Rotating Machines

- Generator
  - DC
  - AC
- Motor
  - DC
  - AC

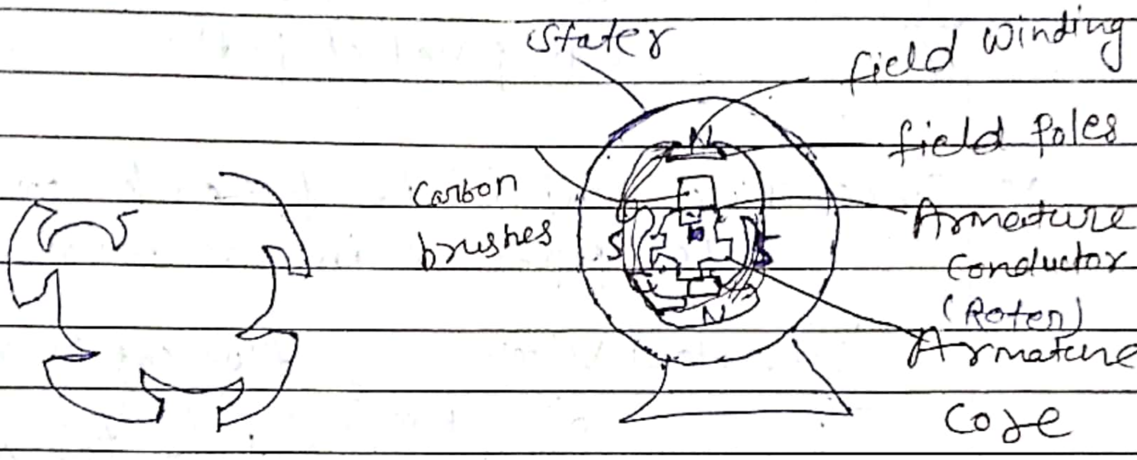


fig. D.C Generator construction | D.C. Motor diagram

EMf Equation of D.C. machine.

1. An armature Rotates, voltage induced on its conductor.
2. In case of ~~motor~~ generator, the emf of rotation is called generated emf E_g.
3. In case of Motor, the emf of rotation is called back emf. E_b.

let ϕ = useful flux perpole in wb.
p = total no. of poles.
Z = total no. of conductor in armator
n = Speed of revolution of armature

in revolution per seconds.

A = No. of parallel path through b/w brushes of opposite polarity.

$\frac{Z}{A}$ = No. of armature conductors in series for each parallel path.

* Since flux per pole is ϕ, each conductor cuts $P\phi$ flux in one revolution.

$$\frac{\text{Generated Voltage}}{\text{per conductor}} = \frac{\text{flux cut per revolution in Wb}}{\text{time for one revolution in seconds}}$$

Since, n revolution are made in one second, so time for one revolution will be $\frac{1}{n}$ sec

$$\text{Average Generated voltage per conductor} = \frac{P\phi}{1/n} = nP\phi \text{ volts.}$$

The average generated voltage is determined by the no. of armature conductors in series per parallel path b/w the brushes. Therefore total voltage generated

$$E = (\text{Avg. voltage per conductor}) \times (\text{No. of conductor in series})$$

$$\boxed{E = (nP\phi) \times \frac{Z}{A} = \frac{nP\phi Z}{A}}$$

$$E = \frac{NP\phi Z}{60A}$$

Back emf | Counter emf

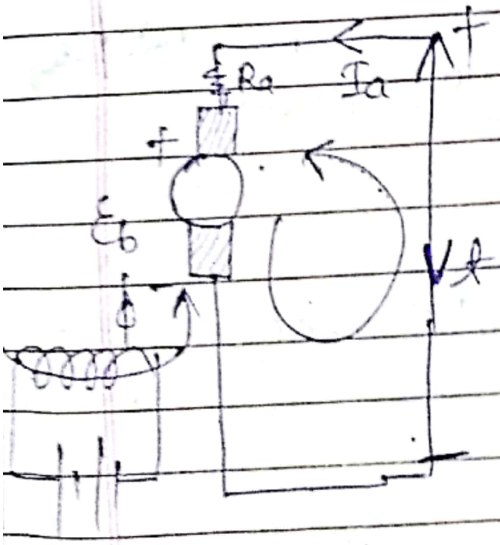
Back emf also known as counter emf is an electromotive force generated in the coil of DC motor which opposes the change in current.

$$E = \frac{nP\phi Z}{A}$$

$60 \times n = N$

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

Torque in DC Motor



By applying KVL:

$$V_t - I_aR_a - E_b = 0$$

$$V_t = E_b + I_aR_a$$

$$\underbrace{V_tI_a}_{\text{Input power}} = \underbrace{E_bI_a}_{\text{output power}} + \underbrace{I_a^2R_a}_{\text{loss}}$$

$$T = \frac{P}{\omega} = \frac{E_b I_a}{2\pi n} = \frac{P\phi Z I_a}{2\pi A}$$

$$\boxed{T = \frac{P\phi Z I_a}{2\pi A}} \ Nm$$

Q. 6 pole DC motor
$I_a = 110A$ at $480V$, $R_a = 0.2\Omega$
flux perpole, $\phi = 50$ mWb
864 lapwound conductors
calculate speed and torque develop by motor

Types of armature winding
(i) lap winding = $P=A$
(ii) wave winding: $A=2$
No. of parallel path

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

$$V = E_b + I_a R_a$$
$$E_b = V - I_a R_a$$
$$E_b = 480 - 110 \times 0.2$$
$$E_b = 458$$

$$T = \frac{P\phi Z I_a}{2\pi A} = \frac{6 \times 50 \times 10^{-3} \times 864 \times 110}{2 \times 3.14 \times 6} = 750 Nm$$

