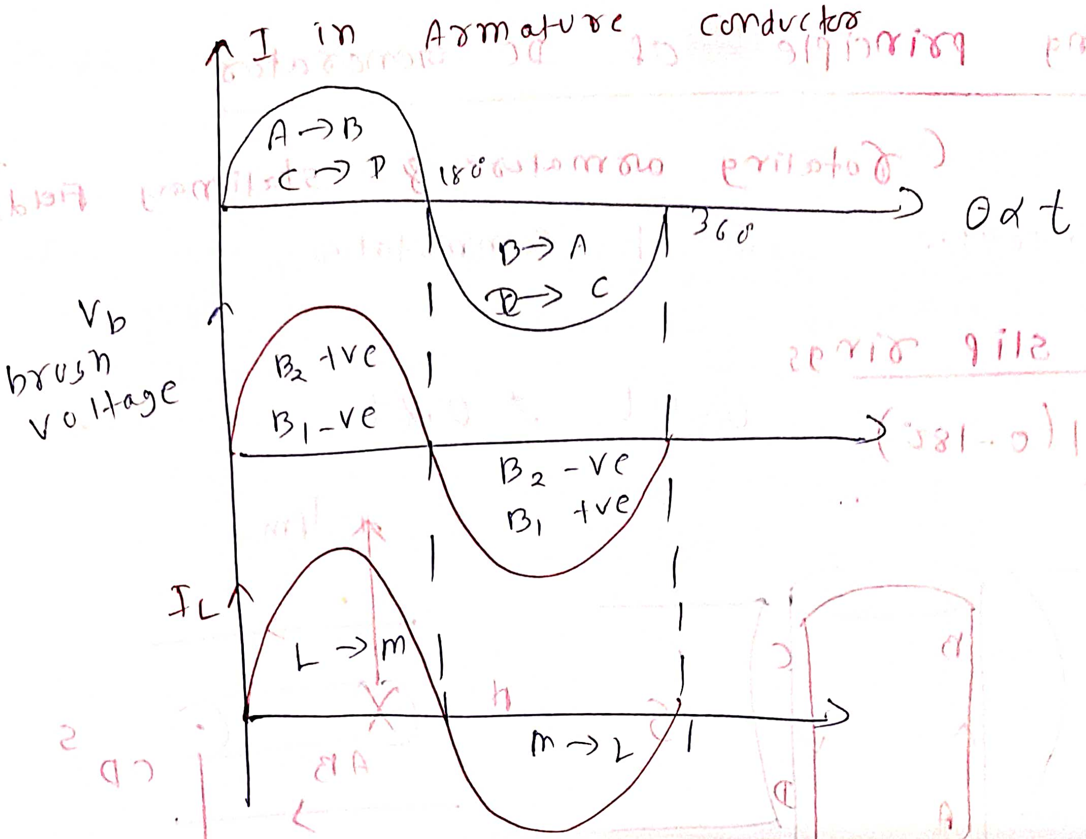




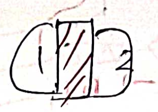
<u>case-II</u> (180°-360°) After $\frac{1}{2}$ cycle rotation



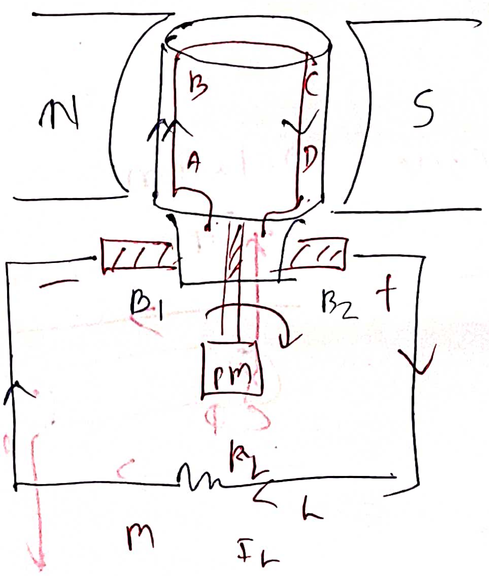


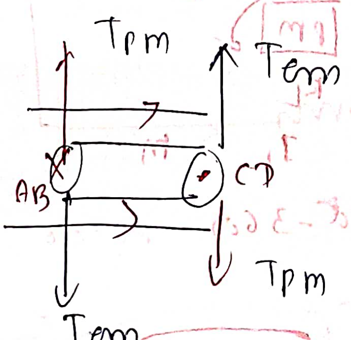


with split rings / commutator

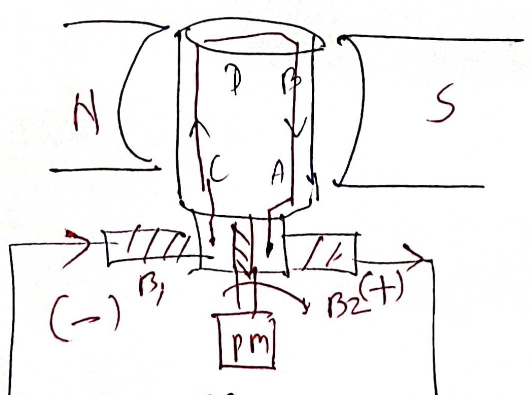


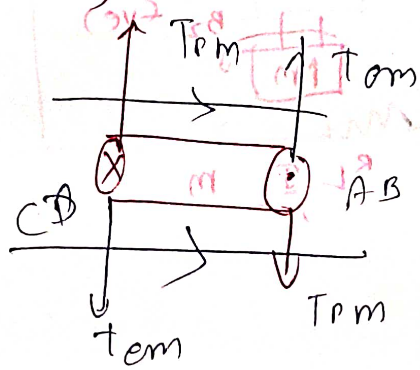
Case - I

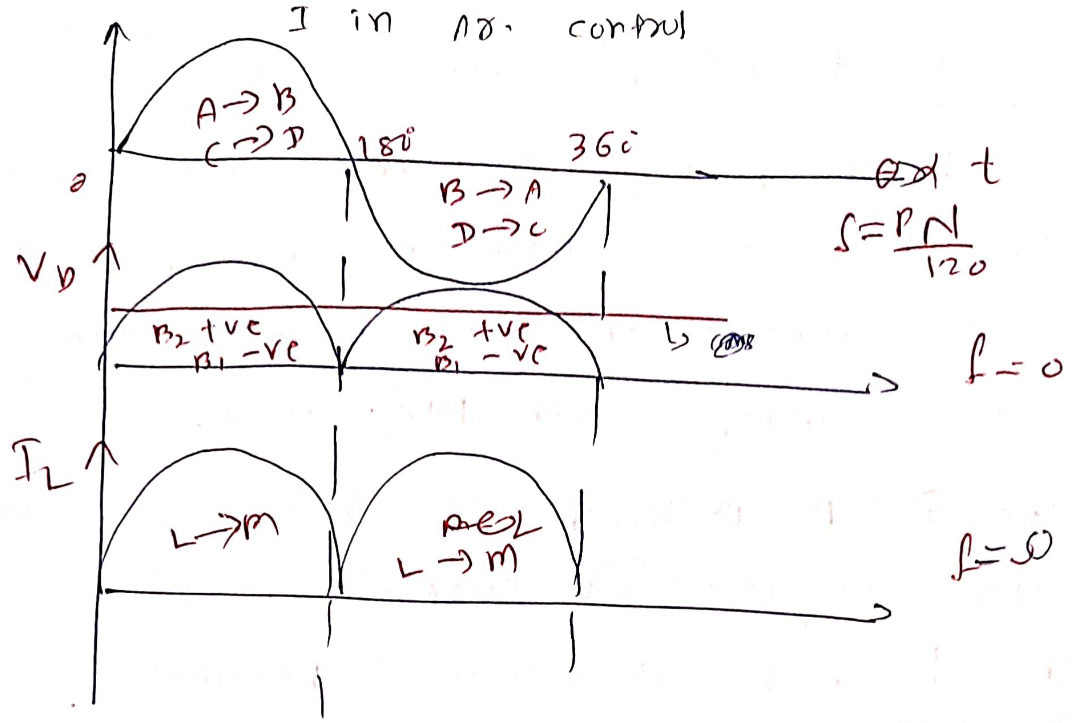




Case - II (after ½ cycle)







(i) With slip ring Brush B_1 is always in contact with conductor AB whether it exists under North pole or south pole.

→ brush B_2 is always in contact with CD whether it exists under N pole or south pole.

(ii) If conductor AB is under 'N' pole, the current in it is ⊗ & brush B_1 polarity becomes -ve. after $\frac{1}{2}$ cyle rotation, conductor AB comes under south pole. The induced current in it is ⊙. & brush B_1 polarity becomes +ve. From the above it is observed that the brush polarity is alternating.

→ Therefore with slip rings the brush voltage load current & current inside the armature conductors are AC. & $f = \frac{PN}{120}$ HZ with commutator / split rings

i) The brush B_1 is always in contact with the conductor that exists under North pole only & brush B_2 always in contact with the conductor that exists under South pole only.

→ in case ① B_1 brush is in contact with AB conductor, the induced current in it is ⊗. & the brush B_1 polarity becomes −ve.

→ after $\frac{1}{2}$ cycle rotation conductor CD comes under the North pole, the induced current in it becomes ⊗. Brush B_1 is in contact with conductor CD through commutator segment ②

there for B_1 brush polarity is −ve, from the above it is observed that the brush polarity is fixed i.e. uni-directional.

→ with split rings, the brush voltage & load current are uni-directional & 'f' '0' Hz. But the current insider the armature conductors is AC & its frequency $f = \frac{PN}{120}$ Hz

Note: The current inside the armature conductors of DC Generator is AC & its 'f' is $\frac{PN}{120}$.

Q) 4 P, DC M/C is running at 1500 rpm, what is 'f' of current inside the armature conductors?

a) 0 HZ b) 50 HZ c) 60 HZ d) 100 HZ

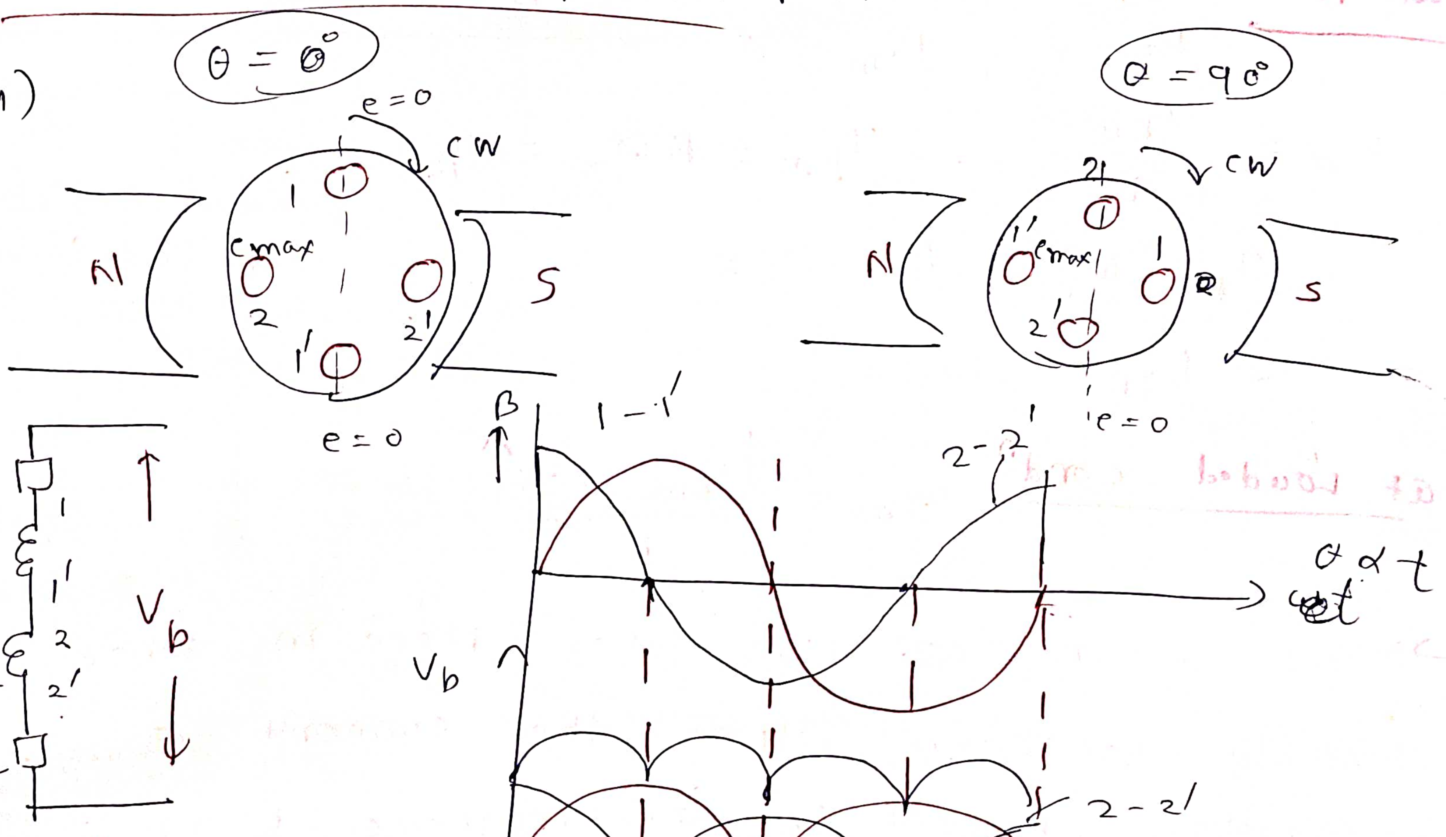
→ Commutator in DC Generator behaves as a mechanical rotating, uncontrolled full wave rectifier.

→ The methods to increase DC O/P voltage & to reduce ripples in the DC O/P voltage are i) by connecting more no. of armature coils in series in each parallel path

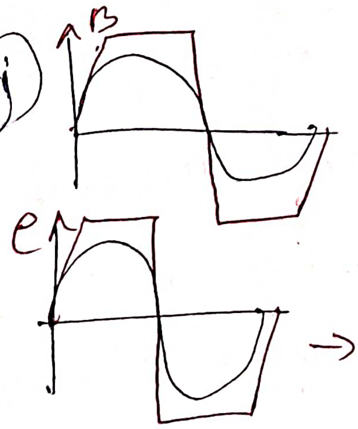
ii) by using flat topped main field flux distribution

The no. of pulses in the DC O/P voltage for every 180° = the no. of armature coils connected in series in each parallel path

i)



ii)



→ more avg. value

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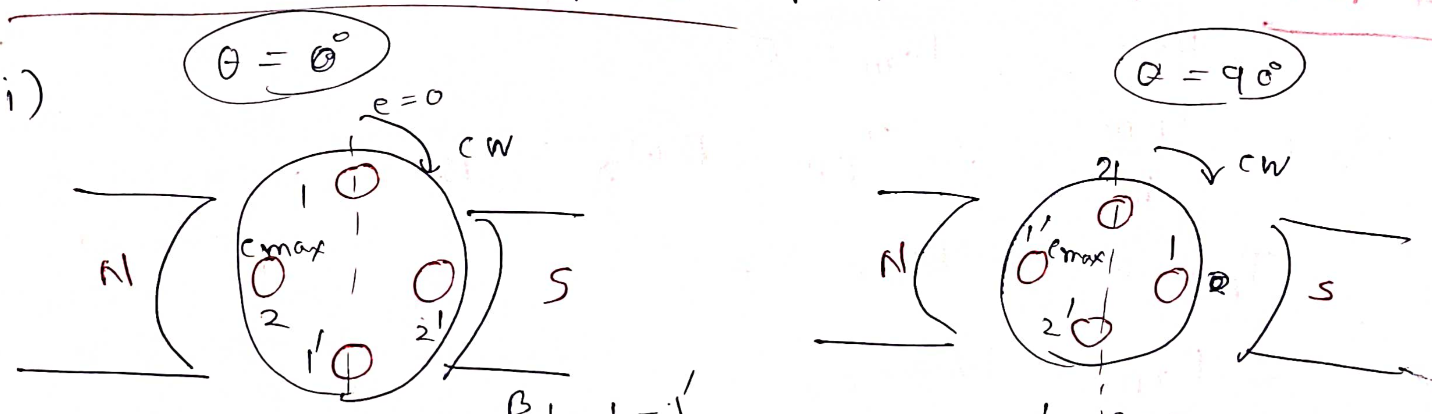
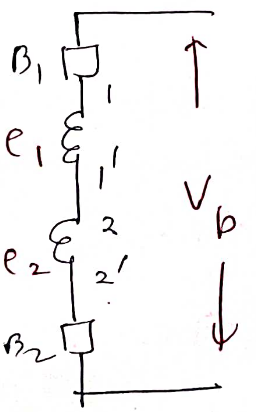
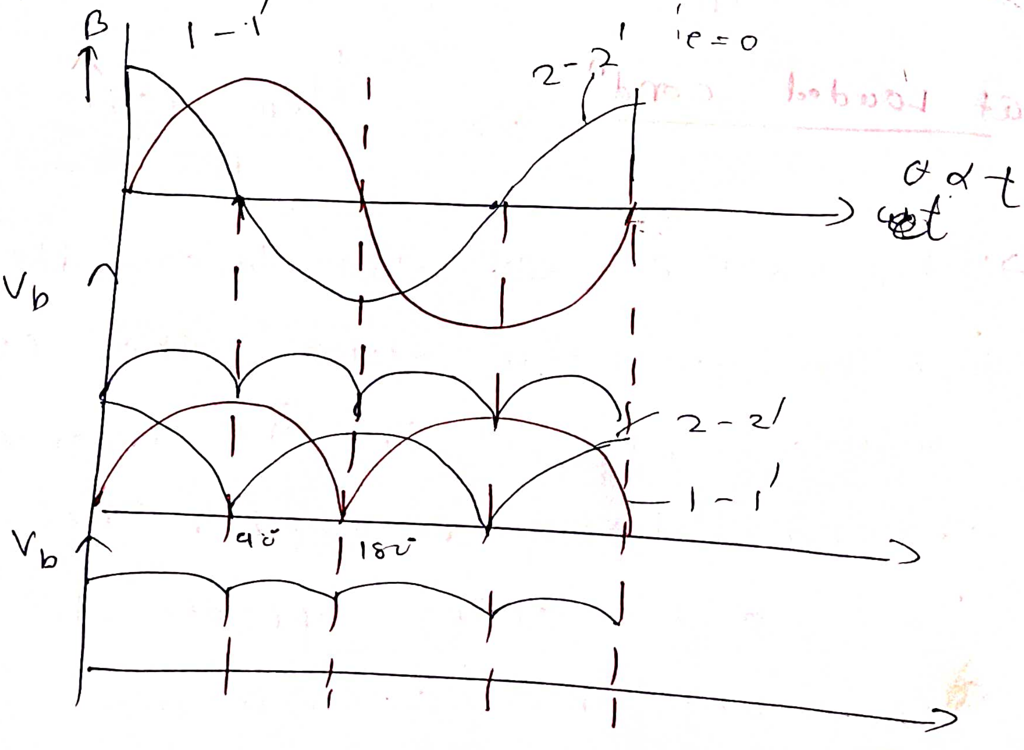
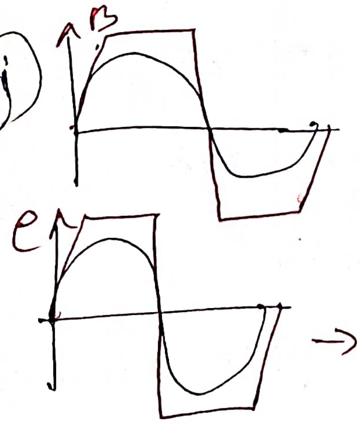




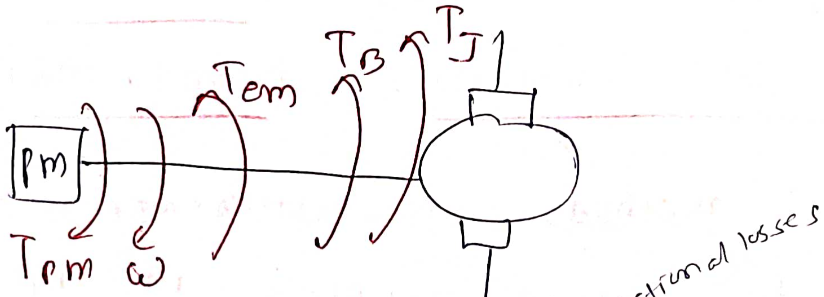


(ii)



→ more avg. value

Generator



$$T_{pm} = T_{em} + T_B + T_J$$

$$T_{pm} = T_{em} + B\cdot\omega_r + J\cdot\frac{d\omega_r}{dt}$$

at Steady state

$\omega_r = \text{const.}$ $\quad T_{pm} = T_{em} + B\cdot\omega_r$

$$\omega_r = \frac{T_{pm} - T_{em}}{B}$$

at N.L

$I_a = 0$, $T_{em} = 0$

$$\omega_r = \frac{T_{pm}}{B} \Rightarrow T_{pm} = B\omega_r = T_B$$

$$\underbrace{T_{pm}\cdot\omega_r}_{P_{in}} = B\omega_r\cdot\omega_r$$

$P_{in} = \text{loss}$

at Loaded cond^n

$$\omega_r = \frac{\uparrow T_{pm} - T_{em}\uparrow}{B}$$

→ Motor action also takes place in generator. Due to generator action, the current carrying conductors, present in the magnetic field therefore, torque produced. The dir^n of this torque is acting opposite to the pm torque that's why this electromagnetic torque produced is called braking torque or counter torque.

or reaction torque or magnetic drag.

→ The direcn of braking torque can be found by applying Fleming's left hand rule.

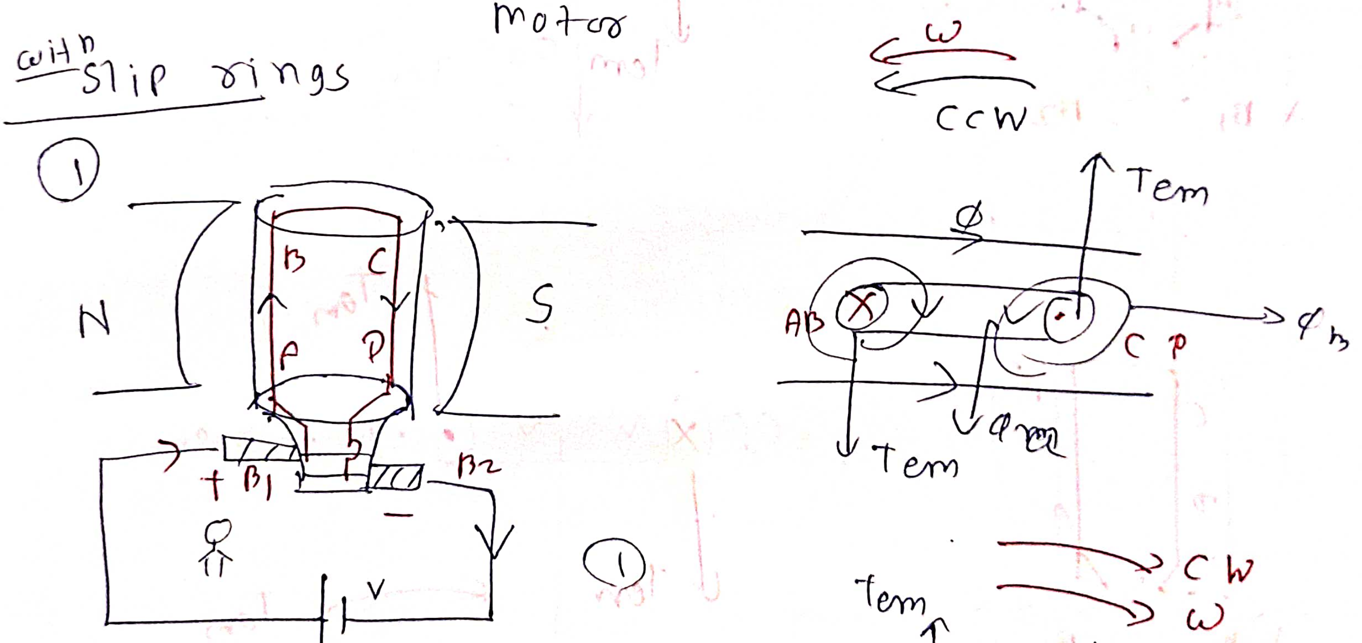
→ torque balance ~~action~~ eqn

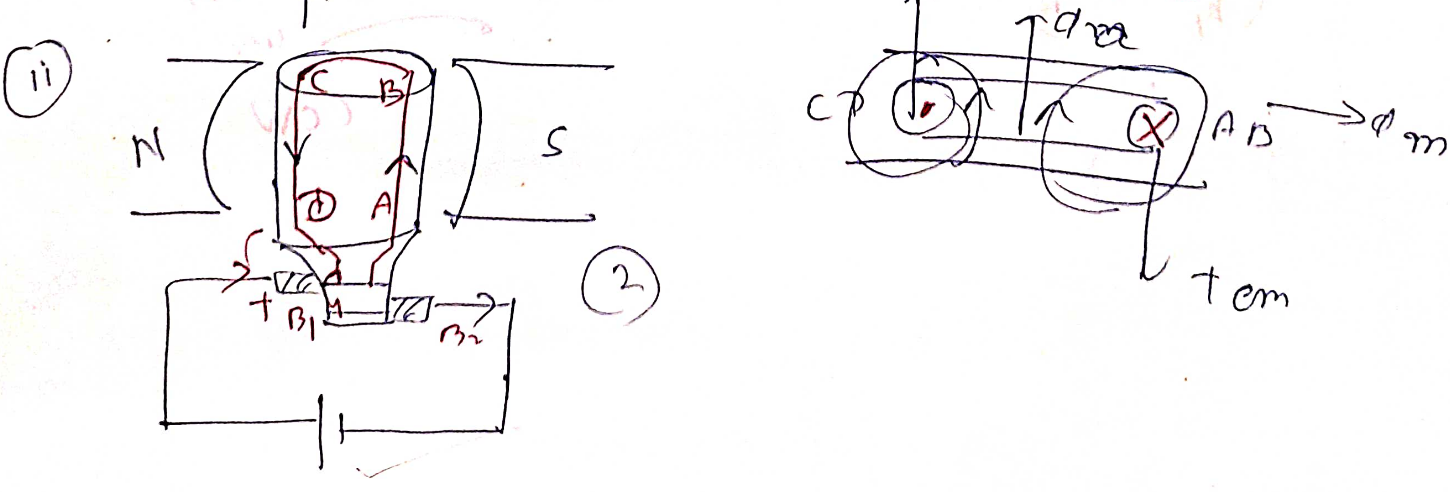
→ under No-load condn, generator demands mechanical power to overcome its internal losses

→ Under loaded condn, generator demands mechanical energy in order to overcome the opposition due to motor action in the generator.

