D.C. MACHINES

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

E_b = Back EMF

ϕ = Flux per pole
Z = Total no of armature conductor
N = Speed or armature in RPM.
P = No. of poles.
A = No of parallel paths

2. Eq. ckt of motor:

2. Motor → electrical energy into mechanical.
Principle: when a current carrying conductor is placed in a magnetic field, it experiences a mech force whose direction is given by Fleming's left-hand Rule. whose magnitude is given by F = BIl N

There's constructionally no diff between D.C Generator & D.C. Motor. Hence, the same D.C Machine can be used interchageably as a generator or as a motor.

When operating as a generator, it is driven by a mech machine & it develops voltage which in turn produces a current flow in an electric ckt. When operating as a motor, it is supplied by electric current & it develops a torque which in turn ~~develops~~ produces mech rotation.

When its field magnets are excited & its armature conductor are supplied with current from the supply mains, experience a force tending to rotate the armature. Armature conductors under N-pole are assumed to carry current downward & those under S-poles to carry current up.

By applying Fleming's Left Hand Rule, the direction of force on each conductor can be found. It is ~~shown~~ seen that each conductor experiences a force F which tends to rotate the armature in anticlock direction. These forces collectively produce a driving torque which sets armature rotating.

→ BACK EMF:

- When motor armature rotates, the conductor also rotate & hence cut the flux.
- In accordance with the laws of EMI, emf is induced in them whose direction, as found by Fleming's Right Hand Rule is in opposition to applied voltage.
- Because of its opposing direction, it is referred as counter emf or back emf E_b.

- The rotating armature generating back emf E_b is like battery. The power reqd to overcome opposition of E_b is $E_b I_a$.

- $E_b = \left(\frac{\phi Z N P}{A}\right) V$. N is in rps.

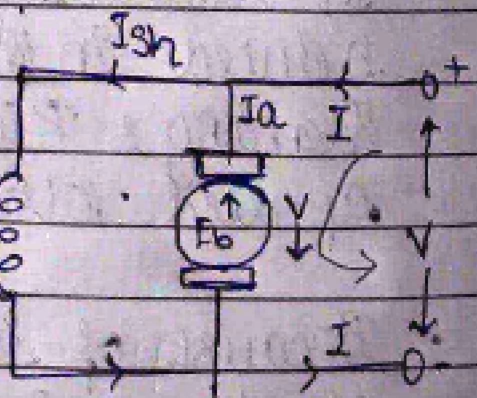
- Back emf depends ~~of~~ on armature speed. Speed ↑, E_b ↑ ⇒ I_a small.

- Speed is less, E_b is less, more current flows which develops motor torque.
- E_b makes a motor self-regulating so that it draws as much current as it is necessary.

→ VOLTAGE EQUATION OF MOTOR:

1. Voltage applied across the motor armature has to
i) overcome back emf E_b &
ii) supply the armature ohmic drop $I_a R_a$.
2. $V = E_b + I_a R_a$.
3. $V I_a = E_a I_a + I_a^2 R_a$

Electrical input to armature — Electrical equivalent of mech power — Cu loss in armature.



4. Motor efficiency is given by the ratio of power developed by the armature to its input i.e. $\frac{E_b I_a}{V I_a} = \frac{E_b}{V}$

5. Condition for max power: $E_b = \frac{V}{2}$

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Principle: Electromechanical energy conversion takes place whenever a change of flux linkages is associated with mechanical motion.

Speed voltage is generated when there is relative motion between coil & field.

Cylindrical structure.

Field windings

i) Primary source of flux

ii) Arranged to produce cyclic north-south distri.

Armature windings

i) series/parallel or star/delta 3-phase connection.

ii) gives desired voltage to supply rated current

current passes thr coils.

Interaction

Produce EM torque which aligns the 2 fields

Stator (stationary)