Q. The induce emf in a DC machine is 200 volts,

$E_b = 200V$ at a speed of 1200 rpm
$I_a = 15A$ $T = ?$ Calculate electromagnetic torque at the armature current 15A

Soln: $P_m = \frac{2\pi NT}{60} = E_b I_a$

mechanical power

$$T = \frac{E_b I_a \times 60}{2\pi N}$$

$$= \frac{200 \times 15 \times 60}{2\pi \times 1200}$$

$$T = 23.87\,Nm$$

P_m = Speed × Torque

$P_m = \omega \times T$

$\omega = 2\pi N$ ← rpm

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

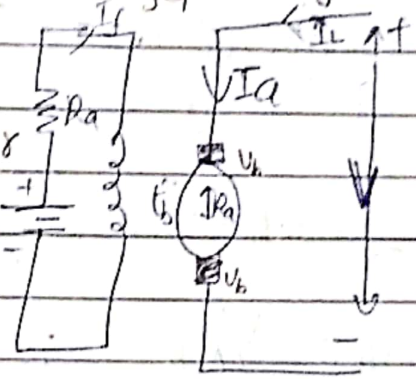
Types of DC Motor

There are two types:

(a) Separately Excited

(b) Self Excited DC motor

Separately Excited.



$V = E_b + I_a R_a$

where: R_a = Armature Resistance

E_b = Back emf generated

eqⁿ: V

(b) Self Excited DC Motor

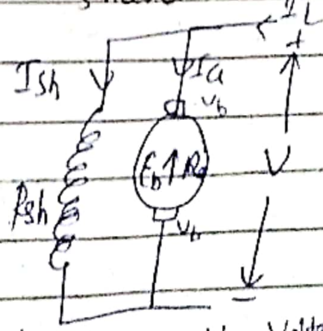
(i) Shunt motors

(ii) Series Motors

(iii) Compound motors

The armature coil will be connected ‖ell to field winding

Shunt Motor



$I_{sh} = V/R_{sh}$

$I_a = I_L - I_{sh}$

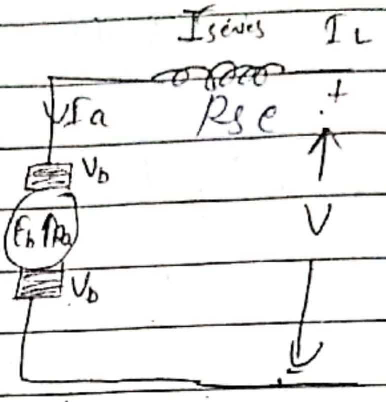
$V = E_b + I_a R_a + 2V_b$

V_b = Voltage drop at brushes

Series Motor:- Armature is connected in series order.

$I_L = I_{se} = I_a$

$V = E_b + I_a(R_a + R_{se}) + 2V_b$

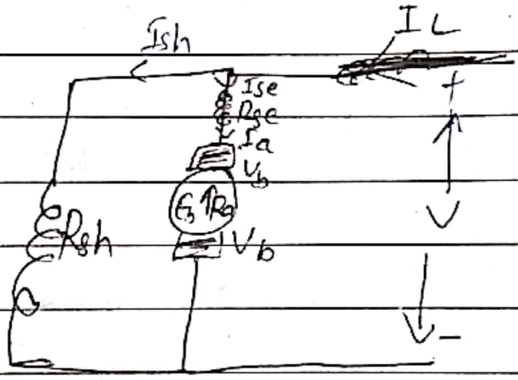


* Compound Motor:- We will have field winding in series as well as shunt both.

$I_a = I_L - I_{sh} = I_{se}$

$I_{sh} = V/R_{sh}$

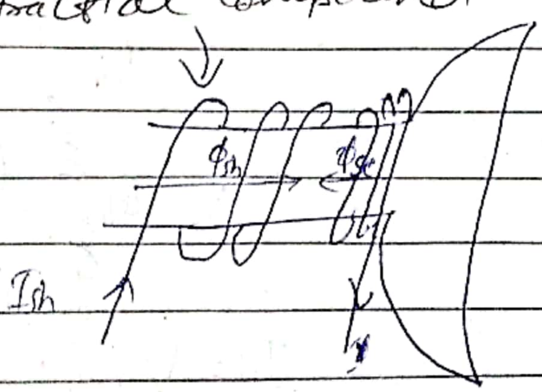
$E_b + I_a(R_a + R_{se}) + 2V_b$



* Compound Motor is a further categories as two types

(I) Cumulative Compound

(II) Differential Compound



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

ϕshunt series

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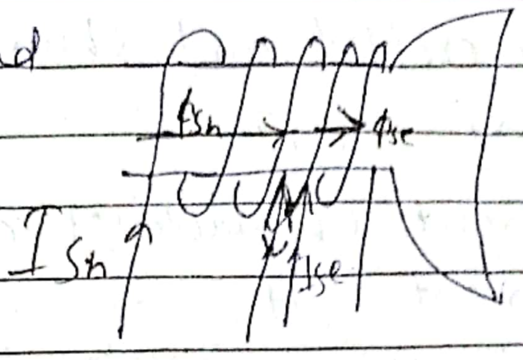
Commulative Compound



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

Q A 4 pole of DC motor has a wave bound armature with 594, The armature current 40A, and flux perpole 7.5 mwb calculate hot power of the motor when running at 40rpm.

