Chapter-4 (12 marks)

Explain the operation of dc machine as dc motor.

Explain the working principle of a d.c motor and derive the equation of torque developed by the armature of the d.c motor. [4+4]

b) What do you mean by back emf in DC motors? Explain the significance of back emf. [4]

c) Explain the speed-current, torque-current and speed-torque characteristics of a DC shunt motor. [6]

a) Using circuit diagram and graphical representation, explain the characteristics of DC series generator and DC shunt generator. Also mention their applications. [8]

100 A current and runs at 1200 RPM. What is value

a) Describe different methods of controlling the speed of shunt DC motor. [8]

a) What is back emf? How does back emf play an important role in DC motor? [2+4]

With the help of a neat sketch, explain the working principle of three terminal DC motor starter. [5]

a) Explain torque-armature current and speed-torque characteristics of DC shunt and DC series motor. [8]

a) Explain the Armature control method and field control method of speed control of DC shunt motor.

Why the dc motor draws large current at starting? Justify it clearly and also describe the working of 3-point dc motor starter. [3+5]

Construction → same as generator

→ A DC motor is an electric motor that converts direct current (DC) electrical energy into mechanical energy.

Working Principle of DC motor (IOE)

A DC motor operates based on the interaction between a magnetic field and current-carrying conductors. When a conductor (part of the motor's armature) carries current and is placed in a magnetic field (produced by the stator's field windings), it experiences a mechanical force. This force is governed by Fleming's Left-Hand Rule, which states that the direction of force is perpendicular to both the magnetic field and the current.

supplied by a dc source

The armature, consisting of multiple conductors, begins to rotate due to these forces. However, to sustain continuous rotation, the direction of current in the armature conductors must reverse every half-cycle. This reversal is achieved using a commutator and carbon brushes. The commutator segments switch the current polarity in the armature coils as they pass the brushes, ensuring that torque remains unidirectional. Without this mechanism, the armature would oscillate instead of rotating continuously.

Derivation of Torque Equation (IOE)

let,

N = Speed of armature

r = radius of armature coil

if T_a is the torque produced by the armature

$T_a = F \times r$

then,

word done by force in one complete rotation $= F \times 2\pi r$

$= T_a \times 2\pi$

time required for N revolution $= 60$ sec

∴ time required for 1 revolution $= \frac{60}{N}$ sec

∴ $\text{power} = \frac{\text{word done}}{\text{time}}$

or, $P_a = \frac{T_a \times 2\pi}{60/N}$

or $P_a = \frac{2\pi N T_a}{60}$ W —— (i)

now the rotating armature conductors are cutting flux so emf will be induced across the armature coil. The emf is known as back emf given by,

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

now,

power developed by armature is,

$$P_a = E_b \times I_a$$

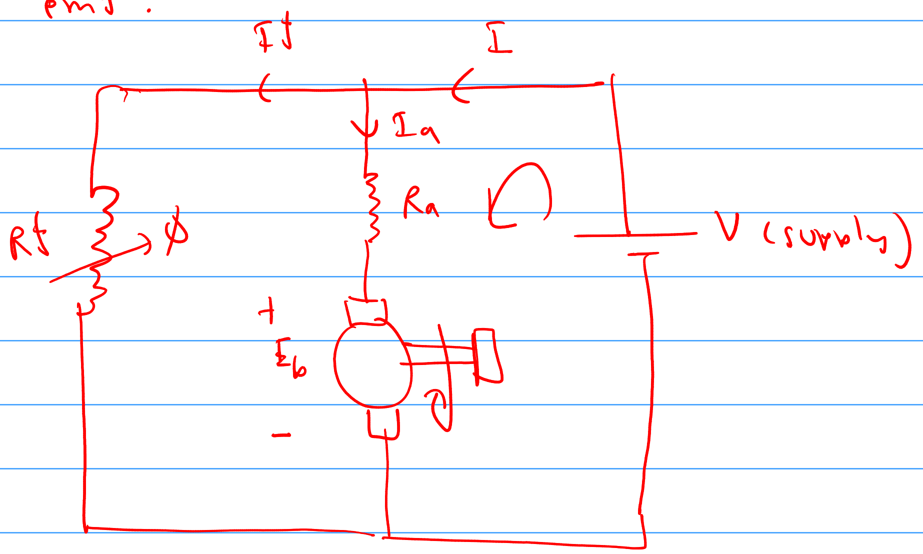
or, $\frac{2\pi \cancel{N} T_a}{\cancel{60}} = \frac{Z\phi \cancel{N}}{\cancel{60}} \times \frac{P}{A} \times I_a$

or, $\boxed{T_a = \frac{1}{2\pi} Z\phi \frac{P}{A} I_a}$

$T_a \propto \phi I_a$

Back Emf and it's Roles (IOE)

→ As the armature rotates within the magnetic field, its conductors cut the magnetic flux lines. The cutting of flux induces a voltage (emf) in the conductors. The direction of the induced emf is opposite to the applied voltage. This opposition is the reason it is called back emf.



