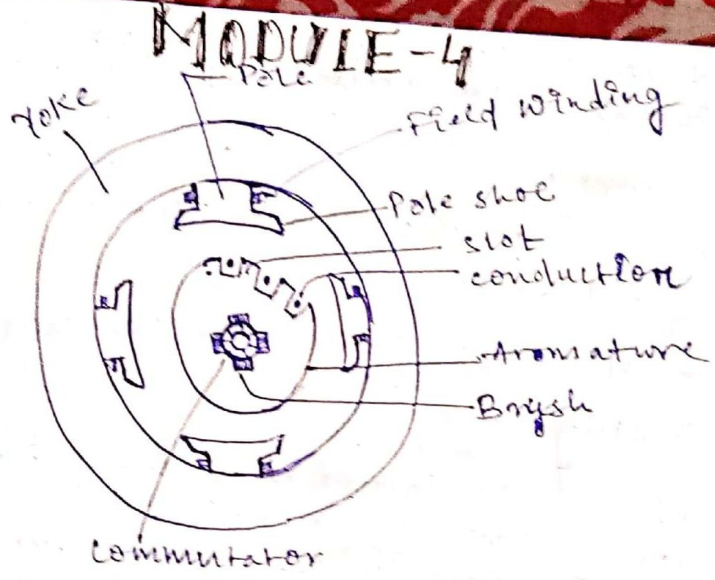
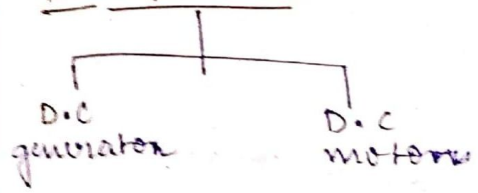
21.11.19

MODULE-4



D.C Machines



D.C Generator :-

It converts mechanical energy into electrical energy which D.C in character.

PRINCIPLE :-

When magnetic flux linkages through a conductor changes then an emf is induced which will cause a current flow through the conductor.

CONSTRUCTION :-

~~Whole~~ All DC machines have 5 imp. components :-

1- Field system
2- Armature core
3- Armature winding
4- commutator
5- Brush

Field system — The func. is to produce uniform magnetic field within which armature rotates.
- It consists of poles volted to a circular frame (yoke). The yoke is made of solid cast steel. Which carry magnetic flux.
- The field coils are mounted on the poles and carry DC exciting current.

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The field coils are connected in such a way that adjacent poles have opposite polarity.

Armature core :-

- It is keyed to the machine shaft and rotates b/w the field poles.
- It consists of soft iron laminations.

Armature winding :-

The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding. This is the winding in which working emf is induced.

commutator :-

- It is a mechanical rectifier which converts alternating voltage generated in the armature winding into direct voltage across the brushes ~~process~~. It is made of copper segments insulated from each other by mica sheets.

Brush :-

The purpose of brushes is to ensure electrical connections b/w. commutator and external load circuit. It is made of carbon.

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Armature Winding :-

It is of two types -

i) Lap winding

ii) wave winding

Lap winding :- In lap winding, no. of parallel path equal to no. of poles.

→ No. of brushes are equal to no. of parallel path.

→ $A = P$

Wave winding :- In wave winding, no. of parallel path (A) are two.

→ In this winding total no. of brushes are two.

→ $A = 2$

EMF Eqn of DC generator -

ϕ = magnetic flux per Pole

P = no. of Poles

ϕ_P = total flux

N = revolution per min i.e r.p.m

So $\frac{N}{60}$ = revolution per sec. i.e r.p.s

= frequency in Hz

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

Z = Total no. of conductors.

A = Total no. of parallel path.

$\frac{Z}{A}$ = no. of conductors in one path

Emf induced in one conductor $= \frac{d\phi}{dt}$

$= \frac{\phi P}{60/N} = \frac{\phi PN}{60}$

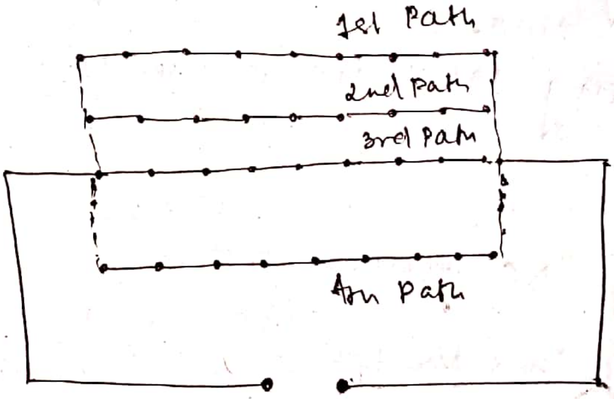
Emf induced in one path $= \frac{\phi PN}{60} \times$ no. of cond. in one path