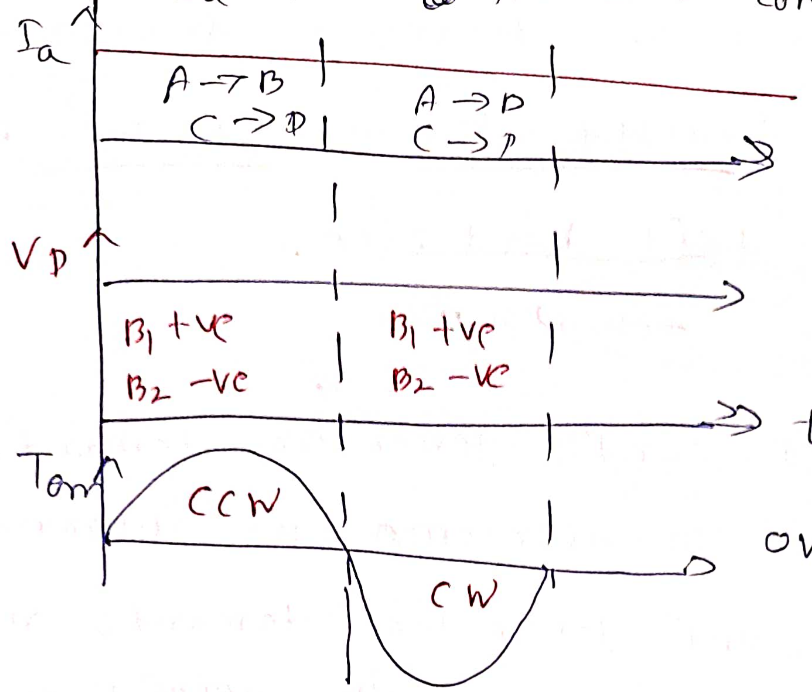
Dc motor working principle

Dc motor = synchronous motor with slip rings + commutator



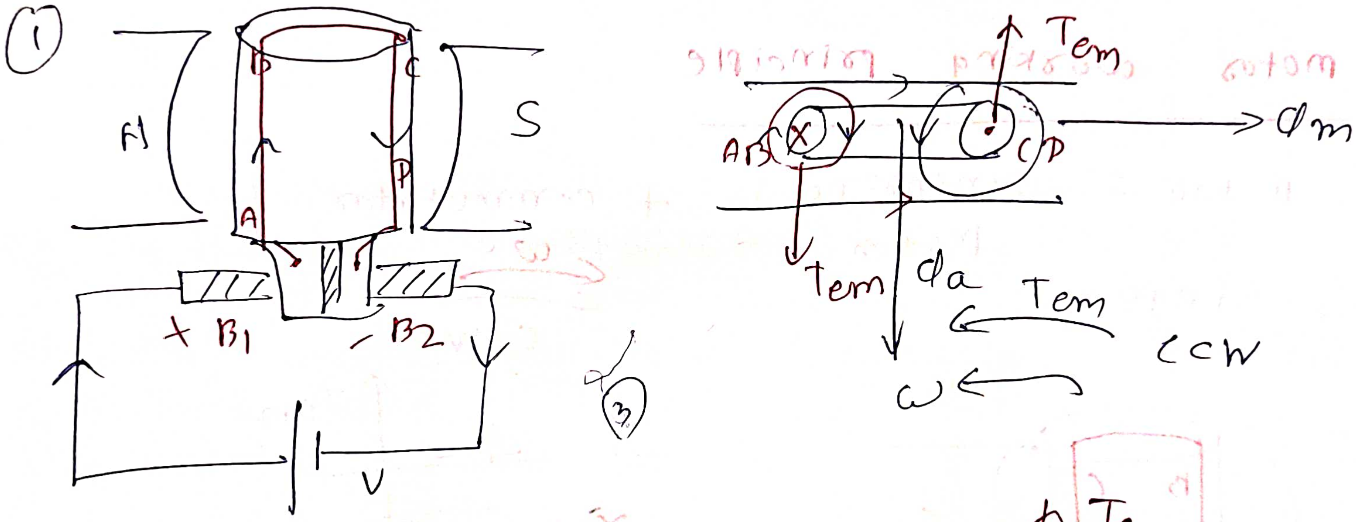


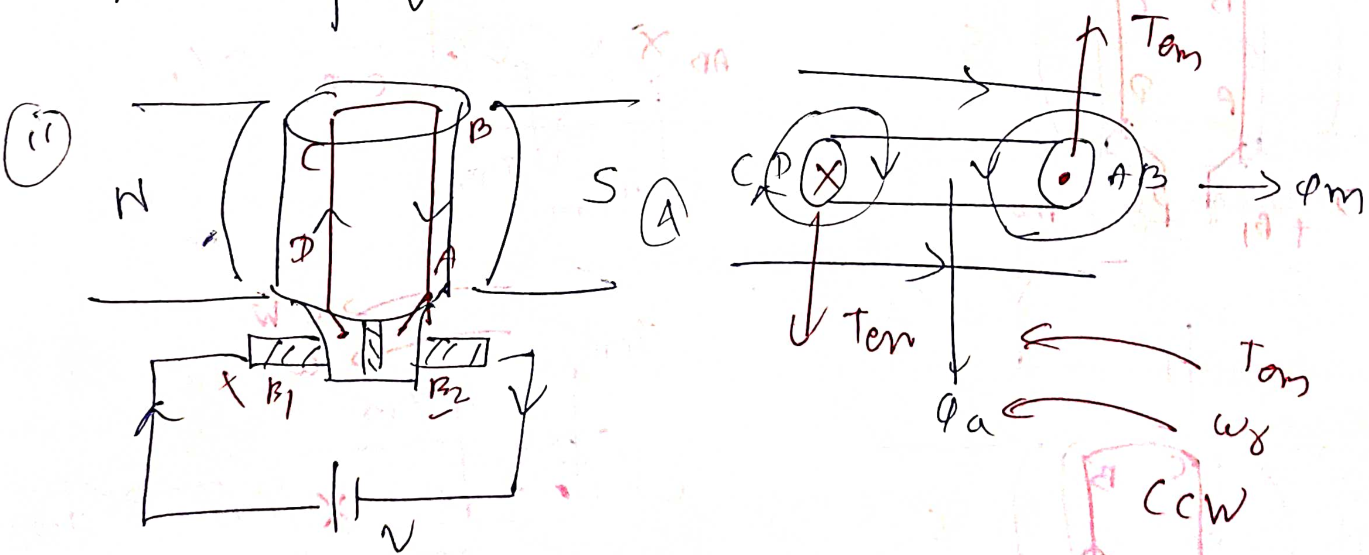
I_a in Armature conductor

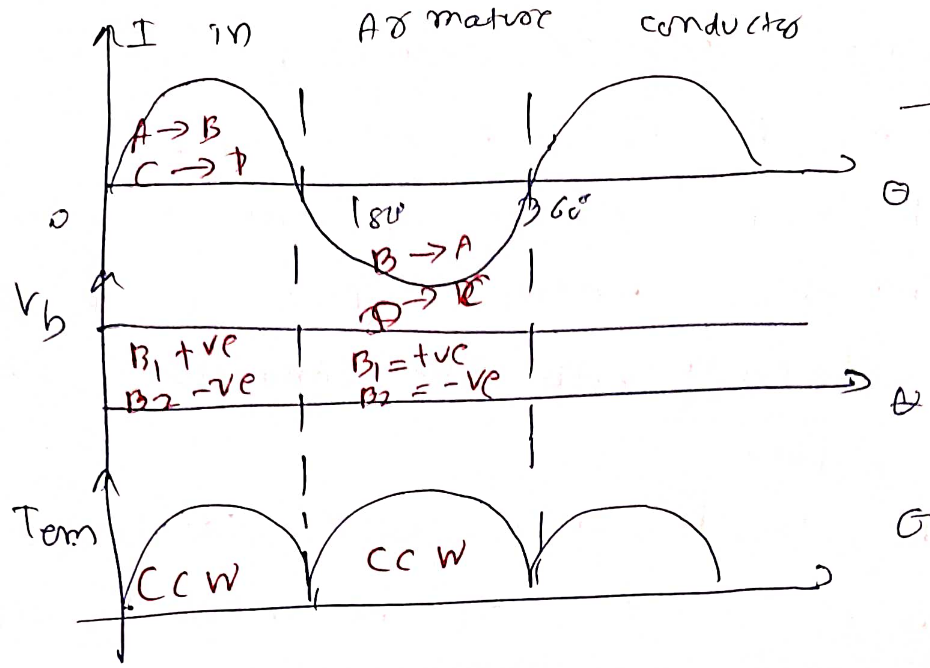


over a one rotation $T_{avg} = 0$

with split rings







→ $f = \frac{NP}{120}$

→ with slip rings DC supply is connected across brushes with B_1 as +ve & B_2 -ve

Case - I

with SR brush B_1 is always in contact with AB conductor & brush B_2 is always in contact with CD conductor whether they exist under N-pole or S-pole. In Fig (1) AB under N-pole the current in it is ⊗, due to supply V & conductor CD under 'S' pole, the current in it is ⊙.

→ Now the torque is produced in the CCW direcⁿ by using this torque, the motor complets half cycle rotation. In Fig (2) AB under south pole, current in it ⊗ & CD under N-pole, current in it is ⊙

Now the torque is produced in the CW direcⁿ

From the above it is observed that the avg. torque over one rotation is zero.

→ with split rings, the DC supply is connected as brushes with B_1 +ve & B_2 -ve with commutator, brush B_1 always in contact with the conductor which exists under N-pole & brush B_2 is always in contact with the conductor which exists under S-pole.

→ in Fig (3) B_1, is in contact with conductor AB the current in it is ⊗. CD is under south pole, the current in it is ⊙ bcoz B_2 brush is in contact with CD conductor. Now the torque produced in the CCW direcⁿ & the arm. complets half cycle rotation.

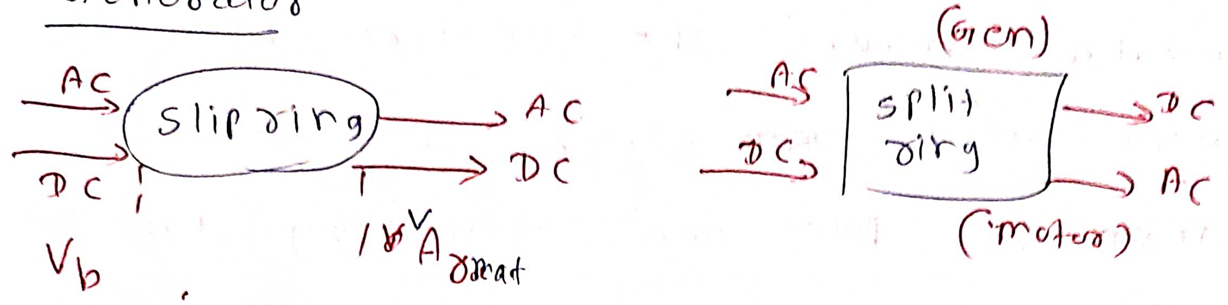
→ After half cycle rotation, in Fig (4) B_1 brush in contact with CD conductor current in it is ⊗ & B_2 brush is in contact with AB conductor, current in it is ⊙. Now the torque is produced in the CCW direcⁿ. From the above it is observed that the unidirectional torque is produced i.e. in CCW direcⁿ.

→ with commutator, the motor the brush voltage is DC but current in the arm. conductors is AC & its 'f' $= \frac{NP}{120}$.

→ commutator in DC motor converts DC across the brushes into AC in the armature conductors. Hence it behaves as a mechanical rotating uncontrolled inverter.

Note.. The current in the armature conductors of DC m/c is always AC & its $f' = \frac{PN}{120}$

Generator



→ Generator action will also take place in the motor, due to motor action, armature conductors are rotating in the magnetic field, they cut the magnetic flux & dynamically induced emf is produced. The direcn of this induced emf is acting opposite to the supply voltage. That's why this induced emf is called back emf or counter emf or reaction voltage.

→ The direcn of back emf can be found by applying ~~Flemings~~ FRHR.

→ The back emf produced in the armature conductors is AC & its frequency is $f = \frac{NP}{120}$ but across the brushes back emf appears as DC. The armature current is proportional to the potential diff $(V - E_b)$.

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

$$I_a V = I_a E_b + I_a^2 R_a$$

$$P_{in} = P_{mech} + \text{Arm. cu losses}$$

$P_{mech} = E_b I_a = T_{em} \times \omega_r$

$T_{em} = \frac{P_{mech}}{\omega_r} = \frac{E_b I_a}{\omega_r}$

→ commutator (mom) makes the armature poles stationery w.r.t ~~arm~~ stator or space

→ The main field poles are stationery in DC m/c, the relative speed b/w the stator poles & rotor poles is equal to zero i.e. stator poles & rotor poles are stationary w.r.t each other.

→ The rotor poles w.r.t rotor is rotating in opposite direction.

→ The relative speed b/w rotor poles & armature equal to $2N_r$.

→ The DC m/c construction is possible with rotating armature & stationery field system configuration only due to commutator action otherwise the commutator action will be failed.

Construction of DC m/c

(i) stator

(*) Yoke / Frame

(*) Field poles
- → pole core
- → pole shoe
- → Field wdg

(ii) Rotor

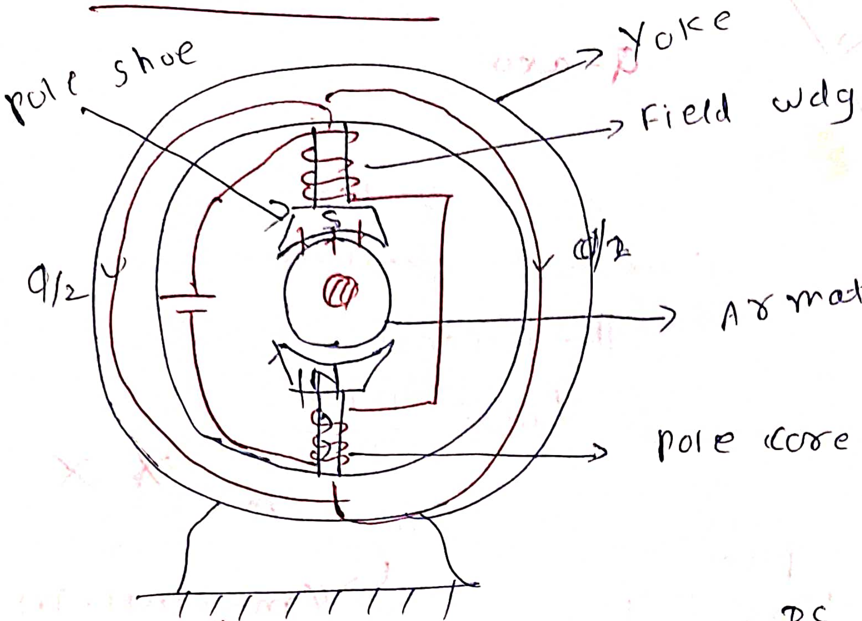
(i) Armature core

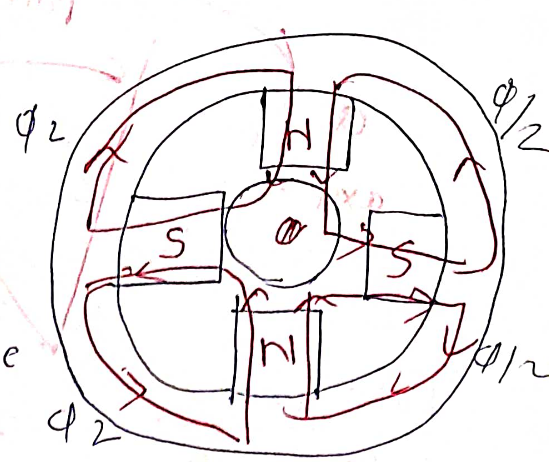
(ii) commutator

(iii) brushes

(iv) Armature windings

* Yoke / Frame





steel = iron + carbon

Yoke : cast iron (small DC m/c)
cast steel (large DC m/c)

Functions

i) It acts as a protective cover for entire m/c.

ii) It provides mechanical support to the field poles.

iii) It provides return path to the main field flux

Note : Flux passing through the yoke or frame is $\frac{\phi}{2}$ where ϕ = Flux / pole.

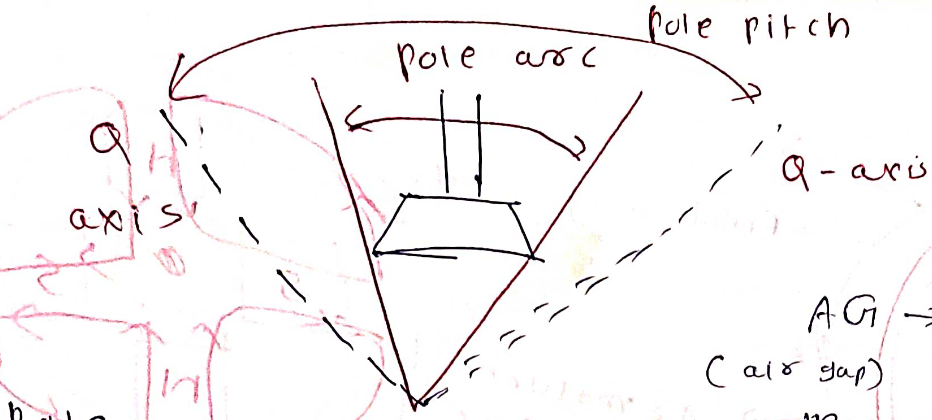
iv) Flux passing through the armature core section is equal to $\phi/2$.

Field Poles

Pole core : Cast steel.

Function : i) It carries field wdg & it provides mechanical support to the pole shoe.

ii) It acts as an electromagnet when the field wdgs are excited.



$$\frac{\text{Pole arc}}{\text{pole pitch}} = 0.7 - 0.9$$

AG → under pole uniform
(air gap)

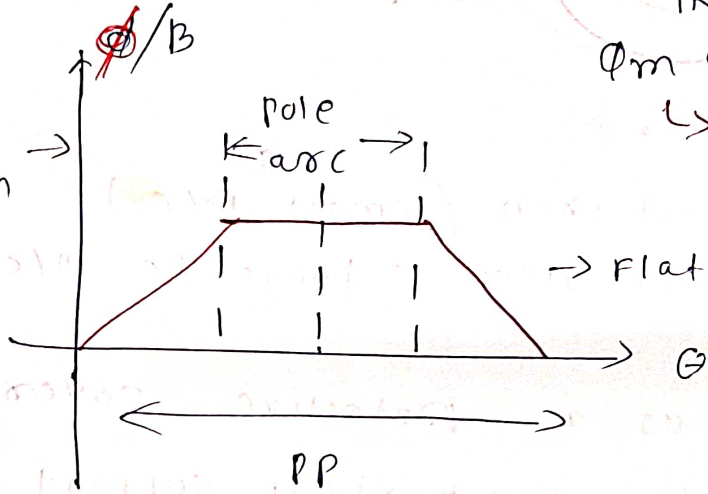
IR → constant

$$\phi_m = \frac{mmf}{IR}$$

$\phi_m \propto I_f$

↳ ϕ_m = const. in Pole arc

Main Field Flux distribution →



Pole shoe: cast steel laminations

Func^n: It distributes magnetic Flux uniformly in the air gap. Therefore avg Flux/Pole increased.

→ generated voltage & torque produced are also increased.

→ Pole arc / Pole pitch ratio is 0.7 - 0.9.

→ Main Field Flux distribution in the DC/mc is a Flat-topped waveform.

Q) Why pole shoe is a laminated part in the DC m/c ?

A: to improve commutation, open slots are preferred in the DC m/c.

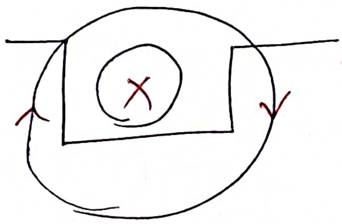
→ with open slots flux density in the pole faces varies w.r.t time, emf induced in the pole shoe & it produces eddy currents which causes eddy current losses. to minimise eddy current losses in the pole shoe, it is made with cast steel laminations.

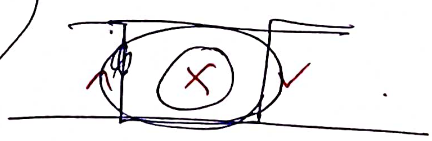
→ The armature flux complete the path through the pole shoe, when the DC m/c is subjected to variable loads the flux passing through pole shoe varies w.r.t time. There fore emf induced & it produces eddy currents & eddy current losses. to minimise ~~pol~~ this pole shoe is a laminated part.

<u>open slot</u>

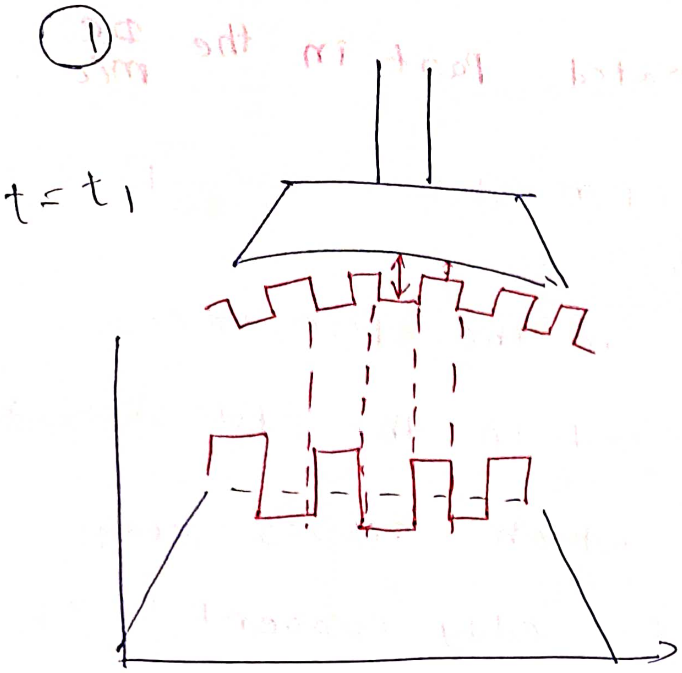
$$U_r = \frac{2 I_c L_c}{T_c}$$

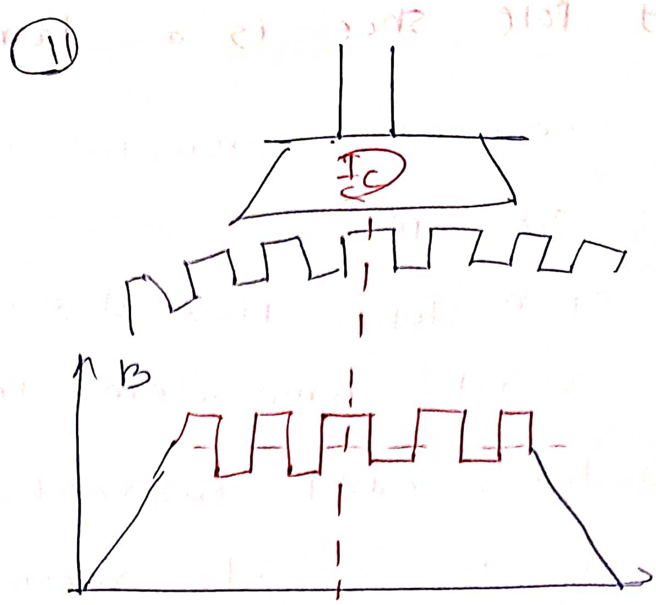
<u>closed slot</u>





open slot	closed slot
L_c	
$R \uparrow$	$R \downarrow$
$\downarrow L_c = \frac{N^2}{R \uparrow}$	$\uparrow L_c = \frac{N^2}{R \downarrow}$
$U_r \downarrow$	$U_r \uparrow$
less sparking	more sparking

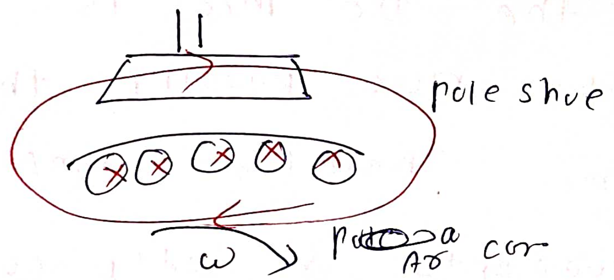




Slot area → less flux

Inter slot area → more flux

→

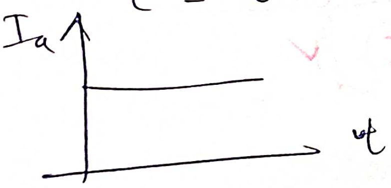


load = const.

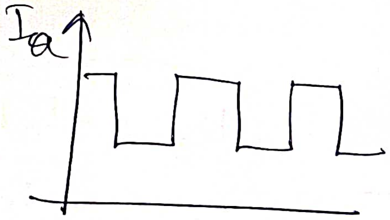
I_a = const.

ϕ_a = const.

e = 0



Variable load



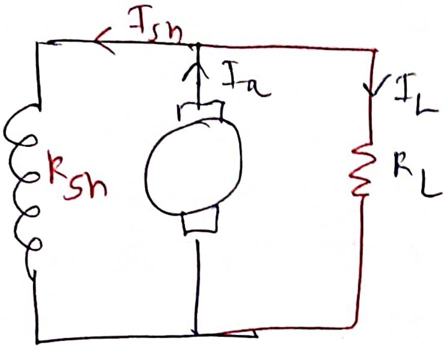
ϕ_a → variable

$e \neq 0$

(4) Field winding

Field wdg

Shunt

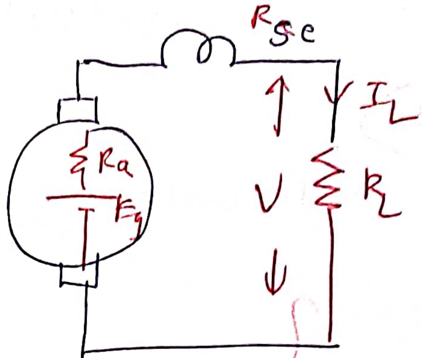


$\uparrow R_{sh} = \rho \frac{l \uparrow}{a \downarrow}$

→ R_{sh} → high (100 – 250 Ω)
(order of 100)

→ more turns of thin copper wires.

Series



$\downarrow R_{se} = \rho \frac{l \downarrow}{a \uparrow}$

→ R_{se} → less (< 1 Ω)

→ Few turns of thick copper wire.

Rotor side

1) Armature core

→ silicon steel lamination in order to reduce both hysteresis losses & eddy current losses.

Functions : i) to accomodate armature wdgs

ii) It provides low reluctance path to the main field flux.

2) Commutator

→ It contains no. of commutator segments

→ commutator segments are made with hard drawn copper. or silvered copper.

→ No. of commutator segments required

is no. of armature coils.

→ commutator segments are insulated from each other by mica insulation of thickness 0.6 to 0.8 mm, its dielectric strength is 30 - 40 Volts.

brushes

→ made with copper, carbon, electrographite, metallic/cu graphite.

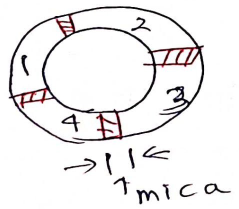
copper }
(II) carbon } → small DC m/c
→ BD 1V / drop brush

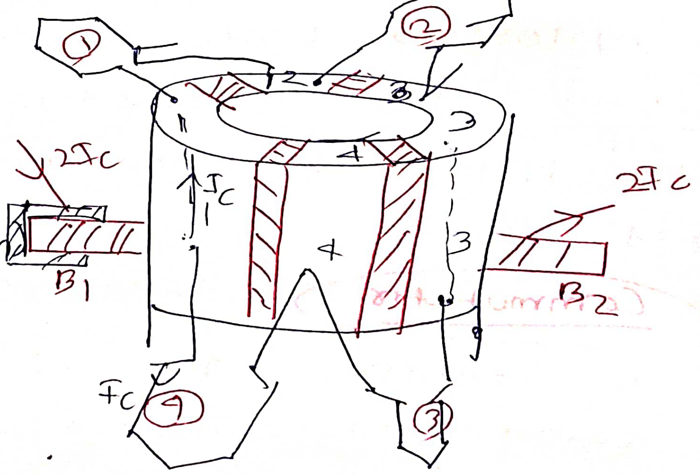
(I) → electrographite → General purpose brush

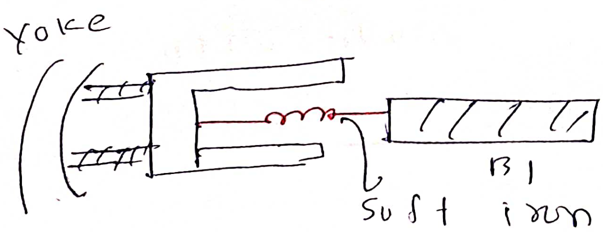
→ metallic graphite → LV, High I DC m/c
↳ brush drop 0.25 - 0.5 V/ brush

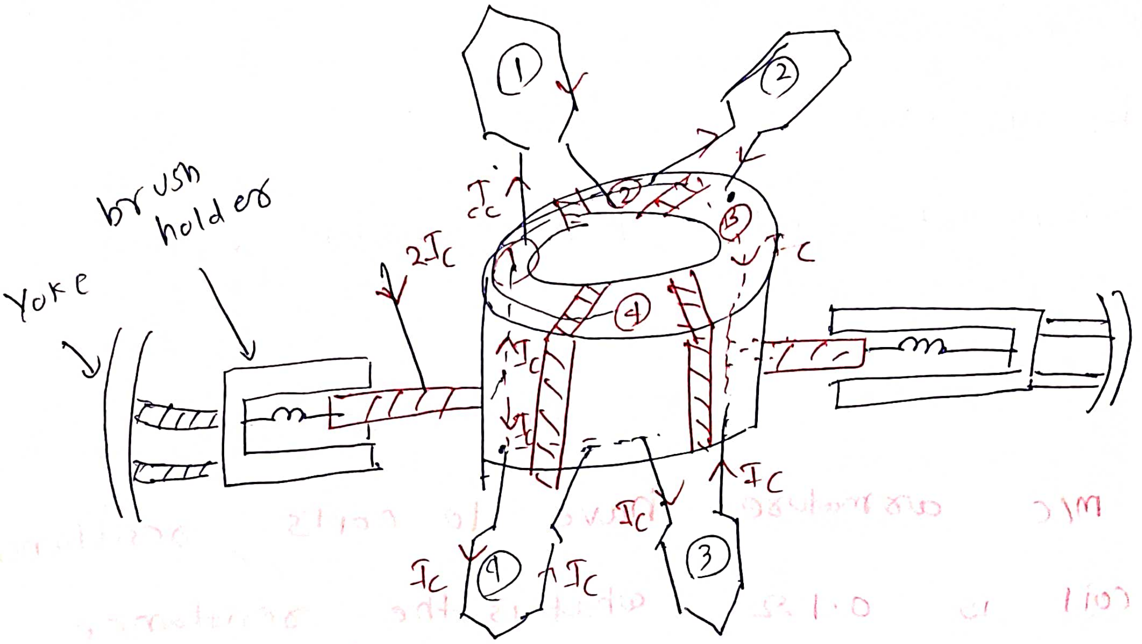
Function

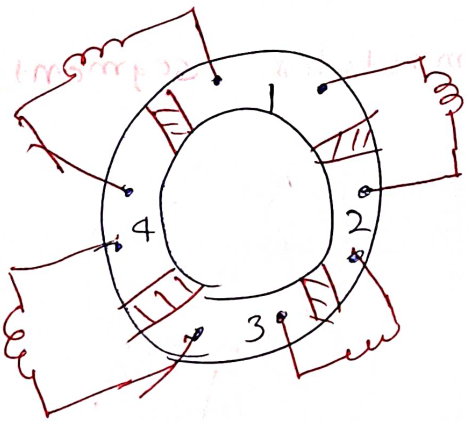
It collect the current from armature conductors through commutator segments or brushes send the current into armature conductors through a commutator segments.