P=4

I_a: 40

ϕ =75

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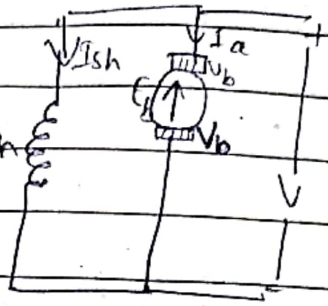
Seperately excited and shunt motor

N, Ia, T

(N - Ia) speed-current Characteristic
(T - Ia) Torque-current "
(N-T) speed- Torque Characte



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

∴ ϕ is constant

(1) N-Ia $N \propto \frac{E_b}{\phi}$

$\boxed{N \propto E_b}$

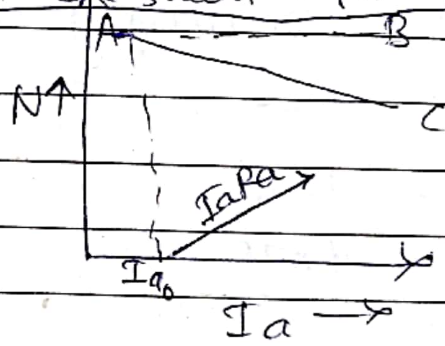
$E_b = \frac{\phi Z N P}{60 A}$

$E_b = K N \phi$

$E_b = V - I_a R_a$

$\boxed{N \propto V - I_a R_a}$

for DC shunt motor



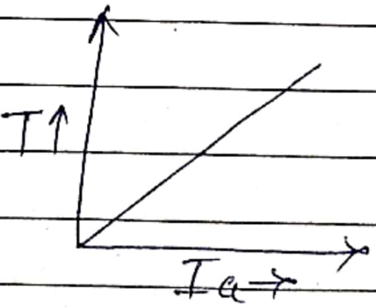
∴ DC Shunt motor are const. speed motors

T-Ia

∵ ~~ϕ is constant~~

$T \propto \phi I_a$

$\boxed{T \propto I_a}$



If a motor has on heavy load it will be need high torque at start and hence high armature current also. therefore shunt motor should be never started on load.

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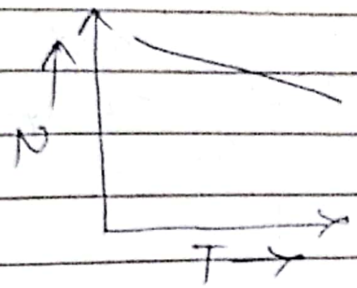
N-T

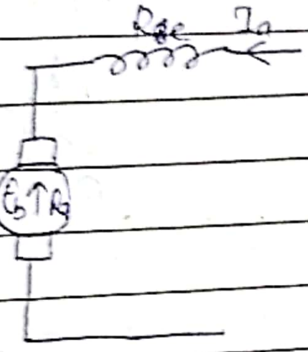
$N \propto E_b$ or $\boxed{N \propto V - I_a R_a \\ T \propto I_a}$

$\boxed{T\uparrow = I_a\uparrow = N\downarrow}$



Characteristic for DC series Motor :-

$\phi \propto I_a$



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

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

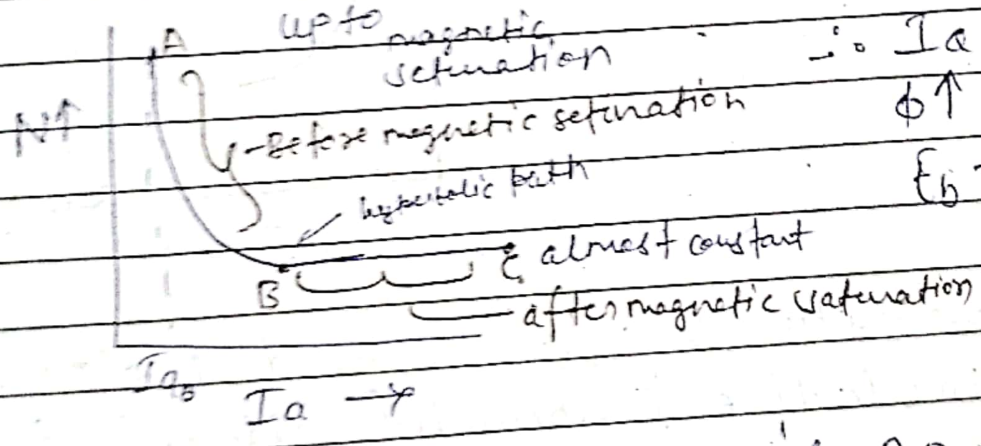
$E_b = V - I_a(R_a + R_{se})$

upto magnetic saturation

$\therefore I_a\uparrow \Rightarrow E_b\downarrow$

$\phi\uparrow \Rightarrow I_a\uparrow$

$E_b \approx$ constant



* A the starting there is no load start Ia is small, then speed very high

At no load I_{a0} is very small which makes the speed very high and this can done it the motor and the other connected component therefore a dc series motor can never started at no load.

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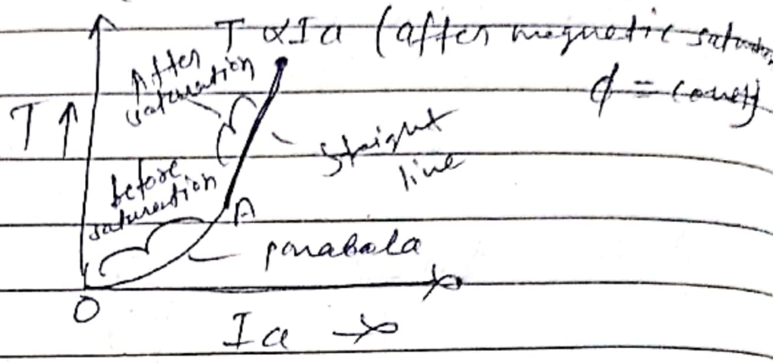
(II) T – Ia