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

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

∴ ~~Total~~ As all paths are connected in parallel, so total emf is –

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



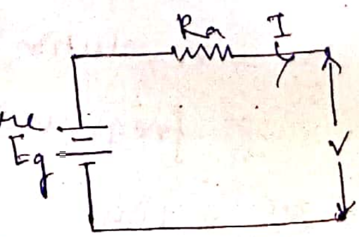
Generator Voltage and Power Eq^n –

R_a = Armature regsistance

E_g = Generated voltage in armature

I = current flows

V = terminal velocity



Apply KVL,

$$E_g - IR_a - V = 0$$

$$E_g - IR_a = V \longrightarrow (1)$$

Multiply I on both sides of eq^n (1) – we get,

$$E_g I - I^2 R_a = VI$$

$$\Rightarrow E_g I - I^2 R_a = P \longrightarrow (2)$$

where $P = VI$ = terminal output power

$E_g I$ = generated electric power in the armature

$I^2 R_a$ = copper loss in the armature

Eqn ② is the power eqn of D.C generator.

To get the condn for maxm power output,

Differential eqn ② w.r.t I. and equated to 0.

$$\frac{dP}{dI} = E_g - 2IR_a$$

$$E_g - 2IR_a = 0$$

$$\Rightarrow E_g = 2IR_a$$

$$\Rightarrow IR_a = \frac{E_g}{2}$$

Putting this value of IR_a in eqn ① we get.

$$E_g - IR_a = V$$

$$E_g - \frac{E_g}{2} = V$$

$$\Rightarrow \frac{E_g}{2} = V$$

∴ Thus, the output power will be maxm when the terminal voltage will have half of generated emf.

Types of DC generator :-

It is of 2 types-

- separately excited DC generator
- self excited DC generator

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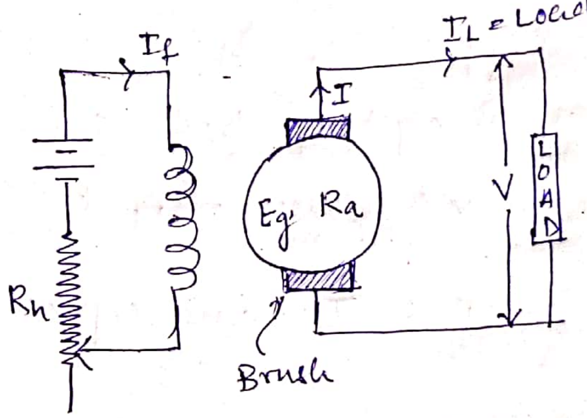
(1) Separately excited DC generators :-



→ A DC generator whose field magnets winding is supplied from an independent external d.c source is called separately excited D.C generator.

I_a = armature current

E_g = Generated emf

R_a = Armature resistance

I_L = Load current

I_f = Field current

→ $I_a = I_L$

$V = E_g - I_a R_a$

= terminal voltage

Power generated = $E_g \times I_a$

Power delivered to load = $E_g I_a - I_a^2 R_a$

$= I_a (E_g - I_a R_a)$

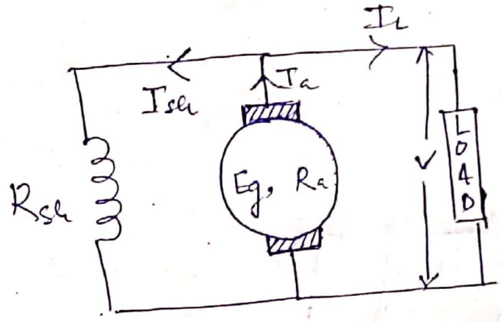
$= I_a V$

(2) Self excited DC generator :-

It is of 3-types :-

- shunt DC generator
- series DC generator
- compound DC generator.

