2

Unit - II

DC Generators

1 → (principle and operation of DC Generator:

principle:

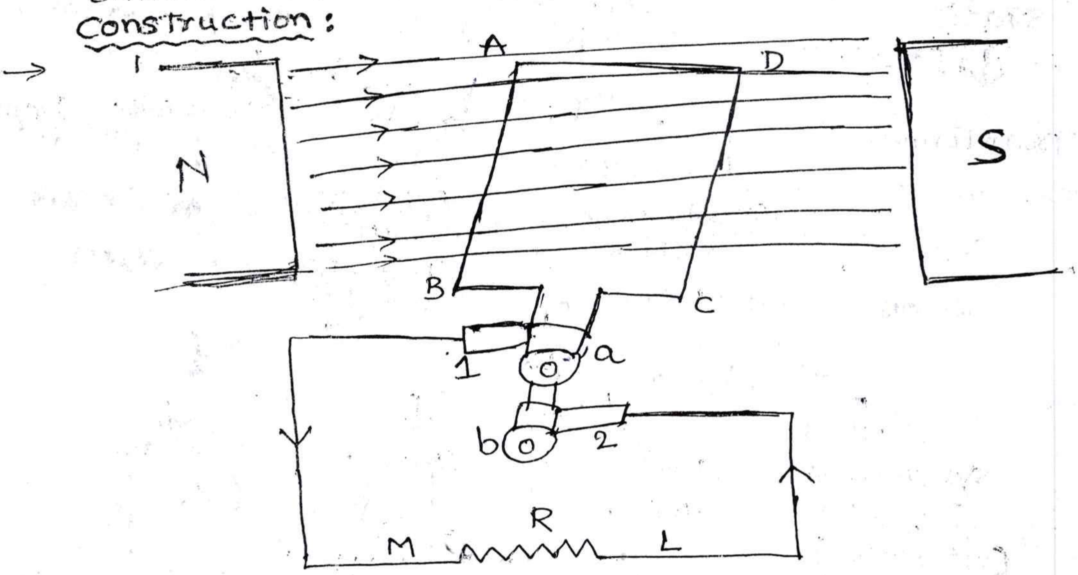
→ An Electrical generator is a machine which converts Mechanical Energy to Electrical Energy.

→ Generator works on the principle of Faradays law of Electromagneti Induction.

→ According to Faradays law, whenever a conductor cuts a magnetic flux, an emf induced in it. This emf causes the current to flow.

Construction:

→



Fig(1):

→ Basic components of a generator are:

1) Magnetic field
2) conductor
3) motion of conductor.

→ Fig(1) shows is a single Turn rectangular copper coil ABCD, rotates about its own axis in a magnetic field

→ The Two ends of a coil are Joined to Two slip rings "a" and "b", which are insulated from each other.

→ Two brushes 1 and 2 are placed on sliprings a & b.

→ The Function of brushes is to collect current induced in the coil and transfer to External load resistance R.

→ Here The magnetic fields is stator and rotating coil forms rotor (armature).

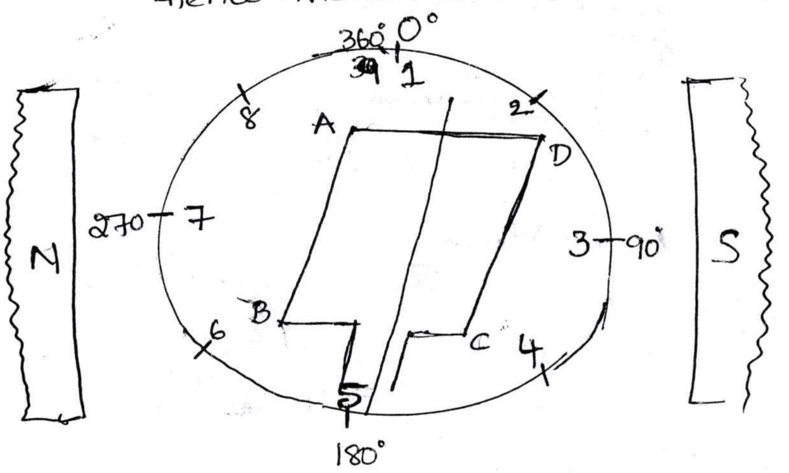
working (or) operation :

→ Imagine the coil to be rotating in clockwise direction.

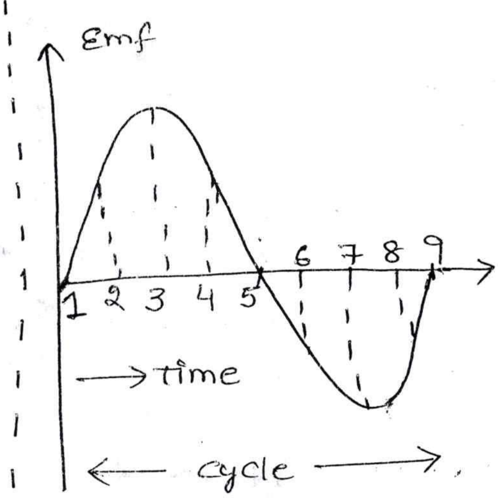
→ when coil is at position 1, The flux (ϕ) linked with coil is maximum, but rate of change of flux $\frac{d\phi}{dt}$ is minimum. Hence the emf induced (E) is minimum, because a/c to Faradays law, $E \propto \frac{d\phi}{dt}$.

→ when coil is at position 3, the flux ϕ linked with coil is minimum, rate of change of flux $\frac{d\phi}{dt}$ is maximum. Hence Emf is maximum, shown in fig(3).

→ when coil is at position 5, flux ϕ linked with coil is maximum, rate of change of flux $\frac{d\phi}{dt}$ is minimum. Hence induced Emf is minimum, shown in fig(3).



fig(2)



fig(3)

→ The direction of this induced emf is given by Flemming right hand rule, which gives its direction from A to B & C to D.

→ In first half revolution, the direction of current flow is A B M L C D shown in fig(1).

→ In next half revolution i.e., from 180° to 360°, the variation in magnitude of Emf is similar to first half revolution.

→ when coil is at position 7, Emf is maximum and when coil is at position 9, Emf is minimum.

→ In Second half revolution, direction of current flow is D C L M B A.

→ we find that a generator reverses its direction, after every half revolution. such a current undergoing periodic reversals is known as alternating current.

→ The two half cycles may be called positive and negitive half.

↳ operation of commutator segments :

→

→ For making the current flow bidirectional to unidirectional slip rings are replaced by split rings (or) commutator, as shown in fig(4).

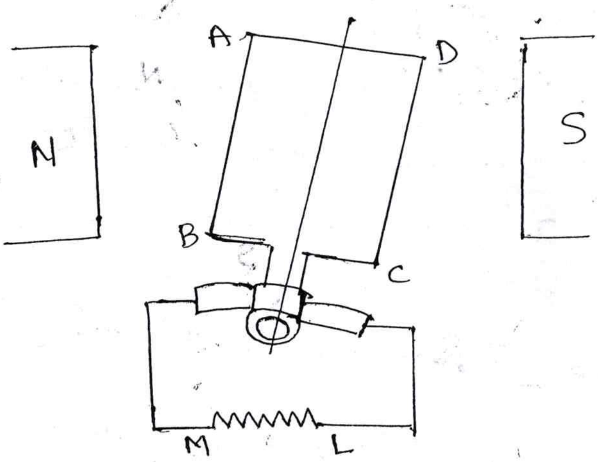
→ The split rings or commutator made up of conducting cylinder which is cut into Two halves (or) Two segments, insulated from each other by thin sheet of mica.