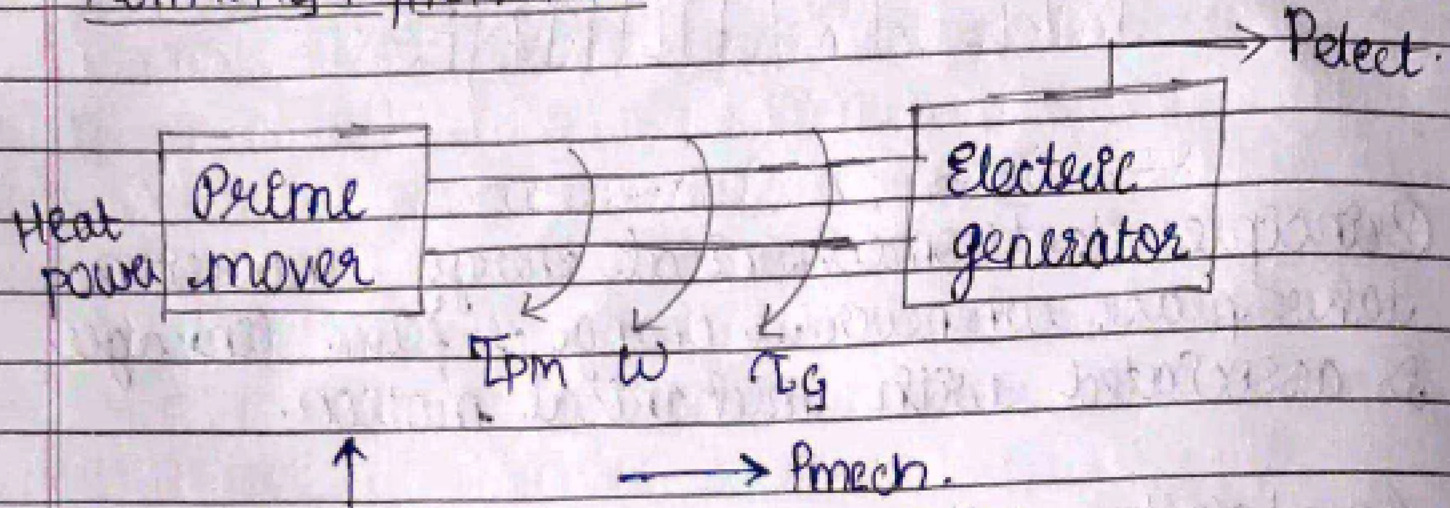
i) Annular portion of cylinder in which cylindrical rotor rotates

Rotor (Rotating)

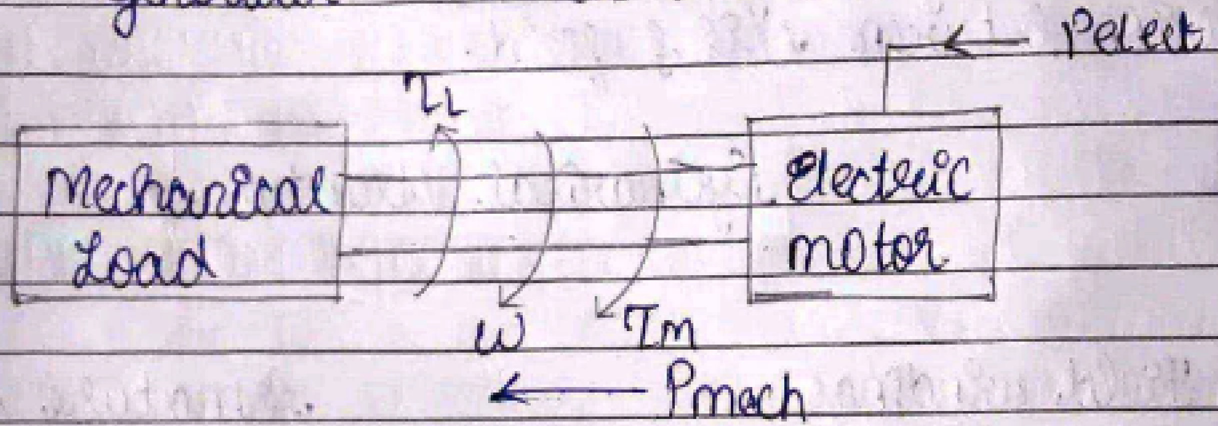
i) Housed with an axle on two sides of stator

ii) High permeability of magnetic material

→ ROTATING MACHINES:



Generator (Mech to elect)

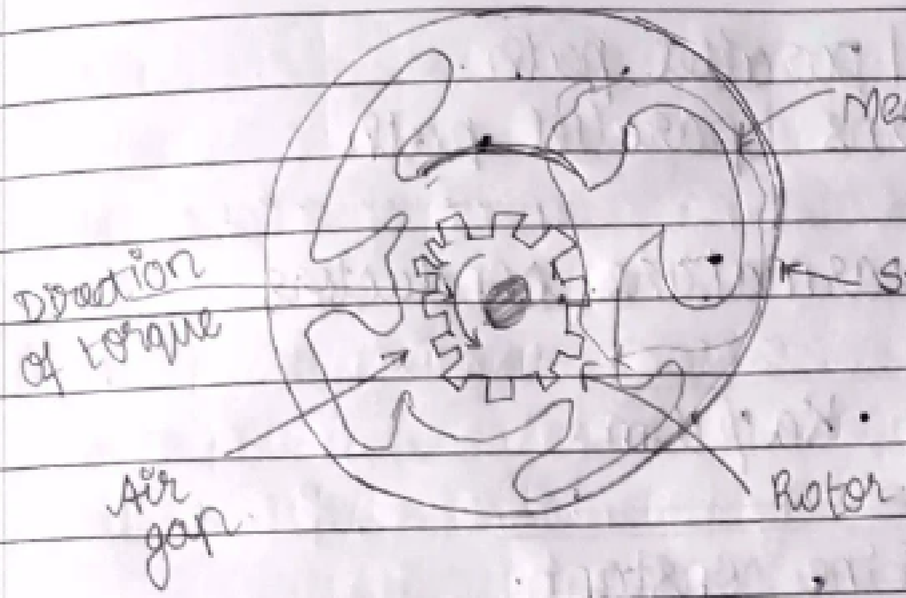


Motor (Elect to Mech)

where T_{pm} = Prime move torque $\Big\} \; T_{pm} = T_G$
T_G = Generator torque
T_L = Load torque $\Big\} \; T_L = T_M$
T_M = Motor torque