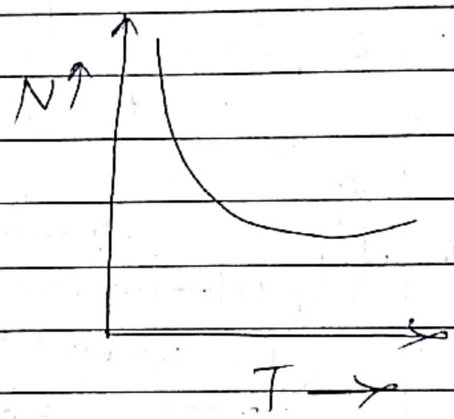
$T \propto \phi I_a$

and $\phi \propto I_a$ (up to magnetic saturation)

$\Rightarrow T \propto I_a^2$ (Up to magnetic saturation)



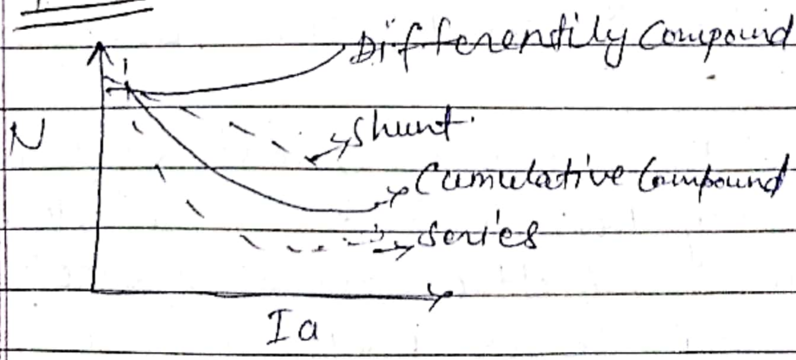
(III) N – T



Characteristic for DC Compound Motor :-

(I) Cumulative Compound (II) Differencial Compound

(I) N – Ia



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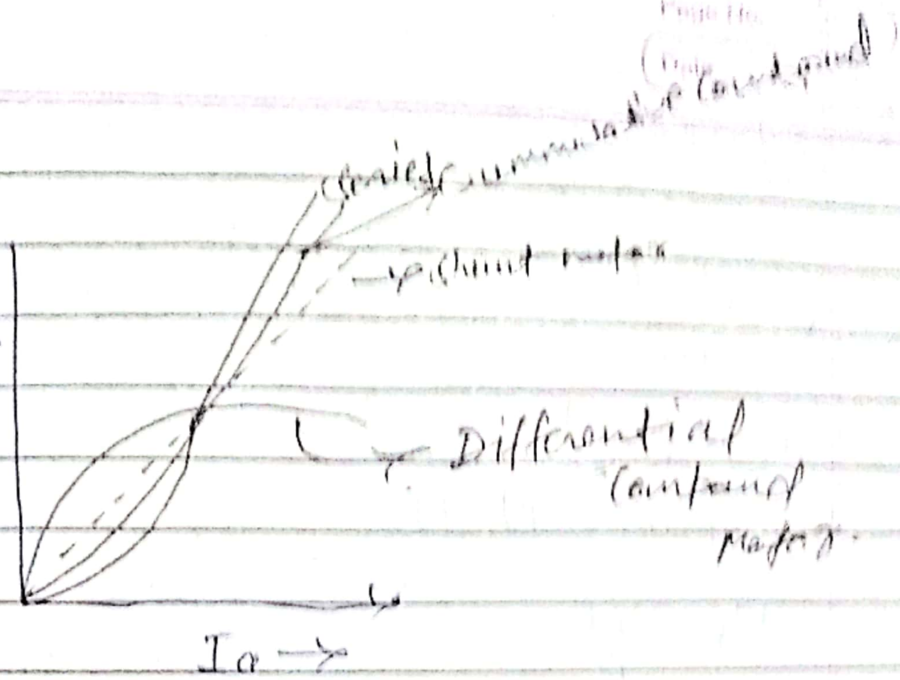
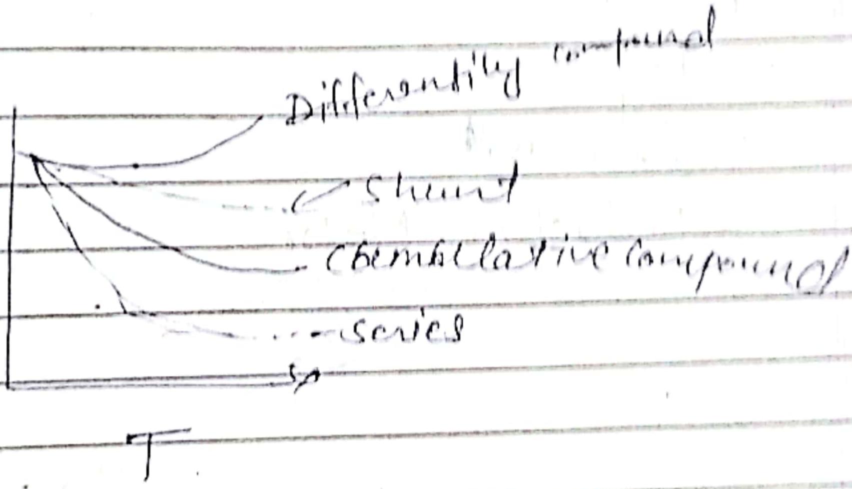
(ii) $T - I_a$



(iii) $N - T$



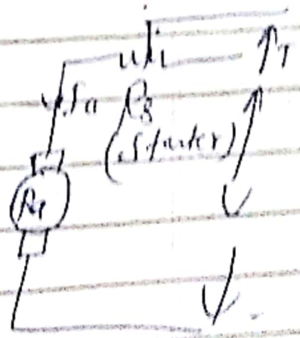
Same to $N - I_a$

Note: Not motor is not running

$N \propto \frac{E_b}{\phi}$ — not produce

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

Starting current $\boxed{I_a = \frac{V}{R_a}} \rightarrow (E_b = 0)$



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

at start $I_a = \frac{V}{R_a + R_s}$

Rotor EMF :

Stator induced emf perphase

$E_1 = 4.44 \times K_{w1} \times T_1 \times f \times \phi_m$

K_{w1} = Winding factor = coil spring factor (K_c) × distribution factor (K_d)

T_1 = No. of turn per phase of stator winding

f = Stator or supply freq.