KVL on right loop

$$V - I_a R_a - E_b = 0$$

or $V = E_b + I_a R_a$ —— (i)

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

→ The back emf reduces the voltage to drive current through the armature

$E_b \uparrow \quad I_a \downarrow \qquad E_b \downarrow \quad I_a \uparrow$

multiply by I_a in (i)

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

or, $E_b I_a = V I_a - I_a^2 R_a$

∴ $\boxed{\text{Power developed by armature} = \text{Input power to armature} - \text{Cu loss in armature winding}}$

$$E_b = \frac{2\phi N}{60} \times \frac{P}{A}$$

→ depends on N and ϕ

Important Roles of Back emf

(i) If $E_b = 0$ (ie no back emf generated) the armature current becomes

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

The motor would draw a very high current, potentially causing damage due to overheating or short circuit conditions.

with back emf $I_a = \frac{V - E_b}{R_a}$ it limits the armature current to a safe value and protects the armature from S/C.

(ii) Back emf acts like a self-regulator for the motor, adjusting current and torque based on the load.

$E_b = \frac{Z\phi N}{60} \times \frac{P}{A}$ | $I_a = \frac{V - E_b}{R_a}$ | $T_a \propto \phi I_a$

→ If load increase, speed (N) ↓ which reduces E_b as $E_b \propto N$. If E_b ↓, I_a ↑ so T_a ↑ providing more torque to maintain speed.

→ If load decrease, N ↑, E_b ↑, I_a ↓, T_a ↓ reducing torque to match lighter load.

Feedback mechanism

load ↑ : $N \downarrow \rightarrow E_b \downarrow \rightarrow I_a \uparrow \rightarrow T_a \uparrow$

load ↓ : $N \uparrow \rightarrow E_b \uparrow \rightarrow I_a \downarrow \rightarrow T_a \downarrow$

(ii) back emf is the key to converting electrical energy into mechanical energy. without it all the input power would turn into heat and motor wouldn't work.

i.e $V I_a = E_b I_a + I_a^2 R_a$

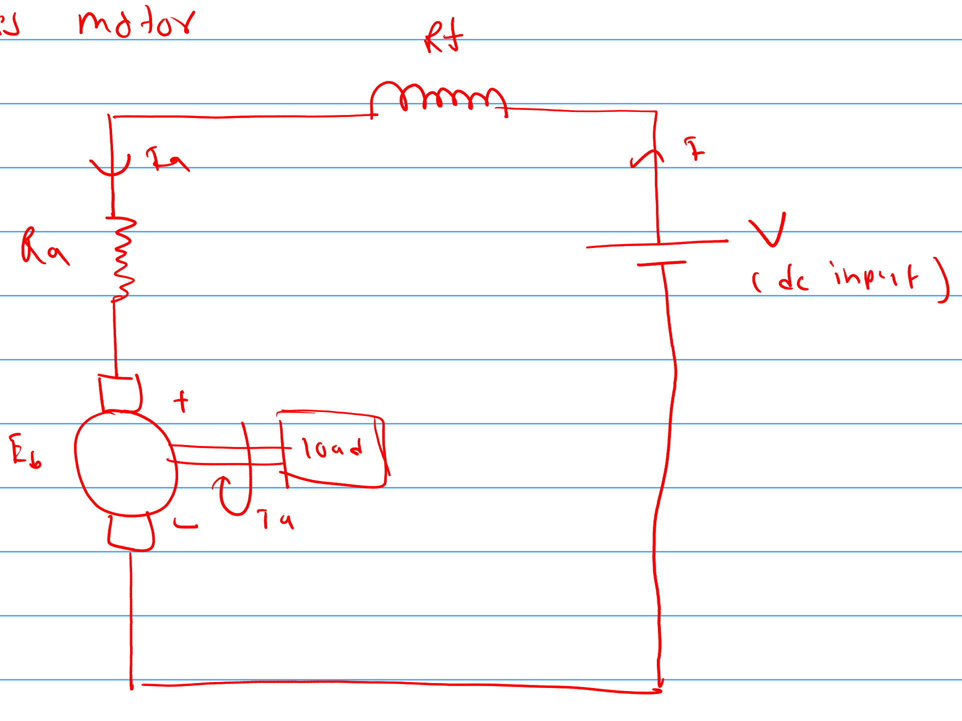
$V I_a$ → i/p power
$E_b I_a$ → mech power
$I_a^2 R_a$ → cu-loss

E_b close to V in steady-state operation most i/p power converted to mech power

In generators it opposes the mechanical input, converting motion into electricity.