→ CONSTRUCTION & WORKING FEATURES:

i) Stator & rotor separated by air gap.
ii) Field windings are primary source of flux.
iii) Rotor is housed in slots uniformly out around the periphery & are connected to armature winding.
iv) Relative motion of field winding & armature winding induces emf which exchanges power.
v) Interaction produces torque of EM origin resulting in conversion.



→ **ARMATURE WINDINGS & COMMUTATOR:**

1. Accomodated in slots of two layers.
2. One side of the coil is in top in one slot & its 2nd side is in bottom of a slot (π rad) away.
3. There are as many commutator segments as the no. of armature coils.

→ **EMF AND TORQUE:**

ϕ = flux/pole

$\lambda_1 = N_c\phi$, $\lambda_2 = -N_c\phi$ (After reversing one pole switch)

$\Delta\lambda = -2N_c\phi$

Time of travel thr one pole switch.

$\Delta t = \frac{2\pi}{P\omega_m} \cdot s$

$E_c = \frac{-\Delta\lambda}{\Delta t} = \phi\omega_m N_c P$

Armature EMF = $\boxed{E_a = \frac{\phi\omega_m (C_p N_c) P}{\pi}}$

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where E_p = coils / parallel path.
$C_p N_c = \frac{Z}{2A}$ = turns / parallel path

Z = Total no of armature conductors

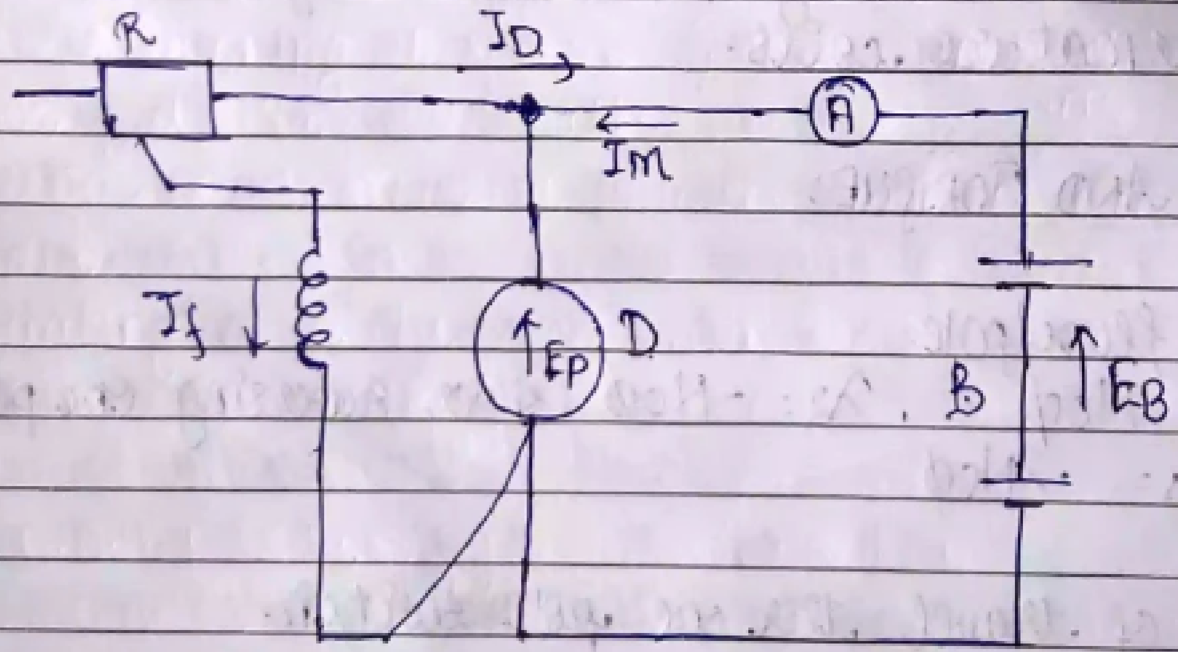
$$\boxed{E_a = \frac{\phi \omega_m Z}{2\pi}\left(\frac{P}{A}\right) = K_a \phi \omega_m}$$

$$\boxed{K_a = \frac{ZP}{2\pi A} = \text{Machine constant}}$$

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

→ TYPES OF DC MACHINES

1.