ϕ_m = max value of flux

→ Rotor Induced emf E_2

$E_2 = 4.44 \times K_{w2} \times T_2 \times f_r \times \phi_m$

f_r = rotor frequency

At standstill (when rotor is non moving)

$$E_{2s} = 4.44 \times K_{w2} \times T_2 \times f\phi_m$$

$$\frac{E_{2s}}{E_1} = \frac{\cancel{4.44} \times K_{w2} \times T_2 \times \cancel{f} \times \cancel{\phi_m}}{\cancel{4.44}\, K_{w1} \times T_1 \times \cancel{f} \times \cancel{\phi_m}} = K\frac{T_2}{T_1}$$

$$\boxed{\frac{E_{2s}}{E_1} \propto \frac{T_2}{T_1} = K = \text{Transformation Ratio}}$$

Ratio of turns in secondary and primary

$f_r = sf$
$s = f_r/f$
$s = 1$ at standstill

At running condition

$$\boxed{E_2 = s \times E_{2s}}$$

⇒ Rotor Impedence :-

$$\bar{Z}_2 = R_2 + jX_2$$

Rotor Resistance $R_2 = \frac{\rho l}{a}$
↓ Cu or Al

* Rotor Reactance (X_2)

leakage inductance (L_2)

$X_2 = 2\pi f_2 L_2 = 2\pi S f L_2$

at standstill: $X_{28} = 2\pi f L_2$

$$\Rightarrow \boxed{X_2 = S X_{28}}$$

$$\vec{Z_2} = R_2 + jX_2$$

$$|Z| = \sqrt{R_2^2 + X_2^2} = \sqrt{R^2 + (SX_2)^2}$$

Torque develop by Induction Motor

$$\underbrace{P_0 = 3I_2^2 R_2 \frac{(1-S)}{S}}_{\text{Elect power}} = \omega T$$

Elect power → Mechanical power

T = Torque developed by inducth motor (Nm)

ω angular speed of motor

$$\boxed{T = \frac{3}{\omega_s} \frac{S E_{28}^2 R_2}{R_2^2 + (SX_{28})^2}}$$

⇓ Torque Eqh of 3φ induction motor

⇓ full load

* Starting torque

$$T_s = \frac{3}{\omega_s} \frac{E_{28}^2 R_2}{R_2^2 + X_{28}^2}$$

Torque slip ~~curve~~ characteristic

(1) $S = 0$ (at $S = 0$ or at synch speed N_s i.e. $S = 0$

and Torque $T = 0$

$Z = R_2 + jSX_{2S}$

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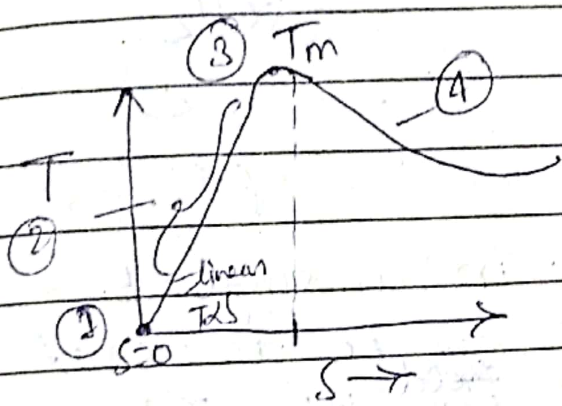
(ii) when rotor speed is close to N_S

$SX_2 \rightarrow$ negligible $\Rightarrow Z = R_2$

The torque, $T = \frac{3}{\omega_s} \times \frac{S E_{2S}^2 R_2}{R_2^2} \propto S = T \propto S$



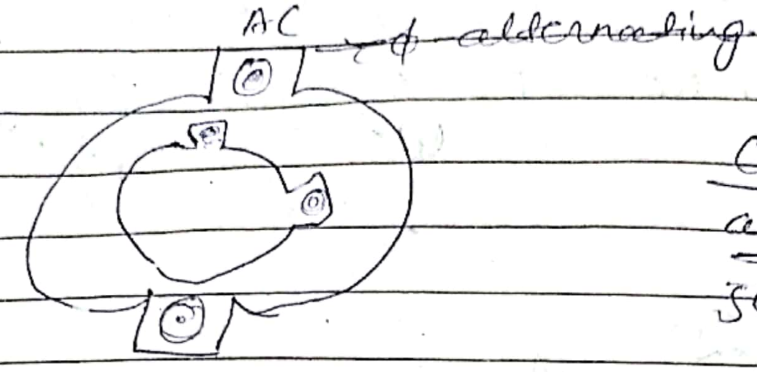
(iii) at $S = R_1/X_{2S}$ Torque maximum
Breakdown Torque

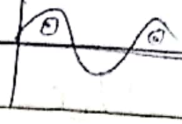
(iv) at high value of slip $\rightarrow R_2$ is negligible