Advantages of carbon brush over copper brush

(i) self lubricating property; due to this brush Frictional losses becomes less, efficiency increased.

(ii) high thermal stability i.e. high melting point due to this current collection capacity of brush increased.

(iii) It improves the commutation i.e. less sparking at the buses.

(iv) brush drop is constant bcoz it has negative temp. co-efficient.

disadvantages

more brush drop

Note. (i) commutator m/cs have closed armature windings.

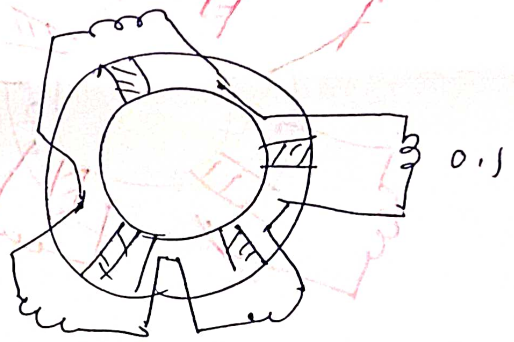
(ii) Ac m/cs have open armature wdgs.

Q) 4P, dc m/c armature have 10 coils, resistance of each coil is 0.1 Ω, what is the resistance b/w any two adjacent commutator segments.

A: $R_{1\&2} = \frac{R_c \times (n-1) R_c}{R_c + (n-1) R_c}$

$= \frac{0.1 \times 9 \times 0.1}{0.1 + 9 \times 0.1}$

$= 0.09 \Omega$



(4) Armature windings

conductor

It is the active length of copper wire which takes active part in the energy conversion process, emf induced & torque produced.

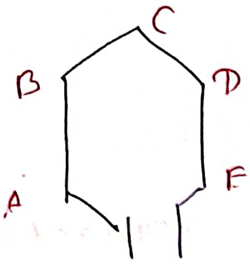
Turn

1 turn = 2 conductors

Coil

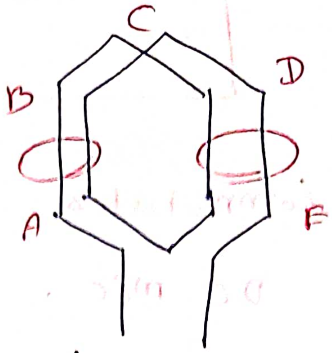
coil contains any no. of turns but it has only 2 coil sides. conductors in each coil side = turns of a coil conductors in a coil = 2 x turns/coil

AB, DE coil side

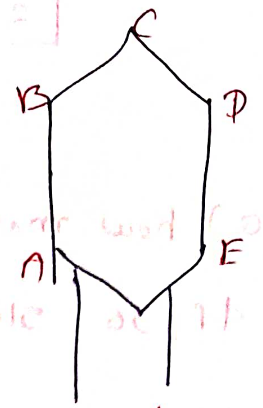


single turn coil

AB, DE → coil sides



two turn coil



n-turn coil

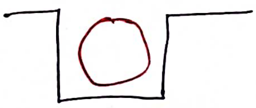
BCD → overhang or end

→ overhang portion can be reduced by using short-pitched coils & by using more no. of poles in the m/c.

→ overhang portion of coil is also called inactive copper in the rotating m/cs. conductors are called active copper in the rotating m/cs.

Types of armature windigs based on coil sides/slot

1) single layer wdg



→ one coil side occupies entire slot area

→ S = slots, C = coil

$C = \frac{S}{2}$ ✓

→ small AC m/c

$u = 1$

double layer wdgs

each slot → even coil sides in 2 layers

top → odd

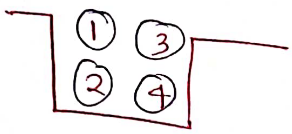
bottom ↳ even no.

→ S = Slot

$C = S$ ✓

(*) commutator m/cs (DC m/c)

large A/C m/c



u = coil sides / slot

$$C = \frac{1}{2} U S$$

u = 2 (default)

Q) how many commutator segments are required in 4P, 36 slots DC m/c. a) 18 b) 36 c) 72 d) 144

$C = \frac{1}{2} \times 2 \times 36$ U = 2

Q) how many commutator segments are required in 4P, 36 slot DC m/c with 4 coil sides / slot.

A: $C = \frac{1}{2} \times 4 \times 36 = 72$ U = 4.

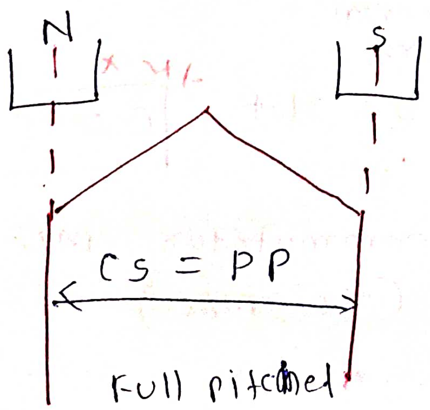
Pole pitch

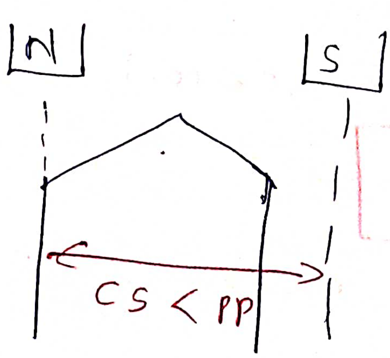
The peripheral distance b/w ~~adjac~~ identical points on the adjacent poles is called pole pitch. pole pitch = $\frac{S}{P}$ = 180°

Coil span

The distance b/w coil sides of a coil is called coil span.

if coil span = PP → Full pitched wdg
if , CS < PP → short pitch wdg



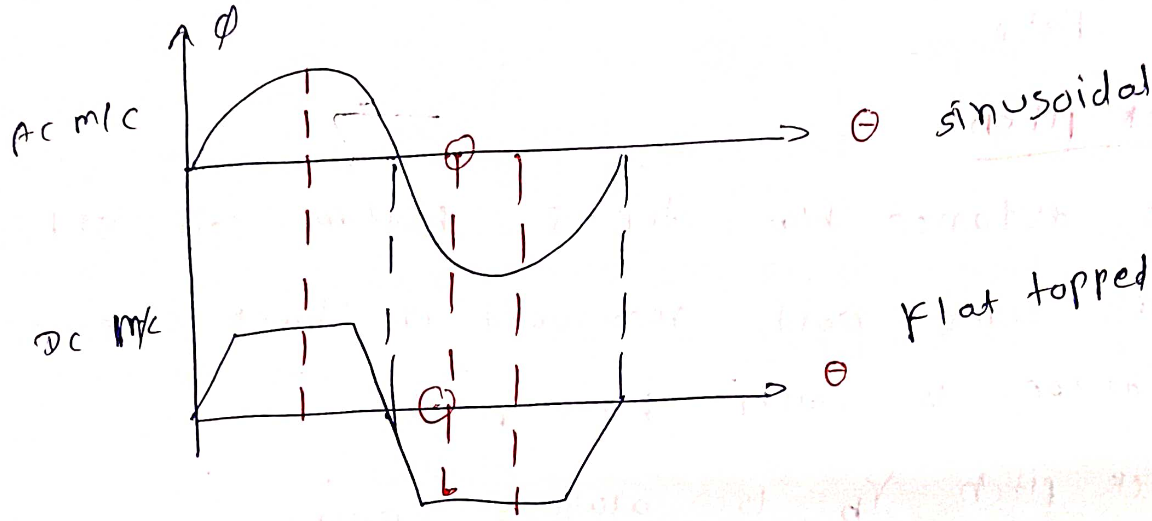


(residual voltage)

with short pitched coil, $L_c \downarrow$, $V_r \downarrow$, less sparking

→ emf remains same in DC m/c for short pitched wdg.

→ For AC m/c, emf ↓, for short pitched wdg.



→ with short pitched wdg, E_g is same as that of full pitched wdg in DC m/c, due to flat topped flux distribution.

→ short pitched wdgs are used in DC m/c in order to improve the commutation.

Types of armature wdgs based on armature coil end connection

i) lap winding
ii) wave "

Lap winding

The finishing end of a coil under one pole is connected to the starting end of next coil existing under same pole pair through a commutator segment.

Wave winding

The Finishing end of ~~one~~ coil exist under one pole pair is connected to the starting end of the next coil exists under its adjacent pole pair.

back pitch

→ The distance b/w top & bottom coil sides of a same coil measured on back side of armature is called back pitch.

→ back pitch Y_b is always odd.

$$Y_b = \frac{2C}{P} \pm k$$

where k may be an integer or Fraction that makes Y_b odd.

Front pitch

The distance b/w coil sides that are connected to the same commutator segment is called Front pitch.

→ Front pitch Y_F is always odd.

→ if $Y_b > Y_F$ → progressive winding
i.e. Left → Right
or Clockwise direction

→ if $Y_b < Y_F$ → Retrogressive winding
i.e. Right ⟶ Left or
CCW direction

Commutator pitch

The distance b/w commutator segments to which starting & finishing ends of the same coil are connected is called commutator pitch

→ $Y_c = \pm m$, Lap winding

$= \frac{c \pm m}{P/2}$ → wave winding

m = 1, simplex wd,
m = 2, duplex wdg
m = 3, Triplex wdg

+ → progressive wdg
− → retrogressive wdg

Winding pitch

The distance b/w consecutive coils of similar tops or bottom coil sides measured in the direcⁿ of wdg progress is called winding pitch.

→ wdg pitch $Y_w = 2Y_c$

$= Y_b - Y_F$; Lap

$= Y_b + Y_F$, wave

Lap winding

double layer

S = 12

P = 4

$C = S$

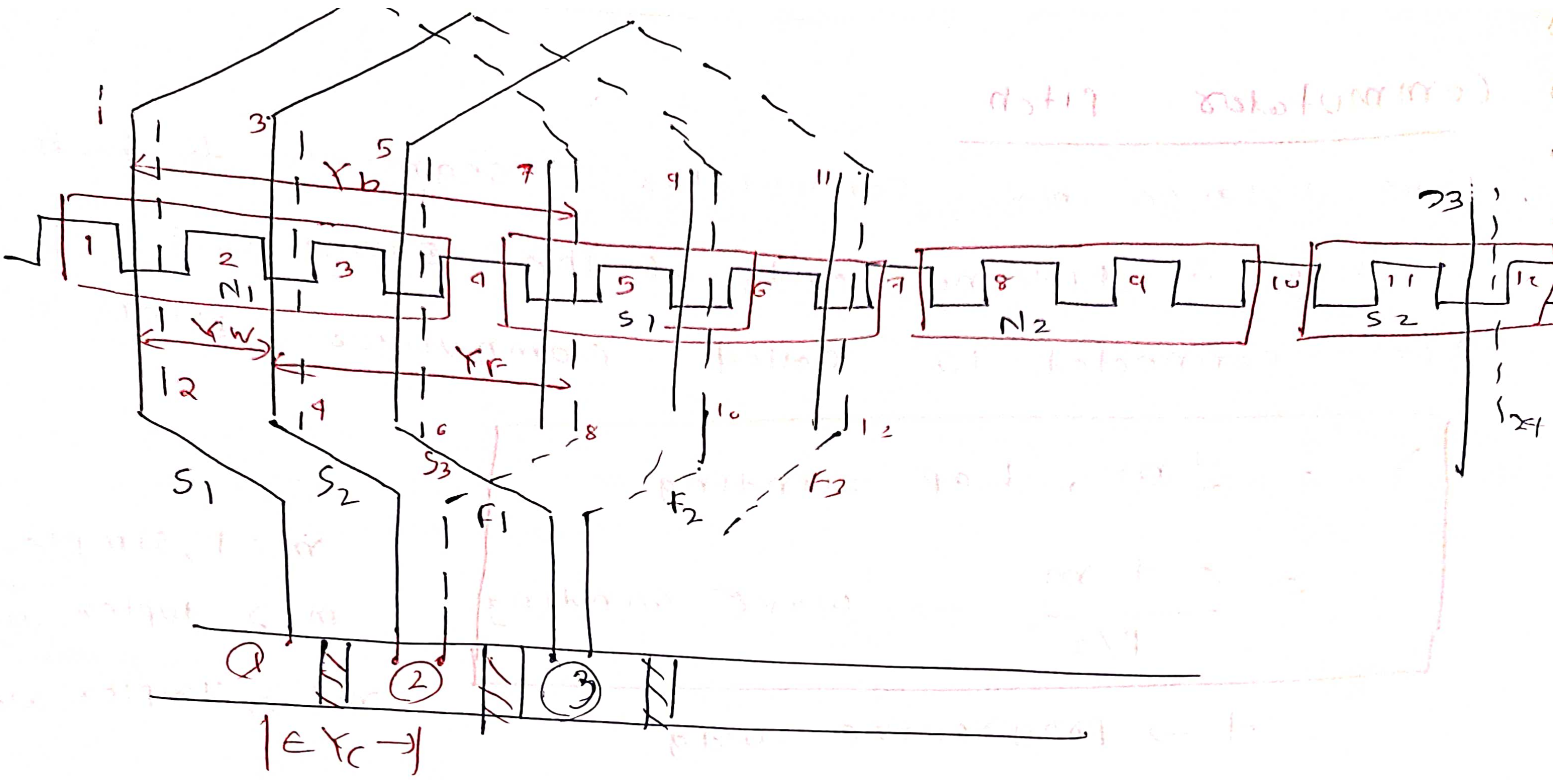
$Y_b = 8-1 = 7$

$Y_F = 8-3 = 5$ S/P = 3 PP = $\frac{S}{P} = \frac{12}{4} = 3$

$Y_c = 2-1 = 1$

$Y_W = 3-1 = 2$

$= Y_b - Y_F$



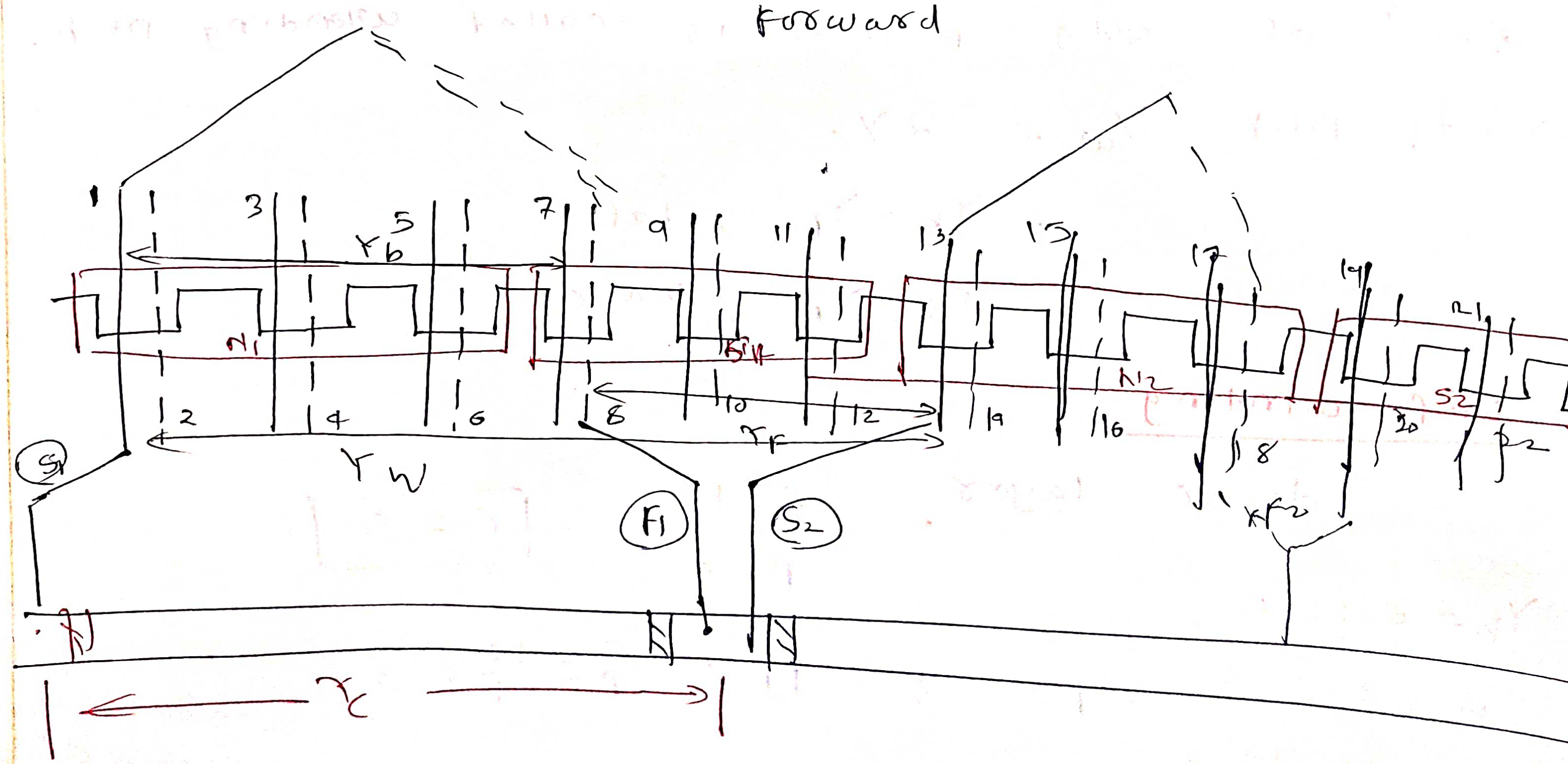
Forward & backward

Wave winding

$S = 12$ $\quad Y_b = 8 - 1 = 7$

$P = 4$ $\quad Y_F = 13 - 8 = 5$

Forward



$Y_b > Y_F$ progressive

$Y_c = \frac{c \pm 1}{P/2}$

$Y_w = 2Y_c = Y_b + Y_F = 7+5 = 12$

$= 13 - 1 = 12$

Dummy coils

if commutator pitch Y_c is an integer, dummy coils are not required, otherwise dummy coils are required. In → Lap winding, $Y_c = \pm m$ always integer, so dummy coils are not required.

→ In wave wdg, $Y_c = \frac{c \pm m}{P/2}$ may be integer or fraction

→ if it is integer, dummy coils are not required. if it is not an integer, dummy coils are required.

→ dummy coils are used to provide mechanical balance. dummy coils are electrically isolated coils i.e. they are not connected to the commutator.

→ No. of dummy coils are $= c' - c$

$c' = \frac{1}{2} US$

$c =$ active coils $= Y_c \cdot \frac{P}{2} \mp m$

Wave $S = 12$

$P = 4$ $c' = 12 = \frac{1}{2} US$

$$Y_c = \frac{12 \pm 1}{4/2} = \frac{13}{2} \text{ or } \frac{11}{2}$$

$= 6.5$ or 5.5

take

$Y_c = 6$

dummy coil $= c' - c$

$C = 6 \cdot \frac{4}{2} - 1$

$= 12 - 11 = 1$ coil

$= 11$

commutator segments required $= 11$

duplex $m = 2$, $Y_c = \frac{12 \pm 2}{4/2} =$ ~~8 or~~ ~~6~~ 7 or 5

no dummy coil is required

multiplex wdgs

multiplex wdgs are preferred intentionally to increase the no. of parallel paths.

→ Generally simplex wdgs are preferred in DC m/c.

Lap

$Y_c = \pm m$ $\boxed{A = mP}$

$m = 1$, $Y_c = \pm 1$, $A = P$

$m = 2$, $Y_c = \pm 2$, $A = 2P$

$m = 3$, $Y_c = \pm 3$, $A = 3P$

∴ For a given armature if $A \uparrow$

$V \downarrow$, $I \uparrow$

wave

$$Y_c = \frac{c \pm m}{P/2}, \quad \boxed{A = 2m}$$

$m = 1$, $Y_c = \frac{c \pm 1}{P/2}$, $A = 2$

$m = 2$, $Y_c = \frac{c \pm 2}{P/2}$, $A = 4$

If $m = 3$, $Y_c = \frac{C \pm 3}{P/2}$, $A = 6$

no. of brushes required $= A$ irrespective of wdg

Lap

$S = 8$, $P = 4$, $A = 4$

$Y_b = \frac{2C}{P} \pm k = \frac{2 \times 8}{4} \pm k = 4 \pm k$ $k = 1$

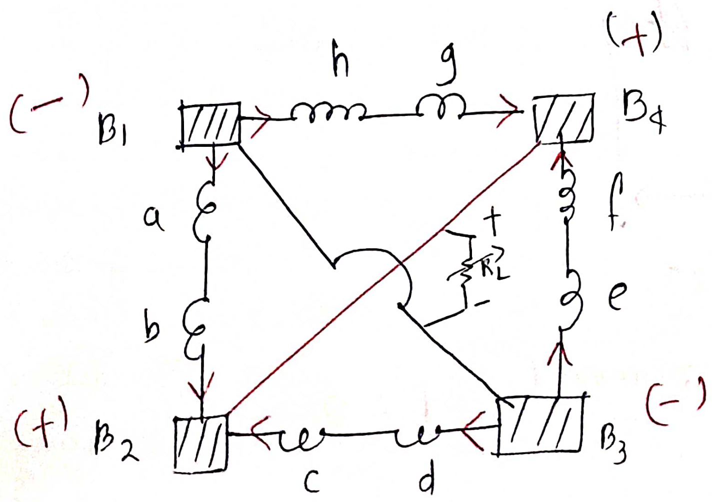
$= 4 + 1 = 5$

simplex $Y_c = +1$

$Y_w = 2Y_c = Y_b - Y_F$

$2 \times 1 = 5 - Y_F$ $Y_F = 5 - 2 = 3$

$Y_b = 5$	$Y_F = 3$
(1) + 5 = 6	6 − 3 = 3
3 + 5 = 8	8 − 3 = 5
5 + 5 = 10	10 − 3 = 7
7 + 5 = 12	12 − 3 = 9
9 + 5 = 14	14 − 3 = 11
11 + 5 = 16	16 − 3 = 13
13 + 5 = 18 (2)	18 − 3 = 15
15 + 5 = 20 (4)	20 − 3 = 17 (1)



$P_o = E I_a = E \cdot 4 I_c$

if one brush is removed (2 parallel paths removed)

$P' = E \, 2I_c$

$P' = \frac{P}{2}$

if two adjacent brushes are removed

$P'' = E \cdot I_c$ $\quad P'' = \frac{P}{4}$

if two opposite brushes are removed

$I = 0$ $\quad E = 0$ $\quad P = 0$

IES Lap, $P = 6$, $E, P \longrightarrow P = E \cdot 6 I_c$

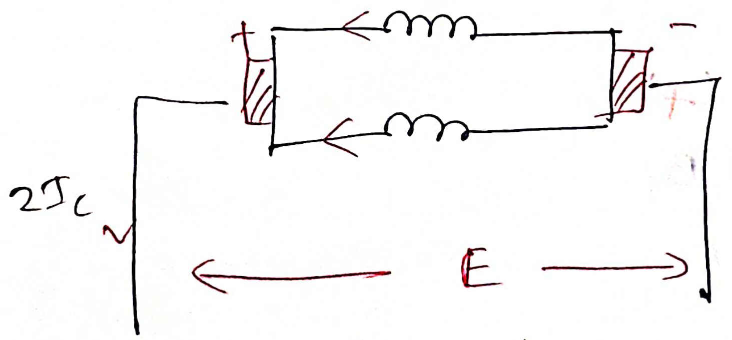
if one brush is removed

$E' = E$, $\quad P' = E \cdot 4 I_c$

$$\frac{P'}{P} = \frac{E \cdot 4 I_c}{E \cdot 6 I_c} = \frac{2}{3} \to P$$

simplex wave

$A = 2$



$P = E \cdot 2 I_c$

if one brush is removed $\quad P' = 0$

equalisier rings

In Lap winding, each parallel path is distributed under one pole pair only. due to flux unbalanced emf's induced in the parallel paths are unequal & the circulating currents comes into picture.

→ due to circulating currents, some brushes are overloading, commutation becomes poor (sparking at the brushes).

→ to avoid over-loading of brushes & to reduce ~~equal~~ equalise the ~~volt~~ flux unbalance effect equalisier rings are used in the lap windings.

→ In wave winding each parallel path is distributed under all poles. Therefore due to flux unbalance, both the parallel paths effects equally & circulating currents are not present in the m/c. Therefor equalisier rings are not required with wave wdg.

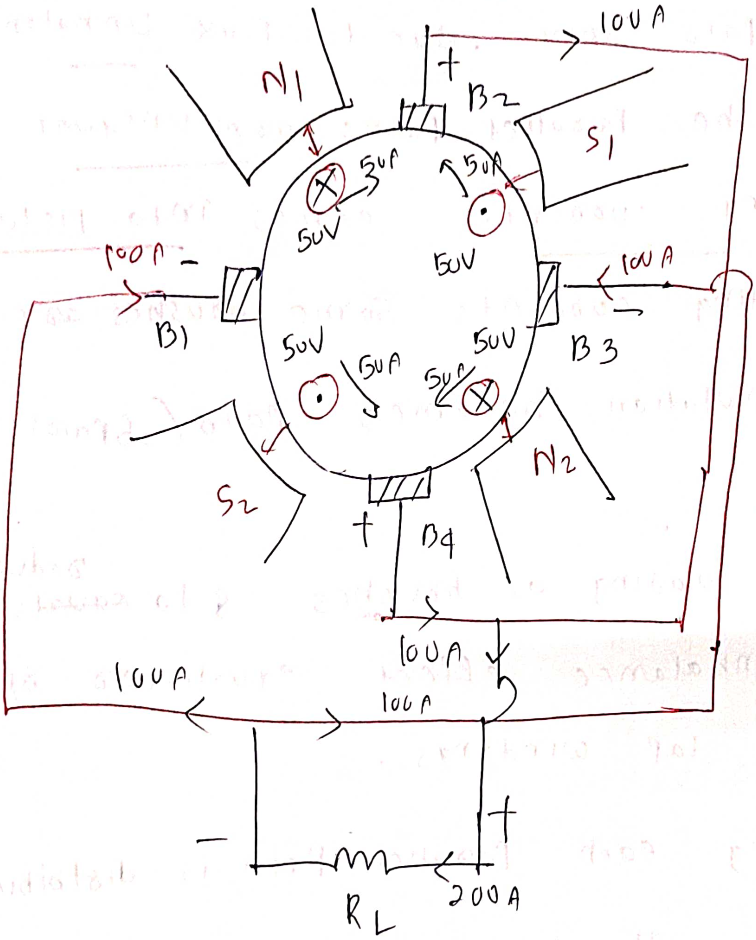
→ equalisier rings are made with copper & were placed on the back side of armature. The equipotential points of the armature wdg are connected to the equilisers rings.

→ The distance b/w equi-potential points is

$$Y_{eq} = \frac{2C}{P}$$

if it is integer, then only equaliser ring connections are possible.