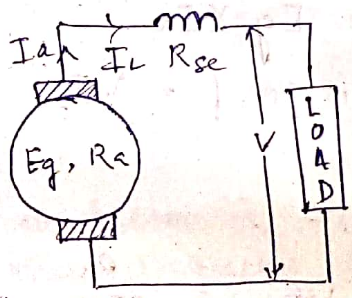
Shunt DC gen. –



- In a shunt gen., the field winding is connected in parallel with armature winding.
- The shunt field winding has many turns.
- shunt field has a high resistance.
- Armature current, $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a R_a$
- shunt current, $I_{sh} = \frac{V}{R_{sh}}$
- Power generated, $E_g \times I_a$

  Power delivered to the load $= V I_L$

Series DC gen. –



- In series ~~wound~~ DC gen., the field winding is connected in series with armature winding.
- series field winding has less no. of turns
- series field winding has low resistance.

  R_{se} = series field resistance

→ Armature current, $I_a = I_L$

→ Terminal voltage, $V = E_g - I(R_a + R_{se})$

→ Power genered = $E_g \times I_a$

→ Power delivered to load $= E_g I_g - I_a^2 (R_a + R_{se})$

$= I_a [E_g - I_a (R_a + R_{se})]$

$= I_a V = V I_a$

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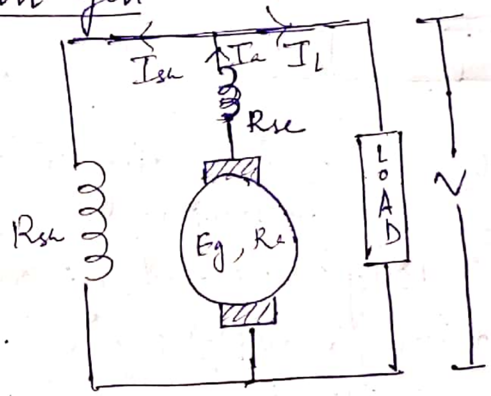
Compound DC generator :-

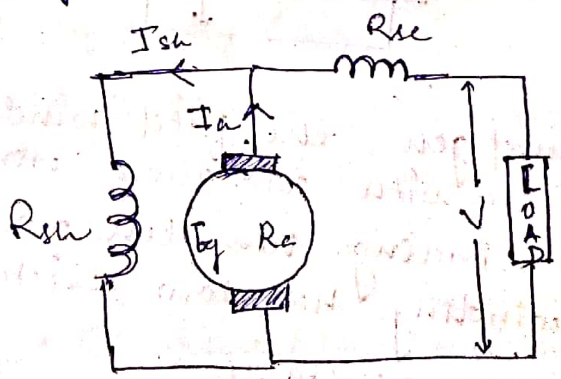
It is of two types-
- Long shunt ~~DC~~ gen.
- Short shunt ~~DC~~ gen.

Long shunt gen -



- In this gen, shunt field winding is in parallel with series field and armature winding.
- Armature current. $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a(R_a + R_{se})$
- shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- Power generated = $E_g \times I_a$
- Power delivered to load = $V I_L$

Short shunt gen. -



- In this gen, shunt field winding is parallel with armature winding.
- Armature current, $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a R_a - I_L R_{se}$

- shunt current, $I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$

- Power generated $= E_g I_a$

- Power delivered to load $= V I_L$

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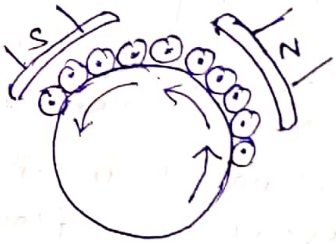
D.C MOTOR :-



It is a machine which converts DC power to mechanical power.

Principle - It states that when a current carrying conductor is placed in a magnetic field then conductor experiences a mechanical force.

It's value is - $\vec{F} = I(\vec{l} \times \vec{B})$

The direction of a vector can be determined by flemmings left hand rule.

$$|\vec{F}| = IlB \sin\theta$$

If $\theta = 90°$. $F = BIl$

Working -

→ Each armature conductor is carrying current and is placed in the magnetic field. A mechanical force acts on it.

→ Force on each conductor is tending to rotate the armature in anticlockwise direction.

All these forces add together to produce a driving torque which sets the armature rotating.

→ Back emf / ~~current~~ counter emf in DC motor -

When ~~DC mo~~ armature of DC motor rotates under the influence of driving torque then the armature conductors move through the magnetic field and hence emf is induced in them.

→ The induced emf acts in opp. direction to the applied voltage V. Hence known as back emf.

$$E_b = \frac{\phi Z N P}{60A}$$, A = no. of parallel path
P = no. of poles
N = speed in rpm
ϕ = flux per pole
Z = total armature conductors

→ The value of E_b is smaller than terminal voltage V.