$Z_2 = SX_{2S}$

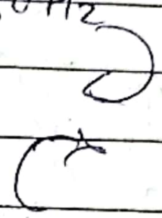
$T = \frac{3}{\omega_s} \times \frac{S E_{2S}^2 R_2}{S^2 X_2 S^2} \propto \frac{1}{S} \Rightarrow \boxed{T \propto \frac{1}{S}}$ Inver Relat

Single ϕ AC → 1ϕ IM



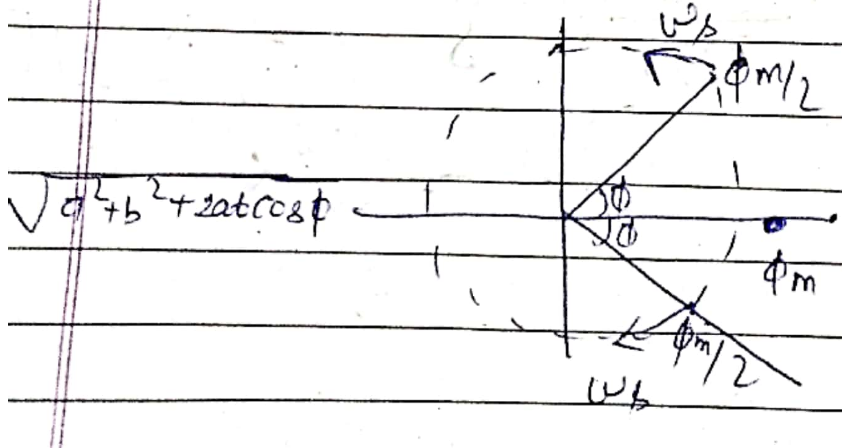


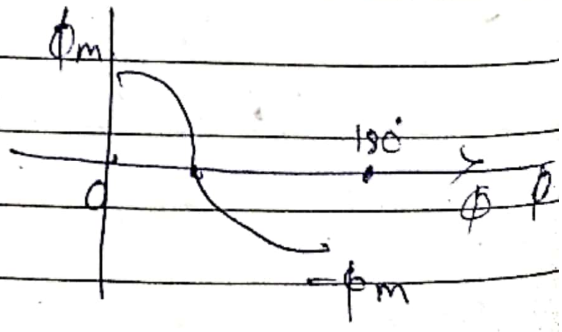
Clockwise
anticlockwise
50Hz



* The field produce in a single phase induction motor can be accelerate by double revolving ~~phase~~ field theory (DRFT), it based on ~~faraday~~ ferrous principle.

pulsating field produced in a 1ϕ motor can be resolved in to 2 ~~armo~~ components of half the magnitude and rotating in opposite dirn. at same synchronous speed.

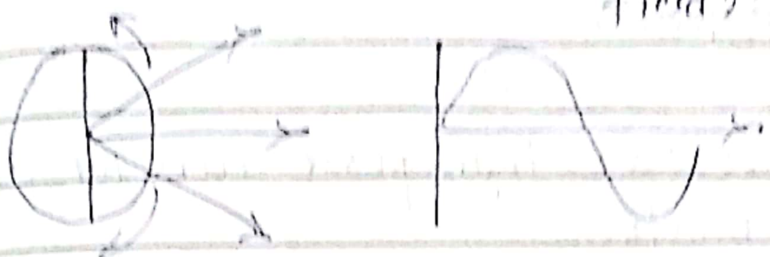


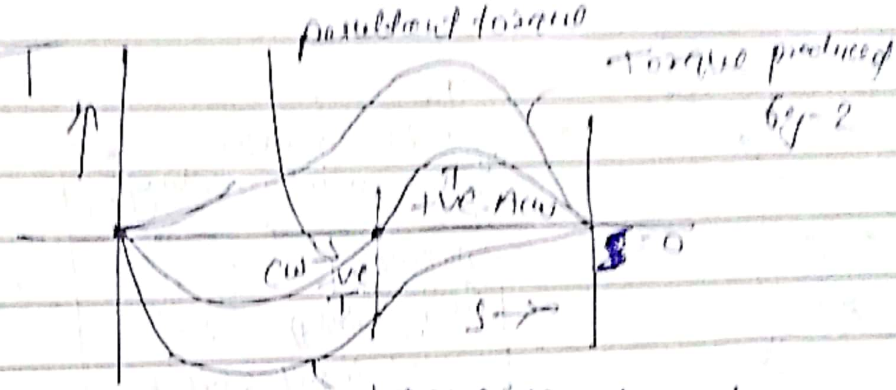


Single Phase Induction motor

DRFT

field 1: Clockwise dirn
field 2: anticlockwise dirn





* At standstill
  Torque 1 = Torque 2
  Net Torque = 0 ⇒ No motion and no rotation.

* At syncronous speed and
  when torque 2 > torque 1

* At s = 0 motor is rotating at synchronous speed (N_s) in anticlockwise ACW

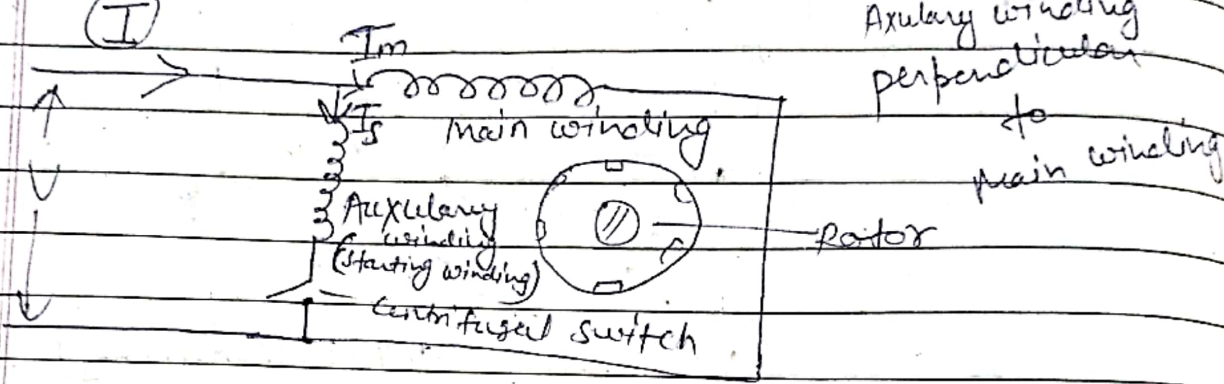
* At s = 2 N_s → CW
  ↑ motor rotating at synchronous speed (N_s) in clockwise dirn.