→ It is seen that in First half revolution, current flows along ABMLCD i.e., the brush 1 contacts with segment 'a' acts as positive and segment 'b' as negitive end of supply

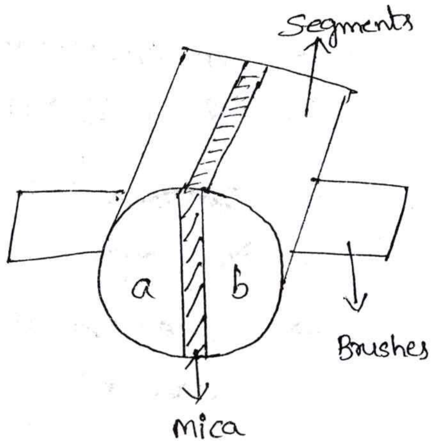
→ In next half revolution, direction of current in the coil is reversed, but at the same time position of segments 'a' and 'b' have also reversed with the result that brush no 1 comes in touch with segment which is positive i.e, segment 'b' in this case.

→ Hence current in the load resistance again flows from M to L. The waveform of current through the external circuit is shown in fig (7)

→ This current is unidirectional but not continuous like pure dc current.



Fig(4)



Fig(5)

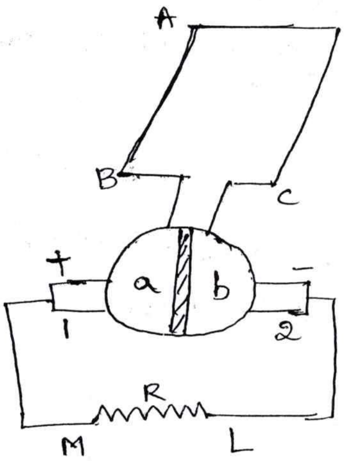


Fig 6(a)

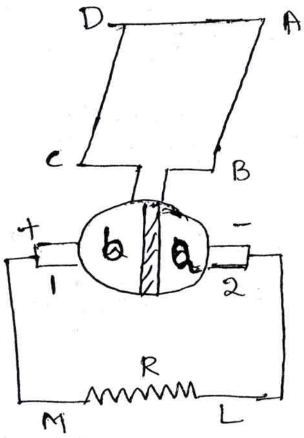


Fig 6(b)

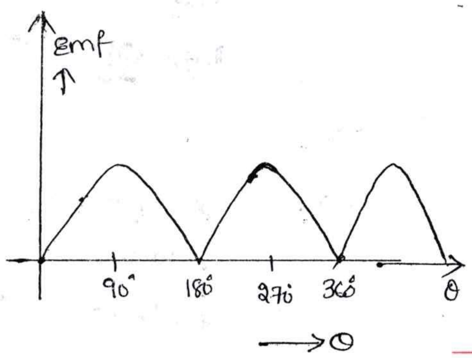


Fig (7)

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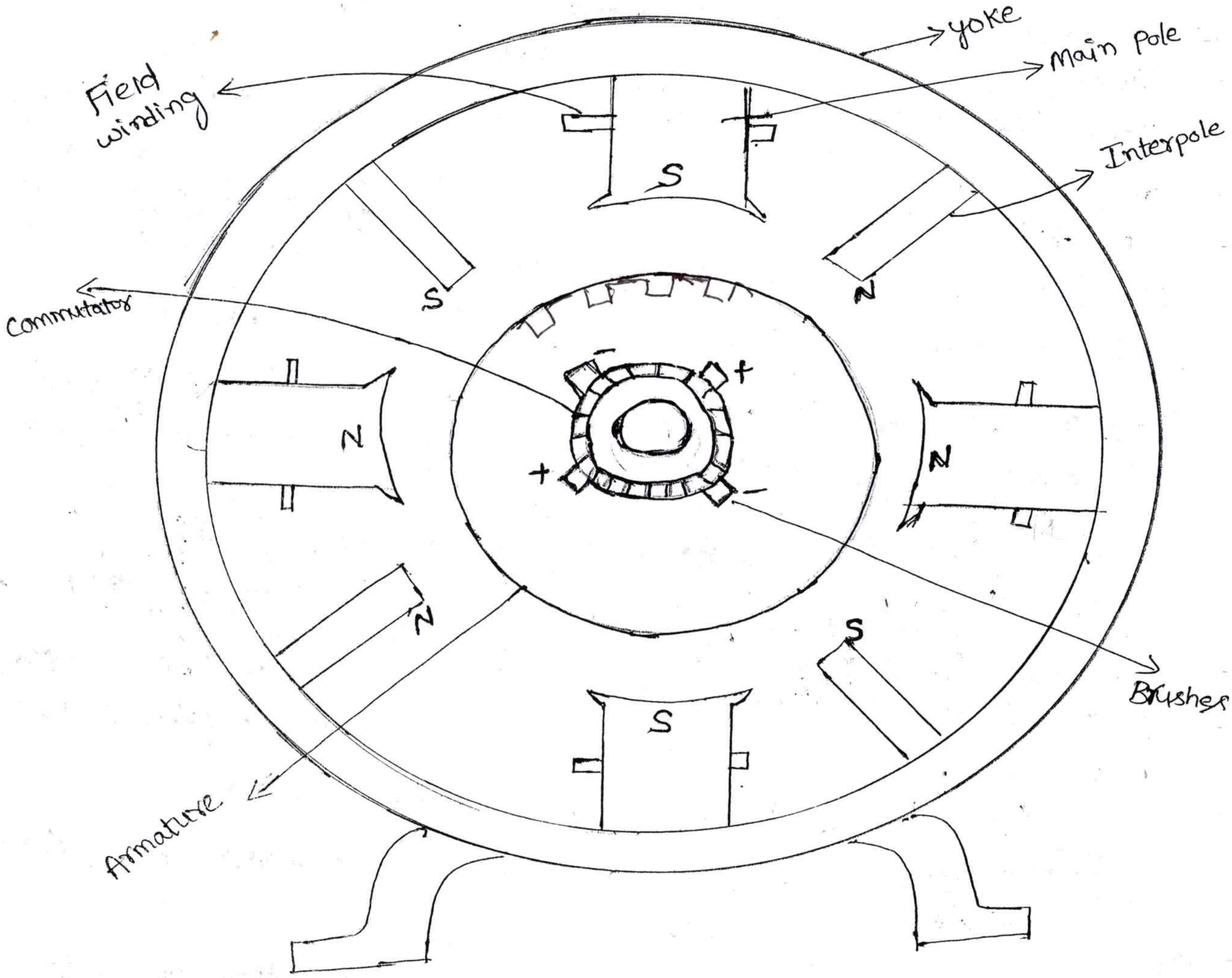
→ Construction details of a Dc machine :-



A dc machine either a generator or a motor essentially consists of following main parts

1) yoke or magnetic frame 2) Pole cores and pole shoes

3) Pole coils (or) Field coils 4) Armature core

5) Armature windings (or) conductors 6) Commutator

7) Brushes and Bearings 8) Interpoles

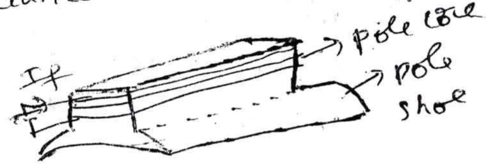
→ **Yoke :** The outerframe of dc machine is called Yoke and is normally made of iron (or) fabricated steel (or) annealed steel laminations.

Cast iron for small
steel " large, laminations to reduce eddy

It serves two purposes :

1) It provides mechanical strength for the poles and acts as a protective cover for the whole machine.

ii) It provides a return path of low reluctance to the magnetic flux produced by the poles.



& made with Si steel lamination

→ **Pole core and Pole shoes :-** The field magnets consists of pole core & pole shoes.

→ Pole core :- In older design it is made up of cast iron or steel whereas in modern design it is made up of laminated annealed steel.

Functions :- i) It provides housing for the field windings
ii) It supports pole shoe iii) It provides low reluctance path for flux.
, Acts as magnet when it is excited with dc

→ Pole shoe : In older design it is made up of laminated steel or iron whereas in modern design it is made up of annealed steel.