→ As the armature rotates back emf E_b is induced which opposes applied voltage V.

→ The applied voltage V has ~~to~~ to force current through armature against E_b.
The workdone in overcoming and causing the current to flow against E_b is converted to mechanical energy developed in the armature.

→ Energy conversion in DC motor is only possible due to the production of E_b.

Voltage eqn of DC motor :-

Let I_a = Armature current
R_a = Armature resistance
V = Applied voltage
E_b = Back emf induced.

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

$\Rightarrow I_a R_a = V - E_b$

$\Rightarrow \boxed{V = I_a R_a + E_b}$

Power eqn of DC motor :-

We know that, $V = E_b + I_a R_a$

$$\boxed{V I_a = E_b I_a + I_a^2 R_a} \longrightarrow (2)$$

where
$V I_a$ = Power supply to armature (Input armature)
$E_b I_a$ = Power developed (Armature output)
$I_a^2 R_a$ = copper loss
↳ Electrical power wasted in armature

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condition for max^m power :-

We know that, power eq^n is —

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

$$\Rightarrow E_b I_a = VI_a - I_a^2 R_a$$

$$\Rightarrow P = VI_a - I_a^2 R_a$$

($P = E_b I_a$ - Power developed in armature)

$$\frac{dP}{dI_a} = V - 2I_a R_a$$

for max^m power,

$$\frac{dP}{dI_a} = 0$$

$$\Rightarrow V - 2I_a R_a = 0$$

$$\Rightarrow V = 2I_a R_a$$

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

Putting this value in voltage eq^n —

$$V = \frac{V}{2} + E_b$$

$$\Rightarrow E_b = V - \frac{V}{2}$$

$$\Rightarrow E_b = \frac{V}{2}$$

mechanical power developed by the motor is max^m when back emf $= \frac{1}{2} \times$ applied voltage.

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Armature Torque in DC motor :-

let r = radius of armature

l = length of armature

A = no. of parallel path

B = magnetic flux density

Z = Total no. of armature conductors.

I_a = armature current flows

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

ϕ = flux per pole

P = total no. of poles

→ Force acting on one conductor,

$$F = B\left(\frac{I_a}{A}\right)l$$

→ Torque due to one conductor.

$$T = F \times r$$
$$= B\left(\frac{I_a}{A}\right)lr$$

→ Total armature torque,

$$T_a = Z B\left(\frac{I_a}{A}\right)lr$$

$$T_a = Z\left(\frac{\phi}{a}\right)\left(\frac{I_a}{A}\right)lr \quad \left\{ \because B = \frac{\text{flux}}{\text{area}} = \frac{\phi}{a} \right\}$$

$$\because a = \frac{2\pi r l}{P}$$

We know that,

$$T_a = Z\left(\frac{\phi}{\frac{2\pi r l}{P}}\right) \times \left(\frac{I_a}{A}\right)lr$$

$$\boxed{T_a = \frac{Z\phi I_a P}{2\pi A}} \quad \text{———— (1)}$$

But we know that -

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

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

eqⁿ ① becomes

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

$$\Rightarrow T_a = \frac{9.55 E_b I_a}{N} \text{ Nm}$$

From eqn ①, $T_a \propto \phi I_a$ $\left\{ \because Z, P \& A \text{ are constant} \right\}$