Conclusion
⇒ No self starting Motor

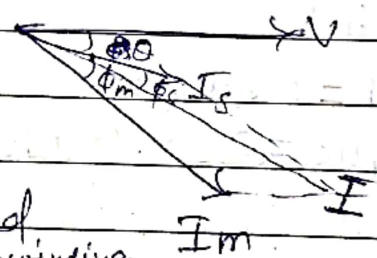
* Types of motor :-
① Split phase motor
② shaded pole motor
③ AC series Motor

Split phase :- single phase current split two parts.

Ⓘ

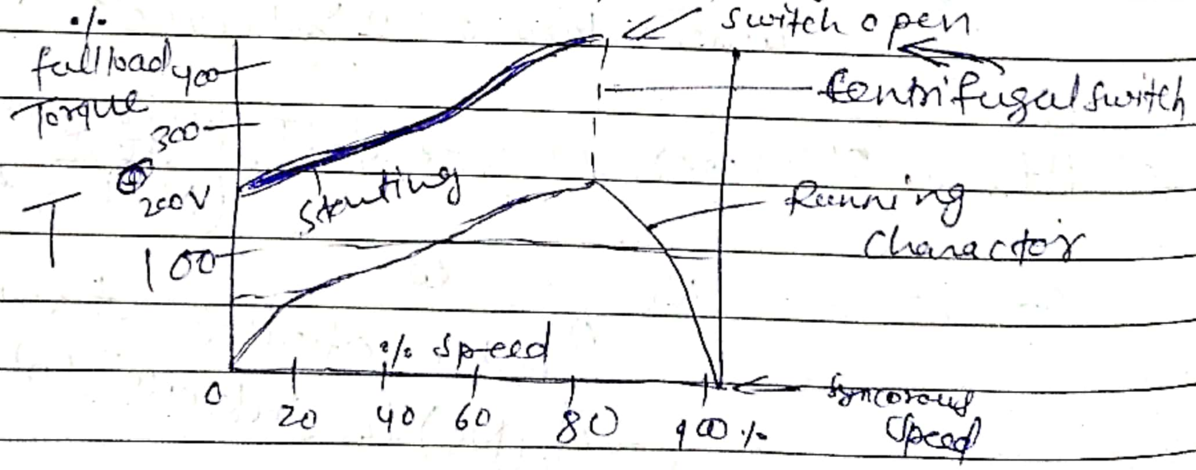


phasor diagram



~~Centrifugal switch is on while starting motion switch~~ gets open when it gets 20% speed so auxilliary winding connection turned off ~~and~~ current will produced from main winding.

Performance characteristic :



Syncoras Speed. $N_s = \frac{120f}{P}$ ← Supply frequency

P → no. of poles

Capacitor Motors

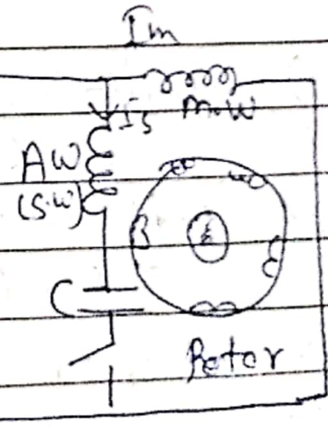
(1) Cap. start motors
(2) Cap run "
(3) Cap. start and Cap. run motor.

(1) Cap. start motors

* High starting torque (400% full load torque) found.
* low starting current (I_s) I
* It is of short duty time

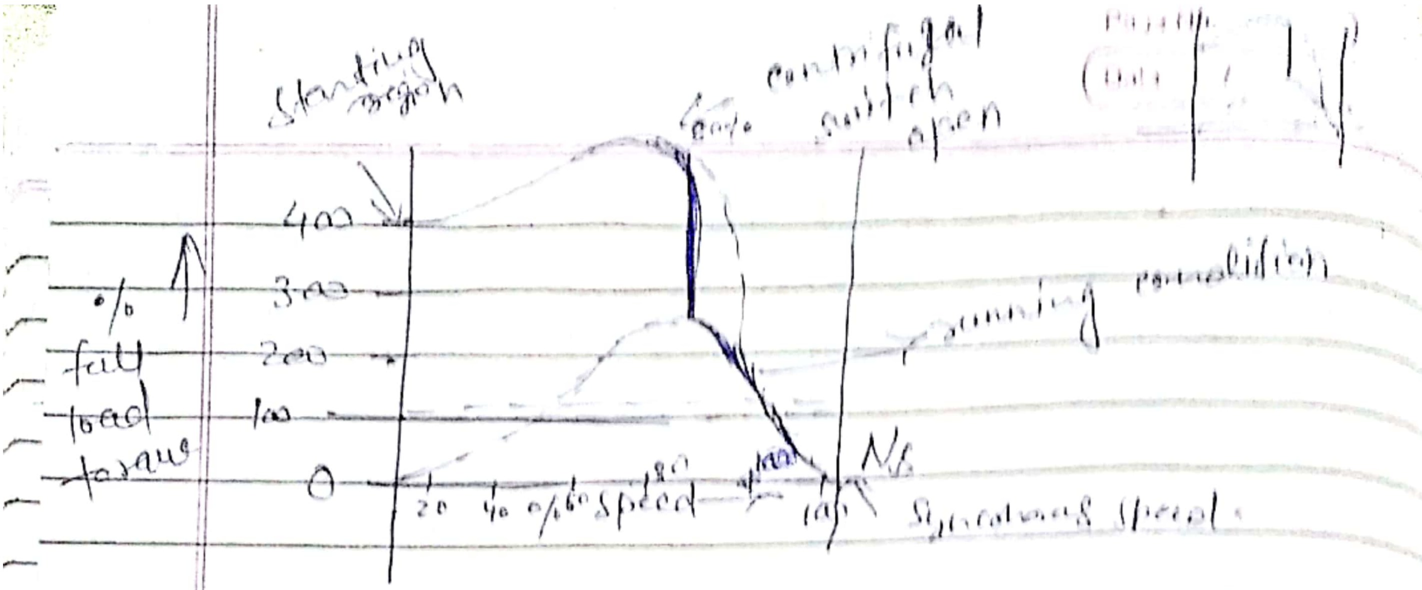
(charging and discharging will be quick.