Shut-Wound Machine

Works as a generator when: current I_D is in the same direction as emf E_D.
As generator: I_D is in the same direction as E_D. and $V < E$

$$\therefore \boxed{V = E - I_a R_a}$$

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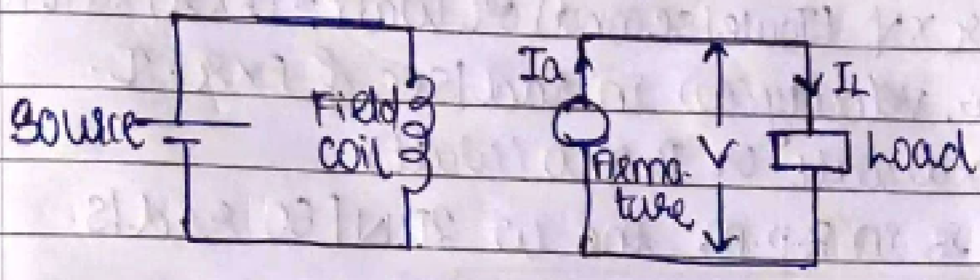
Works as a motor when: Im is in reverse direction as emf E_b.
As motor: $V > E$ $\boxed{\therefore V = E + I_aR_a}$

2. <u>Separately excited generators</u>.

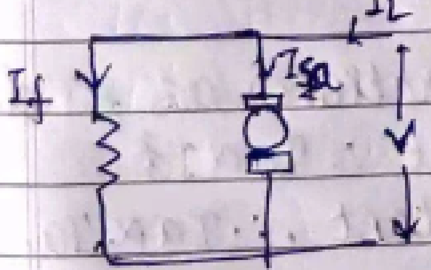


$I_a = I_L = I$.
$V = E - IR_a$.
Power developed $= EI$.
Power delivered $= VI$.

→ <u>~~SELF-EXCITED GENERATORS~~</u>

→Q4. A 4-pole 220-V shunt motor has 540 lap-wound conductor. It takes 32A from supply & develops output power of ~~5.5~~ 5.595kW. The field winding takes 1A. The armature resistance is 0.09Ω & flux per pole is 30mWb. Calculate i) speed ii) torque (Nm)

Lap wound → // parallel = no. poles



$I_a = I_L - I_f$
$= 32 - 8$
$= 31A$

$E_b = V - I_aR_a$
$= 220 - 31 \times 0.09$
$E_b = 217.21V$

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

$217.21 = \frac{30 \times 10^{-3} \times 540 \times N}{60}$

<u>$N = 804.48$ rpm</u>

$T_{sh} = 9.55 \times \frac{O/P}{N}$

$= \frac{9.55 \times 5.595 \times 10^3}{804.48}$

<u>$T_{sh} = 66.42$ Nm</u>

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→ TORQUE

1. Turning or ~~tws~~ twisting moment of a force abt an axis.
2. Of Torque (T) : $T = F \times r$ Newton-metre (N-m)
3. Work done in 1 revolution = $F \times 2\pi r$ (Joule)
   Power : $F \times 2\pi r \times N$ (Joule/second) or Watt = $(F \times r) \times 2\pi N$ Watt
   $2\pi N$ = Angular velocity (ω) in rad/sec & $F \times r = T$.
   ∴ Power :- $T \times \omega$ watt or $P = T\omega$ (Watt)
3. Moreover, if N is in R.p.m. the $\omega = 2\pi N/60$ rad/s.
   ∴ $\boxed{P = \frac{2\pi N}{60} \times T \text{ or } P = \frac{2\pi}{60} NT = \frac{NT}{9.55}}$.

→ ARMATURE TORQUE OF A MOTOR

1. Let Ta be the torque developed by the armature of a motor running at N r.p.s. If Ta is in Nm, then power developed = $T_a \times 2\pi N$ watt.
2. Electric power converted to mech power in armature:- $E_b I_a$ Watt.
3. Equating both $T_a \times 2\pi N = E_b I_a$.
   Subs $E_b = \phi Z N \times \left(\frac{P}{A}\right) V$,

$$\boxed{T_a = 0.159\, \phi Z I_a \times \left(\frac{P}{A}\right)} \quad \boxed{\therefore T_a \propto \phi I_a}$$

4. For series motor, ϕ is $\propto I_a$ (b4 saturation) as field windings carry full armature current ∴ $T_a \propto I_a^2$
   For shunt motor, ϕ is practically constant, ∴ $T_a \propto I_a$.

→ SHAFT TORQUE OF A MOTOR

1. The torque which is available for doing useful work is

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known as shaft torque . Tsh.

2. Output : $T_{sh} \times 2\pi N$ watt provided Tsh is in N-m & N-rps

3. $\therefore T_{sh} = \text{Output in watts}/2\pi N$ N-m , N-rps

$= \text{Output in watts}/2\pi N/60$ N-m , N-rpm.