→ For shunt machine, flux ϕ = const

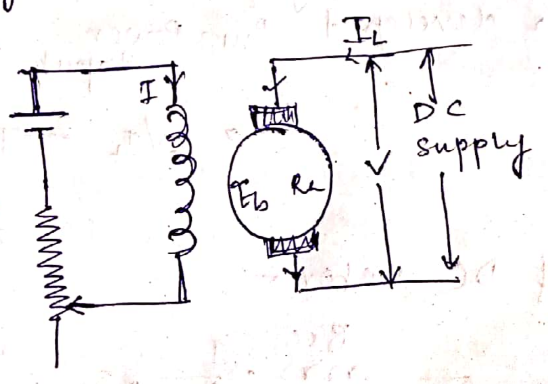
So $\boxed{T_a \propto I_a}$

→ For series machine, flux $\phi \propto I_a$

So $\boxed{T_a \propto I_a^2}$

Types of DC motor :-

(i) Separately excited DC motor



→ Let I_a = Armature current

= line current

= I_L

E_b = back emf produced

= $V - I_a R_a$

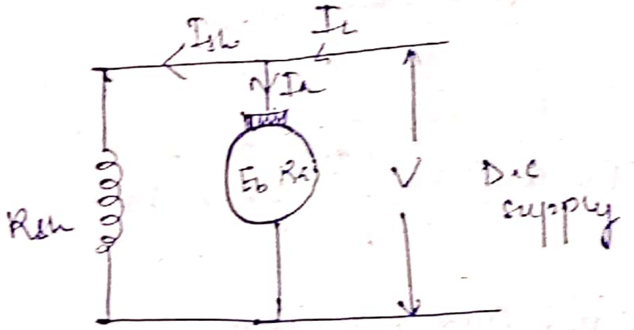
Power drawn from the supply $= V_L$.

Mechanical power developed $= P_m$

$= \text{Power Input to armature} - \text{Power Loss}$

$= VI_L - I_a^2 R_a$

(ii) Shunt type DC motor -



Line current $I_L = I_a + I_{sh}$

$V =$ supply voltage

Back emf developed, $E_b = V - I_a R_a$

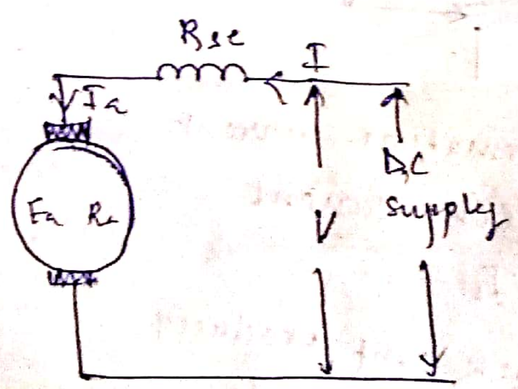
Shunt resistance ~~I_{sh}~~ $R_{sh} = \frac{V}{I_{sh}}$

Power drawn from the supply $= V \times I_L$

Mechanical power developed $P_m = \text{Power Input} - \text{Power loss}$

$= VI_L - I_a^2 R_a - I_{sh} R_{sh}$

(iii) Series type of DC motor -



Line current I_L = Armature current I_a

V = supply voltage.

Back emf induced in the motor. $E_b = V - I_a(R_a + R_{se})$

power drawn from main supply = VI_L

mechanical power developed, $P_m = VI_L - I_a^2(R_a + R_{se})$

$= E_b I_a$

Losses of DC machine -

These are the following losses of DC machine

(i) cu loss

(ii) Fe loss

(iii) mechanical loss / Friction loss

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Cu loss - It is of 3 types - Armature cu loss
- shunt field cu loss
- series field cu loss

Armature cu loss = $I_a^2 R_a$

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

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

Fe loss - It is of 2 types - Hysteresis loss
- Eddy current loss

Hysteresis loss - It occurs in the armature of DC machine since armature is subjected to magnetic field ~~of~~ reversals as it passes under successive poles.

- Hysteresis loss, $P_h = \eta B_m^{1.6} f V$ ~~volt~~ watt

Eddy current loss - when armature rotates in the magnetic field of the poles an emf is induced in it which circulates eddy current in the armature pole. $P_E = K_e B_m^2 f^2 t^2 V$ watt

Mechanical loss -
These loss are due to friction and winding.
Friction loss i.e bearing friction, of
Windage loss i.e air friction or rotating armature

What do you mean by stray loss?
Iron loss and mechanical loss together combine to form stray loss.

Speed control of DC motor :-

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

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

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

$N \propto \frac{V - I_a R_a}{\phi}$ → shunt motor $\{\because E_b = V - I_a R_a\}$

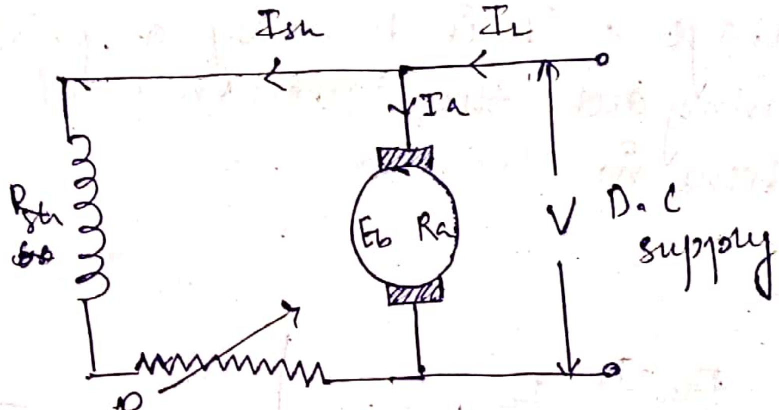
For series motor, $E_b = V - I_a R_{se} - I_a R_a$

$$N = \frac{V - I_a R_{se} - I_a R_a}{\phi}$$

→ ~~It is of~~ speed ~~control~~ of DC motor depends on -
- Magnetic flux per pole (ϕ)
- Resistance of the armature ckt