Methods of Excitation / Types of DC motors and characteristics (IOE)

① DC series motor



Now,

$$\boxed{I = I_f = I_a}$$

$$\boxed{V = I_f R_f + I_a R_a + E_b}$$

(a) $T_a - I_a$ Characteristics / Electrical characteristics

torque armature current

We know,

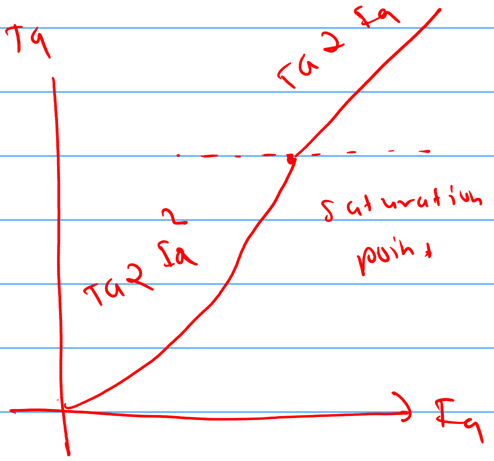
$$T_a \propto \phi I_a \quad \text{—(i)}$$

↳ Torque by armature

$$\phi \propto I_f$$

$$T_a \propto I_a I_a \propto I_a^2$$

$$\therefore T_a \propto I_a^2 \qquad (y = x^2)$$



→ After saturation the magnetic flux does not increase even if armature current (I_a) increases.

$$\boxed{T_a \propto I_a}$$

(b) $N - T_a$ characteristics / mechanical characteristics

speed torque

$$E_b = \frac{Z\phi N}{60} \times \frac{P}{A} \quad \text{—(ii)}$$

or,
$$V = I_f R_f + I_a R_a + E_b$$
$$= I_a R_f + I_a R_a + E_b$$
$$= I_a (R_f + R_a) + E_b$$

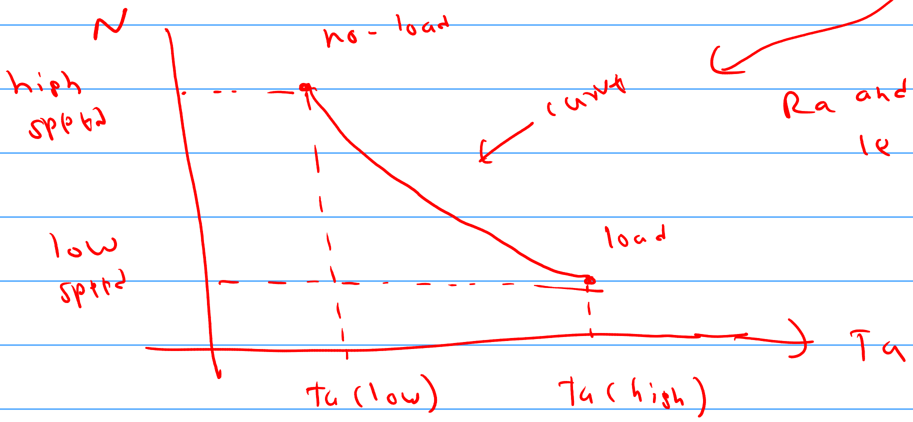
$I_a = \dfrac{V - E_b}{R_f + R_a}$ — (i) $T_a \propto \phi I_a$

(i) no-load, $N \uparrow$ $E_b \uparrow$ $I_a \downarrow$ $T_a \downarrow$

Conclusion: Speed ($\uparrow$), Ta (decrease)

(ii) load increase, $N \downarrow$ $E_b \downarrow$ $I_a \uparrow$ $T_a \uparrow$

conclusion: speed ($\downarrow$), Ta (increases)