Functions :- i) It supports field windings
ii) It establishes magnetic field in the airgap by spreading out the flux uniformly.

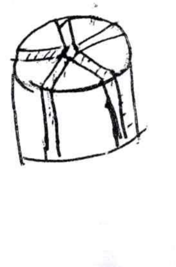
M/c field winding excitation

→ **Field windings :-** It is made up of highly conducting materials like copper.

Function :- It carries the current necessary for the establishment of magnetic flux in dc machine.

made with hard drawn copper

→ * **Commutator :-** A commutator is used for collecting current from the armature conductors. It consists of no. of wedged shaped segments or bars made of copper that are assembled to form



0.3mm

a cylinder. These segments are insulated from each other by thin layers of mica. Each commutator segment is connected to one end of the coil.

→ The no. of commutator segments are decided by the no. of coils. The insulation between the segments is designed to withstand voltage less than 15V.

* → The commutator along with the brush gear helps to convert the AC voltage induced in the armature conductors in to unidirectional voltage across the brushes.

→ Interpoles (or) Commutating poles :-

* → The main function of commutating poles is to improve the commutation in dc machine. They are kept in between the main poles and its winding connected in series with the armature windings so that they carry current proportional to the armature currents and produces flux in order to improve the commutation process.

→ They develop mmf to neutralize the armature mmf only in the commutating zone. Thus the distortion of main field under the poleshoes is not affected by the use of interpoles.

* → The main function of interpoles is to reduce armature reaction there by reducing the sparks at the brush contacts.

→ Armature : Armature is mounted on shaft and rotates in magnetic field. It is the major part in dc machine. It houses armature slots and armature windings. so it has two parts.

Armature core : It is made up of magnetic materials like cast iron or steel in order to provide a path of low reluctance. The body of the core is made up of thin sheets or laminations of steels in order to reduce eddy current loss.

Functions : i) It houses armature coils i.e, armature winding (or) conductors.

ii) It provides path of low reluctance to the magnetic flux generated by the field poles.

→ **Armature windings :-** These are made up of very good conducting materials like copper as they carry the entire load current.

→ **Functions :-** i) To carry current in case of generator they supply current to the load and for motor takes current from the supply.

ii) The Emf in the generator is Induced in these conductors.

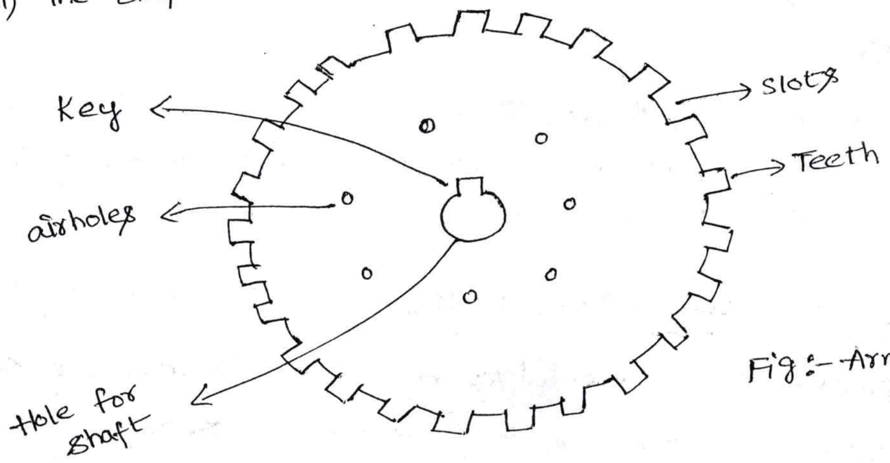


Fig :- Armature laminations

→ **Brushes and Bearings :-**

*→ The brushes whose main function is to collect current from commutator are usually made of carbon or graphite and are in the shape of a rectangular block. These brushes are housed in brush holders usually of the box type variety.

→ The no. of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

→ Because of their reliability, ball bearings are frequently employed, though for heavy duties roller bearings are preferable.

*→ Bearings give support to rotating shaft with minimum friction.

EMF Equation (or) Voltage Induced in a DC Generator:

Let E = EMF induced in any parallel path of armature

P = No. of poles

ϕ = Flux per pole in weber

N = No. of armature rotations in RPM

Z = Total No. of armature conductors

= No. of slots $\times$ No. of conductors per slot

A = No. of parallel paths in armature.

According to Faradays Law of Electromagnetic Induction, $E = N\frac{d\phi}{dt}$

→ Average EMF generated per conductor $E = \frac{d\phi}{dt}$ volts ($\because N = 1$) → (1)

→ During one revolution of armature in a 'P' pole generator, each armature conductor cuts the magnetic flux 'P' times. so that Flux cut per one conductor in one revolution is

$$d\phi = P\phi \longrightarrow (2)$$

Armature revolves $\frac{60}{N}$ times in one second,

Therefore the time required by it for one revolution is dt

i.e, $dt = \frac{60}{N}$ seconds. → (3),

Substituting eq (2) & eq (3) in eq (1) we get

i.e, Emf generated / conductor $= \frac{d\phi}{dt} = \frac{\phi P}{\frac{60}{N}} = \frac{P\phi N}{60}$ volts

The total No. of armature conductors per parallel path $= \frac{Z}{A}$

Total EMF generated / path $= \frac{P\phi N}{60} \times \frac{Z}{A}$

$$\therefore \boxed{E = \frac{P\phi NZ}{60A}}$$

Where $A = P$ for Simplex Lap winding

2 for Simplex wave winding.

Problems:

1) Calculate the Emf generated by a 4 pole wave wound generator having 65 slots with 12 conductors per slot when driven at 1200 rpm. the flux per pole is 0.02 wb.

Sol: Given speed $N = 1200$ rpm

Flux $\phi = 0.02$ wb

pole $P = 4$

No. of conductor Z = No. of slots × No. of conductors / slot

$\therefore Z = 65 \times 12 = 780$

No. of parallel path $A = 2$, For wave winding

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

$= \frac{4 \times 0.02 \times 1200 \times 780}{60 \times 2}$

$\therefore E = 624$ volts

2) The armature of a 6 pole 600 RPM Lap wound generator has 90 slots. If each coil has 4 turns calculate the Flux per pole. to generate an emf of 288 volts.

Sol: Given Emf $E = 288$ volts

pole $P = 6$

Speed $N = 600$ RPM

No. of parallel path, $A = P$ For Lap winding

$\therefore A = 6$

For 1 turn = 2 conductors

4 turns = 4 × 2

= 8 conductors

No. of conductors $Z = 90 \times 4 \times 2$

$= 720$ Conductors

Emf $E = \frac{P \phi N}{60} \times \frac{Z}{A} \Rightarrow \phi = \frac{60 \times \text{EMF} \times A}{Z \times P \times N}$

$\phi = \frac{60 \times 288 \times 6}{720 \times 6 \times 600}$

$\therefore \phi = 0.04$ wb

3) The armature of a 6 pole dc generator having 650 conductors generates an induced EMF of 536.25 volts. when running at a speed of 300 RPM, the flux per pole being 55 mwb. what is the type of simplex winding used.

Sol: Given $P = 6$

$Z = 650$

$E = 536.25$ V

$N = 300$ rpm

$\phi = 55$ m wb $= 55 \times 10^{-3}$ wb

$A = ?$

$$E = \frac{P\phi NZ}{60\,A} \Rightarrow \cancel{A = E \times 60 \times A}$$

$$\Rightarrow A = \frac{P\phi NZ}{60 \times E} = \frac{6 \times 55 \times 10^{-3} \times 300 \times 650}{60 \times 536.25} = 2$$

$\therefore A = 2$

As $A = 2$, the simplex winding used is of "Wave type".

4) An 8 pole Lap wound armature rotated at 350 rpm to generate 260 V. the flux per pole is 0.05 wb. If the armature has 120 slots calculate the no. of conductors per slot.