$= \frac{60 \text{output}}{2\pi N} = \boxed{\frac{9.55 \text{ output}}{N} \text{ N-m.}}$

4. The difference $(T_a - T_{sh})$ is known as lost torque & is due to iron & friction losses in motor.

→ SPEED OF DC MOTOR

$E_b = V - I_a R_a$ or. $\frac{\phi Z N}{60}\left(\frac{P}{A}\right) = V - I_a R_a$

$N = \frac{V - I_a R_a}{\phi} \times \left(\frac{60A}{ZP}\right)$ r.p.m.

$V - I_a R_a = E_b$ $\therefore \boxed{N = \frac{E_b}{\phi} \times \left(\frac{60A}{ZP}\right) \text{ rpm}}$ or $N = K \cdot \frac{E_b}{\phi}$

→ Series motor:

Let N_1 = speed in 1st case : I_{a_1} = armature I in 1st case

ϕ_1 = flux/ pole in the first case.

N_2, I_{a_2}, ϕ_2 - flux, speed, armature current in 2nd case.

$N_1 = \frac{E_{b_1}}{\phi_1}$ where $E_{b_1} = V - I_{a_1} R_a$

$N_2 = \frac{E_{b_2}}{\phi_2}$ where $E_{b_2} = V - I_{a_2} R_a$.

$\therefore \frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$. Prior to magnetic poles saturation:

$\phi \propto I_a$. $\therefore \boxed{\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{I_{a_1}}{I_{a_2}}}$

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→ **For shunt motor**

In this case same eqn:-

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2} \quad \text{if } \phi_1 = \phi_2 = \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

→ **TORQUE & SPEED DC MOTOR**

$$N = K\left(\frac{V - I_a R_a}{\phi}\right) = \frac{KE_b}{\phi}$$

~~$T_a \propto \phi I_a$~~ $T_a \propto \phi I_a$

1. Increase in flux would decrease the speed but increase the armature torque. It cannot be so as torque always tends to produce rotation.
2. If the flux of a motor is decreased by decreasing field current
a) Back emf $(E_b) = (N\phi/K)$ drops instantly (speed remains const because of inertia of heavy armature)
b) Due to decrease in E_b, I_a is increased as $I_a = (V - E_b)/R_a$. Moreover, a small reduction in flux produces a proportionally large (↑) in armature current.
c) ∴ The eqn ~~$T_a \propto$~~ $T_a \propto \phi I_a$, a small decrease in ϕ is more than counter balanced by a large increase in I_a with the result that there is a net increase in T_a.
3. It is ~~then~~ possible to (↑) flux & at the same time (↑) speed provided I_a is held const.

→ **MOTOR CHARACTERISTICS**:-

1. Shows relationship betn:
a) Torque & armature current i.e. T_a/I_a characteristic: electrical characteristic.

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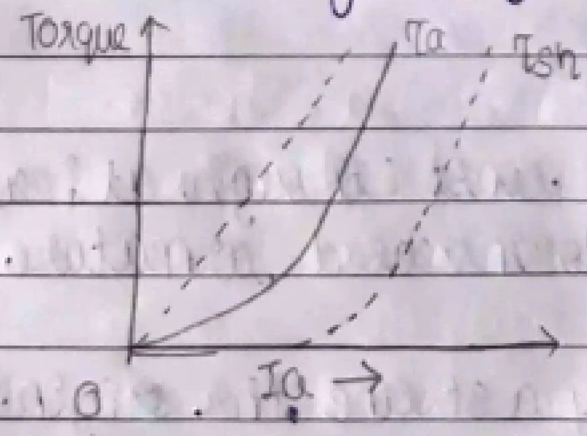
b) Speed & armature current i.e. N/I_a charac.
c) Speed & torque i.e. N/T_a charac : Mech chara.

$$\boxed{T_a = \phi I_a \ \& \ N \propto \frac{E_b}{\phi}}$$

→ <u>SERIES MOTOR :</u>

i) 1. T_a/I_a characters.
2. $T_a \propto \phi I_a$.
3. In this case, as field winding also carry the armature current, $\phi \propto I_a$ upto pt of magnetic saturation. Hence, b4 saturation, $T_a \propto \phi I_a$ & ∴ $T_a \propto I_a^2$.
4. At light loads, I_a & hence ϕ is small. But as I_a (↑), T_a(↑) as ~~cur~~ I^2. Hence T_a/I_a is parabola.
5. After saturation, ϕ is almost independent of I_a & hence $T_a \propto I_a$ only. ∴ St line.
6. Eg. Used in case where huge starting torque is required for accelerating heavy masses quickly in hoists & electric train



ii) 1. N/I_a charact.
2. ~~Eb~~ $N \propto E_b/\phi$
3. When load is heavy, I_a is large ∴ Speed low (this decrease E_b & allows more armature to flow). But when load current & hence I_a falls to a small value, speed becomes dangerously high.