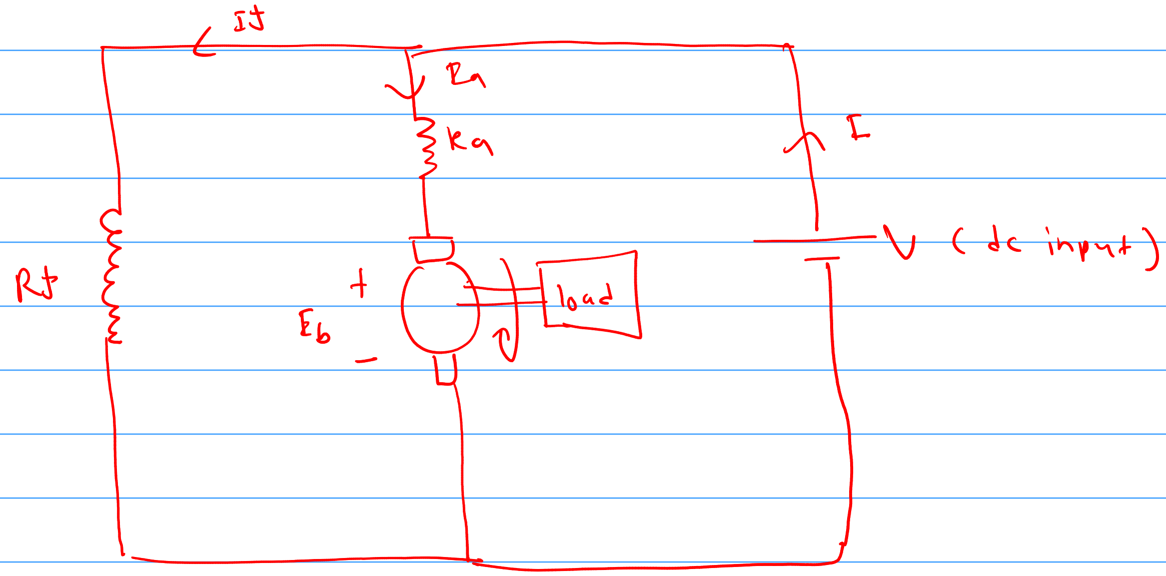


Ra and Rf le garda curve nancha

→ From the above characteristics curve we can see that the dc series motors have very high Starting torque if it has load. So it is ~~sua~~ suitable for electric vehicle, trains etc.

20E (why dc series motors used to start heavy loads)

② DC Shunt motor



$\boxed{I = I_a + Rf}$

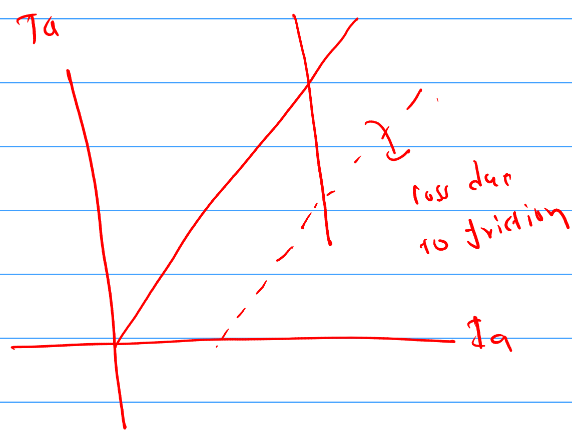
$\boxed{V = I_a R_a + E_b}$ $\boxed{V = I_f R_f}$

$\boxed{I_f R_f = I_a R_a + E_b}$

ⓐ T_a - I_a char

$T_a \propto \phi I_a$, $\phi \propto I_f$

$T_a \propto I_f I_a$



(b) N - Ta char

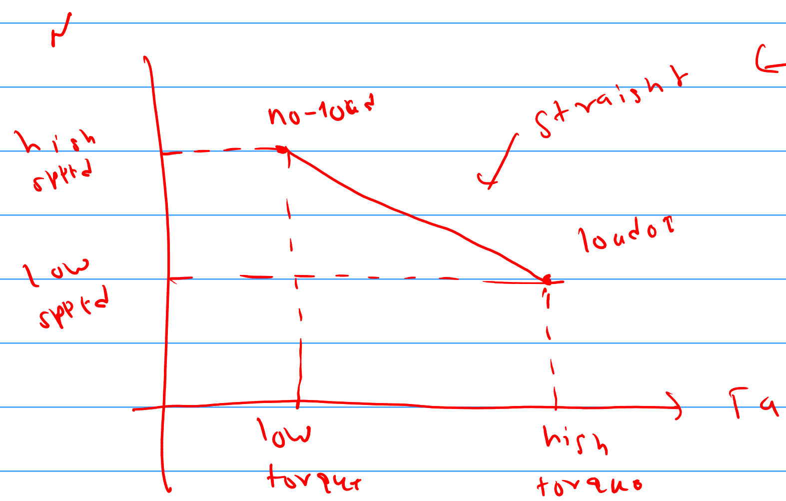
$E_b = \frac{2 \phi N}{60} \times \frac{P}{A}$ $\quad V = I_a R_a + E_b$