→ It is of 2 types → Flux controlled method
→ Armature controlled method.

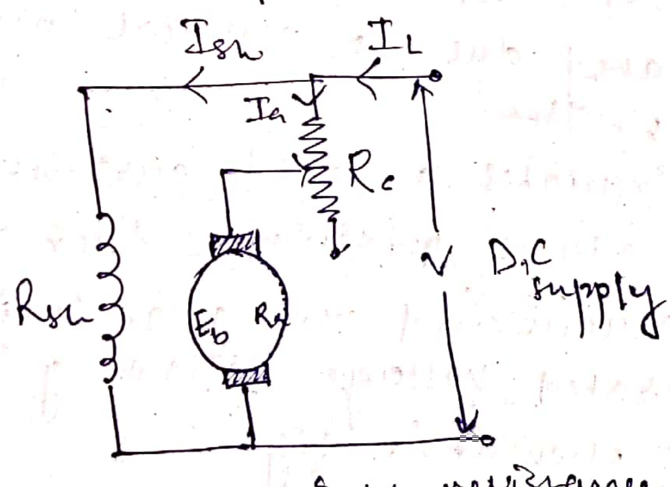
Flux controlled method -



We know, $N \propto \frac{1}{\phi}$

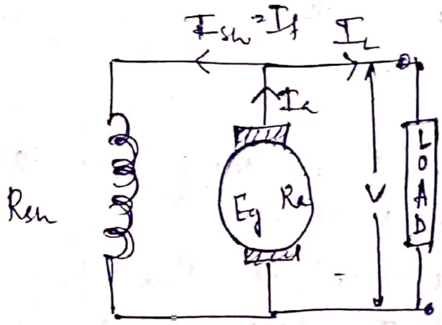
- In this method, A variable Resistance (R) is connected in series with shunt field.
- The shunt field resistance is $R_{sh} + R$
- If we ~~vary~~ $\uparrow$ sel R then I_{sh} decreases. so flux ϕ decreases therefore speed (N) of the motor increases.

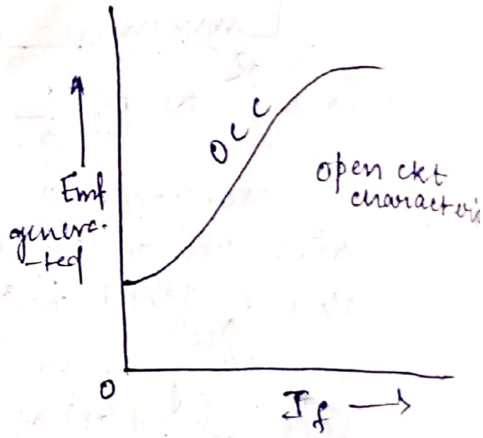
Armature controlled method -



- In this method a variable resistance ~~value~~ of R_e is connected in series with armature.
- Due to voltage drop in R_e the back emf (E_b) decreases, ~~So~~ but $N \propto E_b$. So speed of the motor decreases

Q Describe the self excited D.C shunt generator builds its terminal voltage as it is run by a prime mover. Clearly bring out the importance of residual magnetism in the core





Let us consider a shunt generator as shown in fig.

If the generator is run at a const speed, some emf will be generated due to residual magnetism in the main poles. ~~The~~

This small emf circulates a field current (I_f) which in turn produces additional flux ~~this~~

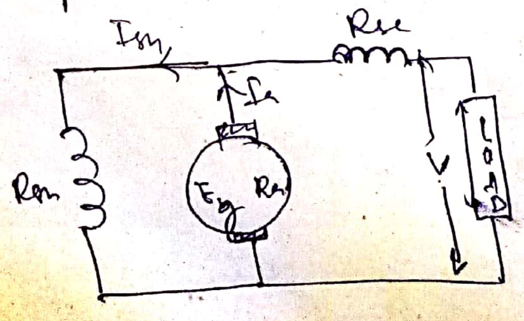
This process continuous and the gen. builds up the normal generated voltage following the open ckt characteristic shown in fig.