Sol: Given $N = 350$ rpm, $\phi = 0.05$ wb, Emf $E = 260$ V

No. of Slots $= 120$

$P = 8$

For Lap wdg, $A = P = 8$,

$Z = ?$

$$E = \frac{P\phi NZ}{60\,A} \Rightarrow Z = \frac{E \times 60 \times A}{P\,\phi\,N} = \frac{260 \times 60 \times 8}{8 \times 0.05 \times 350}$$

$Z = 890.$

No. of conductors per slot $= \frac{Z}{120} = \frac{890}{120} = 8$

5) The armature of 2 pole wave wound 200 V generator has 400 conductors and runs at 300 rpm. If the no. of turns in each field coil is 1200. what is the average value of EMF induced in each coil on breaking the field if the flux dies away completely in 0.1 sec

Sol :- Given pole $P = 2$

For wave wound, No. of parallel path $A = 2$.

No. of conductors $Z = 400$

speed $N = 300$ rpm

$$E = \frac{P\phi NZ}{60A} \Rightarrow \phi = \frac{E \times 60 \times A}{P \times N \times Z} = \frac{200 \times 60 \times 2}{2 \times 300 \times 400} = 0.1$$

$$\phi = 0.1 \text{ wb}.$$

Average EMF, $E = N \times \frac{d\phi}{dt}$.

(here N = No. of Turns, $N = 1200$ given)

$$E = 1200 \times \frac{0.1}{0.1}$$

$$\therefore E = 1200 \text{ Volts}$$

6) The armature of 6 pole generator has a wave winding containing 664 conductors. Calculate the generated EMF when flux per pole is 60 mwb and the speed is 250 rpm. Find speed at which the armature must be driven to generate an EMF of 550V. If the flux per pole is reduced to 58 mwb.

Given $P = 6$

$A = 2$ For wave winding

$Z = 664$.

$\phi_1 = 60 \text{ mwb} = 60 \times 10^{-3}$

$N_1 = 250$ rpm.

$E_1 = ?$

$$E_1 = \frac{P \phi_1 N_1 Z}{60 A} = \frac{6 \times 60 \times 10^{-3} \times 250 \times 664}{60 \times 2} = 498$$

$\therefore E_1 = 498 V$

New flux $\phi_2 = 58$ mwb

$E_2 = 550 V$

$N_2 = ?$

$$E_2 = \frac{P \phi_2 N_2 Z}{60 A} \Rightarrow N_2 = \frac{E_2 \times 60 \times A}{P \times \phi_2 \times Z}$$

$$\Rightarrow N_2 = \frac{550 \times 60 \times 2}{6 \times 58 \times 10^{-3} \times 664} = 285.6252$$

$\therefore N_2 = 285.6252$ rpm.

7) An 8 pole DC generator has per pole flux of 40 mwb & winding is connected in Lap with 960 conductors calculate the generated EmF on open circuit when it runs at 400 rpm. If the armature is wave wound at what speed must the machine be driven to generate the same voltage.

Sol : Given $P = 8$

$\phi = 40$ m wb $= 40 \times 10^{-3}$ wb

$A = P = 8$, For Lap connection

$Z = 960$.

$E_1 = ?$ at $N_1 = 400$ rpm

1) For Lap

1) $E = \dfrac{P \phi N Z}{60 A} \Rightarrow \cancel{N = \dfrac{E \times 60 \times A}{P \phi Z}}$

$$= \frac{8 \times 40 \times 10^{-3} \times 400 \times 960}{60 \times 8}$$

$E = 256$ Volts.

(ii) For wave winding:

when the armature is wave wound, & the Emf induced is 256 Volts

and here $A = 2$ for wave winding.

$N = ?$

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

$$= \frac{256 \times 60 \times 2}{8 \times 40 \times 10^{-3} \times 960}$$

$$\therefore N = 100 \text{ RPM}$$

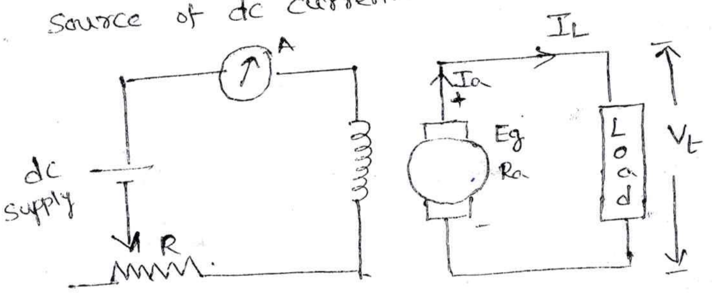
→ **Types of DC Generators (or) Methods of Excitation :-**

DC Generators

- Separately excited
- Self Excited
  - Series wound
  - Shunt wound
  - Compound wound
    - Long shunt
    - Short shunt

Generators are usually classified according to the way in which their fields are excited. Generators may be divided in to
a) Separately excited generators b) Self excited generators.

a) Separately excited dc generators :- These generators are those whose field windings are energised from an independent external source of dc current.



Here

$$I_a = I_L$$

$$E_g = V_t + I_a R_a + V_{brushdrop}$$

$$\Rightarrow V_t = E_g - I_a R_a$$

Power developed in the armature $P_a = E_g I_a$

Power delivered to the load P_t (or) $P_L = E_g I_a - I_a^2 R_a$.

where E_g = generated Emf , V_t = Terminal Voltage

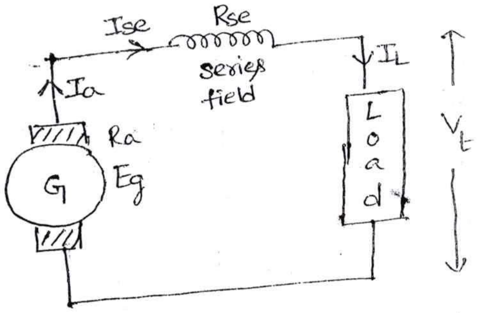
I_a = Armature current R_a = Armature resistance

I_L = Load current.

b) <u>self Excited dc generators</u> :- are those whose field magnets are energised by current produced by the generators themselves.

There are 3 Types of self excited generators named according to the manner in which their field coils or windings are connected to the armature.

(i) Series generator :- In this the field windings are connected in series with armature windings.



Here $I_a = I_{se} = I_L$

$$E_g = V_t + I_a R_a + I_{se} R_{se}$$

$$\therefore E_g = V_t + I_a (R_a + R_{se}) \quad (\because I_a = I_{se})$$

$$\Rightarrow V_t = E_g - I_a R_a - I_{se} R_{se}$$

power developed in the armature

$$P_a = E_g I_a$$

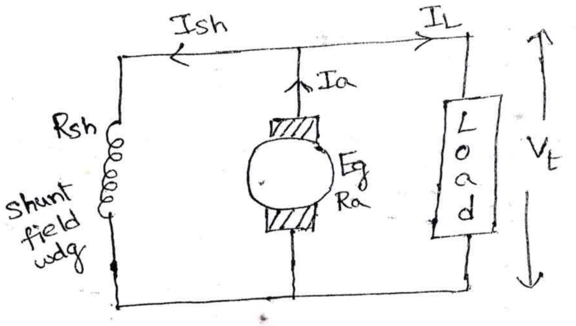
power delivered to the load

$$P_t \text{ or } P_L = E_g I_a - I_a^2 (R_a + R_{se})$$

where R_{se} = series field resistance

I_{se} = Series field current.

ii) shunt generators :- In this field windings are connected in parallel with the armature windings and have full voltage of generator applied across them.