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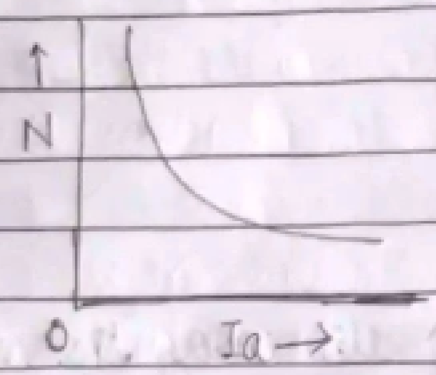
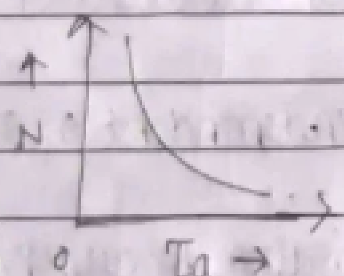
4. Hence a series motor should never be started without some mech (not belt-driven) load on it, else it may develop excessive speed & get damaged due to heavy centrifugal forces so produced.
5. It is variable speed motor.

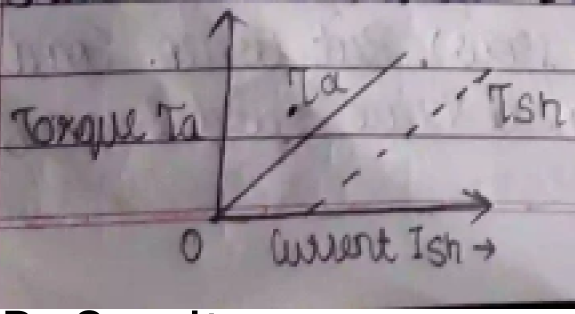


iii) N/Ta or mech
When speed is high, torque is low & vice-versa.



→ SHUNT MOTOR:

i) 1. Ta/Ia charac.
2. Assuming ϕ to be practically const (though at heavy loads, ϕ decreases somewhat due to increased armature reacn), we find that $T_a \propto I_a$.
3. ∴ Electrical charact. is practically a st. line thr origin. Shaft torque is shown ~~as~~ dotted.
4. Since heavy starting will need heavy starting current; shunt motor should never be started on (heavy load).



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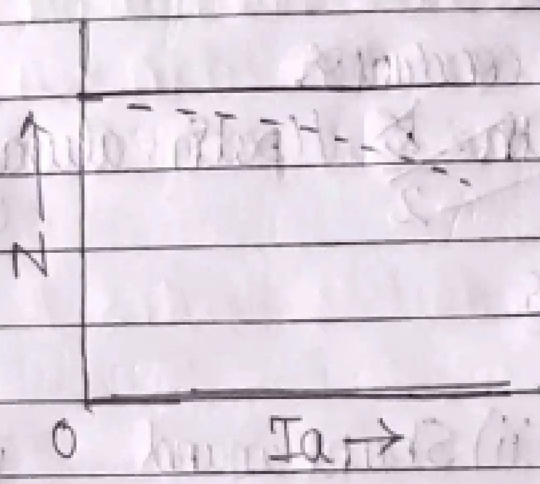
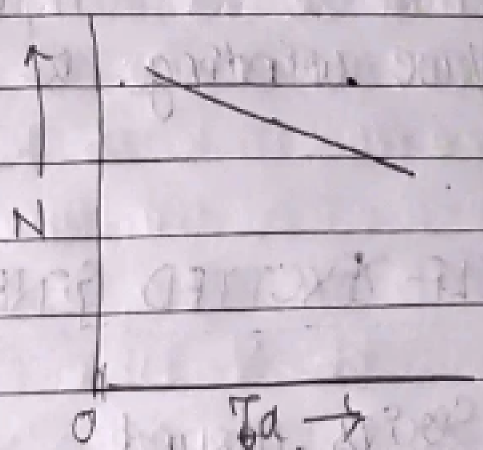
ii) N/Ia charact.