AG under N_1, S_1, N_2, S_2 same



$V_{B_1B_3} = +50V - 50V = 0V$

$V_{B_2B_4} = -50+50 = 0V$

$I_C = 0$

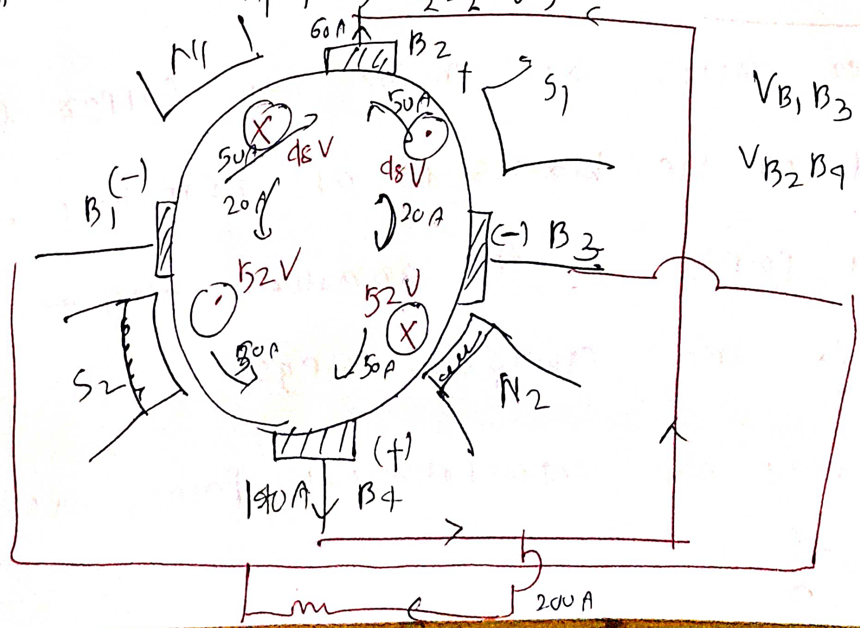
→ if resistance of each parallel path = 0.1 Ω

Armature cu loss = $I_a^2 R_a$

$= 4 I_p^2 R_p = 4 \times 50^2 \times 0.1$

$= 1000 W$

AG under $N_1 S_1 \uparrow$, $N_2 S_2 \downarrow$, due to wear of bearing



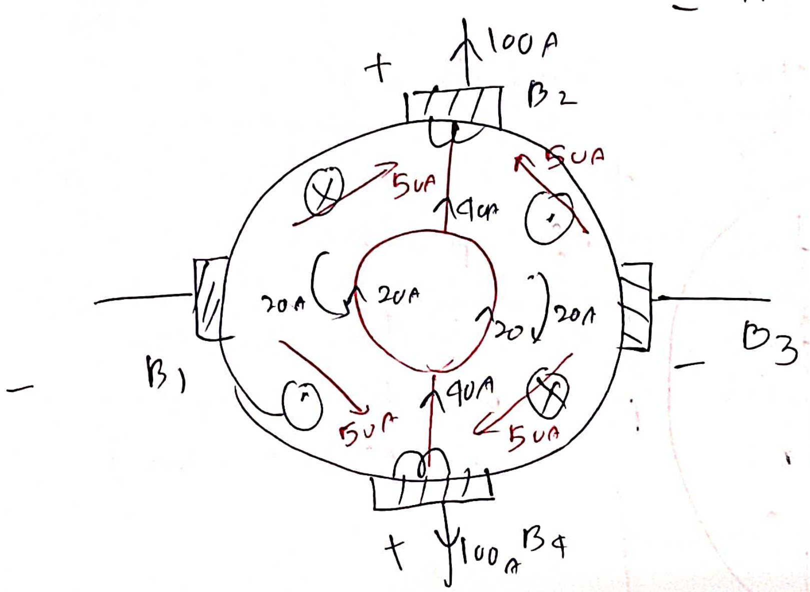
$V_{B_1B_3} = -48 + 48 = 0V$

$V_{B_2B_4} = -48 + 52 = 4V$

$$I_C = \frac{V_{B_2B_4}}{R_{B_2B_3} + R_{B_3B_4}} = \frac{4}{0.1 + 0.1} = 20 \text{ Amp}$$

Armature copper losses $= 2 \times (70)^2 \times 0.1 + 2 \times (30)^2 \times 0.1$

$= 1160 \text{ W} \uparrow, \eta \downarrow$



Applications

Lap → LV, HI

wave → HV, LI

large DC m/c → composite winding

→ Advantages of wave winding

i) only 2 ~~buses~~ brushes are required.

ii) equiliser rings are not required.

iii) In large commutator m/c, composite windings or Frog legs windings are used. composite winding is a combⁿ of simplex lap & multiplex wave winding

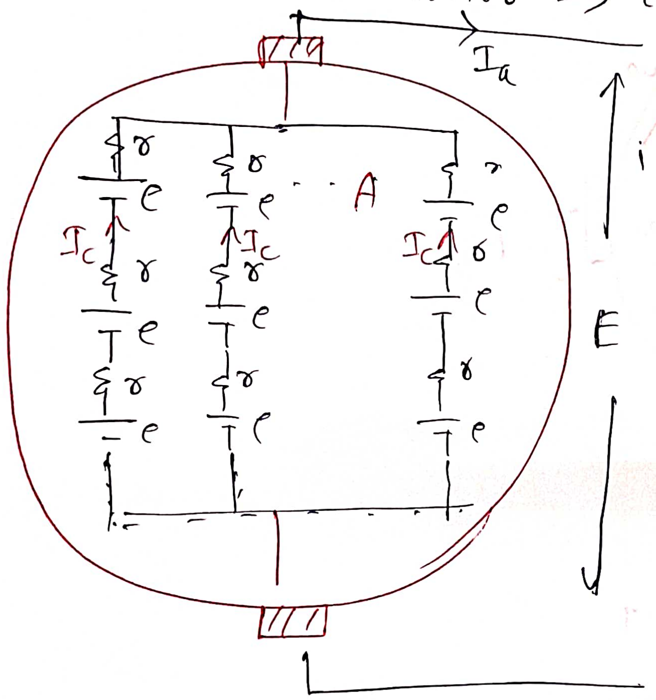
This winding does not require dummy coils & equiliser rings

Circuit model of a DC m/c

Z = total conductors

A = No. of parallel path

each coil conductor → cell (r, e)



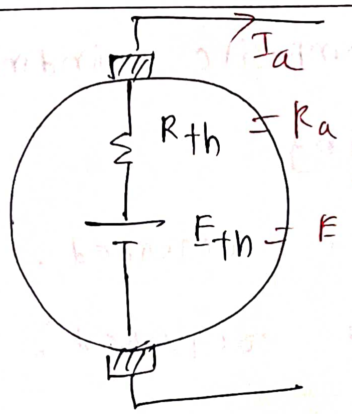
if P = 4

A = 4

B = 4

(2 +ve, 2 −ve)

Thevenin's equivalent ckt



$E_{th} = E_{oc} = E$

$$E = e \times \frac{Z}{A}$$

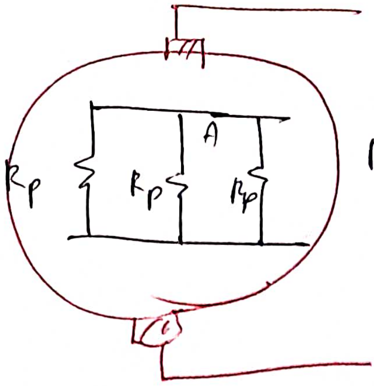
$E \propto \frac{1}{A}$

$$\frac{E_{Lap}}{E_{Wave}} = \frac{A_{wave}}{A_{Lap}}$$

→ $$\frac{E_{Lap}}{E_{wave}} = \frac{2}{P}$$

(*) $R_{th} = R_a$

Path resistance $R_p = r \frac{Z}{A}$



$R_{th} = R_a$

$$R_a = \frac{R_p}{A} = \frac{\gamma \frac{Z}{A}}{A}$$

$$R_a = \gamma \cdot \frac{Z}{A^2}$$

$$R_a \propto \frac{1}{A^2}$$

$$\boxed{\frac{R_{aw}}{R_{aL}} = \left(\frac{A_L}{A_W}\right)^2 = \left(\frac{P}{2}\right)^2}$$

(*) $I_a = A \cdot I_c$

$$\boxed{\frac{I_{aL}}{I_{aW}} = \frac{A_L}{A_W} = \frac{P}{2}}$$

(*) $$\frac{P_{Lap}}{P_{wave}} = \frac{E_L \cdot I_{aL}}{E_W \cdot I_{aW}} = \frac{2}{P} \times \frac{P}{2} = 1$$

$$\therefore \boxed{P_{Lap} = P_{wave}}$$

Q) 4 pole, DC m/c have 100 conductors emf induced in each conductor is 2V. The max^m current without overheating of armature supplied by the conductor is 10 Amp. Resistance of each conductor is 0.01 Ω, calculate power rating of DC m/c with lap winding & wave winding & calculate armature copper losses with lap winding & wave winding?

A: $Z = 100$, $e = 2V$, $I_c = 10\,A$

$\gamma = 0.01$

$P_{lap} = E_L \cdot I_{aL}$

$= e \times \frac{Z}{A} \times A I_c$

$= 2 \times \frac{100}{2} \times 10 = 500$ watt

$E_L = e \times \frac{Z}{A}$

$I_{aL} = A I_c$

$P_{lap} = E_L I_{aL} = e \times \frac{Z}{A} \times A I_c$

$= 2 \times 100 \times 10$

$= 2 kW$

$P_{wave} = E_w \cdot I_{aw} = e \times \frac{Z}{A} \times /A I_c$

$= 2 kW$

$R_{aL} = r \cdot \frac{Z}{A_L^2} = 0.01 \times \frac{100}{4^2} = \frac{1}{16} \Omega$

$R_{aw} = r \cdot \frac{Z}{A_w^2} = 0.01 \times \frac{100}{2^2} = \frac{1}{4} \Omega$

Armature copper loss (wave) $= I_{aw}^2 R_{aw}$

$= (20)^2 \times \frac{1}{4}$

$= \frac{400}{4} = 100 W$

" (lap) $= (40)^2 \frac{1}{16} = 100 W$

Q-15 $P = 4$, wave $E = 230V$, $P = 5kW$, $N = 1500$ rpm

windings reconnected as Lap $E = ?$, $P = ?$

$N = 1500$ rpm

A: P = same $= 5kW$

$\frac{E_L}{E_W} = \frac{A_W}{A_L} \Rightarrow \frac{E_L}{230} = \frac{2}{4}$

$\Rightarrow E_L = 115V$

(5) Emf eqⁿ & torque eqⁿ

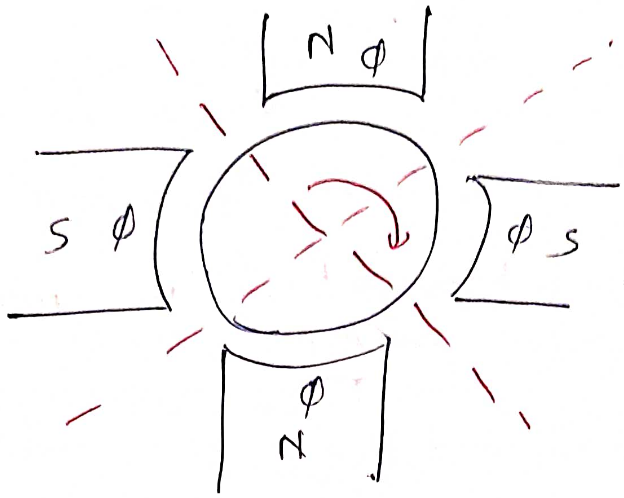
Z

ϕ

N → rpm

A

P



$\phi_1 = 0$

$t_1 = 0$

$E = e \times \frac{Z}{A}$

$\frac{N}{60}$ → rps

one rotation

Flux cut $= P\phi$ wb $= \phi_2$

Time $= \frac{60}{N}$ sec $= t_2$

$e = \frac{d\phi}{dt} = \frac{\phi_2 - \phi_1}{t_2 - t_1} = \frac{P\phi}{60/N}$ $\quad e = \frac{\phi P N}{60}$ V

$E = e \times \frac{Z}{A}$

** $$E = \frac{P\phi Z N}{60 A}$$

$E \propto \phi N$

$$\frac{E_2}{E_1} = \frac{\phi_2}{\phi_1} \times \frac{N_2}{N_1}$$

→ Lap $\quad A = P, \quad E = \frac{\phi Z N}{60}$

if $P = 2P$, $\quad E$ = same

→ wave, $\quad A = 2 \quad E = \frac{P\phi Z N}{60 \times 2}$ V

$E \propto P$

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

$$\omega = \frac{2\pi N}{60} \text{ rad/sec}$$

$$\frac{N}{60} = \frac{\omega}{2\pi}$$

$$E = \frac{\phi Z P}{A} \times \frac{\omega}{2\pi}$$

$$\boxed{E = K \phi \omega}$$

$$K = \frac{ZP}{2\pi A} = \text{DC m/c constant}$$

Torque eqn

$$P = T_{em} \times \omega = E I_a$$

$$T_{em} \times \omega = E I_a$$

$$T_{em} = \frac{P}{\omega} = \frac{E I_a}{\omega} \ N\text{-}m$$

$$T_{em} \times \frac{2\pi N}{60} = \frac{\phi Z N P}{60 A} \times I_a$$

$$\boxed{T_{em} = \frac{1}{2\pi} \frac{\phi Z I_a P}{A} \ N\text{-}m}$$

$$T_{em} = K \phi I_a \ N\text{-}m$$

$$T_{em} \propto \phi I_a$$

$$\boxed{\frac{T_2}{T_1} = \frac{\phi_2}{\phi_1} \times \frac{I_{a2}}{I_{a1}}}$$

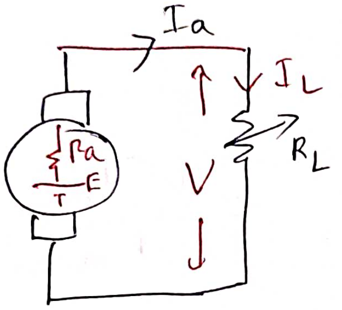
6) **Types of DC m/c**

- separately excited DC m/c
- self excited DC m/c
  - shunt
  - series
  - compound

Compound → long shunt
→ short shunt

PM DC M/C permanent magnet DC M/C

ϕ = const. $E \propto N$ no field wdg is present $T \propto I_a$

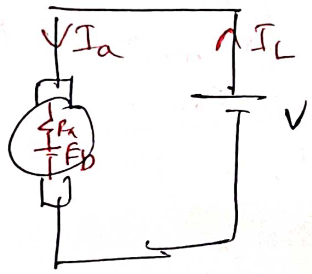


$E = V + I_a R_a + B.D$

$E = K \phi \omega_r = k_1 \omega_r$ $\quad k_1 = \frac{\phi Z P}{2\pi A}$

$T = K \phi I_a = k_1 I_a$

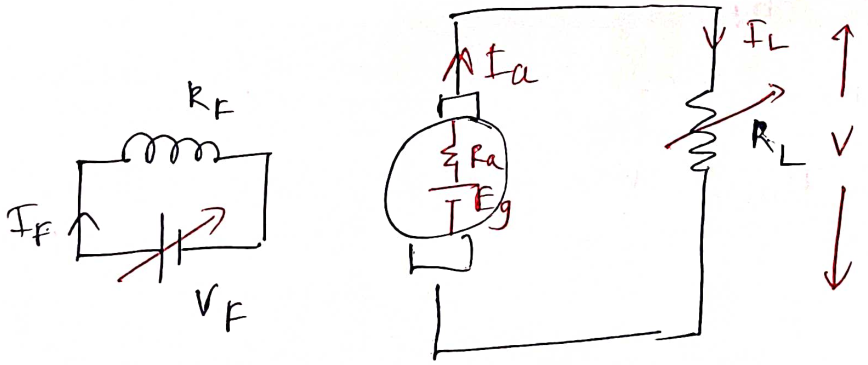
motor



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

B.D = 2 X B.D /each brush

Separately excited DC Generator



$V = I_L R_L$

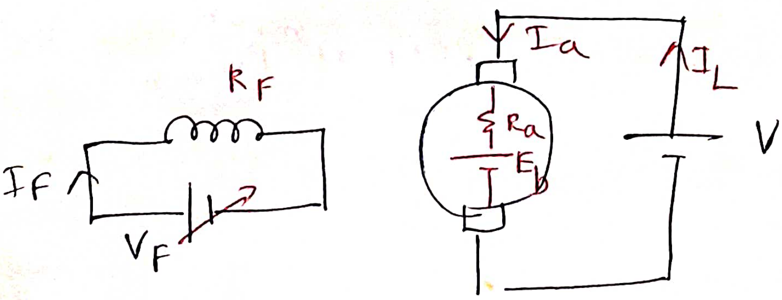
$E_g = V + I_a R_a + B.D$

$I_L = I_a$

$P_o = V I_L$

$P_g = E_g I_a$

separately excited motor



* $E_b = V - I_a R_a - B.D$

$I_L = I_a$

B.D. neglected

E_b $\quad P_{in} = V I_L$

$I_a E_b = I_a V_a - I_a^2 R_a$

$P_{mech} = P_{in} -$ armature copper losses

$P_{mech} = V I_a - I_a^2 R_a$

Cond^n for max^m P_{mech} O/P

$$\frac{dP_{mech}}{dI_a} = 0$$

$V - 2I_a R_a = 0$ $\qquad I_a = \frac{V}{2R_a} = \frac{V - E_b}{R_a}$

$E_b = \frac{V}{2}$ $\qquad N$ at max^m $P_{mech} = \frac{N_{N.L}}{2}$

(a) $V = 200V$ $\quad E_b$ at max P_{mech} $\quad E_b = 100V$

(q) $N_0 = 1200$ rpm $\quad N$ at max $P_{mech} = ?$

N.L = $I_a \simeq 0$, $E_{b_1} = V$

$N_0 \propto E_{b_1} = V$

At max P_{mech}, $E_{b_2} = V/2$

$N_2 \propto E_{b_2} = \frac{V}{2}$

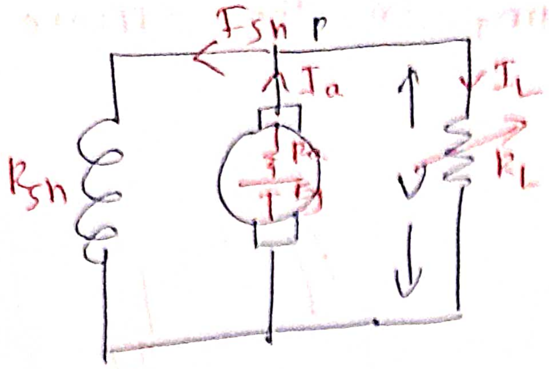
$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}$$

$\Rightarrow \frac{N_2}{N_0} = \frac{V/2}{V} = \frac{1}{2} \Rightarrow N_2 = \frac{N_0}{2}$

$= 600$ rpm

= Speed at max^m P_{mech}

DC shunt generator



KCL

$I_a = I_{sh} + I_L$

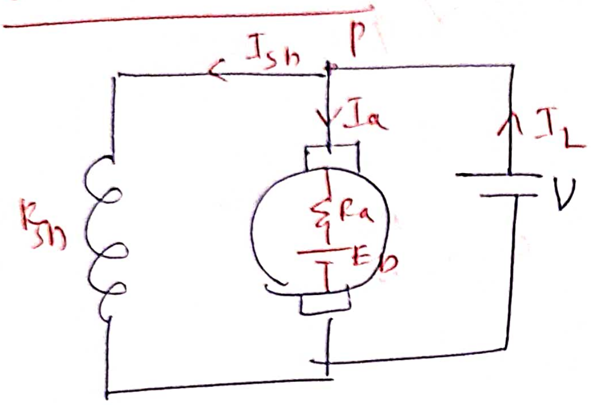
$I_{sh} = \frac{V}{R_{sh}}$

$\phi \propto I_{sh}$

KVL

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

DC shunt motor



KCL

$I_L = I_{sh} + I_a$

$I_a = I_L - I_{sh}$

$\phi \propto I_{sh} = \frac{V}{R_{sh}} = \phi_{const.}$

→ constant flux motor.

KVL $\boxed{E_b = V - I_a R_a - B.D.}$

DC shunt m/c

$E = V \pm I_a R_a \pm B.D$

$I_a = I_L \pm I_{sh}$ $\quad I_{sh} = \frac{V}{R_{sh}}$

+ → Gen

− → motor

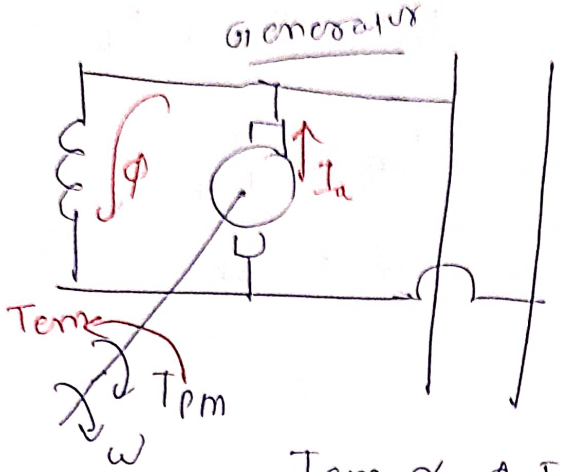
Q) DC belt driven shunt generator supplies power to the DC busbar. if its belt snaps (PM failed) the m/c behaves as a

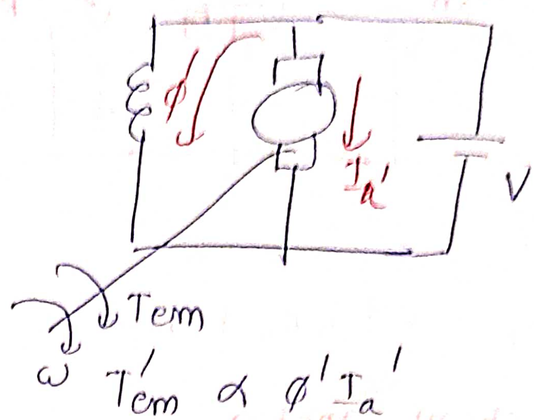
a) DC shunt generator rotating in the same direction

b) DC shunt generator rotating in the opposite direcn

c) DC shunt motor rotating in the same direction

d) DC shunt motor rotating in the opposite "





$T_{em} \propto \phi I_a$

↳ CCW

$\omega \rightarrow CW$

$T'_{em} \propto \phi' I_a'$

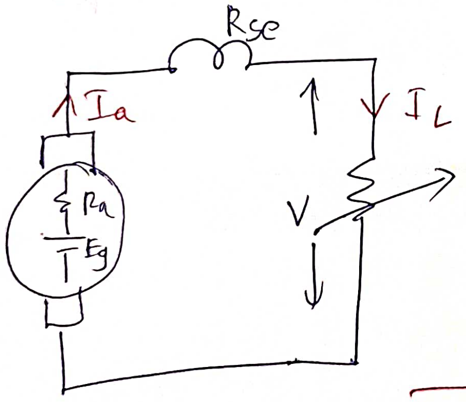
$\propto \phi(-I_a)$

$T'_{em} \propto -T_{em}$

↳ CCW

$\omega \rightarrow CW$

DC series generator



$I_a = I_L$

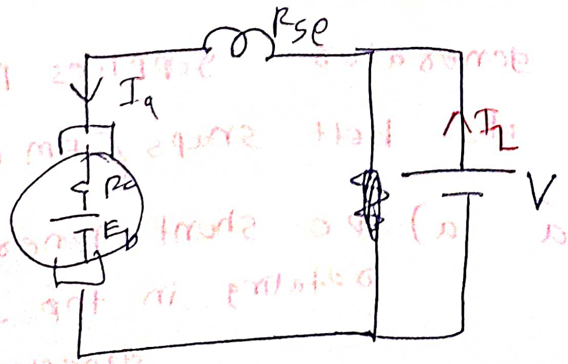
$\phi \propto I_a = I_L$

KVL

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

$$E_g = V + I_a(R_a + R_{se}) + BD$$

DC series motor



$I_L = I_a$

KVL

$V = E_b + I_a R_a + I_a R_{se} + BD$

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

DC series m/c

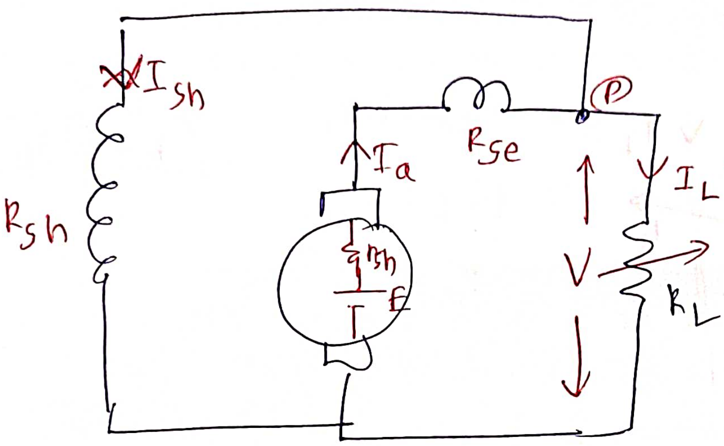
$E = V \pm I_a(R_a + R_{se}) \pm B.D$

+ → gen
− → motor

$I_a = I_L$ $\phi \propto I_a = I_L$

compound m/c

long shunt : shunt field connected across armature & series field



$\phi_{se} \propto I_a$ ∵ $\phi_{sh} \propto I_{sh}$

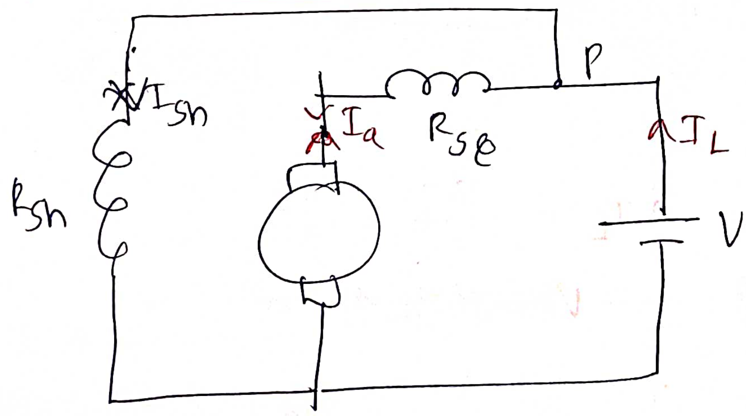
$I_{sh} = \frac{V}{R_{sh}}$

KCL

$I_a = I_L + I_{sh}$

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

long shunt compound motor



$\phi_{se} \propto I_a$

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

KCL $I_L = I_a + I_{sh}$

$I_a = I_L - I_{sh}$

KVL $V = E_b + I_aR_a + I_aR_{se} + BD$.