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

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

$$E_g = V_t + I_a R_a$$

$$\Rightarrow V_t = E_g - I_a R_a$$

power developed in the armature, $P_a = E_g I_a$

power deliverd to load, $P_L = V_t I_L$

where R_{sh} = shunt field Resistance

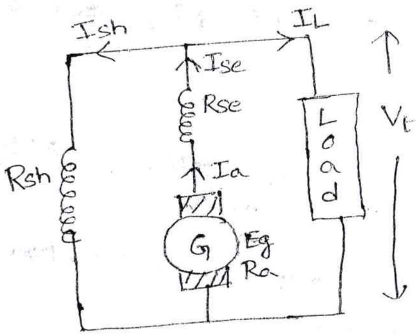
I_{sh} = shunt field current

iii) Compound wound :-

It is the combination of ~~ate~~ few series and a few shunt windings. can be either short shunt or long shunt.

→ In a compound generator the shunt field is stronger than the series field. when the series field aids the shunt field is said to be commutatively compounded. on the other hand if the series field opposes the shunt field the generator is said to be differentially compounded generators.

a) ~~short~~ Long shunt generators :



Here $R_{sh} \parallel (R_a + R_{se})$

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

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

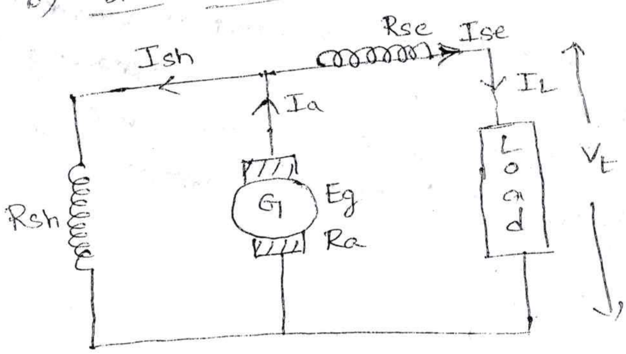
$$E_g = V_t + I_a R_a + I_{se} R_{se}$$

$$E_g = V_t + I_a (R_a + R_{se}) \quad (\because I_a = I_{se})$$

power developed in the armature $P_a = E_g I_a$

Power delivered to the load $P_L = V_t I_L$

b) short shunt generators :-



Here $R_{sh} \parallel R_a$ only.

$$I_{se} = I_L$$

$$I_a = \underbrace{I_{se}} + I_{sh}$$

$$\Rightarrow I_a = I_L + I_{sh}$$

~~$E_g = V_t + I_a R_a$~~

$$I_{sh} = \frac{V_t + I_{se} R_{se}}{R_{sh}}$$

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

$$E_g = V_t + I_a R_a + \underbrace{I_{se}} R_{se}$$

$$\therefore E_g = V_t + I_a R_a + I_L R_{se}$$

Power developed in the armature $P_a = E_g I_a$

Power delivered to the load $P_L = V_t I_L$

Applications of DC generators :-

1) **Separately excited dc generators :-** Though it is so expensive, it has applications where self excited generators could be relatively unsatisfactorily. They are used where quick and definite response to control is important.

The applications of separately excited dc generators are as follows :

1) Used in power generating station to serve as an excitation source for large alternators.

2) Used in Ward Leonard system of speed control to serve as a control generator.

2) **DC series generators:-**

1) Used in dc locomotives

2) This is mainly used as boosters in certain types of distribution systems particularly in railways.

However series generators are not used for power supply because of their rising characteristics.

3) **DC shunt generators :-**

shunt generator with field regulators are used for ordinary lighting and power supply purposes.

They are also used for charging batteries because their Terminal voltages are almost constant (or) can be kept constant.

4) **compound generators :-**

i) cumulatively compound generator is most widely used as dc generator. because its external characteristics can be adjusted for compensating the voltage drop in the linear resistance.

ii) The differential compound generator has an external characteristics similar to that of shunt generator but with large demagnetization armature reaction. Hence it is widely used in Arc welding where larger voltage drop is desirable with increase in current.

Cumulative and Differential Compound Generator :-

In compound generator, the two windings, shunt field & series field are wound on the same pole. Depending on the direction of winding on the pole, two fluxes produced by shunt and series field may help or may oppose each other. This fact decides whether generator is cumulative or differential compound.

Cumulative compound generator: If the two fluxes shunt & series, help each other (add each other) then the generator is called cumulative compound generator., it is shown in fig (1).

$$\boxed{\phi_T = \phi_{sh} + \phi_{se}}$$

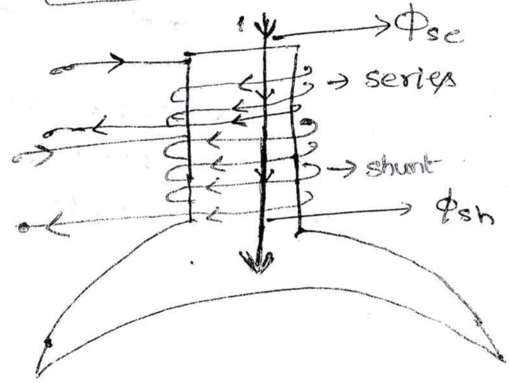
where ϕ_T = Total flux

ϕ_{sh} = flux produced by shunt field winding

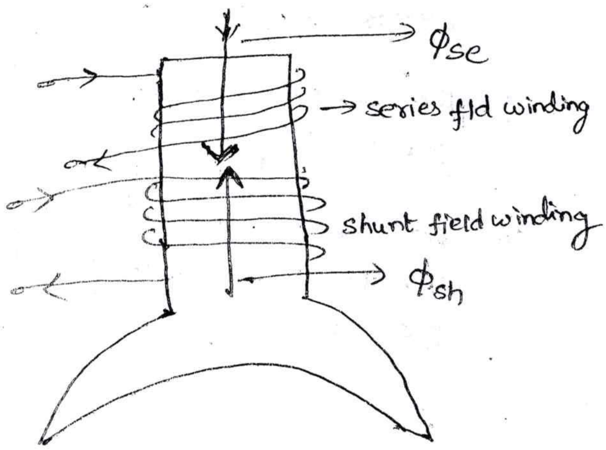
ϕ_{se} = flux produced by series field winding

Differential Compound generator :- If the two windings are wound in such a direction that the fluxes produced by them opposes ~~each other~~ the generator is known as differential each other then compound generator. This is shown in fig (2).

$$\boxed{\phi_T = \phi_{sh} \sim \phi_{se}}$$



Fig(1): Cumulative Compound



Fig(2): Differential Compound.

21) Differences between self excited and separately excited generators :-

Self Excited

1) In self excited the field windings are excited by the armature current

2) The current flowing through the field winding depends on load.

3) It does not require any external source or battery

4) Presence of residual magnetism is mandatory

5) There are chances that the self excited may fail to build up voltage due to absence of residual magnetism.

6) The circuit diagram for self excited generator is shown in the following figure :

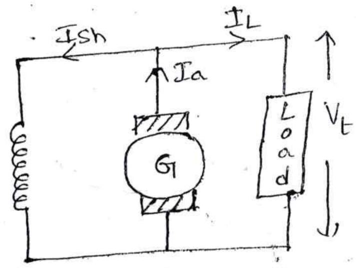


fig: self excited shunt generator.

7) Resistance of this field winding should be less than critical field resistance

8) The generated voltage at higher current is less

9) DC shunt generators are used in charging of batteries and lightning purpose

Separately Excited

1) In this the field windings are excited by a separate dc source.

2) The current flowing through the field winding is independent of load.

3) It requires an external source (or) battery.

4) Presence of residual magnetism is not essential.

5) There are chances of failure of voltage to build up.

6) The circuit diagram for separately excited generator shown below :

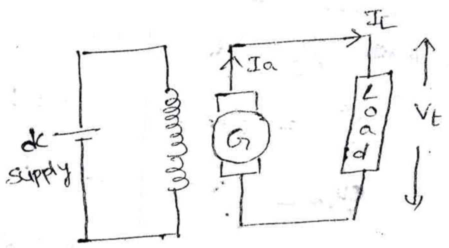


Fig: separately excited generator

7) The field winding resistance should be high inorder to limit field current.