iii) N/Ia

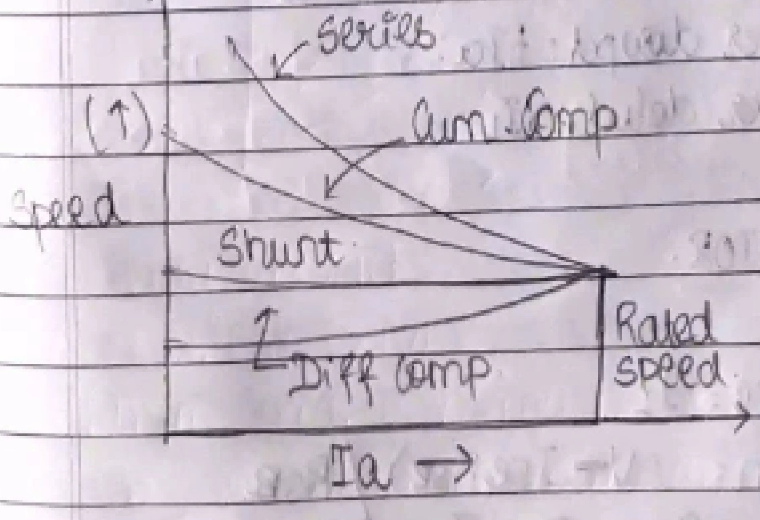


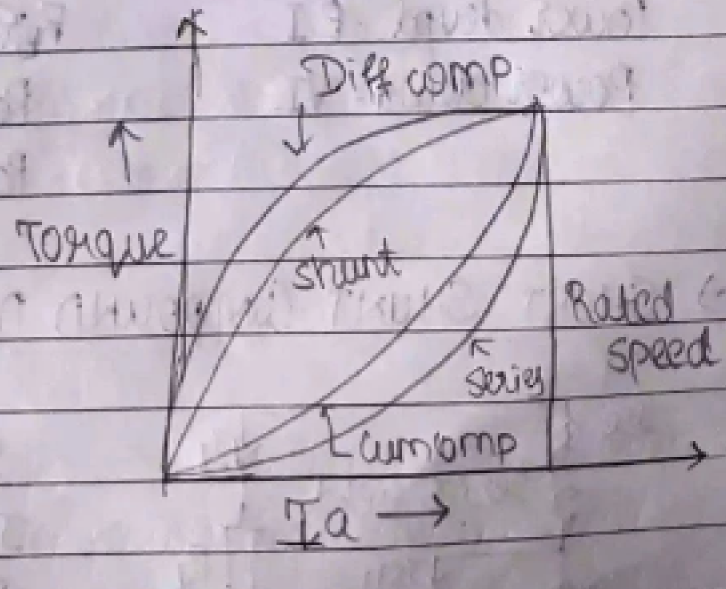
→ Constant speed motor.

→ COMPOUND MOTOR:

i) Have both series & shunt windings.

Compound
→ Cummulatively → Series flux is in same direction as shunt ~~field~~ flux
→ Differentially → Series flux opposes shunt flux.





→ Lap winding: Z = No. of conductors, P = poles

// paths = P.

→ Wave winding: Z = No. of conductor

~~//path = $Z/2$~~ //path = always 2 (irrespective of no. of poles).

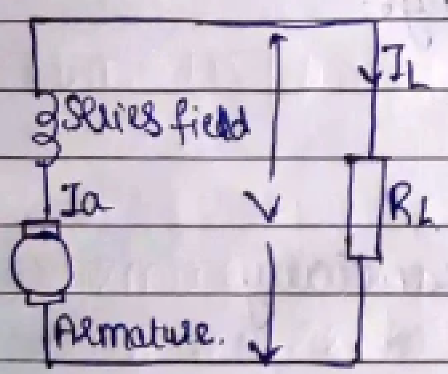
→ SELF-EXCITED GENERATORS

i) Series wound

↓

Field coils in series with armature ckt

↓



$I_a = I_{se} = I_L = I$

$\cancel{E_b}\ \cancel{V} = I(R_a + R_{sc})$

Power devpd = EI

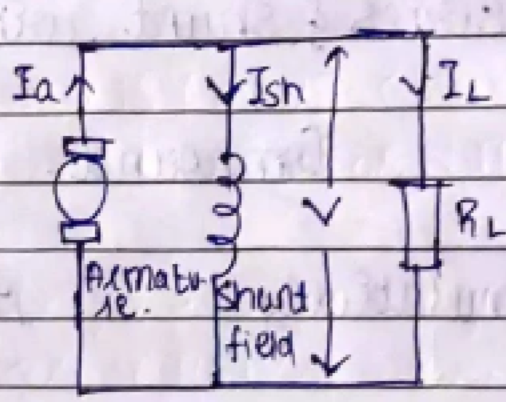
Power delvd = VI

ii) Shunt wound

↓

Field coils connected across armature ckt

↓



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

~~$I_a = I_{sh} + I_L$~~ $I_a = I_L - I_{sh}$

~~$E_b = V = I_aR_a$~~ $E_b = V - I_aR_a$

Power devpd: EI_a.

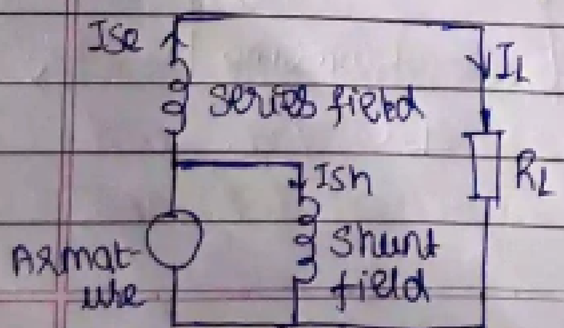
Power delvd: VI_L

iii) Compound wound

↓

One in parallel other in series

→ SHORT-SHUNT COMPOUND MOTOR.