$E_b = V - I_aR_a - I_aR_{se} - B.D$

long shunt m/c

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

$I_a = I_L \pm I_{sh}$ $\phi_{se} \propto I_a$

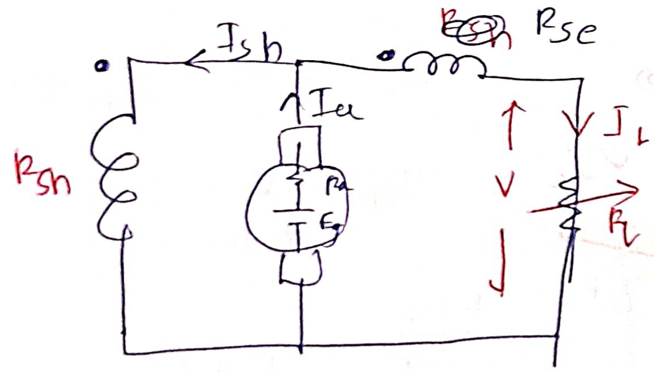
$+ \rightarrow G$

$- \rightarrow m$ $\phi_{sh} \propto I_{sh} = \frac{V}{R_{sh}}$

Short shunt

Shunt Field is connected across armature only

i) Generator



$\phi_{se} \propto I_L$; $\phi_{sh} \propto I_{sh}$

KCL

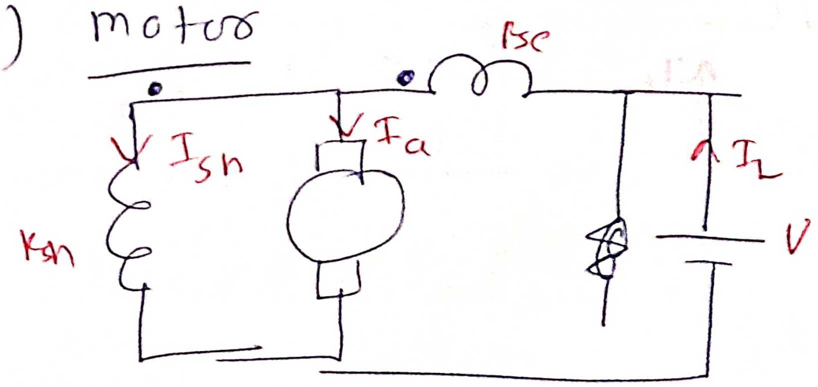
$I_a = I_L + I_{sh}$

KVL

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

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$

ii) motor



$\phi_{se} \propto I_L$

$\phi_{sh} \propto I_{sh}$

KCL

$I_L = I_a + I_{sh}$

$I_a = I_L - I_{sh}$

KVL

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

$E_b = V - I_a R_a - I_L R_{se} - B.D$

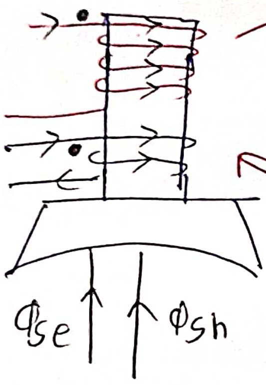
$$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}}$$

DC compound m/c short shunt

$E = V \pm I_a R_a \pm I_L R_{se} \pm B.D$

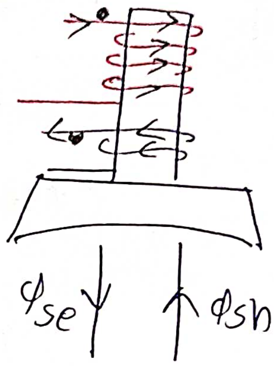
$I_a = I_L \pm I_{sh}$

$\phi_{se} \propto I_a$; $\phi_{sh} \propto I_{sh} = \frac{V \pm I_L R_{se}}{R_{sh}}$ + → Gen, − → motor



$\phi = \phi_{sh} + \phi_{se}$

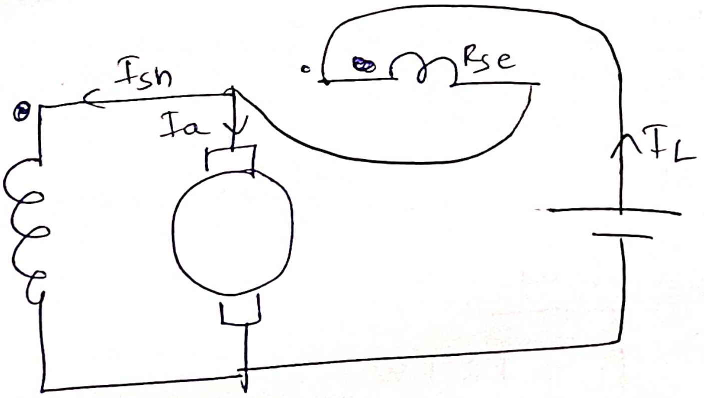
cumulative compound



$\phi = \phi_{sh} - \phi_{se}$

differential compound

under normal working condn, $\phi_{sh} > \phi_{se}$



cumulative

Q) cumulative compound generator supplies power to the DC bus. if its prime mover is failed then it behaves as a

a) cumulative compound motor rotating in the same direction

b) C C M rotating in " opposite "

c) D C M " " " " "

d) D C M " " " same " ✓

Armature reaction ①

The effect of armature Flux (ϕ_a) on main field Flux (ϕ_m) is called Armature reaction.

effects

1) Demagnetisation (Reduction of net flux)

→ In Generator, Generated voltage & terminal voltage will decrease.

→ In motor, speed is increased & torque is decreased. since $N \propto \frac{1}{\phi}$ and $T \propto \phi$.

2) crossmagnetisation (distortion of Air gap Flux) → sparking at the brushes

GNA (Geometrically Neutral axis)

→ GNA is the axis which is always perpendicular to the main field flux or d-axis.

→ The GNA is itself qudrature axis and also called Brush axis, since the brushes are always fixed along the GNA.

→ GNA is also called axis of commutation, since commutation process takes place along the brush axis GNA.

MNA (magnetic Neutral axis)

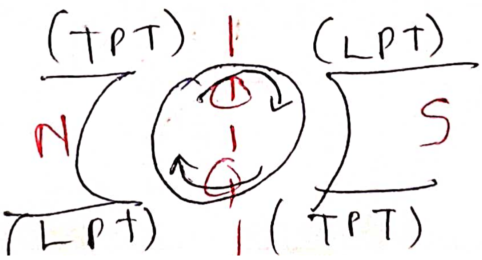
→ It is always perpendicular to the resultant Flux distribution.

(Leading pole tip) LPT

It is the pole end at which the armature conductors are entering into the magnetic field.

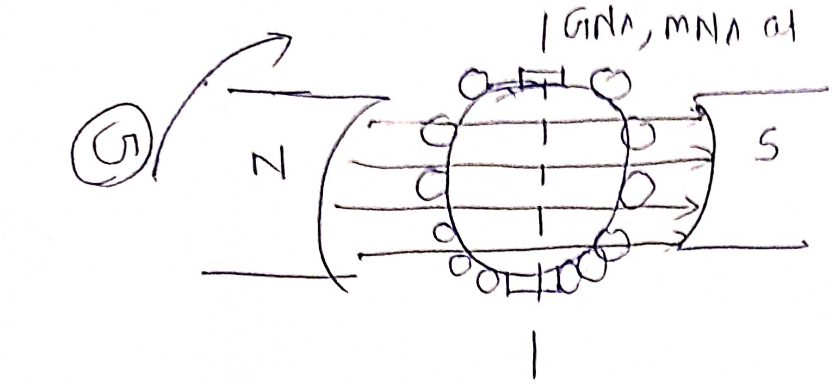
(Trailing Pole tip) TPT

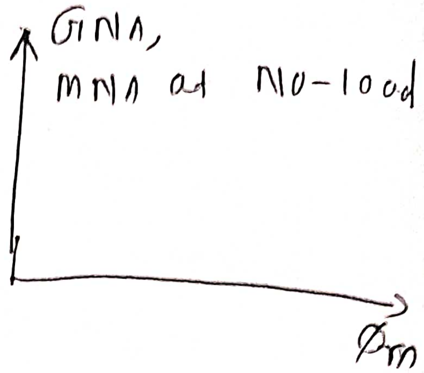
Pole end at which the armature conductors are leaving from the magnetic field.



* At no-load ($I_f \neq 0$, $I_a = 0$)

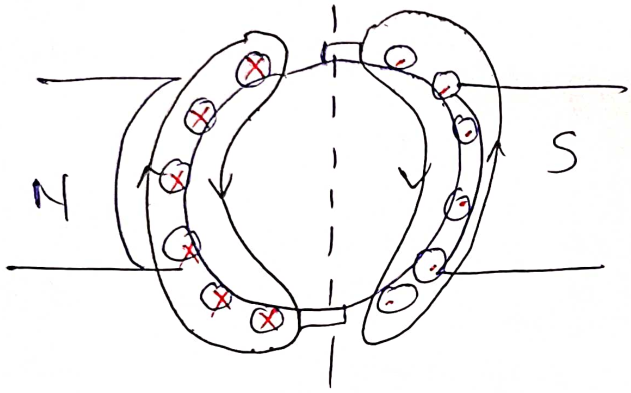
only field current (I_f) is considered, $I_a = 0$

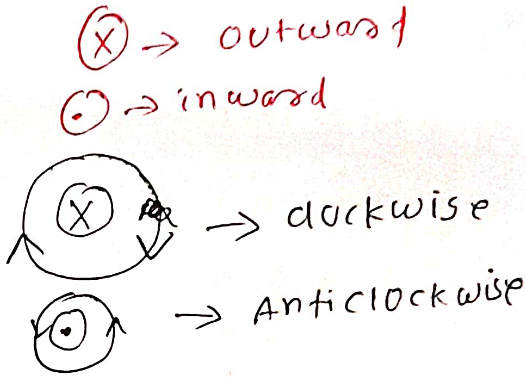


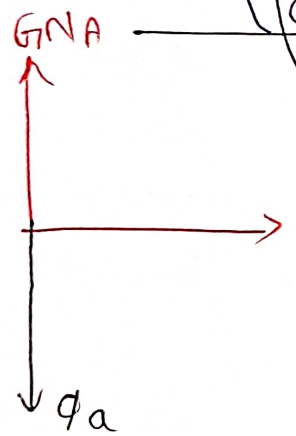


* on-load condⁿ ($I_f = 0$, $I_a \neq 0$)

only armature current is considered :

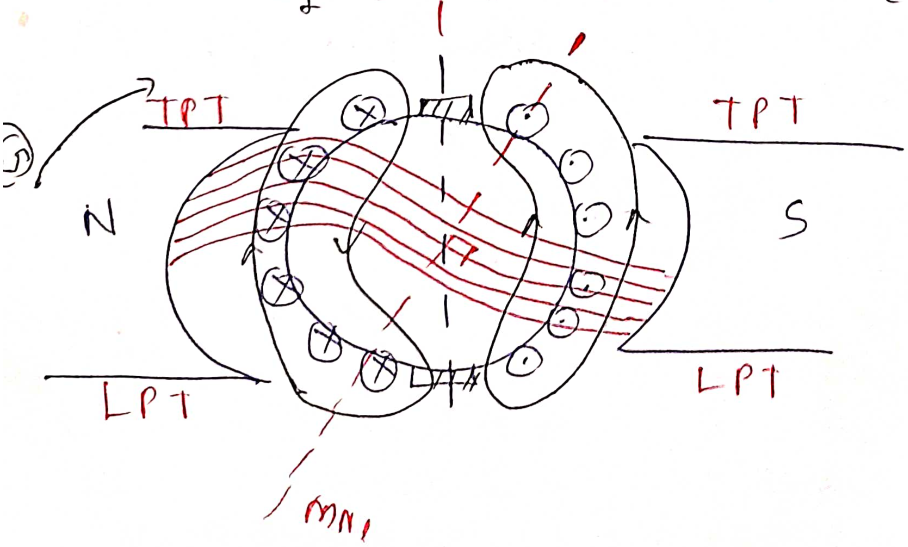


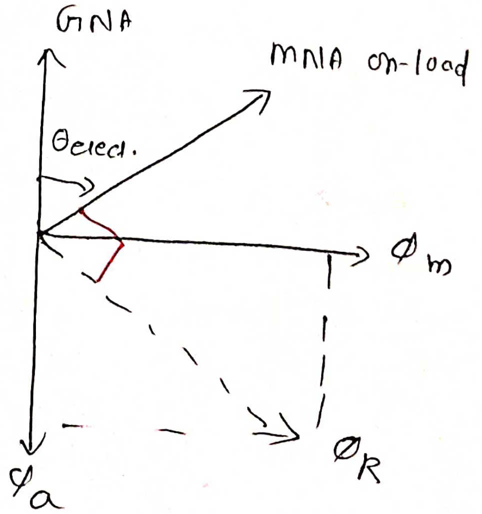




* on-load condⁿ (practical case) ($I_f \neq 0$, $I_a \neq 0$)

both I_f & I_a are considered





Under No-load condⁿ, armature current is zero. Armature flux is zero. MNA coincides with GNA.

Under loaded condⁿ, in Generator at LPT armature flux is acting opposite to the main field flux.

→ At the trailing pole tip the armature flux adds to the main field flux and at the leading pole tip opposes & therefore strengthening effect at trailing pole tip & weakening effect at leading pole tip.

→ Therefore the flux under the pole becomes less than no-load value. This is called demagnetising effect.

The demagnetising effect can be overcome by adding extra turns to the main field winding or by increasing cross-section of field winding copper wire. This method requires more copper, cost of the machine increases, Field copper loss ↑, efficiency of the m/c ↓.

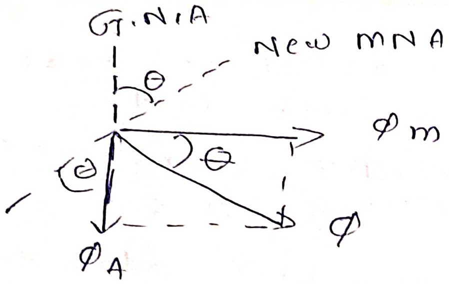
Cross magnetisation

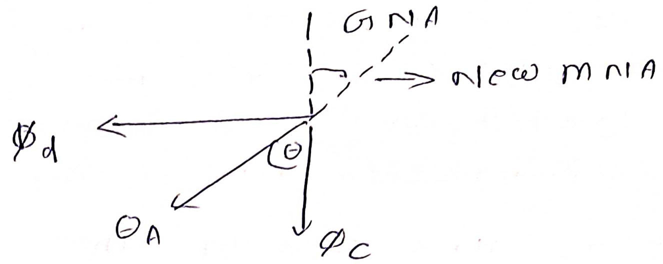
→ Armature flux crosses the main field flux. Hence this flux is called cross flux & effect due to this flux is called cross magnetising effect.

effects of cross magnetisation

i) MNA shifts from GNA by an angle θ in the direction of Generator rotation or opposite to the motor rotation.

ii) Iron losses will be increased, efficiency will decrease.





→ The component ϕ_d is in direct opposition to the main Flux (ϕ_m). It has a demagnetising effect on the main Field Poles. It is called demagnetisi[ng] component of Armature reaction.

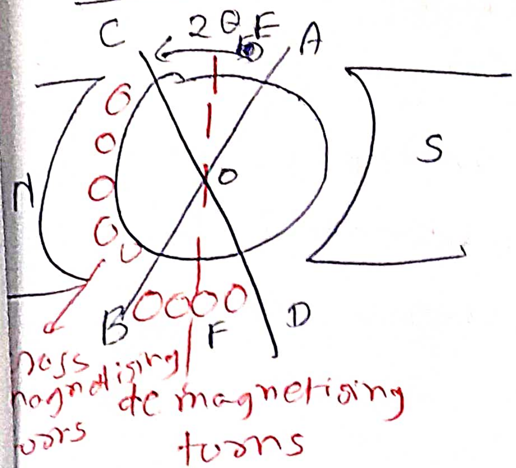
→ ϕ_c is right angles to the ϕ_m. It distorts the main field. It is called the cross-magnetising or distorting component of Armature reaction.

Conclusion

i) with brushes located along GNA (i.e. $\theta = 0°$), there is no demagnetising component of armature reaction ($\phi_d = 0$). There is only distorting or cross magnetising effect of Armature reaction.

ii) with brushes shifted from GNA armature reaction will have both demagnetising & cross magnetising component. Their magnitude depend on amount of shift which is directly proportional to the armature current.

Demagnetising & cross magnetising conductors



Let Z = total No. of Armature conductors

I = current in each armature conductor

$= I_a/2$ ... For wave winding

$= I_a/P$ ... For lap winding

θ_m = Forward lead in mechanical degrees

The no. of armature conductors in angles AOC & BOD is $\frac{4\theta_m}{360} \times Z$

As two conductors constitute one turn.

total No. of turns in these angles $= \frac{2\theta_m}{360} \times ZI$

Demagnetising Amp-turns per pair of poles $= \frac{2\theta_m}{360} \times ZI$

" " per pole $= \frac{\theta_m}{360} \times ZI$

$$AT_d/\text{pole} = \frac{\theta_m}{360} \times ZI$$

cross magnetising Amp-conductor/pole $= \frac{Z}{P} - Z \times \frac{2\theta_m}{360}$

$= \frac{Z}{P}\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$

$$AT_c/\text{pole} = ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$$

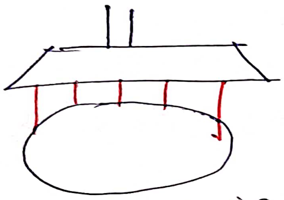
methods to limit cross magnetising effect

① by using high reluctance pole tips

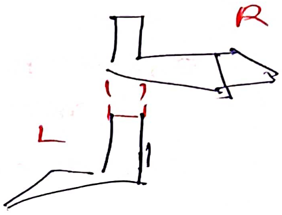
This is achieved by the following methods

a) by using eccentric poles or chamferred poles

b) by arrangening pole shoe laminations left & right alternatey.

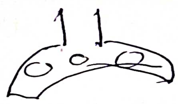


eccentric poles



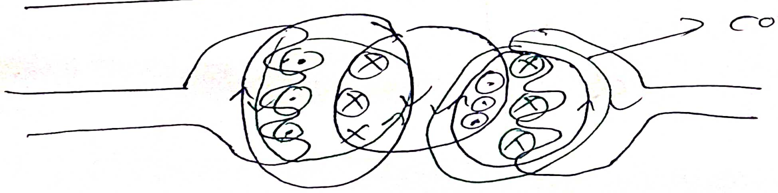
$$\downarrow \phi_a = \frac{ATa}{R\uparrow}$$

② Armature flux path reluctance can be increased by drilling holes in the pole shoe.



→ due to above 2 methods main field flux is also decreased in addition to the armature flux. The reduction in main field flux can be compensated by adding extra turns to the main field winding therefore more copper is required, field copper loss ↑, efficiency ↓, cost of the m/c ↑.

③ By using compensating winding / compoles



→ compensating winding is inserted in the slots made on the pole faces (pole shoe)

→ compensating wdg is connected in series with the armature winding.

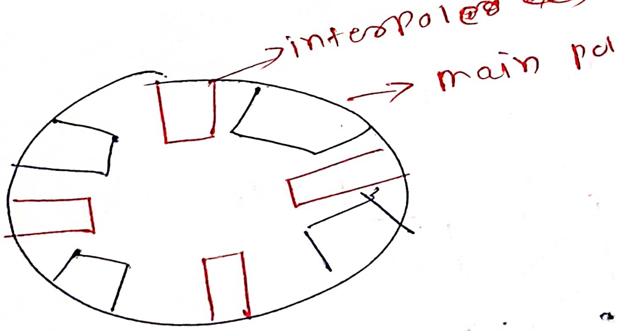
→ mmf produced by the compensating wdg is acting opposite to the armature mmf. Therefore armature mmf under the pole is neutralised.

by using interpoles

→ ~~Interpolar axis~~
Interpoles are placed along the quadrature axis i.e. interpolar axis.

→ interpole wdg is connected in series with the armature wdg through the brushes. So the cross magnetising effect at interpolar region is neutralised.

→ No. of interpoles required is equal to main poles 'p' but in order to reduce the cost of small DC machine no of interpoles used is equal to $\frac{p}{2}$.



Commutation

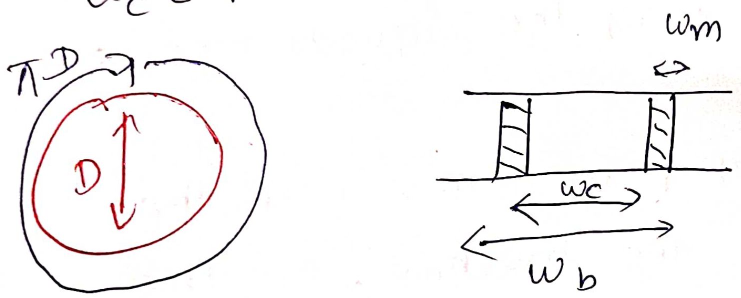
The process of current reversal in an armature coil by means of brushes & commutator segments is called commutation.

Commutation period

It is the time required for commutator to advance one commutator segment.

$$T_c = \frac{W_c}{U_c} \text{ sec} = \frac{W_b}{U_c}$$

U_c = peripheral velocity $= \frac{\pi D N}{60}$ m/s



$W_b = W_c + W_m$

$W_c = W_b - W_m$

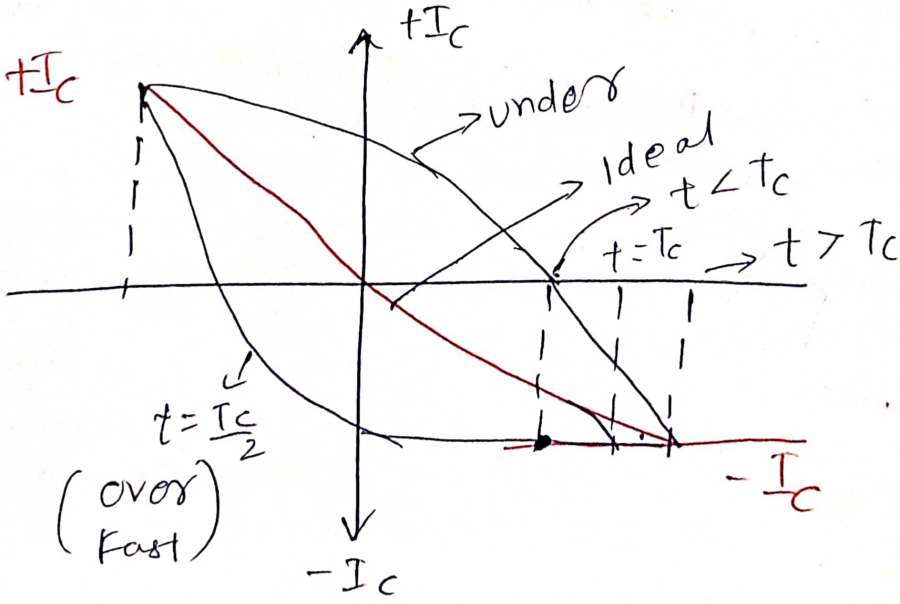
$W_c \simeq W_b$

t = time for current reversal

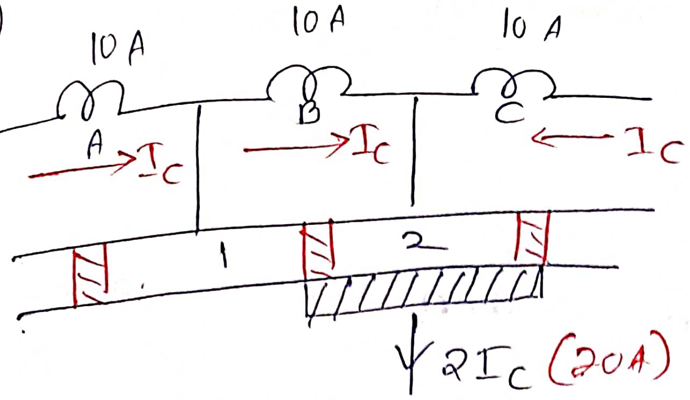
→ if t = T_c (commutation period) → Ideal commutation

if $t > T_c$ → delayed commutation / under commutation

if $t < T_c$ → Fast commutation / over commutation



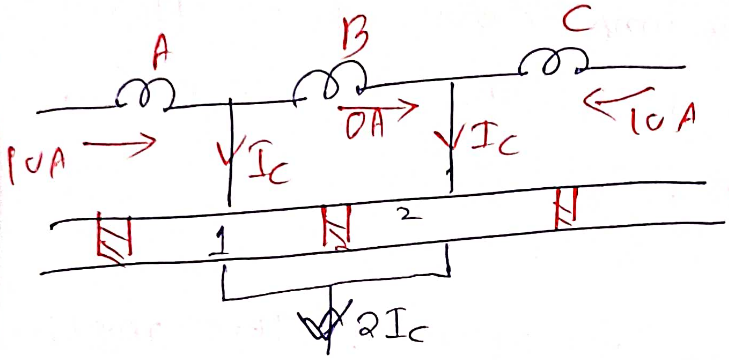
(1)



100% brush segment (2)

coil (B) $i = +I_c$

(2)

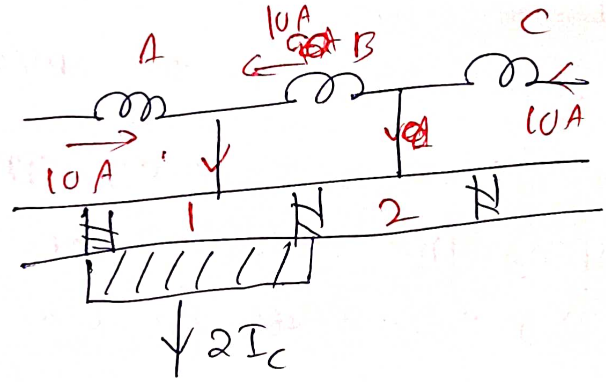


coil (B) $i = 0$

50% brush → segment (1)

50% brush → segment (2)

(3)



coil (B), $I = -I_c$

100% brush → segment (1)

coil B $i = -I_c$

practical DC m/c has delayed commutation.

The reason for delayed commutation is

i) cross-magnetising effect of AR

ii) self inductance of a coil

$$\text{reactance voltage } (V_r) = L_c \frac{2I_c}{T_c} \text{ volt}$$

$$L \frac{I_c - (-I_c)}{T_c} = \frac{2LI_c}{T_c}$$

Methods for improving commutation

i) Resistance commutation
ii) Voltage commutation

Resistance commutation

→ This is acheived by using carbon brushes insteed of copper brushes.
→ with carbon brushes, the time constant of the local circuit is decreased & the response from coil decays at faster rate.

Voltage commutation

→ This is acheived by using interpoles. This method is suitable for both large & small DC m/c.
→ The direction of interpole Flux is acting opposite to the armature Flux along the brush axis. Therefore cross-magnetising effect in b/w the poles is neutralized.
→ The coil undergoing commutation cuts the interpole axis & dynamically induced emf is produced in it.
→ This emf is acting in phase opposition to the reactance voltage present in the coil. Therefore reactance voltage effect is also neutralized.
→ Good commutation is possible with interpoles.

DC Generator characteristics

1) Open circuit characteristics (O.C.C) E_0 vs I_f $|_{N=const.}$

→ This curve shows the relationship b/w the generated emf at no-load (E_0) and the field current (I_f) at constant speed.

→ it is also known as magnetisation characteristics.

2) Internal characteristics (E_g vs I_a) N = const.

→ This curve shows the relationship b/w the generated emf on load (E_g) & the armature current (I_a).

→ This Emf (E_g) is less than (E_0) due to demagnetising effect of Armature reaction. Therefore, this curve will lie below the O.C.C.

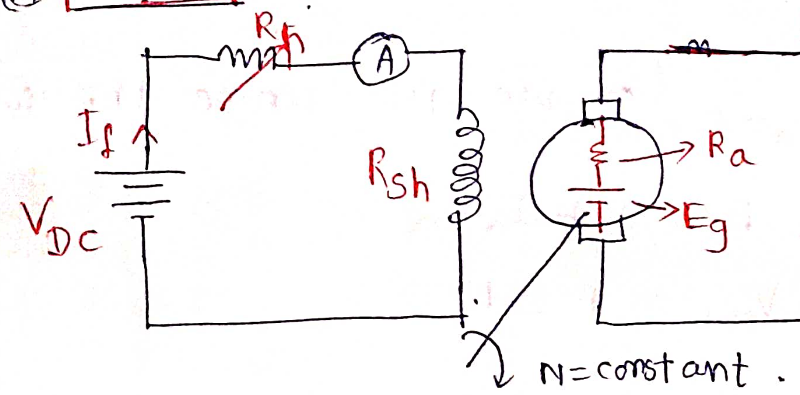
3) External characteristics (V_t vs I_L) $|_{N=const.}$

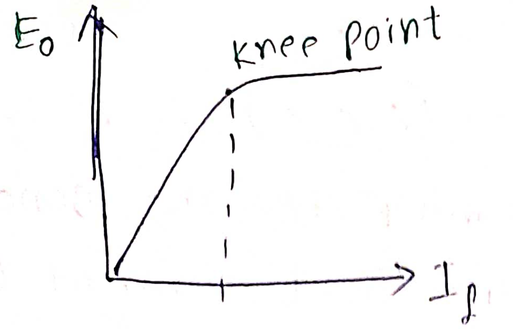
→ This curve shows the relationship b/w the terminal voltage (V_t) & load current (I_L).

→ The terminal voltage (V_t) will be less than E_g due to a voltage drop in the armature circuit. Therefore this curve will lie below the internal characteristics.

Characteristics of separately excited DC Generator

① **O.C.C**





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

$E_g \propto \phi N$ → speed const

$$\boxed{E_g \propto \phi \propto I_f}$$

$$\phi \propto I_f = \frac{V_{DC}}{R_{sh} + R_h} \quad \text{if } I_f = 0,\ \phi = 0$$

Before Saturation

$\phi \propto I_f$ $\boxed{\therefore E_0 \propto I_f}$

→ The curve is a ~~straigh~~ straight line starting from zero so long as the poles are unsaturated.