8) The generated voltage at higher current is more.

9) Used in ward leonard systems of speed control to serve as a control generator.

Problems on Types of generator :-

1) A 250V, 10 kW separately Excited generator has an emf induced of 255 V at full load if the brush drop is 2V per brush. calculate the armature resistance of the generator.

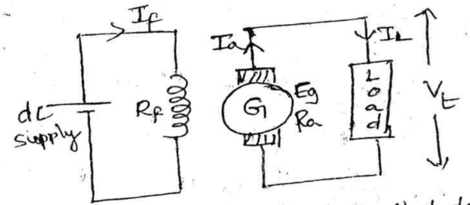
Sol : 

fig :- separately Excited dc generator

Given,

Terminal Voltage $V_t = 250V$,

output power (or) load power

$P_L = 10\,kW = 10 \times 10^3\,W$

Induced Emf $E_g = 255\,V$

Brush drop voltage per brush $= 2V$.

For two brushes, Total brush drop $= V_{brushdrop} = 2 \times 2 = 4V$.

Armature resistance $R_a = ?$

We know that $P_L = V_t I_L \Rightarrow I_L = \frac{P_L}{V_t} = \frac{10 \times 10^3}{250} = 40A$

$\Rightarrow I_L = 40\,A$

For separately excited dc generator, $I_a = I_L = 40\,A$.

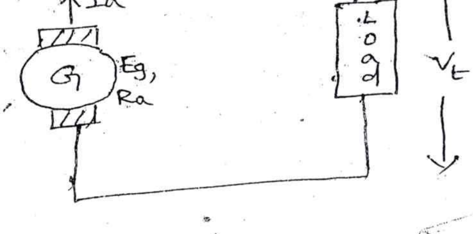
$E_g = V_t + I_a R_a + V_{brushdrop}$

$255 = 250 + 40(R_a) + 4$

$\Rightarrow 255 - 254 = 40(R_a) \Rightarrow R_a = \frac{1}{40}$

$\Rightarrow \boxed{R_a = 0.025\,\Omega}$

2) A DC series generator has an armature resistance of 0.5Ω and series field resistance of 0.03Ω it drives a load of 50 A. It has 6 turns per coil and total 540 coils on the armature and is driven at 1500 RPM. Calculate the terminal voltage at the load. Assume 4 poles, Lap type winding, flux per pole has 2 mwb and Total brush drop as 2V.

Sol : 

Given

armature resistance $R_a = 0.5\Omega$

Series field resistance $R_{se} = 0.03\Omega$

Load current $I_L = 50\,A$.

No. of coils = 540

Given 6 turns / coil,

1 turn = 2 conductor

So, No. of conductor $Z = 540 \times 6 \times 2$

$Z = 6480$

Speed $N = 1500$ rpm

pole $P = 4$

For lap connection, $A = P = 4$.

flux $\phi = 2$ mwb $= 2 \times 10^{-3}$ wb

Total brush drop $V_{brushdrop} = 2V$

$$E_g = \frac{P\phi NZ}{60A} = \frac{4 \times 2 \times 10^{-3} \times 1500 \times 6480}{60 \times 4} = 324\ V$$

$\Rightarrow \boxed{E_g = 324\ V}$

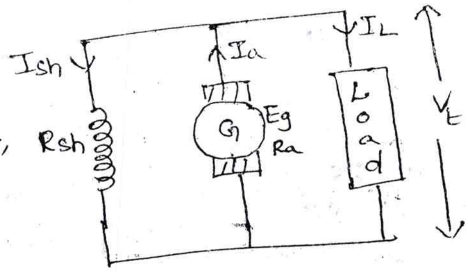
For series generator, $I_a = I_L = I_{se} = 50$ A.

$\Rightarrow E_g = V_t + I_a(R_a + R_{se}) + V_{brushdrop}$

$324 = V_t + 50(0.5 + 0.03) + 2$

$\Rightarrow \boxed{V_t = 295.5\ V}$

3) A DC shunt generator has shunt field winding resistance of 100Ω, It is supplying a load of 5kw at a voltage of 250 V if its armature resistance is 0.22Ω. Calculate the induced emf of generator.



Sol : Given,

Shunt field winding resistance $R_{sh} = 100\Omega$,

Load power $P_L = 5$ KW

$P_L = 5 \times 10^3$ Watts

Terminal voltage $V_t = 250V$.

armature resistance $R_a = 0.22\Omega$.

Induced emf $E_g = ?$

$P_L = V_t \times I_L \Rightarrow I_L = \frac{P_L}{V_t} = \frac{5 \times 10^3}{250} = 20$ A

$\Rightarrow I_L = 20A$

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{250}{100} = 2.5\,A$$

$\Rightarrow I_{sh} = 2.5\,A$

$I_a = I_L + I_{sh}$

$= 20 + 2.5$

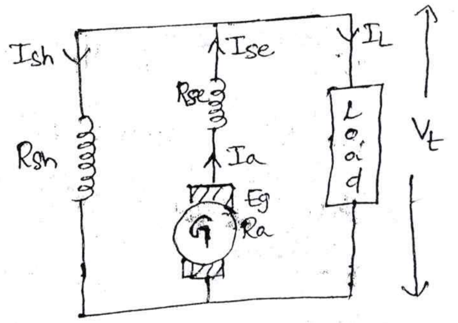
$\Rightarrow \boxed{I_a = 22.5\,A}$

$E_g = V_t + I_a R_a$

$= 250 + 22.5\,(0.22)$

$\Rightarrow \boxed{E_g = 254.95\,V}$

4) A long shunt compound generator delivers a load current of 50A at 500V and has armature, series field and shunt field resistance of 0.05 Ω, 0.03 Ω & 250 Ω. Calculate the generated emf & armature current. Allow 1.0V for brush for contact drop.



Sol: Given Load current $I_L = 50\,A$.

Terminal voltage $V_t = 500\,V$

armature resistance $R_a = 0.05\,\Omega$

series field resistance $R_{se} = 0.03\,\Omega$

shunt field resistance $R_{sh} = 250\,\Omega$.

brush drop, $V_{brush\,drop} = 1\,V$.

Induced emf $E_g = ?$

armature current $I_a = ?$

$I_a = I_L + I_{sh}$

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

$$I_{sh} = \frac{500}{250} = 2\,A$$

$\Rightarrow I_{sh} = 2\,A$

$I_a = I_L + I_{sh}$

$= 50 + 2$

$I_a = 52\,A$

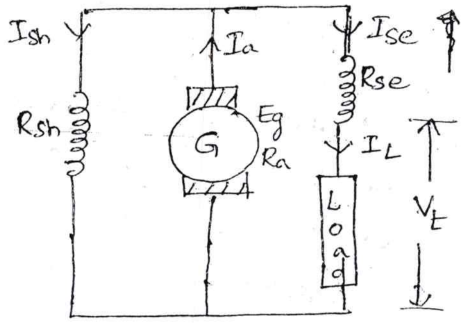
$$E_g = V_t + I_a(R_a + R_{se}) + V_{brushdrop}$$

$$= 500 + 52(0.05 + 0.03) + 1$$

$$\Rightarrow \boxed{E_g = 505.16 \text{ V}}$$

5) A short shunt dc compound generator supplies a current of 75 A at a voltage of 225 V. Calculate the generated voltage if the resistance of armature, shunt field and series field winding are 0.04 Ω, 90 Ω and 0.02 Ω respectively.

Sol:



Given

Load current $I_L = 75$ A

Terminal voltage $V_t = 225$ V.

armature resistance $R_a = 0.04\,\Omega$

Shunt field resistance $R_{sh} = 90\,\Omega$

Series field resistance $R_{se} = 0.02\,\Omega$.