supply Voltage



* Short duty time (capacitor) must be of electrolytic capacitor.

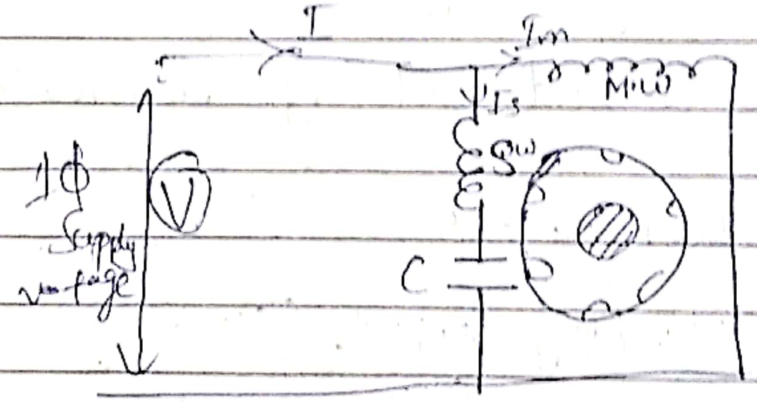
© It is used where hight starting Torque required



speed is almost 80% of the slip and high starting torque (400% of full load torque

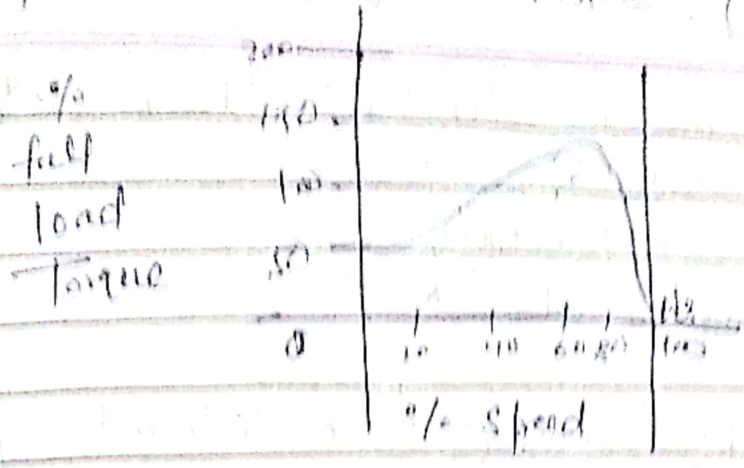
when motor is running condition

Capacitor Run Motor



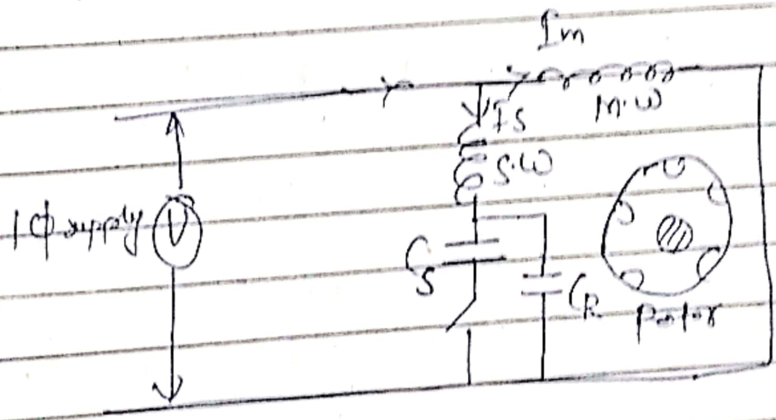
- Capacitor is paramenently connected in the starting winding.
- Both main winding and starting winding are of same rating.
- Paper Capacitor is used
- Electroletic capecitor is not used because electrolytic capacitor has short

Performance & Characteristic



* Starting torque is lower 50 to 100% of full load torque
* power factor improve about unity (is improve)
* Efficiency nearly 75%
* Application → Home appliance → fan, room coolers, Ceiling fan

③ Capacitor start and Capacitor run motor



* Two capacitors are used ① Cs → capacitor start (electrolytic) ② CR → Capacitor Run (Paper type)
* At 75% of Synchronous speed (Ns) start at switch at open Cs disconnected
* Costly → expensive
* Noiseless operation
* High starting torque and Running better

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- C_s value is higher than C_R.
- Higher power factor
- better efficiency.
- low current.

Performance Characteristics