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

$T_a \propto \phi I_a$

loaded	non-loaded
$N \downarrow$	$N \uparrow$
$E_b \downarrow$	$E_b \uparrow$
$I_a \uparrow$	$I_a \downarrow$
$T_a \uparrow$	$T_a \downarrow$

only R_a



(3) DC compound motor

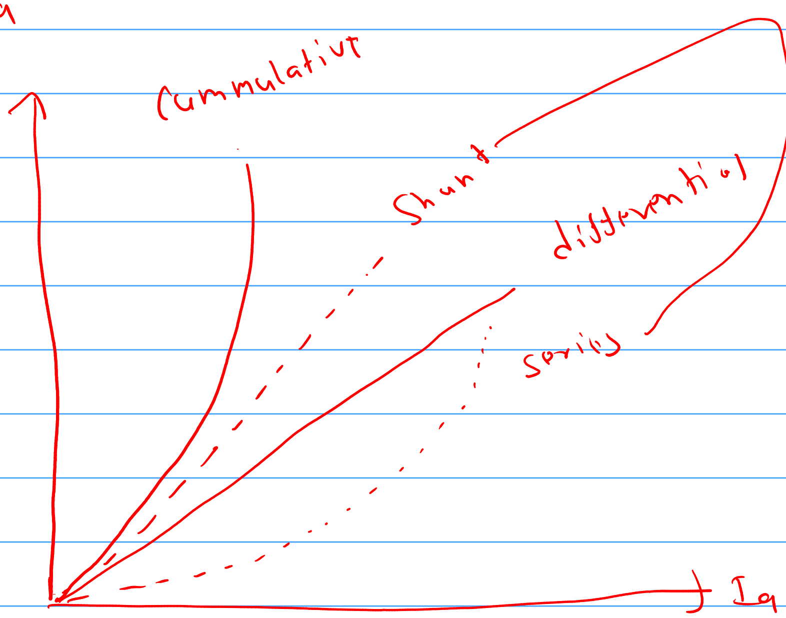
(1) Cummulative compound generator : If the series field wdg produces the flux in the same direction as produced by armature field winding.

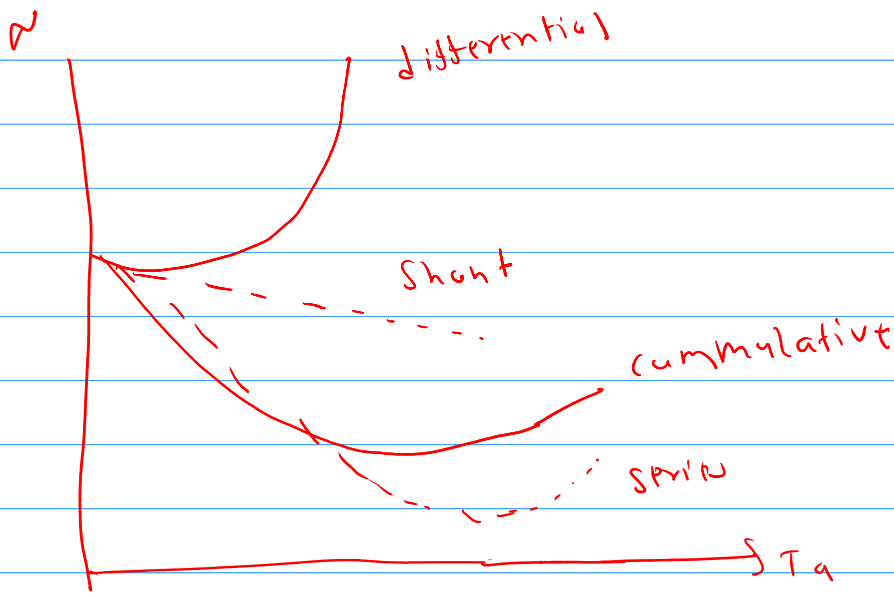
② Differential compound motor : If the series field winding produce flux in the opposite direction as produced by the armature field winding.