Induced Emf $E_g = ?$

we have, $I_{sh} = \dfrac{E_g - I_a R_a}{R_{sh}} = \dfrac{V_t + I_L R_{se}}{R_{sh}}$

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

$$= \frac{225 + 75(0.02)}{90}$$

$$I_{sh} = 2.51 \text{ A.}$$

$I_a = I_L + I_{sh}$

$= 75 + 2.516$

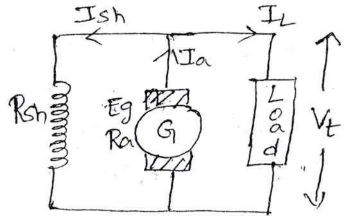
$\Rightarrow \boxed{I_a = 77.516\ A}$

$\therefore E_g = V_t + I_a R_a + I_L R_{se}$

$= 225 + 77.516 \times 0.04 + 75 \times 0.02$

$\Rightarrow \boxed{E_g = 229.6\ V}$

6) A 20 KW 200V shunt generator has an armature resistance of 0.05 Ω and shunt field resistance of 200 Ω. calculate the power developed in the armature when it delivers rated output.



Sol: Given

load power $P_L = 20$ KW

Terminal Voltage $V_t = 200$ V

$P_L = V_t \times I_L \Rightarrow I_L = \frac{P_L}{V_t} = \frac{20 \times 10^3}{200} = 100\ A$

$\Rightarrow \boxed{I_L = 100\ A}$

$I_{sh} = \frac{V_t}{R_{sh}} = \frac{200}{200} = 1A \Rightarrow \boxed{I_{sh} = 1A}$

$\therefore I_a = I_L + I_{sh} = 1 + 100 = 101\ A$

$\Rightarrow \boxed{I_a = 101\ A}$

$E_g = V_t + I_a R_a$

$= 200 + 101 (0.05)$

$\Rightarrow E_g = 205.05 V$

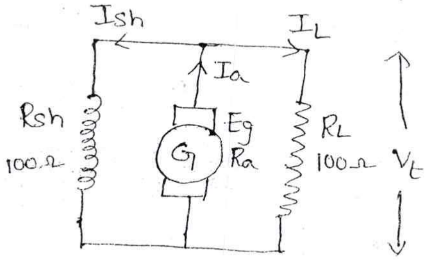
power delivered in the armature $P_a = E_g I_a$

$= 205.05 \times 101$

$\Rightarrow P_a = 20.71005$ KW

7) A 4 Pole dc generator with a shunt field resistance of 100 Ω and an armature resistance of 1 Ω has 378 wave connected conductors in the armature. The flux per pole is 0.02 wb. If the load resistance of 100 Ω is connected across the armature terminals and the generator is driven at 1000 rpm. Calculate the power absorbed by the load.

Sol:



Given Pole $P = 4$

conductors $Z = 378$

for wave connection, $A = 2$

speed $N = 1000$ rpm

flux $\phi = 0.02$ wb

armature resistance $R_a = 1\,\Omega$

shunt field resistance $R_{sh} = 100\,\Omega$

load resistance $R_L = 100\,\Omega$.

load Power $P_L = ?$

$$E_g = \frac{P\phi NZ}{60A} = \frac{0.02 \times 4 \times 1000 \times 378}{60 \times 2} = 252\text{ V}$$

$$E_g = 252\text{ V}$$

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

Now $I_L = \frac{V_t}{R_L}$ and $I_{sh} = \frac{V_t}{R_{sh}}$

$$\therefore I_a = I_L + I_{sh} = \frac{V_t}{R_L} + \frac{V_t}{R_{sh}}$$

$$\Rightarrow E_g = V_t + I_a R_a$$

$$\Rightarrow E_g = V_t + \left[\frac{V_t}{R_{sh}} + \frac{V_t}{R_L}\right] R_a$$

$$\Rightarrow 252 = V_t + \left[\frac{V_t}{100} + \frac{V_t}{100}\right] \times 1$$

$$\Rightarrow V_t = 247.0588\text{ V}$$

$$\therefore I_L = \frac{V_t}{R_L} = \frac{247.0588}{100} = 2.47058\text{ A}$$

Power absorbed by load $P_L = V_t I_L = 247.0588 \times 2.470588$

$\therefore P_L = 610.378$ Watts

8) In a 110V dc compound generator the resistance of the armature, shunt field and series field are 0.06Ω, 25Ω and 0.4Ω respectively. The load consists of 200 lamps each rated at 55W, 110V. Find the total Emf generated and the armature current when the machine is connected in a) Long shunt b) short shunt.

Sol: Given armature resistance $R_a = 0.06\Omega$

Shunt field resistance $R_{sh} = 25\Omega$

Series field resistance $R_{se} = 0.4\Omega$

Terminal voltage $V_t = 110\,V$

given 200 lamps load

load power (or) output power $P_L = 200 \text{ lamps} \times 55 \text{ watts}$

$= 11\,000 \text{ Watts}$

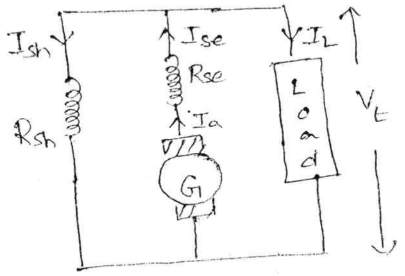
$\therefore P_L = V_t I_L \Rightarrow I_L = \frac{P_L}{V_L} = \frac{11000}{110} = 100\,A$

Load current $I_L = 100\,A$

Armature current $I_a = ?$

Generated Emf $E_g = ?$

a) <u>Long shunt</u> :-



Here $I_a = I_L + I_{sh}$

$I_{sh} = \frac{V_t}{R_{sh}} = \frac{110}{25} = 4.4\,A$

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

$= 100 + 4.4$

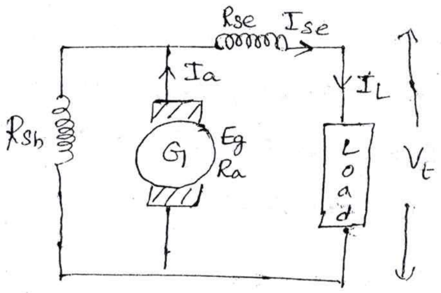
$\therefore I_a = 104.4\,A$

Induced emf $E_g = V_t + I_a(R_a + R_{se})$

$= 110 + 104.4\,(0.06 + 0.4)$

$\therefore E_g = 158.024 \text{ Volts}$

b) Short shunt generator :-



$$I_{sh} = \frac{E_g - I_a R_a}{R_{sh}} = \frac{V_t + I_L R_{se}}{R_{sh}}$$

Here $I_{se} = I_L = 100\ A$

$$I_{sh} = \frac{V_t + I_L R_{se}}{R_{sh}} = \frac{110 + 100(0.4)}{25}$$

$$\therefore I_{sh} = 6\ A$$

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

$$= 100 + 6$$

$$\therefore I_a = 106\ A$$

$$\therefore E_g = V_t + I_a R_a + I_{se} R_{se}$$

$$= 110 + 106(0.06) + 100(0.4)$$

$$\therefore E_g = 156.36\ V$$

previous Question paper problems :-

9) A 6 pole generator has 1000 armature conductors and is wave wound. If the flux per pole is 0.02 wb and the speed is 500 rpm. calculate the Emf generated. If the above machine is self Excited and the armature and field resistances are 0.5 Ω and 250 Ω respectively. calculate the output current when the armature current is 40 A (set 1, NOV 2012 EEE)

Sol :-

given pole $P = 6$

armature conductors $Z = 1000$.

For wave connection, No. of parallel path $A = 2$.

Flux $\phi = 0.02$ wb

Speed $N = 500$ rpm.