Q A 50 KW, 250 V short shunt compound generator has the following data, $R_a = 0.06\,\Omega$

$R_{se} = 0.04\,\Omega$

$R_{sh} = 125\,\Omega$

Calculate the induced armature voltage at rated load and terminal voltage. Take 2 volt. as gross drop.



Given, $V = 250$ volt

O/P power $= 50 \times 10^3$ watt

$$I_L = \frac{\text{Power}}{\text{voltage}} = \frac{50 \times 10^3}{250} = 200 \text{ Amp.}$$

$$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}} = \frac{\cancel{250}\ 250 + 200 \times 0.04}{125}$$

$$= \frac{258}{125}$$

$$= 2.064 \text{ Amp}$$

$$I_a = I_L + I_{sh} = 200 + 2.064$$

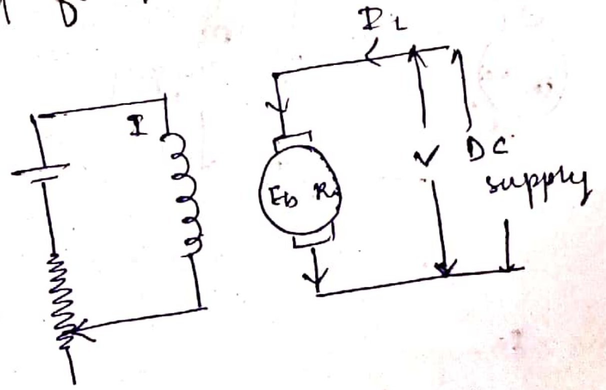
$$= 202.064 \text{ Amp}$$

$$E_g = V + I_L R_{se} + I_a R_a + \text{gross drop}$$

$$= 250 + 200 \times 0.04 + 202.064 \times 0.06 + 2$$

$$= 272.12$$

Q A 20KW, 230V separately excited generator has armature resistance 0.2 Ω and load current 100 Amp. find generated voltage when terminal voltage is 230 V and find output power.



$V = 230$ V

$R_a = 0.2\ \Omega$

$I_L = 100$ Amp. $= I_a$

$$E_g = V + I_a R_a$$

$$= 230 + 100 \times 0.2$$

$$= 250 \text{ V}$$

O/P power = O/P voltage × O/P current

$$= 230 \times 100$$

$$= 23 \text{ KW}$$

Q. A 120V, 10 Amp, DC shunt generator has $R_a = 0.6\Omega$, $I_{sh} = 2$ Amp. Calculate the generated emf in the generator.

$V = 120V$

$I_L = 10$

$R_a = 0.6\Omega$

$I_{sh} = 2$ Amp

$I_a = I_L + I_{sh}$

$= 10 + 2$

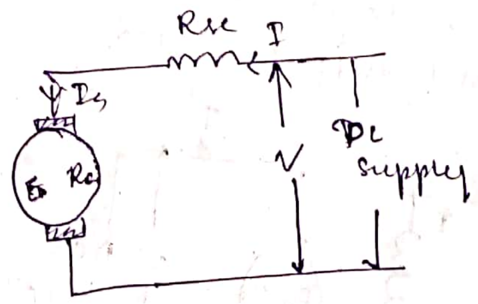
$= 12$

$E_g = V + I_a R_a$

$= 120 + 12 \times 0.6$

$= 127.2$

Q. A DC series motor operates at 800rpm with line current 100 Amp from 230V mains. Given $R_a = 0.15\Omega$, $R_{se} = 0.1\Omega$, find the speed at which more runs at a line current of 25 Amp. Assuming flux at this current (25) 45% of flux at 100 A.



we know,

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

$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{\phi_2}{\phi_1}$ —— (1)

$E_{b1} = V - I_a [R_a + R_{se}]$

$= 230 - 100 [0.15 + 0.1]$

$= 205V$

$E_{b2} = 230 - 25 [0.15 + 0.1]$

$= 223.75V.$

$N_1 = 800$

$\phi_2 = 0.45\ \phi_1$

$$\frac{800}{N_2} = \frac{205}{223.75} \times \frac{0.45}{1}$$

$$\frac{800 \times 223.75}{205 \times 0.45} = N_2$$

$$N_2 = \frac{179000}{92.25}$$

$$= 1940.37 \text{ rpm.}$$

A 4 pole 500 V DC shunt motor has total conductors 720 which are wave connected. The full load armature current 60 Amp. and flux per pole 0.03 Wb $R_a = 0.2\ \Omega$, voltage per ~~gross~~ brush is 1 volt. Calculate the full load speed.