Characteristics

agadi bata

Ta - Ia

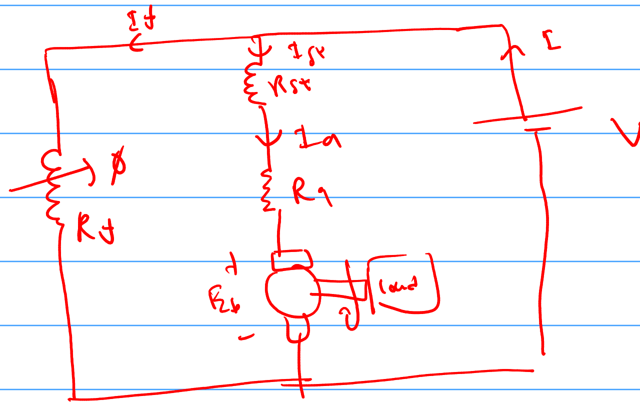




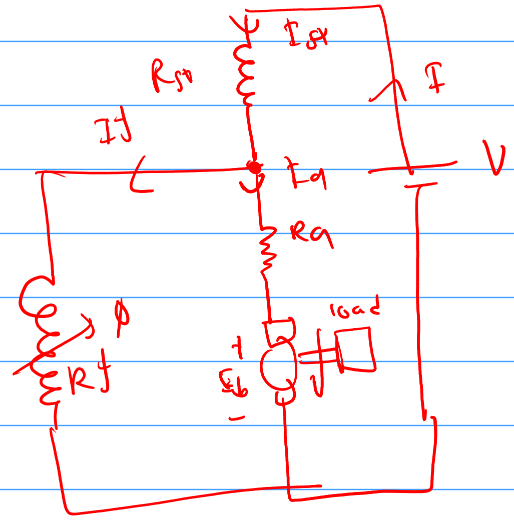
Series → curve, shunt → straight

extra

long shunt c.d. motor



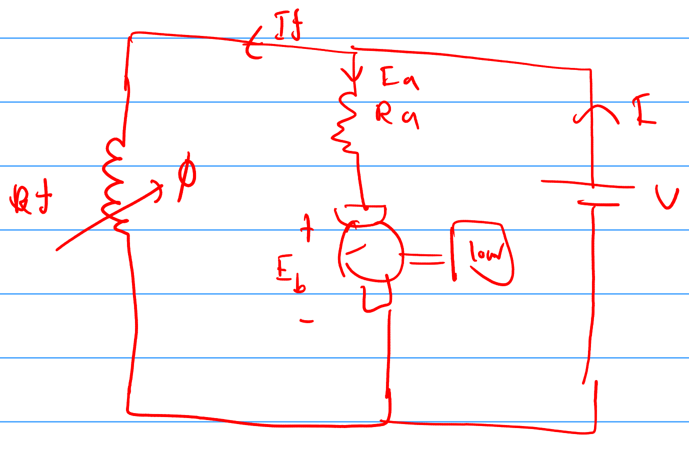
short shunt c.d. motor



(not dc-motor ma just replace load by dc voltage source, current direction starts from voltage source rest same)

Speed control of DC motors (IOE)

① DC shunt motor



① Field control method (flux control method)

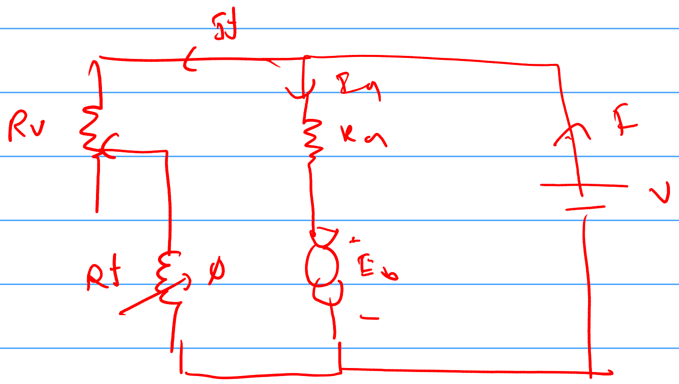
$$E_b = \frac{\phi Z N}{60} \times \frac{P}{A} \qquad N = \frac{E_b \times 60 \times A}{Z \phi P}$$

$$\boxed{N \propto \frac{E_b}{\phi}} \qquad \boxed{\phi \propto I_f} \qquad V = I_a R_a + E_b$$

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

→ Since ϕ is produced by the field winding, we can control it by adjusting the field current (I_f) (R_v)

→ A variable resistor is connected in series with the field winding to control the field current



$$\phi \propto I_f$$

$$V = I_f (R_v + R_f)$$

$$I_f = \frac{V}{R_v + R_f}$$

$R_v \uparrow$, $I_f \downarrow$, $\phi \downarrow$, $N \uparrow$

$R_v \downarrow$, $I_f \uparrow$, $\phi \uparrow$, $N \downarrow$

Working

② Armature control method

→ a variable resistor (R_v) is added in series with the armature winding.