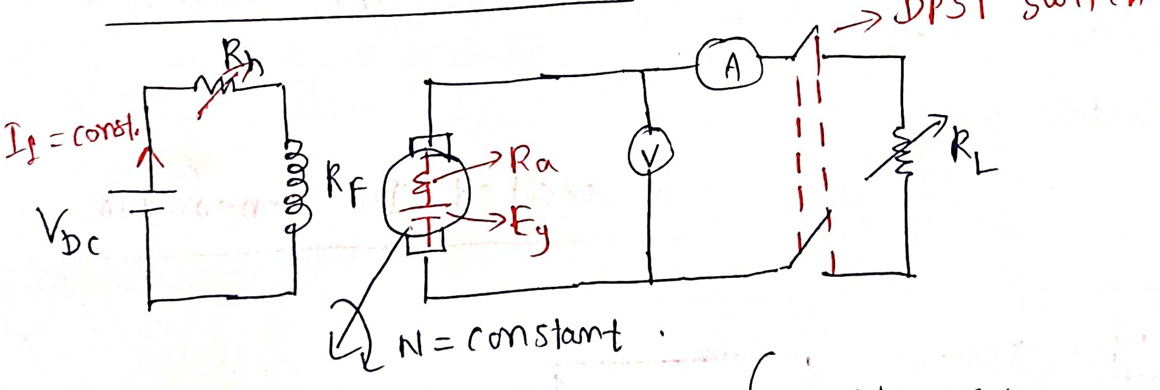
After Saturation

→ As the flux density increases, the poles become saturated.

→ So increase in I_f will not increase E_0 accordingly.

$\phi = \phi_{sat}$ = constant. $\boxed{E_0 = \text{constant}}$

2) & 3) **External characteristics** (V_t & I_L) & **internal characteristics** (E_g vs I_a)



(Double pole single throw)

when DPST = open, $I_a = 0$

$\phi = \phi_{rated}$

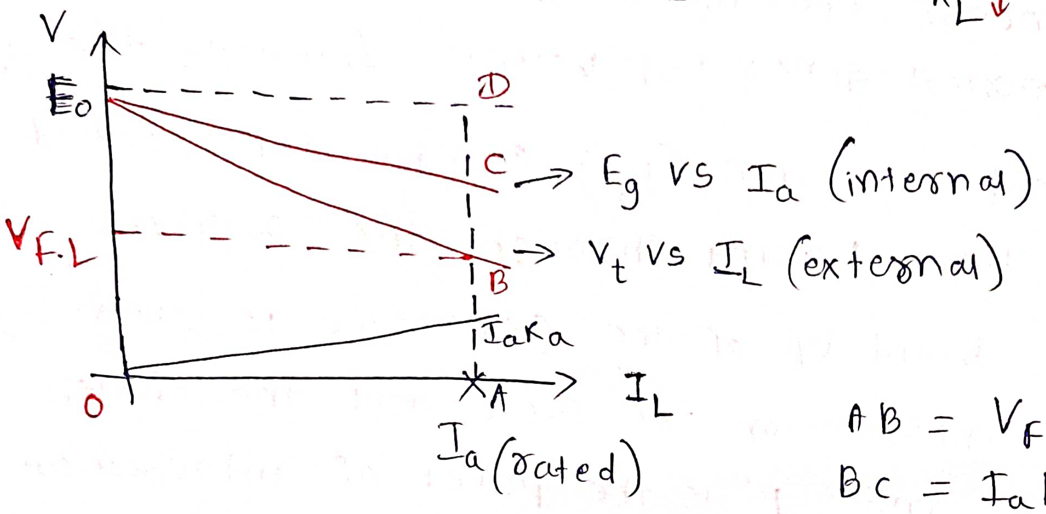
$N = N_{rated}$

$E = V + I_a R_a$ ($I_a R_a \to 0$)

$V_{N.L} = E = E_0$

DPST close

Vary R_L in steps record V & I_L. $\uparrow I_L = \frac{V}{R_L \downarrow}$



AB = V_{FL}

BC = $I_a R_a$ drop

CD = drop due to Armature reaction

when load ↑, voltage ↓

Reason for voltage drop

i) $I_a R_a$ drop

ii) drop due to Armature reaction

Applications

i) used as voltage source

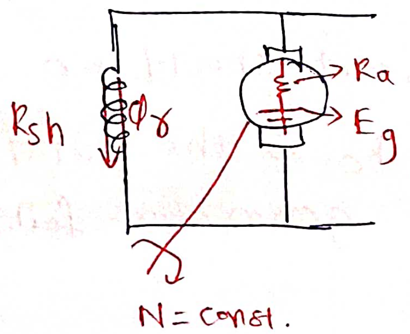
ii) battery charger

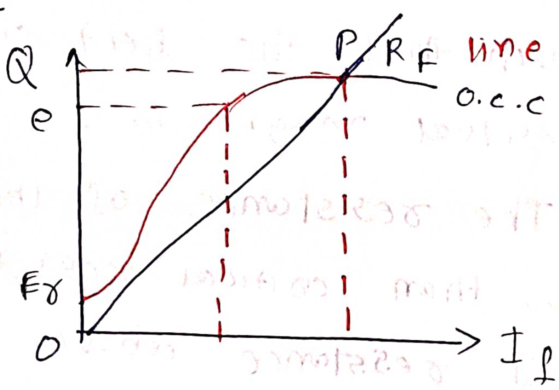
iii) main exciter of synchronous machine ;

characterstics of self-excited Generator

Cond^{n}s to buildup the voltage

1) Shunt generator





→ if the generator runs at a constant speed, some amount of e.m.f. will be generated due to residual magnetism in the main poles.

→ This small e.m.f circulates a field current which in turn produces additional flux to reinforce the original residual flux.

→ This process continues and the generator build up the normal generated voltage following the O.C.C.

→ The field resistance (R_f) can be represented by a straight line passing through the origin.

→ Voltage build up of the generator is given by the point of intersection of O.C.C and the field resistance line. 'P' is the point of intersection of two curves. Hence the generator will build up a voltage OQ.

Cond^ns for voltage build up of a self excited Generator :-

1) There must be some residual magnetism in generator poles. Due to retentivity property, all magnetic materials posses some amount of flux called "Residual magnetism" which is (5-10%) of rated value.

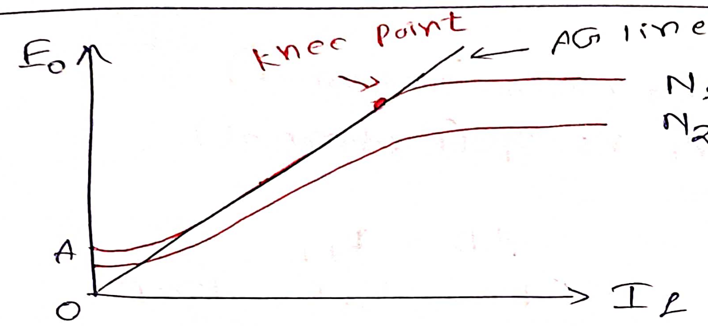
2) The connections of the field winding should be such that the field current strengthens the residual magnetism.

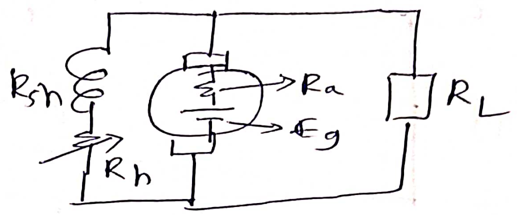
3) The resistance of the field circuit should be less than critical resistance (R_c). R_c is the total field resistance above which the generator fails to build up voltage.

4) The speed of the generator should be higher than the critical speed. Critical speed is the speed below which the Generator fails to build up it's voltage.

when the generator build up voltage under load - $cond^n$, the load resistance must be more than critical load resistance (R_{LC}).

O.C.C. in shunt generator E_0 vs $I_f \mid_{N = const.}$





when $I_f = 0$, $\phi = \phi_r$, $E = E_r = OA$

→ OA = residual flux voltage (2-6) volt

(*) Before saturation

$\phi \propto I_f$

$E_0 \propto I_f$

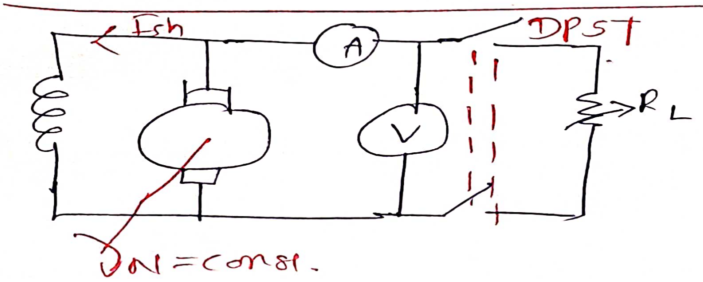
(*) After saturation

$\phi = \phi_{sat}$ (after saturation)

$= const.$

$E_0 =$ constant

External & internal characteristics of shunt Generator



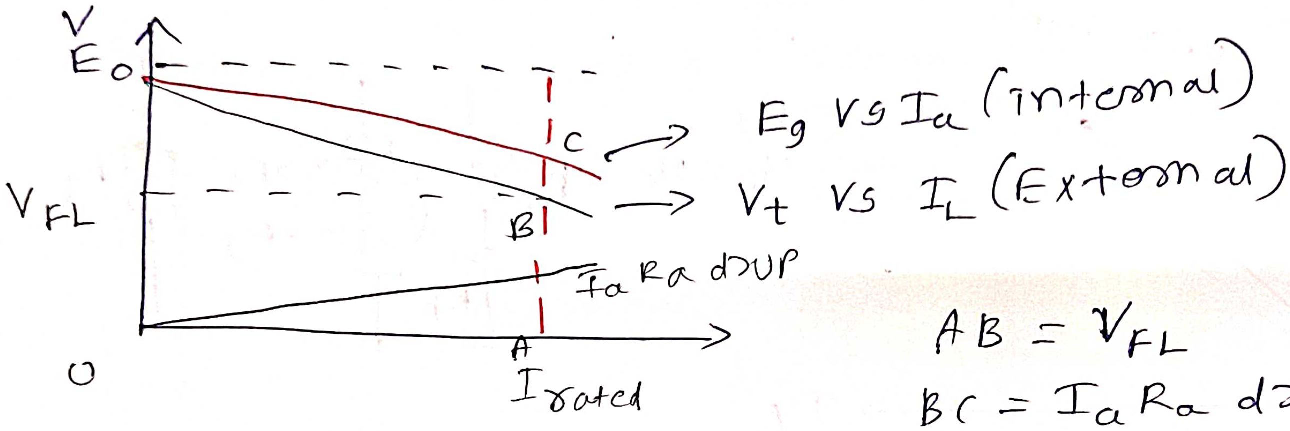
When DPST open $I_a \simeq 0$

$V = E_g - I_a R_a$

$V_{N.L} = E_g = E_0$

DPST close

Vary R_L in steps record V_t & I_L



$AB = V_{FL}$

$BC = I_a R_a$ drop

when load ↑, voltage ↓

Reasons for voltage drop

(i) $I_a R_a$ drop

(ii) drop due to Armature reaction

(iii) drop due to reduction in field current.

$\left(\downarrow I_{sh} = \frac{V}{R_{sh}}\right)$ load ↑, V_t ↓, I_{sh} ↓, ϕ ↓

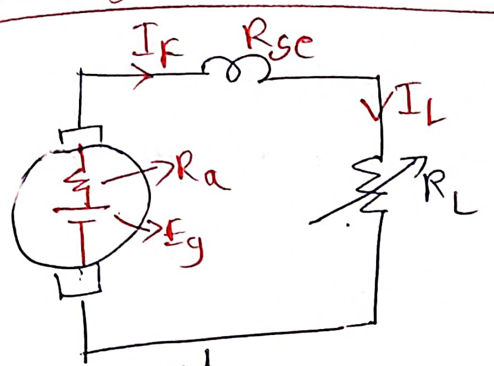
Applications

i) Used as voltage source for battery charging.

ii) Pilot excitor of alternator.

Series Generator

Voltage build up condⁿ



$I_F = I_L$

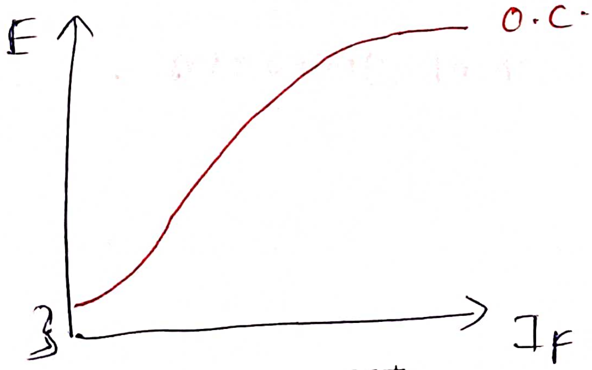
i) Generator must have residual flux.

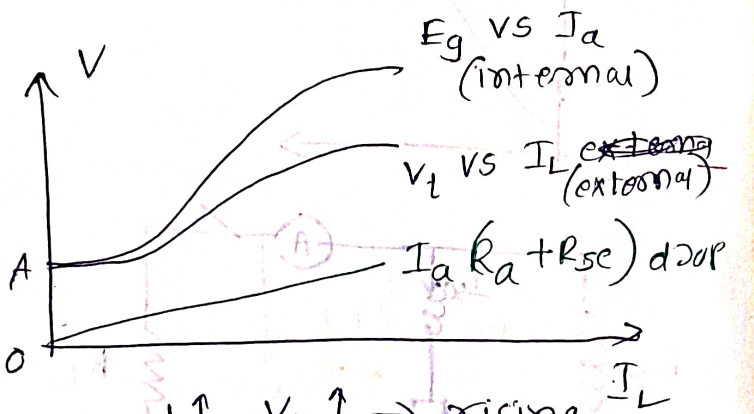
ii) Field terminals are properly connected to the armature.

iii) The total series circuit resistance should be less than critical resistance (R_c).

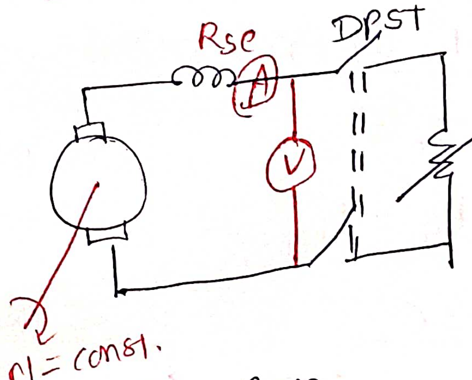
iv) The speed of prime mover should be greater than critical speed.

O.C.C





load ↑, V_t ↑ → rising characteristics.



DPST open

$I_a = 0$, $V_{N.L} = E_g = E_r = (2-6)$ volt

DPST close

Vary R_L in steps & record I_L.

Uses :

boosters in DC transmission line to compensate line drops.

Note : The series Generator is a variable voltage generator. It is therefore never used as a voltage source.

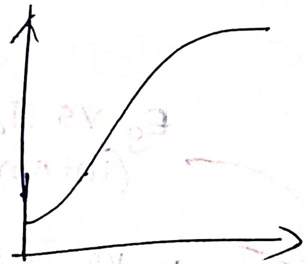
Compound generator

→ compound generator voltage build up process is same as shunt generator.

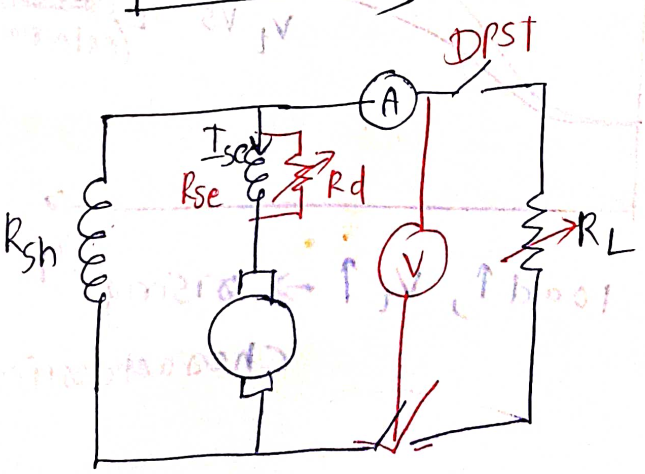
1. Cumulative compound
   - → over compound ($V > E$)
   - → under compound ($V < E$)
   - → Flat / level compound ($V = E$)

2) Differential compound

O.C.C



→ same as shunt generator.



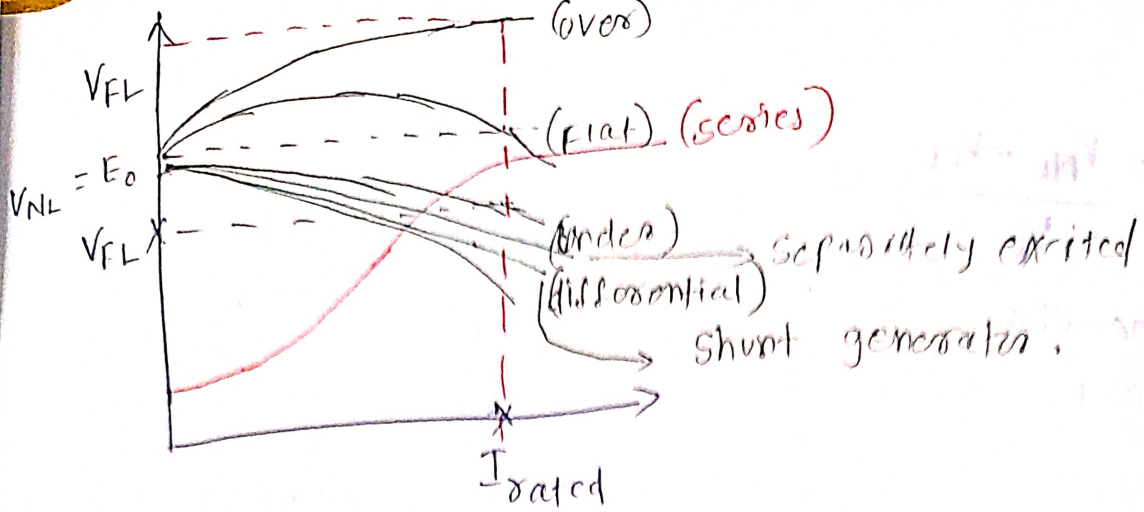
when DPST open

$I_a \simeq 0, \ I_L = 0$

$V_{N.L} = E_g = E_0$

DPST close

Vary R_L in steps & record V & I.



→ when load ↑, I_L ↑, I_a ↑, ϕ_{se} ↑

$$\phi_{sh} \propto I_{sh} = \frac{V}{R_{sh}} = \text{const.}$$

differential

$$\downarrow \phi_T = \phi_{sh} - \phi_{se} \uparrow, \downarrow E_g \propto \phi_T \downarrow, V \downarrow$$

cumulative

load ↑, $\uparrow \phi_T = \phi_{sh} + \phi_{se} \uparrow$, $\uparrow E_g$, $\uparrow V$

level/degree of compounding is controlled by connecting low resistance i.e. divertor across the series field winding.

~~$\phi_{se} \propto I_{se}$~~

Applications

cumulative compound generator

i) voltage source
ii) battery charging
iii) Excitor of alternator

differential compound generator

i) welding purpose

Voltage regulation

$$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

The change in terminal voltage b/w Full No load to F.L. w.r.t. Full load is known as voltage regulation.

+V.R → differential, shunt, separately excited,

- V.R → over, series

zero V.R → Flat compound generator

Flat → load > F.L , V.R is +ve ; load < F.L , V.R → -ve

→ poorest V.R → series Generator

→ +ve. poorest V.R → differential Generator

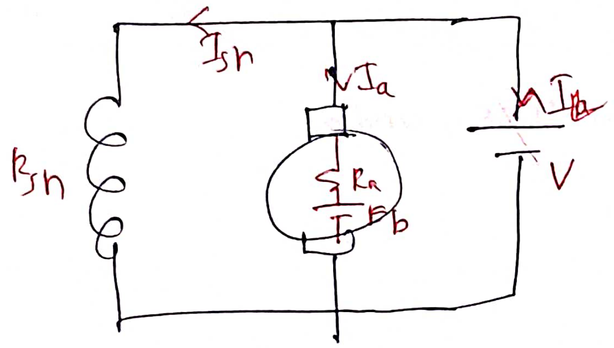
(9). Dc motor characterstics

(i) N vs I_a } elect. characterstics

(ii) T vs I_a }

(iii) N vs T } mech. "

Shunt motor



$\phi_a \propto I_{sh} = \frac{V}{R_{sh}} = \text{const.}$

(i) $N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$

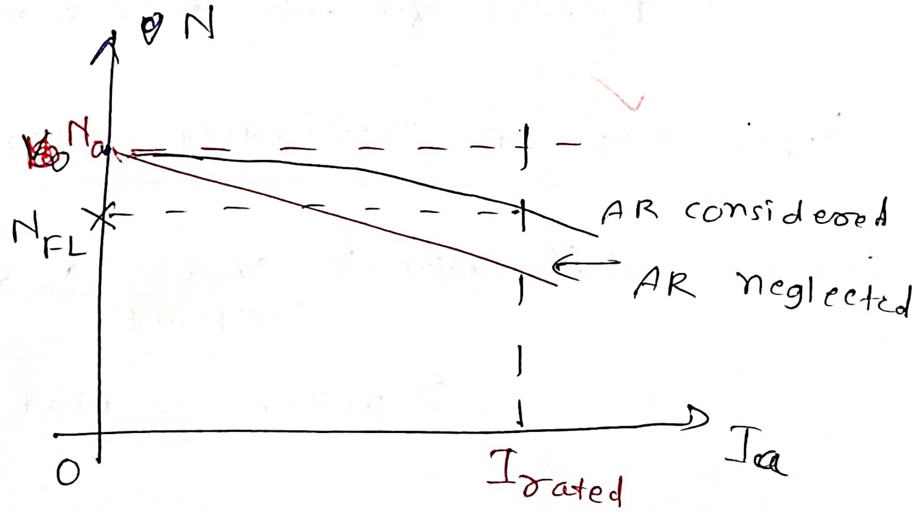
(ii) $T \propto \phi I_a$

$T \propto I_a$

(1) N vs I_a

N.L $I_a \simeq 0$

$N \propto V$



mech load ↑,

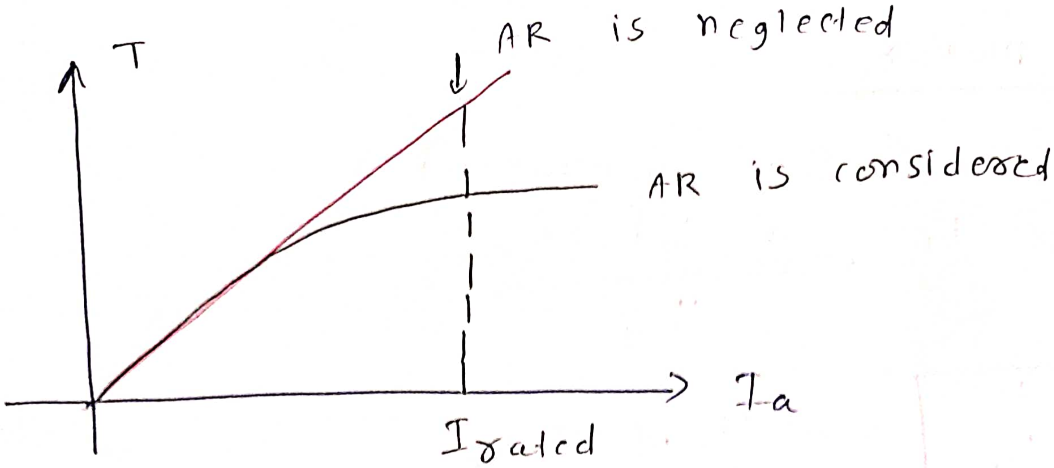
$I_a \uparrow \downarrow N \propto V - I_a R_a$

loaded due to AR, $\phi \downarrow \uparrow N \propto \frac{1}{\phi \downarrow}$

DC shunt motor is a constant speed motor.

(2) T vs I_a

$T \propto I_a$ (ϕ = const.)



AR considered, $\downarrow T \propto \downarrow \phi I_a$ (in light load, I_a less linear)

(iii) N vs T

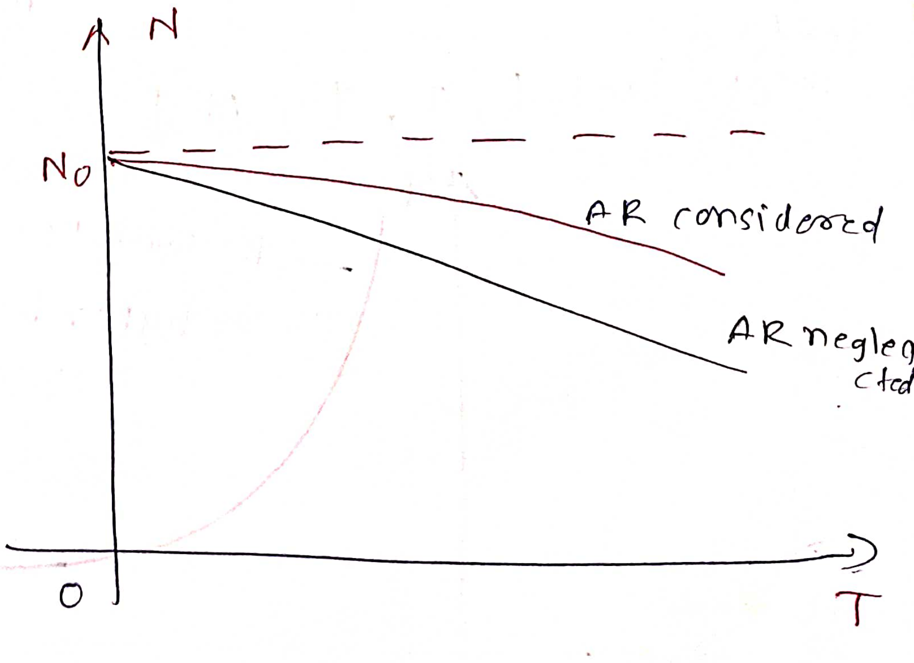
$T \propto I_a \Rightarrow T = k_1 I_a$ $I_a = \frac{T}{K_1}$

$$N \propto \frac{V - \frac{T}{K_1} R_a}{\phi}$$

No load: $I_a \simeq 0$, $T_{em} = 0$, $N \propto \frac{V}{\phi}$

loaded: load ↑, T_{em} ↑, N ↓

with AR: $\phi \downarrow$, N ↑



Application

Fan
centrifugal pumps
lathe
machine tools
line shafting

Series motor

(*) $\phi \propto I_a$ (before saturation)

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a(R_a + R_{se})}{I_a}$$

$$\boxed{N \propto \frac{1}{I_a}}$$

$$T \propto \phi I_a$$

$$\boxed{T \propto I_a^2}$$ ✓

(*) After saturation

$$\phi = \phi_{sat} = \text{constant}$$

$$N \propto V - I_a(R_a + R_{se})$$

$$\boxed{T \propto I_a}$$

(1) N vs I_a

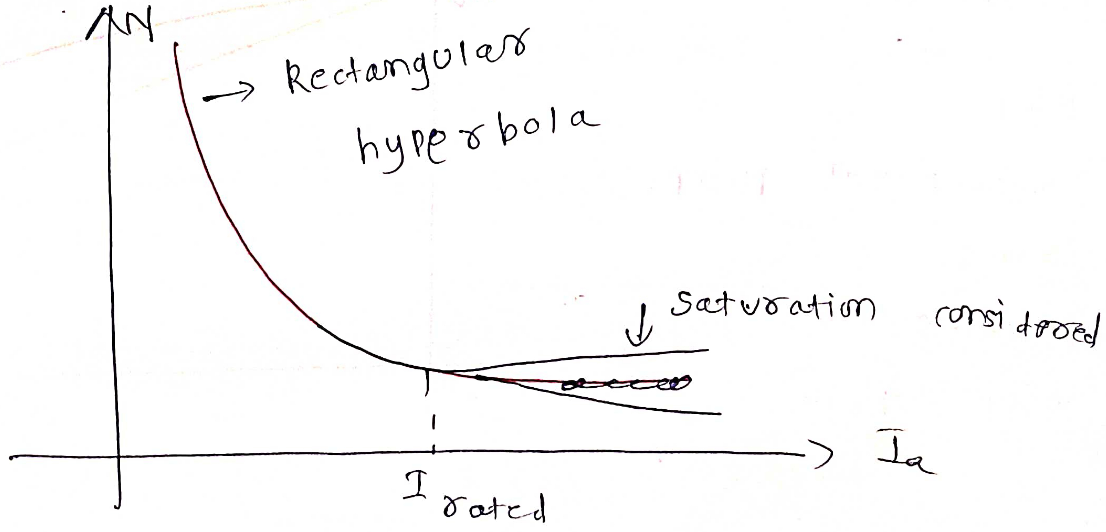
NL $I_a \simeq 0$ ($\uparrow^{\infty} N \propto \frac{1}{I_a \to 0}$)

→ NL speed of DC series motor is dangerously high speed.