$$E_b = V - I_a R_a - \text{gross drop}$$
$$= 500 - 60 \times 0.2 - 2$$
$$= 486$$

wave connected = 2

lap connected = 1

$$N = \frac{E_b \times 60A}{\phi Z P}$$
$$= \frac{480 \times 60 \times 2}{0.03 \times 720 \times 4}$$
$$= 675$$

Q Will a DC shunt motor operate on AC supply?

Shunt has large turns, it has inductance ~~were~~ when AC applied large inductive reactance X_L of shunt winding generates which reduces shunt current (I_{sh}) so motor will not run actually on AC supply.

15.11.19

Q A dc motor runs on a 200V supply and has negligible armature resistance. What happens to its speed if the armature voltage is reduced by 20% and the field current increased by 30%.

$V = 200$ volt

$R_a = 0$

$I_a R_a = 0$

$I_{f_2} = 1.3 I_{f_1}$

$E_{b_2} = 0.8 E_{b_1}$

$E_{b_1} = 100$

$E_{b_2} = 100 - 20$

$= \frac{80}{100}$

$\frac{130}{100}$

flux $\phi \propto I_f$

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

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

$$= \frac{0.8 E_{b_1}}{E_{b_1}} \times \frac{\phi_1}{1.3 \phi_1}$$

$$= \frac{0.8}{1.3}$$

$N_2 = 0.61 N_1$

$= (1 - 0.39) N_1$

So, speed decreased by 39%.

Q A dc shunt generator generates an emf of 520 V. ~~At~~ at a speed of 1200 rpm. It has 2000 armature conductors and the flux per pole is 0.013 wb. The armature winding has 4 parallel paths.

(i) Determine the no. of poles.

(ii) Find the generated voltage if the armatu winding is wave connected.

Ans $V = 520\,V$.

$Z = 2000$

$\phi = 0.013\,Wb$

$A = 4$

$N = 1200$

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

$520 = \frac{P \times 0.013 \times 2000 \times 1200}{60 \times 4}$

$\Rightarrow \frac{124800}{31200} = P$

$\Rightarrow P = 4$

(ii) $E_g = 2E_g = 1040\,V$ (parallel path ↓ voltage ↑ inversely prop.)

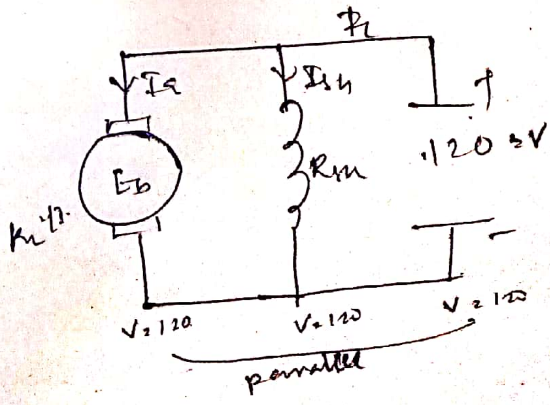
Q A D.C shunt motor rotating at 1500 rpm is fed by 120 V AC source. The line current run by the motor is 51 Amp. The shunt field resistance is 120 ohm. Find —

(i) the back emf E_b.

(ii) the mechanical power and torque developed the motor. assume the armature 0.1 Ω.

$I_L = 51\,Amp$ $R_{sh} = 120\,\Omega$ $R_a = 0.1\,\Omega$

$E_b = V - I_a R_a$



$I_{sh} = \frac{V}{R_{sh}} = \frac{120}{120} = 1\,A$

$I_a = 51 - 1 = 50\,A$

$E_b = 120 - 50 \times 0.1$

$= 115$

mechanical power = $E_b I_a$

$= 115 \times 50$

$= 5.75$ KW

Mechanical Torque $= \frac{P}{\omega} = \frac{5750}{2\pi f}$

$= \frac{5750}{2\pi \frac{N}{60}} = \frac{5750}{\frac{2 \times 3.14 \times 1500}{60}}$

$= 36.6$

$\simeq 37$