$$V = I_a(R_a + R_v) + E_b$$

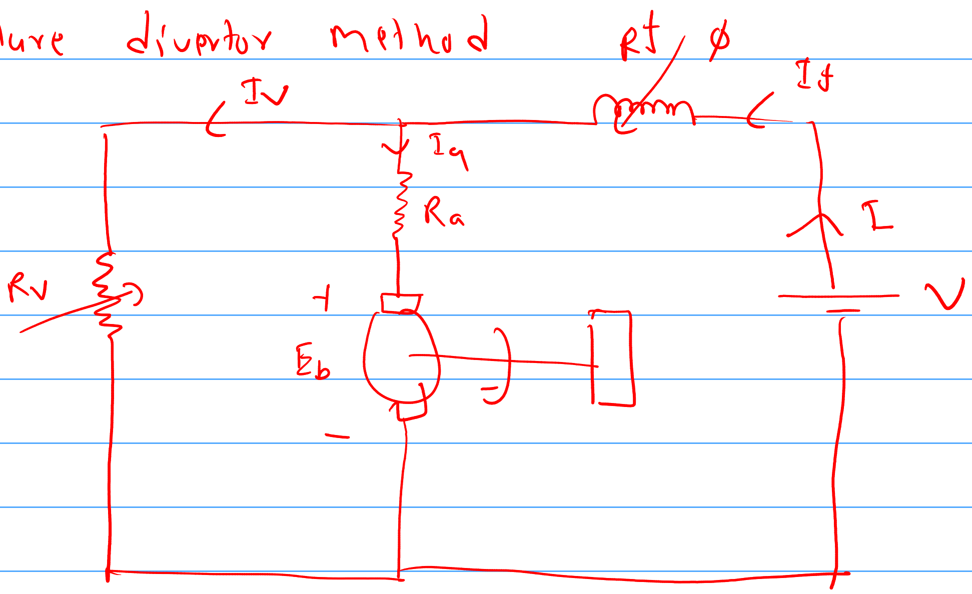
$$N \propto \frac{(V - I_a(R_a + R_v))}{\phi} \quad \Bigg| \quad N \propto \frac{E_b}{\phi}$$

$R_v \uparrow$, $N \downarrow$

$R_v \downarrow$ $N \uparrow$

Speed control of DC series motor

(i) Armature diverter method



→ a variable resistance R_V is connected in parallel with armature circuit for speed control purpose.

→ When R_V is connected some current I_V will flow through it therefore the new field winding current is :-

$$I_f = I_a + I_V$$

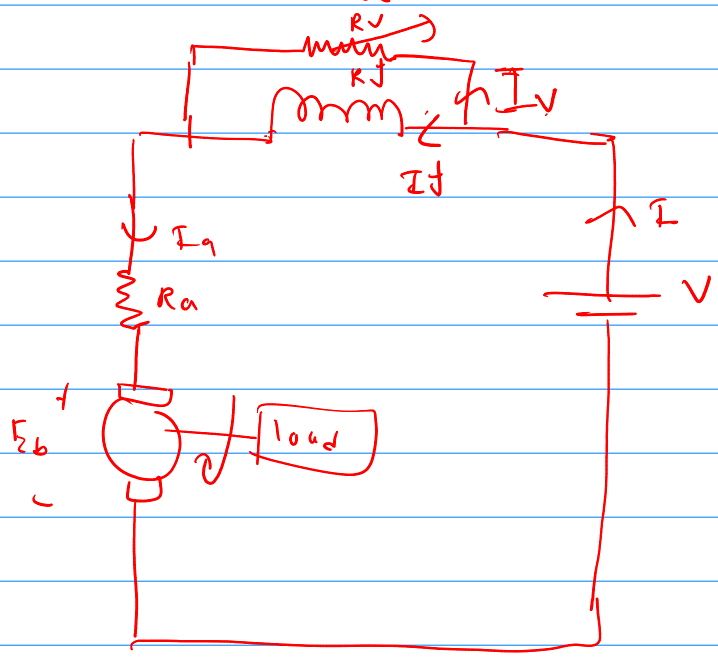
I_f will increase and produce more flux per pole.

$$\phi \propto I_f$$

We know $N \propto \frac{E_b}{\phi} \propto \frac{E_b}{I_f}$ ↑

So the speed decreases.

(ii) Field divertor method.



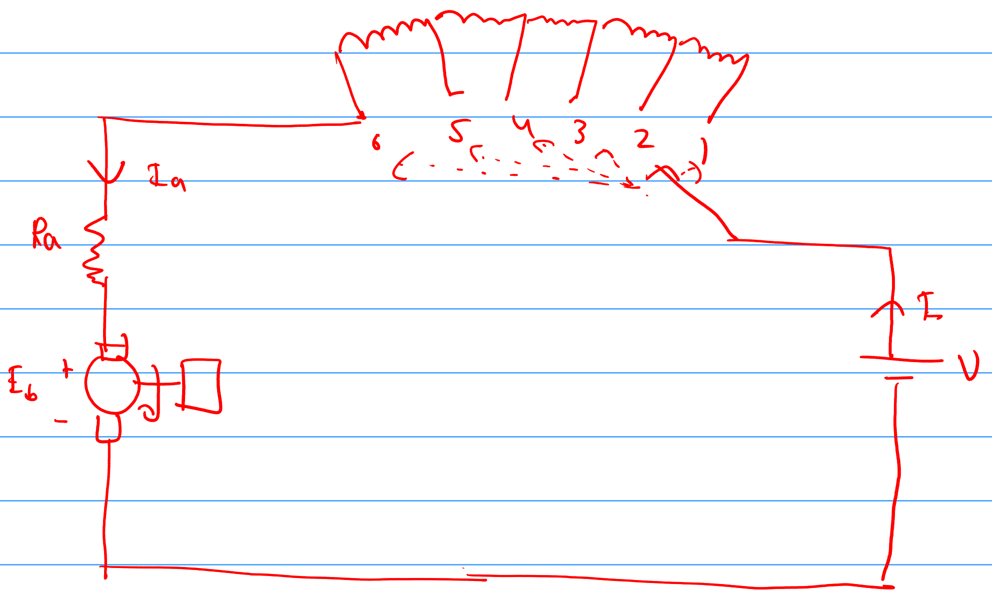
→ A variable resistance is connected in parallel with the field winding for the speed control purposes.