$I_{se} = I_L$

$I_{sh} = (V + I_{se}R_{se}) / R_{sh}$

~~$I_a = I_{sh} + I_L$~~ $I_a = I_L - I_{sh}$

$V = E - I_aR_a - I_{se}R_{se}$

Power dvd = EI_a, Power delv = VI_L

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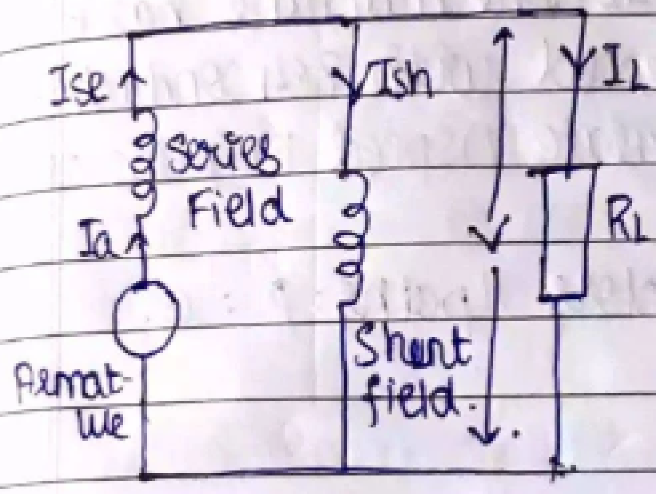
LONG-SHUNT



$I_a = I_{se} = \cancel{I_{sh}+I_L}\ I_L - I_{sh}$

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

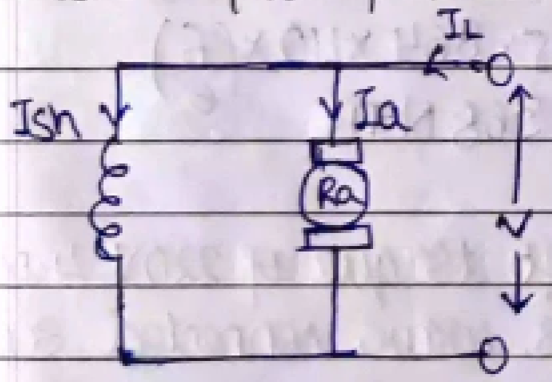
$V = E - I_aR_a - I_aR_{se}$

$\therefore \cancel{E}\ V = E - I_a(R_a + R_{se})$

Power dvpd $= EI_a$

Power delivd $= VI_L$

→Q.1 A 440V shunt motor has armature has resis of $0.8\,\Omega$ & field resistance of $200\,\Omega$. Determine back emf when giving an output of 7.46 KW at 85% efficiency.



$E_b = V - I_aR_a$

$\eta = \frac{O/P}{I/P}$

$\therefore$ Motor input power $= \frac{O/P}{\eta}$

$= \frac{7.46 \times 10^3}{0.85}$

$I/P = 8.776\,KW$

Motor input current $= 877k/440$

$I_L = 20A$

$I_{sh} = \frac{V}{R_{sh}} = \frac{440}{200} = 2.2A$

$I_a = I_L - I_{sh} = 20 - 2.2 = 17.8A$

$E_b = V - I_aR_a$

$= 440 - 17.8 \times \cancel{200}\ 0.8$

$E_b = 425.76V$

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→Q.2. A D.C. Motor takes an armature current at 110A at 480V. The armature ckt resistance is 0.2Ω. The machine has 6-poles of the armature is lap-connected with 864 conductors. The flux/pole is 0.05Wb. Calculate i) speed ii) Gross torque developed by armature

Lap connected ⇒ No. of ~~conductors~~ ∥paths = $P = 6$.

$E_b = V - I_aR_a$

$= 480 - 110 \times 0.2$

$= 458V$

$E_b = \frac{\phi Z N P}{60 A} = \frac{0.05 \times 864 \times N}{60} \times \left(\frac{6}{6}\right) = 458.$

∴ $N = 636.11$ rpm.

$T_a = 0.159 \phi Z I_a \left(\frac{P}{A}\right) = 0.159 \times 0.05 \times 864 \times 110 \times \left(\frac{6}{6}\right)$

$T_a = 755.568$ N-m

→Q.3 Determine developed torque of shaft torque of 220V, 4-pole series motors with 800 conductors, wave connected, supplying a load of 8.2kW by taking 45A from mains. Flux/pole is 25mWb of its armature ckt resistance is 0.6Ω.

Wave connected = ∥path $= \frac{Z}{2} = 400$.

$T_a = 0.159 \times \phi \times Z \times I_a \times \left(\frac{P}{A}\right)$

$= 0.159 \times 25 \times 10^{-3} \times 800 \times 45 \times \left(\frac{4}{400}\right)$

$T_a = 1.431$.

$E_b = V - I_aR_a$

$= 220 - 45 \times 0.6$

$E_b = 193V$

$T_{sh} =$

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