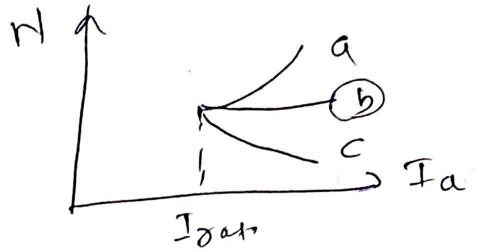
→ Never start DC series motor without load.

load

mech load ↑, I_a ↑, N ↓



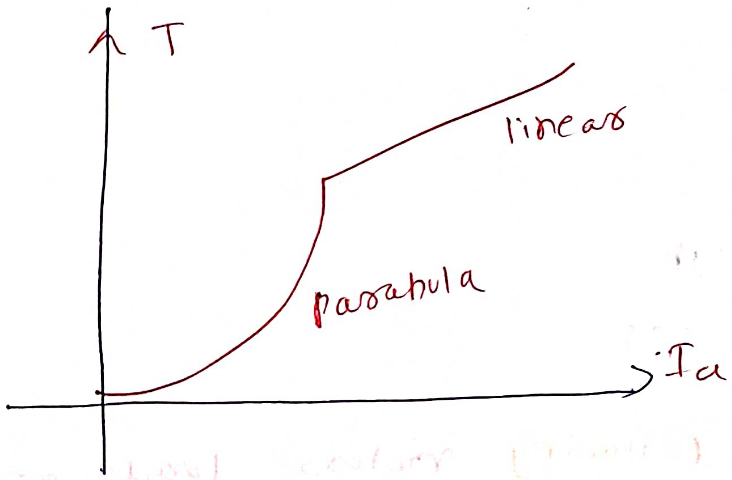
Q) gate DC series motor Field poles are saturated,



b → Ans.

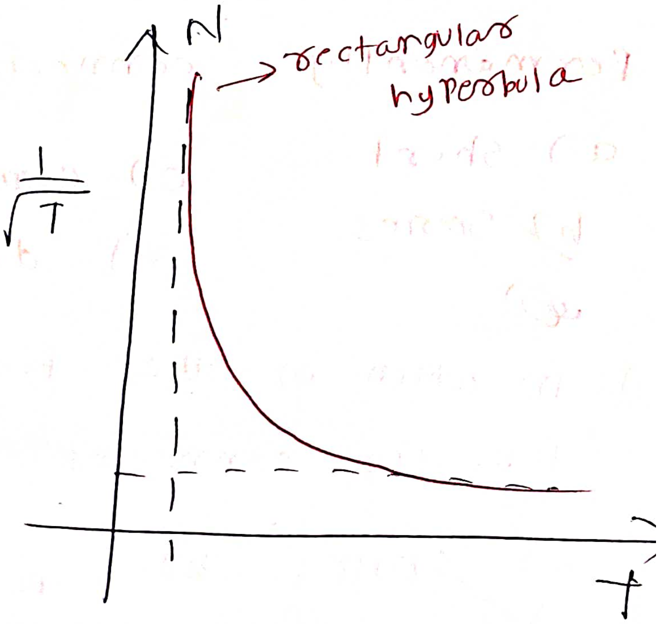
② T vs Ia $T \propto I_a^2$ before saturation

$T \propto I_a$ after saturation



③ N vs T $I_a \propto \sqrt{T}$

$N \propto \frac{1}{I_a}$ $N \propto \frac{1}{\sqrt{T}}$



NL Tem = 0, N = ∞

mech load ↑, Tem ↑, N ↓

$P = T\omega$

if P const. $T\omega$ = const.

$$\boxed{N \propto \frac{1}{T}}$$

→ DC series motor behaves as a constant power drive.

$T_{st} \propto I_{st}^2$ → series

$T_{st} \propto I_{st}$ → shunt

→ series motor : T_{st} is very high.

(high inertia load)

Application

i) Electric traction
ii) lift
iii) crane

traction

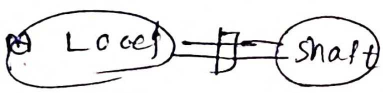
(*) N = low, T → high
(*) N = high, T → less

Q) In which of the following motors loads are permanently connected to the shaft.

a) shunt
b) series ✓
c) cumulative compound
d) differential "

Q) In which of the following motors loads are directly connected to the shaft?

a) series ✓
b)



3) Compound motor characteristics

$$N \propto \frac{E_b}{\phi_T} \qquad N \propto \frac{E_b}{\phi_{sh} \pm \phi_{se}}$$

$\phi_{sh} \propto I_{sh} = \frac{V}{R_{sh}} = \text{const.}$ $\phi_{se} \propto I_a$

$T \propto \phi I_a$

$T \propto (\phi_{sh} \pm \phi_{se}) I_a$

$T_{em} \propto \phi_{sh} I_a \pm \phi_{se} I_a$

1) N vs I_a

No load

$I_a \simeq 0, \phi_{se} = 0$ $N \propto \frac{E_b}{\phi_{sh}} \propto \frac{V}{\phi_{sh}}$

$E_b \propto \frac{V - I_a(R_a + R_{se})}{\phi_T}$ $N = N_0$

load

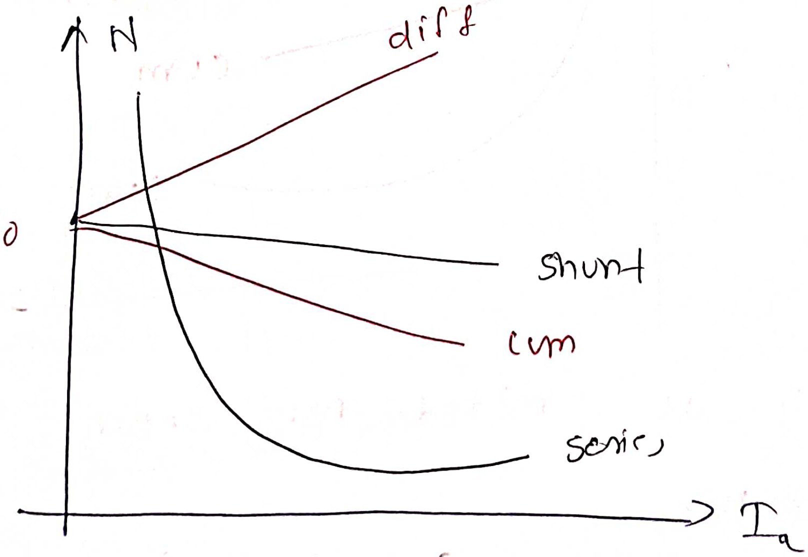
mech load ↑, I_a ↑, ϕ_{se} ↑

cumulative

↓ $N \propto \frac{E_b}{(\phi_{sh} + \uparrow\phi_{se})} \uparrow$

diff

↑ $N \propto \frac{E_b}{(\phi_{sh} - \uparrow\phi_{se})} \downarrow$

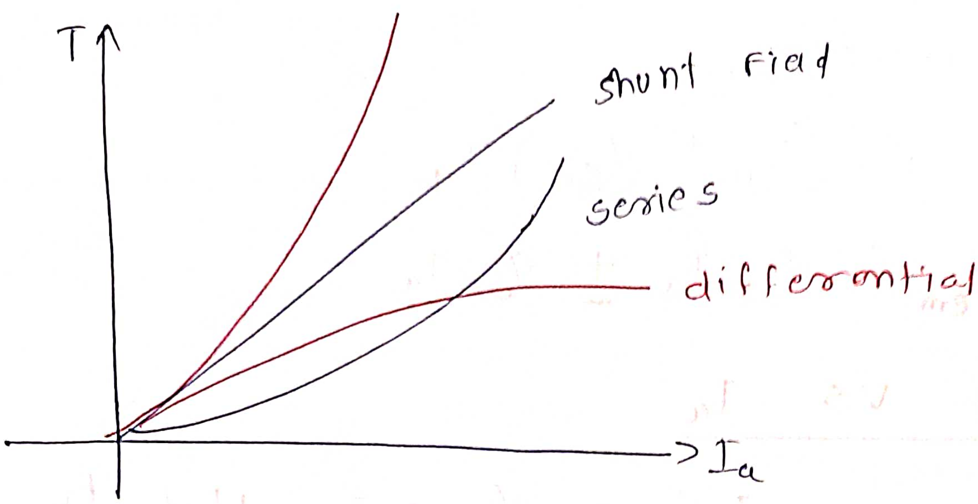


(2) T vs I_a

$T \propto (\phi_{sh} I_a \pm \phi_{se} I_a)$

shunt series

No load $I_a = 0$, $T = 0$



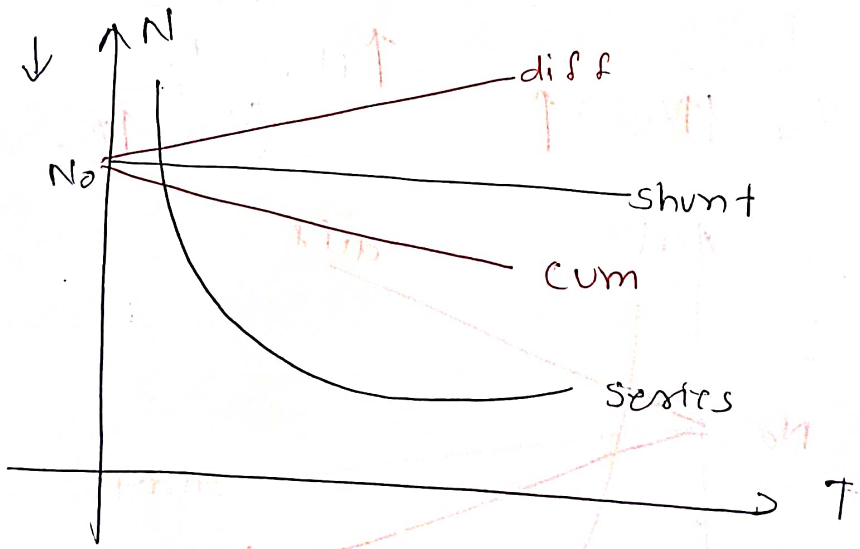
T = const.

$\downarrow(\phi_{sh} - \phi_{se})\, I_a \uparrow = $ const.

③ N vs T

No load $T = 0$, $I_a = 0$, $N = N_0$

load $T\uparrow$, $N\downarrow$



Application

moderate T at limited NL speed

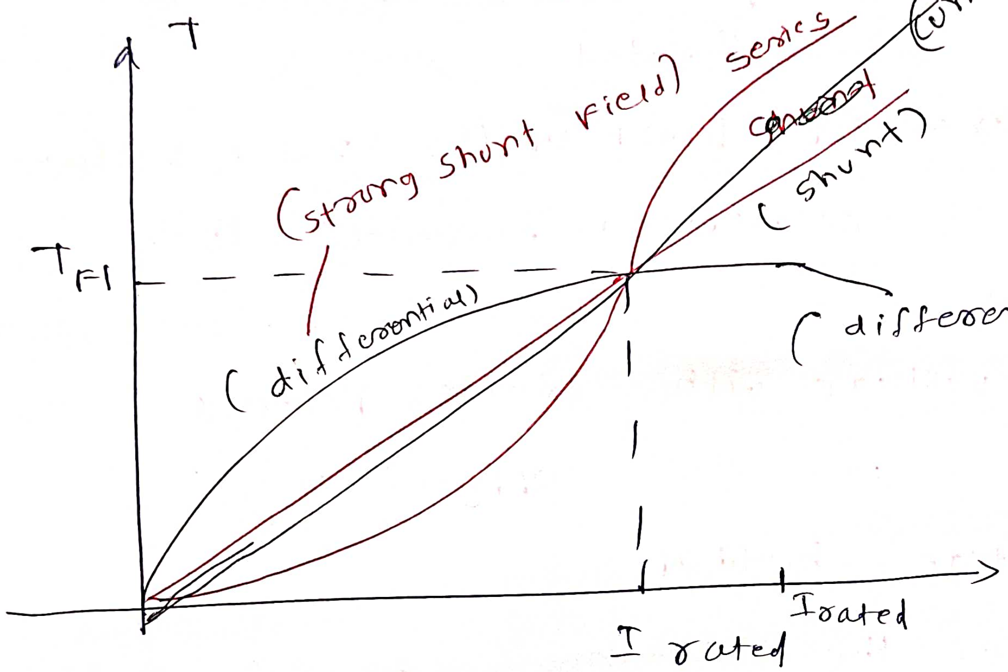
(i) punching m/c
(ii) drilling m/c
(iii) steel mills
(iv) cement mills
(v) paper mill

} cumulative compound

(no application for differential compound motor)

Q) if all the motors are designed to produce same torque at F.L, which of the following motor produces more torque before full load.

a) series b) shunt c) cumulative compound d) differential compound ✓



before full load

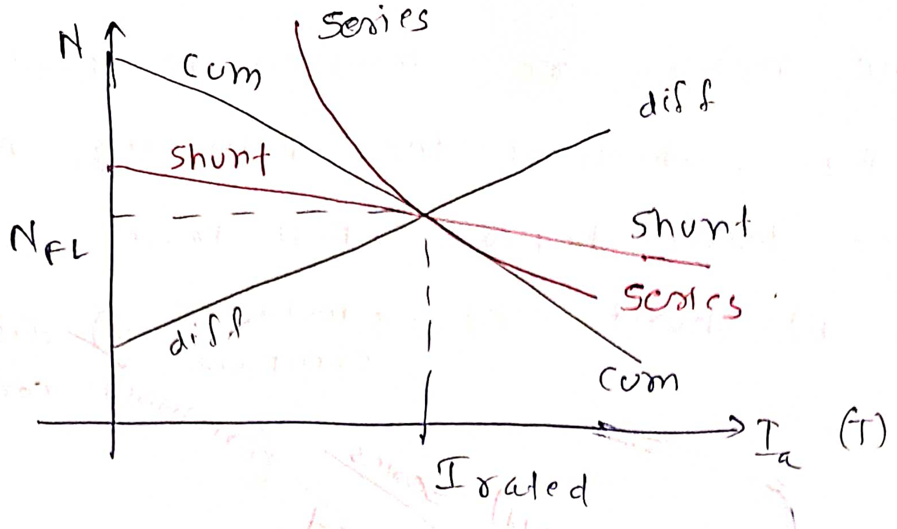
Tem in Descending order

differential > shunt > cumulative > series

After F.L

series > cumulative > shunt > differential

→ if all motors are designed to produce same speed at F.L.



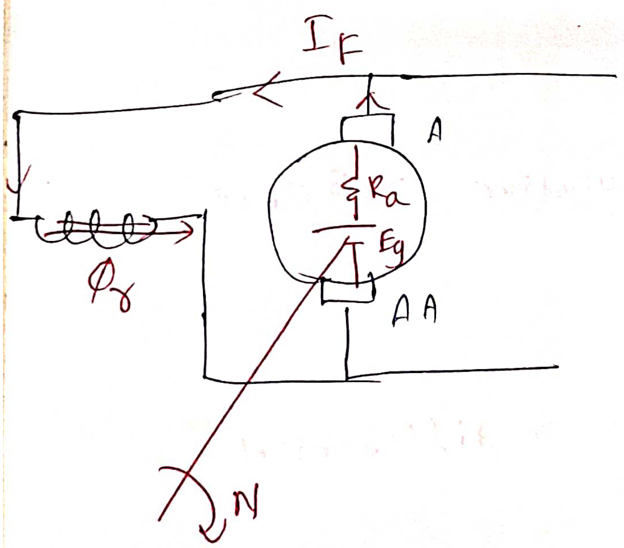
Q) DC shunt generator build up its rated voltage if its direction of rotation is reversed then generator will

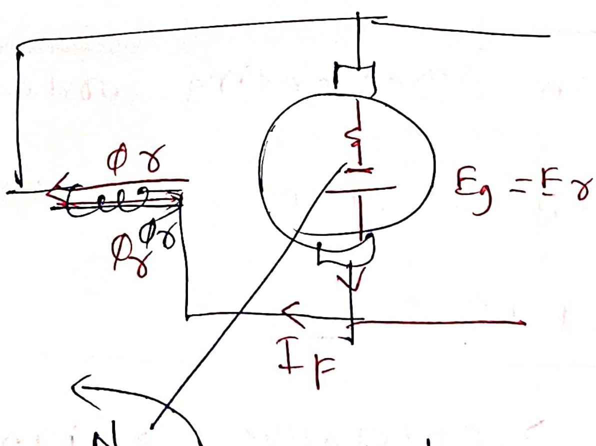
a) build up voltage with same polarity

b) " " " opposite "

c) No voltage build up ✓

d) None of the above





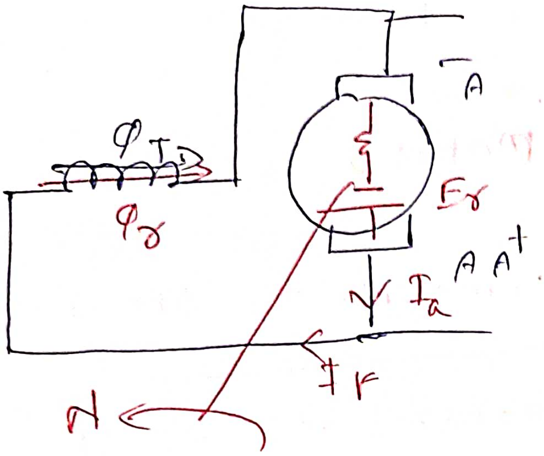
$\phi_T \downarrow$

$E_g \downarrow$

no voltage buildup

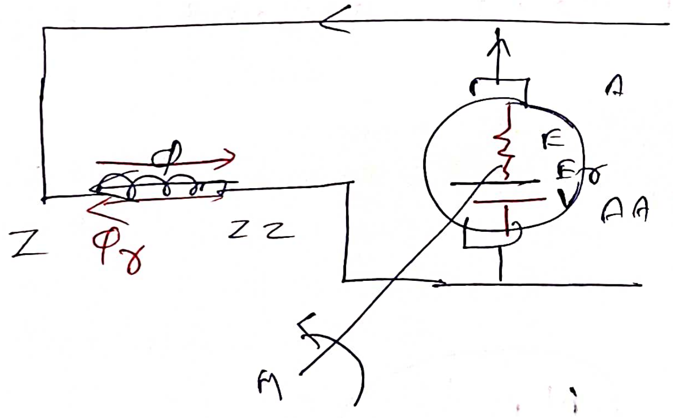
Q) DC shunt generator build up its rated voltage if its direcn of rotation & field connections are reversed, then the m/c will (same option).

(b) build up voltage with oppsite Pulurity



$\phi \uparrow$, $E_g \uparrow$

Q) DC shunt generator build up its rated voltage. if the direcn of rotation & residual Flux direcn are reversed then generator will

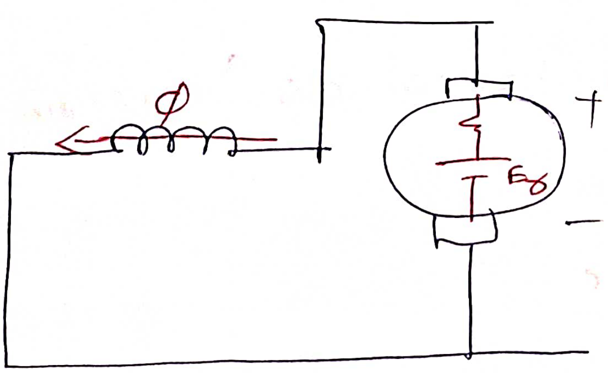


$E_r \propto \phi_r N$

$\phi_{rT} \downarrow$, $E_r \downarrow$,

No voltage build up

Q) The shunt generator build up its rated voltage if its direcn of rotation, recidual Flux direcn & Field terminals are reversed then generator will



$\phi_r \uparrow$, $E_g \uparrow$,

build up voltage with Same polarity.

Note

during voltage build up residual flux voltage initiates the voltage build up process.

(10) Speed control of DC motors

Base speed or rated speed / Name plate speed :

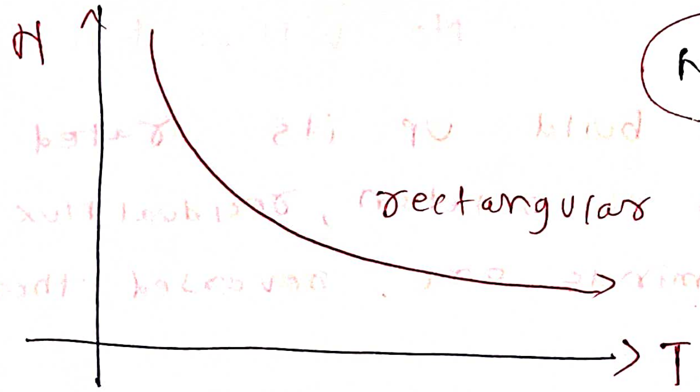
→ It is the speed of the motor at rated supply voltage & at rated flux.

Constant power drive

The shaft power remains constant for a given speed range.

$$P_{sh} = T_{sh} \times \omega = \text{const.}$$

$$T\,N = \text{const.}$$

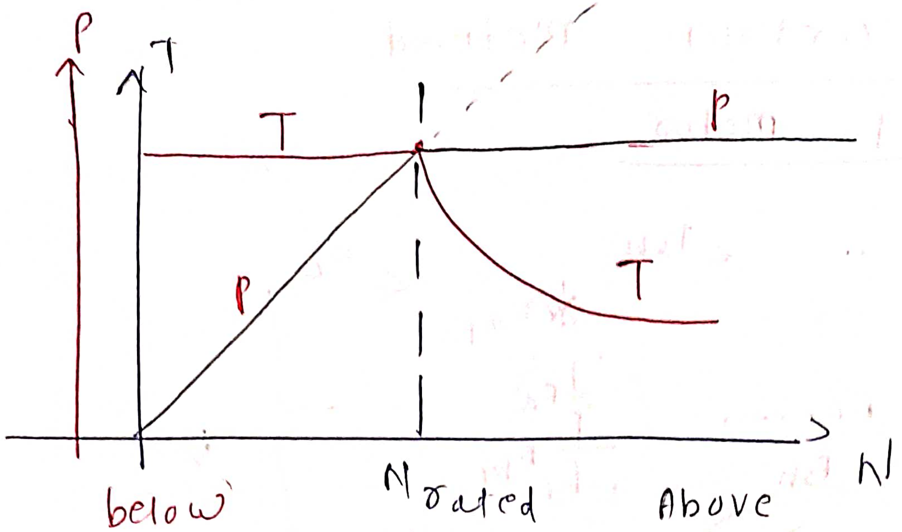


$$N \propto \frac{1}{T}$$

ex : electric traction, lifts, cranes.

→ DC series motor behaves as a constant power drive.

→ **Adjustable speed drive**



below N rated
T = const.
P ∝ N
Constant torque variable 'p' drive

Above rated
Constant 'p' & variable 'T' drive

advantages of adjustable speed drive over cons. speed drives

i) smooth & noiseless operation

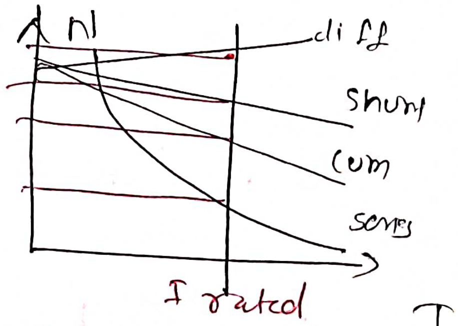
ii) power saving

ex : steel mills, cement mills, paper mills, coal mines etc

Speed control methods

Speed control → load on the m/c = constant

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$$



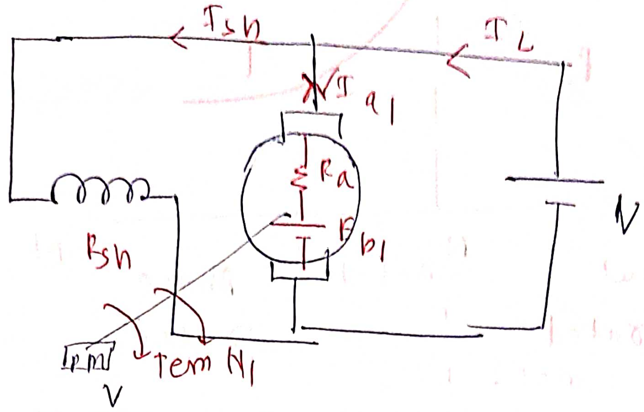
i) Flux control method
Field weakening method

(ii) Armature resistance control method

(iii) Armature voltage control method

① Flux control method

shunt motor



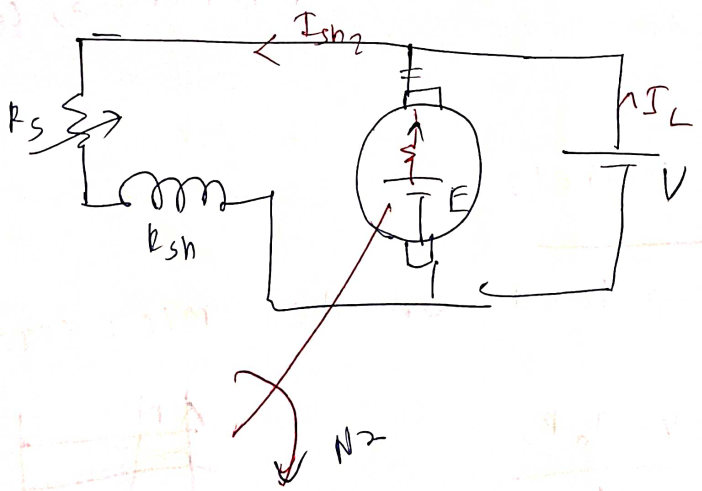
$\phi_1 \propto I_{sh_1} = \frac{V}{R_{sh}}$ = Rated I_F

$I_{a_1} = \frac{V - E_{b1}}{R_a}$ = rated armature current

$N_1 = N_{rated}$ .. (i)

$N_1 \propto \frac{E_b}{\phi} \propto \frac{V - I_{a1} R_a}{\phi_1}$ .. (1)

Field regulator



$\phi_2 \propto I_{sh} = \frac{V}{R_s + R_{sh}}$ $\phi_2 < \phi_1$

$N_2 \propto \frac{E_{b2}}{\phi_2} \propto \frac{V - I_{a2} R_a}{\phi_1}$

$N_2 > N_1 = N_{rated}$

→ Above N_{rated} possible.

$\phi \downarrow$, $N \uparrow$, $E_b \propto \downarrow\phi N \uparrow$ = const.