→ In this ckt, the variable resistance R_v splits (diverts) the field winding current and the flux decreases.

$$\uparrow N \propto \frac{E_b}{\phi \downarrow} \propto \frac{E_b}{I_f \downarrow}$$

So the speed of motor increases.

(iii) Tapped field control method



→ By changing the tapping points no of turns in field winding can be changed.

→ If the no of turns is reduced, flux produced by the field winding decreases and speed increases.

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

→ This method is generally used in very small dc motor such as dc motor in electric toys.

Losses and Efficiency

(1) Cu-loss (load dependent)

→ armature wdg ($I_a^2 R_a$)

→ field wdg ($I_f^2 R_f$ and $I_{se}^2 R_{se}$)

(2) Iron loss or core loss (constant)

→ hysteresis loss

→ eddy current loss

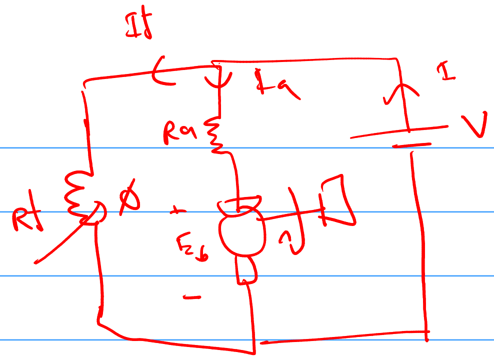
(3) Mechanical loss

→ Friction loss of bearings and commutator

→ Air-friction (windage) loss rotating armature

$$\eta = \frac{\text{mech power O/P}}{\text{electrical power i/p (VI)}}$$

Starting of DC motors (20E)



Why dc motor require starter ?

→ It is due to back emf (E_b) as it opposes the supply dc voltage.

$$E_b = \frac{2 \phi N}{60} \times \frac{P}{A}$$

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

At starting $N = 0$, $E_b = 0$
Hence,

$$I_a = \frac{V - 0}{R_a} = \frac{V}{R_a}$$ will be much high

To limit the starting current to an allowable lower value, we use 3-point starter.

3-point starter → DC shunt motor ko lagi

(dig difficult to remember just study working)

→ When handle is in the off position; the circuit is open.
→ no current flows and both armature and field windings are disconnected.
→ Moving the handle to the first contact point closes the circuit.
→ full voltage is applied immediately to the field winding creating the magnetic field.

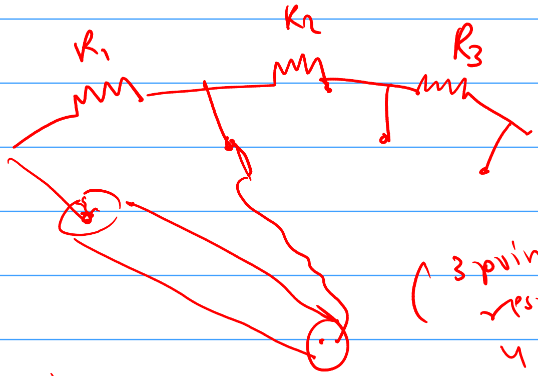
→ voltage goes to the armature through starting resistors that limit the initial current, allowing the motor to start turning slowly and build up a small back emf.

→ as motor rotates, the increasing back emf reduces the net voltage across the armature. → (supply voltage − back emf)

→ the operator advances the handle to the next stud, which reduces some of the resistance.

→ This causes less voltage drop across the resistor, so more of the supply voltage reaches the armature, boost the current and speeds up the motor gradually.

voltage across armature increased



(3 point - 3 resistance
4 point - 4 resistance)

Starting

→ When handle reaches the final point, all resistance is removed. The armature gets full supply voltage, and the field windings stays energized with full voltage and motor operates at it's normal speed with the back emf regulating the armature current to a steady value.