$E_{b2} = E_{b1}$

$I_{a2} = \frac{V - E_{b2}}{R_a}$

$= \frac{V - E_{b1}}{R_a} = I_{a1}$

= rated I

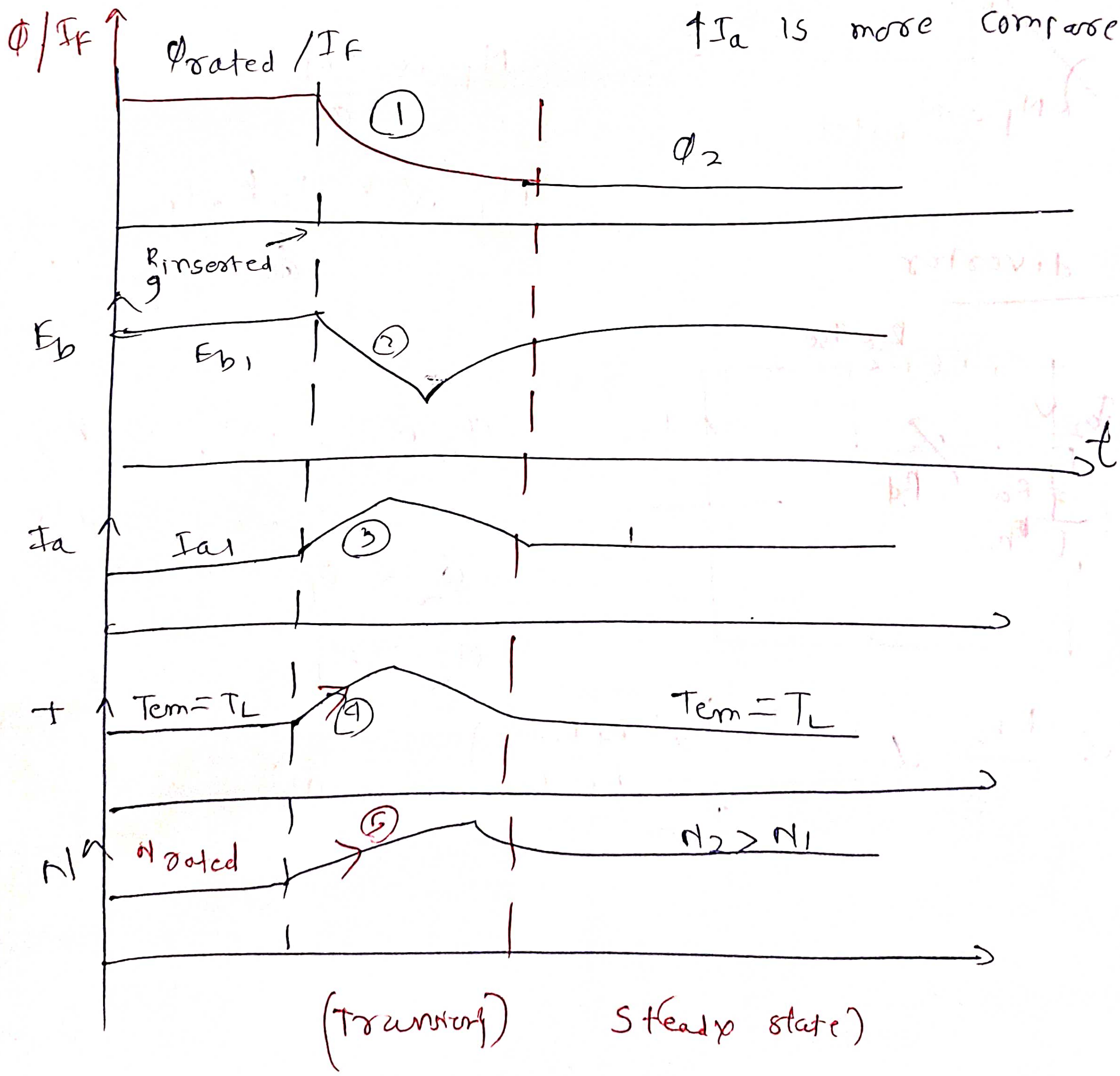
$P_{mech} = E_b I_a$

= const.

$\downarrow T \propto \downarrow\phi \; I_a$ ✗ , $N \uparrow$, $P \propto \uparrow T N \downarrow$ ~~remove~~

⇒ const. power variable torque drive.
(~~Sce shunt motor~~)

↑I_a is more compare to $\phi\downarrow$



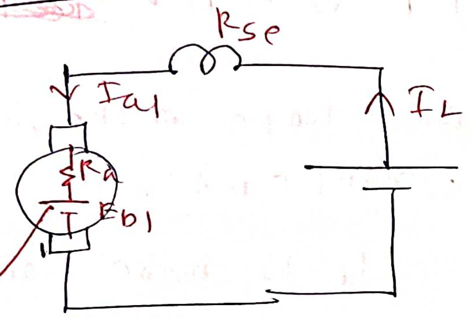
Series motor

Flux of series motor can be controlled by using the following methods

i) diverter control
ii) Tapped Field control
iii) series & parallel connection of field coils

1) diverter control

without diverter



$N_1 = N_{rated}$

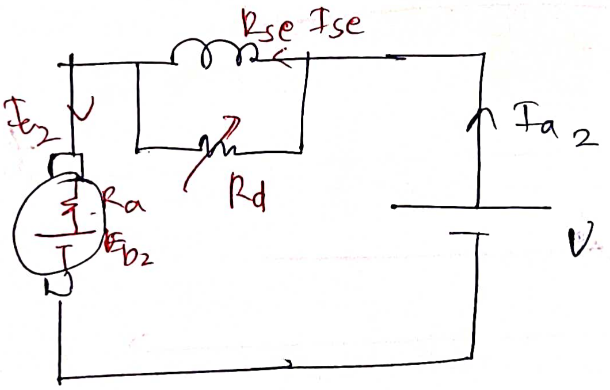
$I_{a1} = I_a(rated)$

$\phi \propto I_{a1}$

$N_1 \propto \frac{E_{b1}}{\phi_1}$

$N_1 \propto \frac{V - I_{a1}(R_a + R_{se})}{I_{a1}}$ .. (i)

with diverter



$\phi_2 \propto I_{se} = I_{a2} \times \frac{R_d}{R_d + R_{se}}$

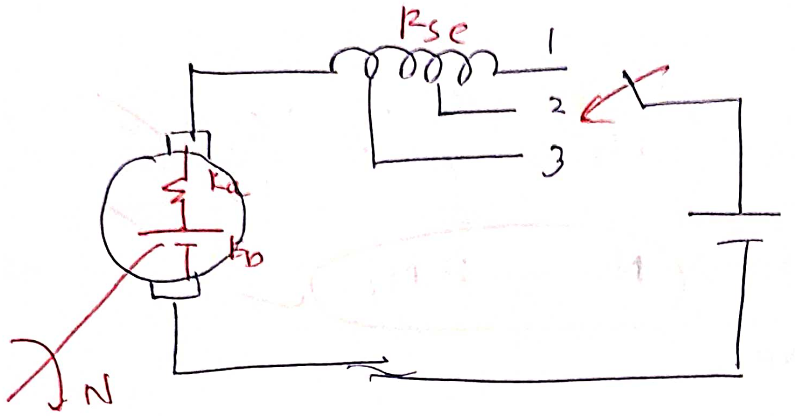
$\phi_2 < \phi_1$

$N_2 > N_1$

$N_2 \propto \frac{E_{b2}}{\phi_2} \propto \frac{V - I_{a2}\left(R_a + \frac{R_d R_{se}}{R_d + R_{se}}\right)}{I_{se}}$ .. (ii)

$\frac{N_1}{N_2}$

③ Tapped Field control (Traction motors)



$\phi \propto mmf$

$\phi \propto T I_a$

At ① $\phi_1 \propto T_1$

At ② $\phi_2 \propto T_2$

At ③ $\phi_3 \propto T_3$

$T_1 > T_2 > T_3$

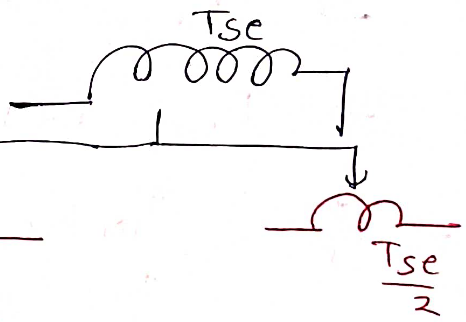
$\phi_1 > \phi_2 > \phi_3$

$N_1 < N_2 < N_3$

drawback

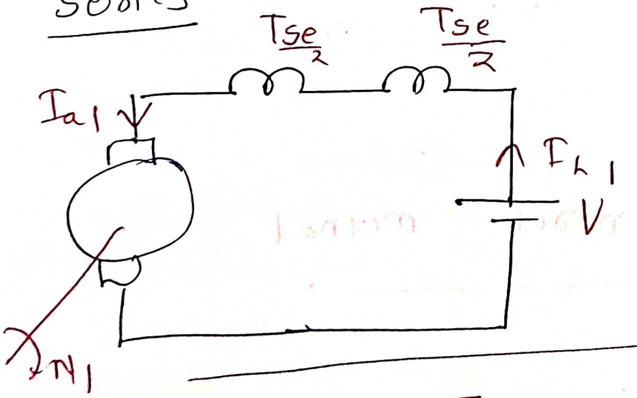
step by step speed control method

③ Series, parallel connection



①

series



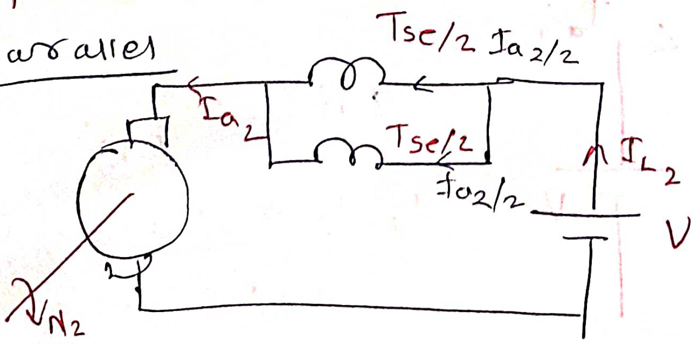
$\phi_1 \propto mmf$

$= I_{a_1} \frac{Tse}{2} + I_{a_1} \frac{Tse}{2}$

$\phi_1 \propto I_{a_1} Tse$

---

parallel



$\phi_2 \propto mmf$

$= \frac{Tse}{2} \times \frac{I_{a2}}{2} + \frac{Tse}{2} \times \frac{I_{a2}}{2}$

$\phi_2 \propto \frac{Tse \, I_{a2}}{2}$

(i) const. 'P' drive

$P_2 = P_1 \Rightarrow V_2 I_{a_2} = V_1 I_{a1}$

$I_{a_2} = I_{a1}$

$\phi_1 \propto I_{a_1} T_{se}$

$\phi_2 \propto I_{a_2} \frac{T_{se}}{2}$

$\frac{N_2}{N_1} = \frac{\phi_1}{\phi_2} = \frac{I_{a1} T_{se}}{I_{a2} T_{se}} \times 2$

$N_2 = 2 N_1$

(ii) const. torque drive

$T_2 = T_1 \Rightarrow \phi_2 I_{a_2} = \phi_1 I_{a_1}$

$\Rightarrow T_{se} \frac{I_{a_2}}{2} \cdot I_{a_2} = T_{se} I_{a1} I_{a1}$

$\Rightarrow \frac{I_{a_2}^2}{2} = I_{a_1}^2$

$\Rightarrow I_{a_2}^2 = 2 I_{a_1}^2$

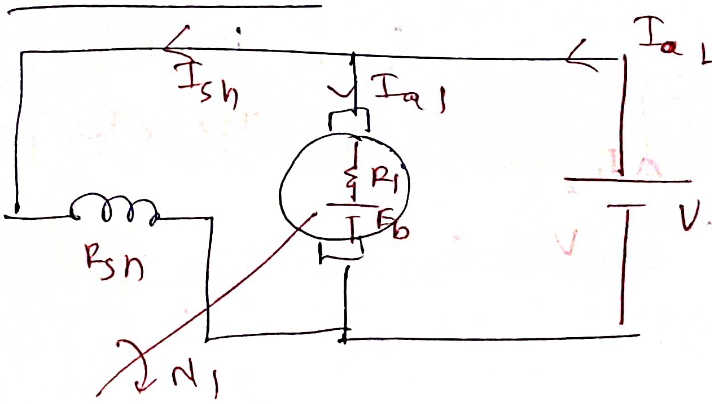
$\Rightarrow I_{a_2} = \sqrt{2} \cdot I_{a_1}$

$\frac{N_2}{N_1} = \frac{\phi_1}{\phi_2} = \frac{I_{a1} T_{se}}{I_{a2} \frac{T_{se}}{2}} = \frac{2 I_{a1}}{I_{a2}} = 2 \times \frac{I_{a1}}{\sqrt{2} I_{a1}}$

$N_2 = \sqrt{2} N_1$

(2) Armature resistance control method

shunt motor



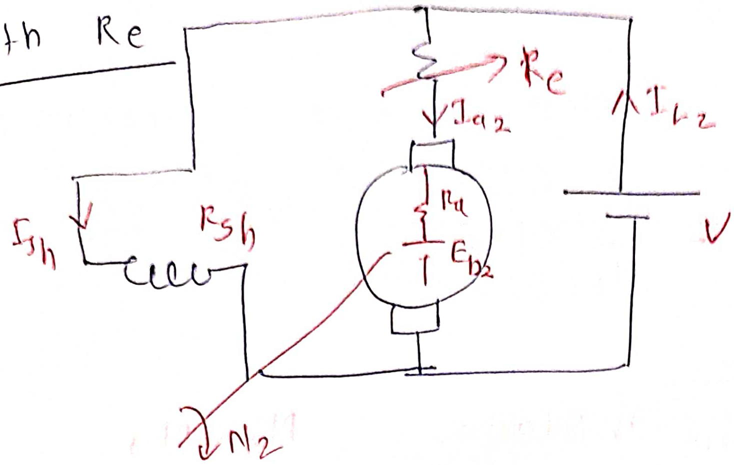
$\phi \propto I_{sh} = \frac{V}{R_{sh}}$

$I_{a_1} = \frac{V - E_{b1}}{R_a}$ = rated armature current

$N_1 \propto \frac{E_{b1}}{\phi_1}$ $\quad N_1 \propto \frac{V - I_{a1} R_a}{\phi_1}$

$N_1 = N$ rated

with R_e



$\phi_2 \propto I_{sh} = \frac{V}{R_{sh}}$

$\phi_2 = \phi_1$ ✓

$$I_{a2} = \frac{V - E_{b2}}{R_a + R_e}$$

$N_2 \propto \frac{E_{b2}}{\phi_2}$ $\quad \therefore N_2 \propto \frac{V - I_{a2}(R_a + R_e)}{\phi_2}$

$$\frac{N_2}{N_1} = \frac{V - I_{a2}(R_a + R_e)}{V - I_{a1} R_a}$$

if $R_e \uparrow$, $N \downarrow$, $\downarrow E_b \propto \not{\phi} N \downarrow$ $\quad \therefore E_{b2} < E_{b1}$ ✓

$I_{a2} = \frac{(V - E_{b2}\downarrow)\uparrow}{\uparrow(R_a + R_e\uparrow)} = \text{Const.}$

$I_{a2} = I_{a1}$ ✓

= rated armature current.

$T \propto \phi I_a \rightarrow$ const.

$N \downarrow$, $\downarrow P \propto \not{T} N \downarrow$

$\therefore$ It behaves as constant torque & variable 'P' drive.

$R_e >> R_a \rightarrow$ neglect

$$\frac{N_2}{N_1} = \frac{V - I_a R_e}{V}$$

$$\eta \simeq \frac{P_{mech}}{P_{in}} = \frac{E_b \cancel{I_a}}{V \cancel{I_a}} \qquad I_L \simeq I_a$$

$$\eta \simeq \frac{E_{b2}}{V} = \frac{V - I_a(R_a + R_e)}{V}$$

$$R_a << R_e$$

$$\% \eta = \frac{V - I_a R_e}{V} = \frac{N_2}{N_1} \times 100$$

$N_1 = 1000$ rpm

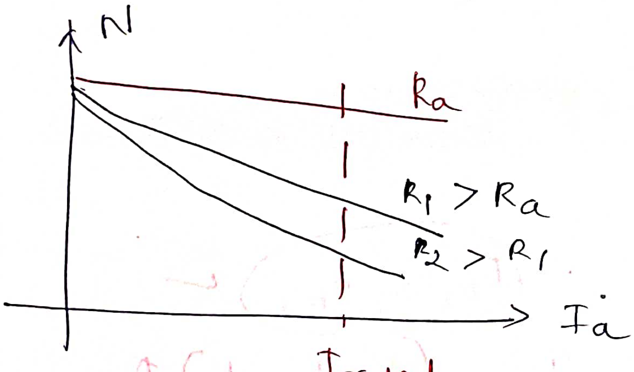
η at $N_2 = 1000$ rpm, $\eta = 100\%$

$= 800$ ", $\eta = 80\%$

$= 600$ ", $\eta = 60\%$

$= 100$ ", $\eta = 10\%$

$N_2 < N_1$, only → below rated speed

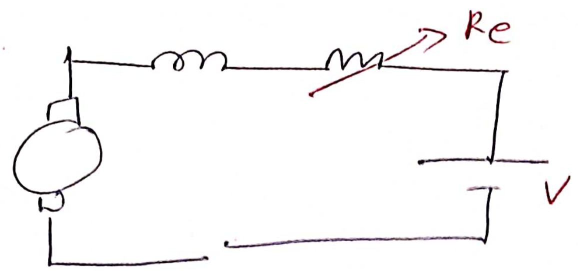


series motor

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} = \frac{V - I_{a2}(R_a + R_{se} + R_e)}{V - I_{a1}(R_a + R_{se})}$$

$$(R_a + R_{se}) << R_e$$

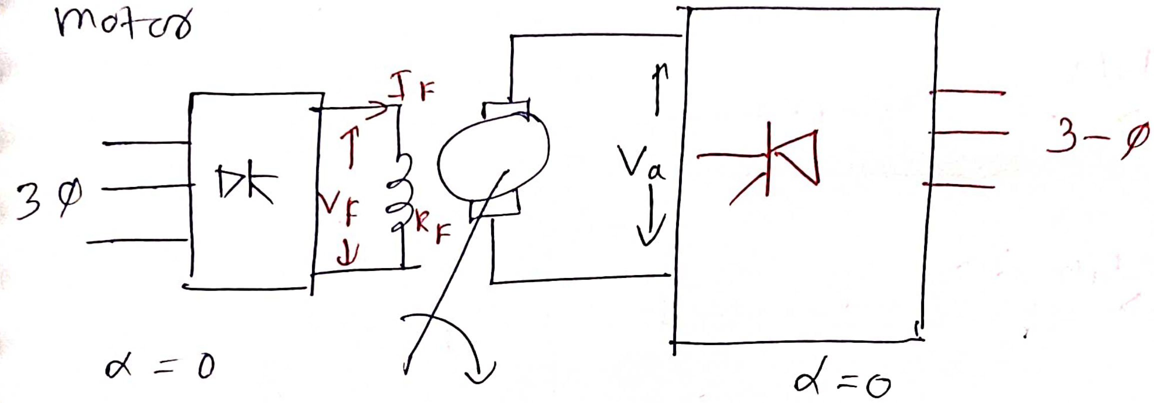
$$\frac{N_2}{N_1} = \frac{V - I_a R_e}{V}$$



Armature voltage control method (below rated speed)

(i) (by using static rectifiers)

(*) run the motor as separately excited motor



$\alpha = 0$ $\qquad$ N_{rated} $\qquad$ $\alpha = 0$

$V_F = V_{rated}$ $\qquad$ $V_a = V_{a\,rated}$

$N \propto \frac{E_b}{\phi}$

$\propto \frac{V - I_a R_a}{\phi}$ ✗

$\phi = \phi_{rated}$

$= \text{const.}$

$N \propto V_a$

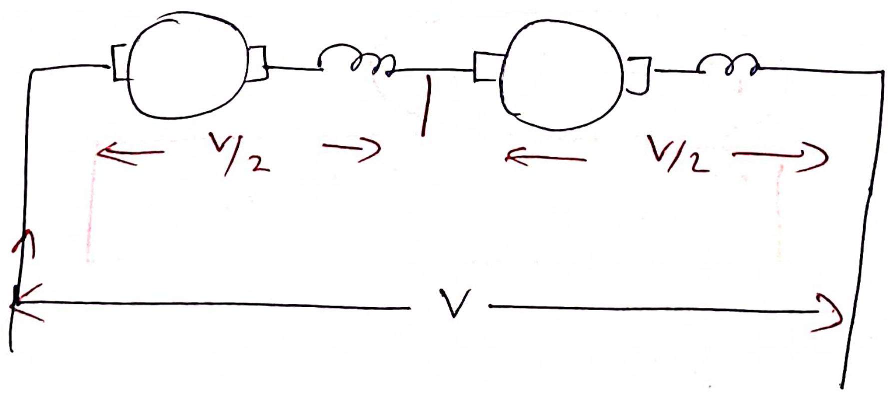
$V_a = V_{rated}$ $\qquad$ $N = N_{rated}$

$\alpha \uparrow$, $V_a \downarrow$, $\downarrow N \propto V_a \downarrow$

(ii) series - parallel connection of series motor

Traction

Series



$N_1 \propto \frac{E_b}{\phi}$

in series

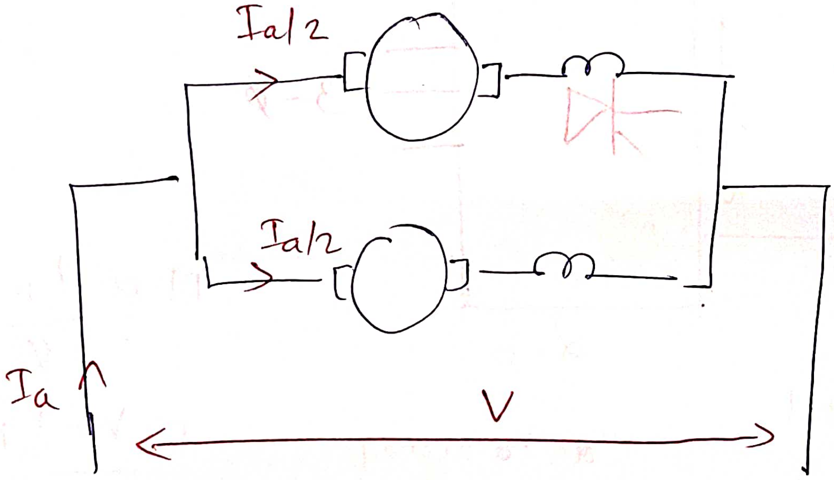
$\phi \propto I_a$

Neglect $I_a(R_a + R_{se})$ drop

$N_1 \propto \frac{\frac{V}{2}}{I_a}$ $N_1 \propto \frac{V}{2I_a}$ ... (i)

$T_1 \propto I_a^2$ .. (ii)

Parallel



$N_2 \propto \frac{E_{b2}}{\phi_2}$

$\phi_2 \propto \frac{I_a}{2}$ $N_2 \propto \frac{V}{(I_a/2)}$

$N_2 \propto \frac{2V}{I_a}$ .. (iii)

$T_2 \propto \left(\frac{I_a}{2}\right)^2$ .. (iv)

$\frac{(3)}{(1)} = \frac{N_2}{N_1} = \frac{2V}{I_a} \times \frac{2I_a}{V} = 4$

$N_2 = 4N_1$

$N_{parallel} = 4 N_{series}$

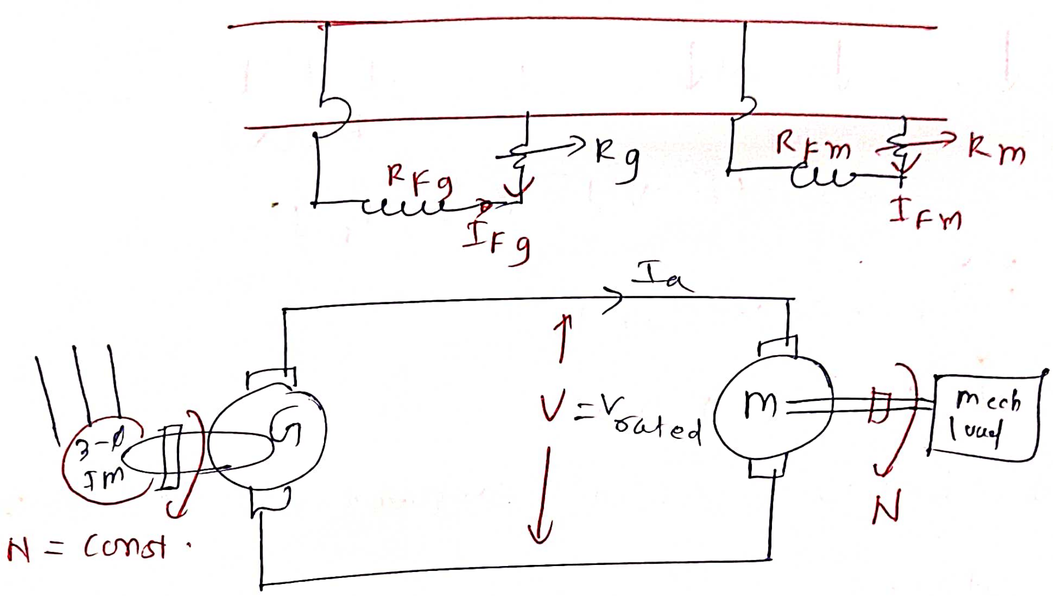
$$\frac{(iii)}{(iv)} = \frac{T_1}{T_2} = \left(\frac{I_a^2}{I_a^2}\right) 4$$

$T_1 = 4\, T_2$ Traction

$\Rightarrow \boxed{T_{se} = 4\, T_{parallel}}$

Ward - Leonard systems

→ run motor as separately excited motor.



→ comb^n of flux control & armature voltage control.

$E_b \propto \phi \propto I_{fm}$

$\phi_g \propto I_{Fg}$

$E_g \propto V \propto I_{Fg}$

→ armature voltage control

~~obtained by adjusting the I_{Fg}~~

Case - 1

$V = V_{rated}$

$I_{Fm} = \text{rated } I_f$

$N = N_{rated}$

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

(*) armature voltage control

$N \propto V$ (below N_{rated} speed)

→ obtained by adj's I_{Fg}

$I_{Fg}\downarrow, V\downarrow, N\downarrow$ $\quad I_a = \frac{V\downarrow - E_b\downarrow}{R_a(X)} = \text{const.}$

if $V\downarrow, N\downarrow, E_b\downarrow$

$T \propto \overset{\times}{\phi}\, \overset{\times}{I_a}$ → constant

$P = \overset{\times}{T} \times \omega$ $\quad P \propto N$

motor behaves as a constant torque & variable P' drive

(*) Flux control method (Above N_{rated})

→ obtained by adjusting I_{fm}

but maintain $V = V_{rated}$

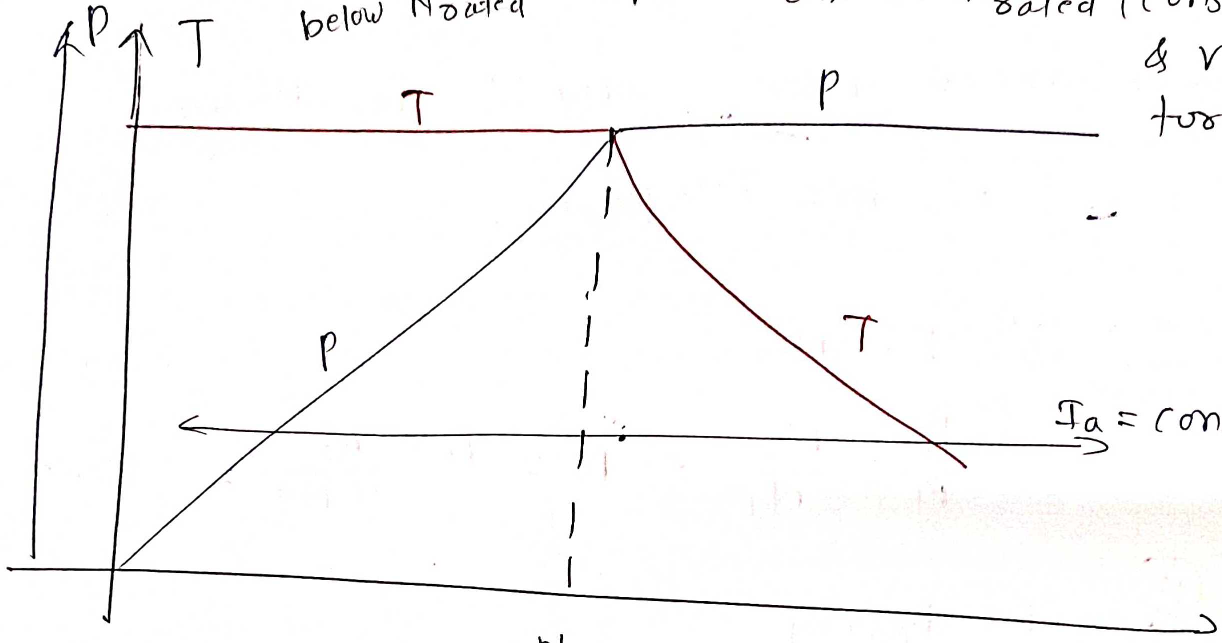
$\downarrow\phi \propto I_{Fm}\downarrow, N\uparrow, E_b = \text{const.}$

$E_b \propto \phi\downarrow N\uparrow$

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

$\downarrow T \propto \phi\downarrow \overset{\times}{I_a}$ $\quad$ P' $\quad P \propto T\downarrow N\uparrow = \text{const}$

→ motor behaves as constant power variable torque drive. (const. T & variable P below N_{rated} above N_{rated} (const. P & variable torque)



Advantages

1) The speed of the motor can be controlled in wide range.
2) Smooth speed control is possible.
3) both above & below rated speed possible.

$N_2 = 4N_1$ (with interpole)

$N_2 = 2N_1$ (without interpole)

4) wide range of speed control is possible in either direcn. Good efficiency.

disadvantages (i) MG set is required, high initial cost.

5) efficiency at low speed is better as compared to other methods. (armature resistance control method.