Emf $E = ?$

and also given, ~~mech~~ armature resistance $R_a = 0.5\,\Omega$

(Shunt) field resistance $R_{sh} = 250\,\Omega$

armature current $I_a = 40$ A.

output current $I_L = ?$.

given machine is self Excited, from above data field resistance $R = 250\,\Omega$ it is shunt field. The machine is dc shunt generator.

we know $E_g = \dfrac{P \phi N Z}{60 \times A}$

$$= \frac{6 \times 0.02 \times 500 \times 1000}{60 \times 2} = 500\text{ V}$$

$$\therefore \boxed{E_g = 500\text{ V}}$$

$\because$ $I_a = I_L + I_{sh}$ for dc shunt generator.

$\Rightarrow I_L = I_a - I_{sh}$. ——— (1)

$\Rightarrow I_{sh} = \dfrac{V}{R_{sh}}$ ——— (2)

$\Rightarrow E_g = V + I_a R_a$.

$\therefore V = E_g - I_a R_a$. ——— (3)

From (2), $I_{sh} = \dfrac{V}{R_{sh}} = \dfrac{E_g - I_a R_a}{R_{sh}} = \dfrac{500 - 40(0.5)}{250} = \dfrac{480}{250}$

$\boxed{I_{sh} = 1.92\text{ A}}$

Substituting I_{sh} and I_a values in Eqn ①,

$$I_L = I_a - I_{sh}$$
$$= 40 - 1.92$$
$$I_L = 38.08 \text{ A}$$

$\therefore$ output current $\boxed{I_L = 38.08 \text{ A}}$

10) → A short shunt compound generator has armature, series field and shunt field resistances of 0.8Ω, 0.6Ω and 45Ω respectively. The machine supplies a load of 5 Kw at 250V calculate the emf generated in armature and armature current.
(Set 3, EEE Nov 2012)

Sol: Given Armature resistance $R_a = 0.8\Omega$
series field resistance $R_{se} = 0.6\Omega$
Shunt field resistance $R_{sh} = 45\Omega$
Load power (or) output power $= P_{out} = 5$ Kw $= 5\times10^3$ W
output voltage (or) Terminal voltage $= V_t = 250$ V.
generated Emf $= E_g = ?$
armature current $= I_a = ?$

O/P power, P_{out} (or) $P_L = V_t I_L$

$$\Rightarrow I_L = \frac{P_{out}}{V_L} = \frac{5\times10^3}{250} = 20 \text{ A}$$

$$\Rightarrow \boxed{I_L = 20 \text{ A}}$$

Shunt ~~current~~, $I_{sh} \neq \cancel{\frac{V}{R_{sh}}} = \cancel{\frac{250}{45}} \Rightarrow$ 5.5 A. $\Rightarrow \boxed{\cancel{I_{sh} = 5.5 \text{ A}}}$

armature current $\cancel{I_a} = \cancel{I_L + I_{sh}}$
$= 20 + \cancel{5.5}$ A
$= \cancel{25.5}$ A

~~$I_a = 25.5$ A~~

For short shunt generator,

$$I_{sh} = \frac{E_g - I_a R_a}{R_{sh}} = \frac{V_t + I_L R_{se}}{R_{sh}}$$

$$\therefore \; I_{sh} = \frac{V_t + I_L R_{se}}{R_{sh}} = \frac{250 + 20(0.6)}{45} = \frac{262}{45} = 5.8$$

$$\boxed{I_{sh} = 5.8 \text{ A}}$$

armature current, $I_a = I_L + I_{sh}$

$= 20 + 5.8$

$$\boxed{I_a = 25.8 \text{ A}}$$

generated emf $E_g = V_t + I_a R_a + I_{se} R_{se}$.

$= 250 + 25.8(0.8) + 20(0.6)$

$$\therefore \boxed{E_g = 282.64 \text{ Volts}}$$

17) A 4 pole Lap wound Long shunt dc compound generator has 1250 armature conductors. The armature, series field and shunt field resistance are respectively 0.6 Ω, 0.75 Ω and 225 Ω. If the shunt field flux and series field flux per pole are respectively 0.075 wb and 0.0025 wb. calculate the speed at which the machine has ~~rotatote~~ to deliver a load of 120 A at 450 V. consider the total brush drop as 2 V. (EEE, set 4, NOV 2012)

Sol :- given pole $P = 4$

For Lap connection, $A = P = 4$.

armature conductor $Z = 1250$

series field resistance $R_{se} = \cancel{0.6\,\Omega}\; 0.75\,\Omega$

shunt " " $R_{sh} = \cancel{225}\; 225\,\Omega$

armature resistance $R_a = \cancel{0.75\,\Omega}\; 0.6\,\Omega$

shunt field flux $\phi_{sh} = 0.075$ wb

series field flux $\phi_{se} = 0.0025$ wb.

load current $I_L = 120$ A

load voltage (or) Terminal voltage, V_t (or) $V_L = 450$ V

Total brush drop voltage, $V_{brush} = 2$ V speed $N = ?$

generated emf $E_g = ?$

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

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{450}{225} = 2\ A$$

$\Rightarrow \boxed{I_{sh} = 2\ A}$

$I_a = I_L + I_{sh}$

$I_a = 120 + 2 = 122$

$\therefore \boxed{I_a = 122\ A}$

$E_g = V_t + I_a R_a + I_{se} R_{se} + V_{brush}$ $(\because I_a = I_{se})$

$= V_t + I_a R_a + I_a R_{se} + V_{brush}$

$E_g = V_t + I_a (R_a + R_{se}) + V_{brush}$

$= 450 + 122(0.6 + 0.75) + 2 = 616.7 V$

$\boxed{E_g = 616.7 \text{ Volts}}$

we know, For cumullative compound generator

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

For differential compound generator, $\phi = \phi_{sh} \sim \phi_{se}$

→ In our problem, it is not given whether the generator is cumulative compound (or) differential compound.

Assume it is cumulative compound generator,

$\phi = \phi_{sh} + \phi_{se} = 0.075 + 0.0025 = 0.0775$ wb

$\boxed{\phi = 0.0775\ wb}$

We know $E_g = \frac{P \phi N Z}{60 A} \Rightarrow N = \frac{E_g \times 60 \times A}{P \times \phi \times Z}$

$= \frac{616.7 \times 60 \times 4}{4 \times 0.0775 \times 1250}$

$= \frac{148008}{387.5} = 381.9$ rpm.

$\therefore$ Speed $\boxed{N = 381.9 \text{ rpm}}$

(Previous Question paper problem - CSE Nov 12)

A long shunt compound generator delivers a load current of 50A at 500V and has armature, series field resistance of 0·05 Ω, 0·03 Ω, & 250 Ω respectively. calculate the generated emf and the armature current. Allow 1·0 V for brush contact drop.

(CSE, NOV-12, set-2, set-3)

Given

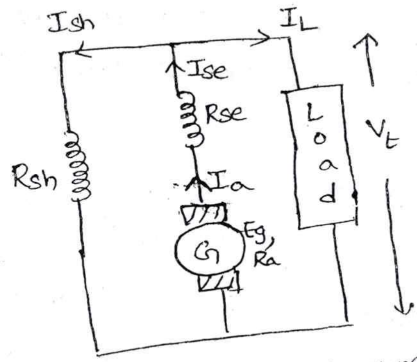


fig: Long shunt compound generator

Load current $I_L = 50 A$

Load (or) Terminal voltage $V_t = 500V$

armature resistance $R_a = 0·05 \Omega$

series field resistance $R_{se} = 0·03 \Omega$

shunt field resistance $R_{sh} = 250 \Omega$

brush voltage drop $V_{brushdrop} = 1V$

generated emf $E_g = ?$

armature current $I_a = ?$

We have $I_a = I_L + I_{sh}$

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{500}{250} = 2 A$$

$$\Rightarrow I_{sh} = 2A$$

$$I_a = I_L + I_{sh} = 50 + 2 = 52 A$$

$$\Rightarrow \boxed{I_a = 52 A}$$

$$E_g = V_t + I_a R_a + I_{se} R_{se} + V_{brushdrop}$$

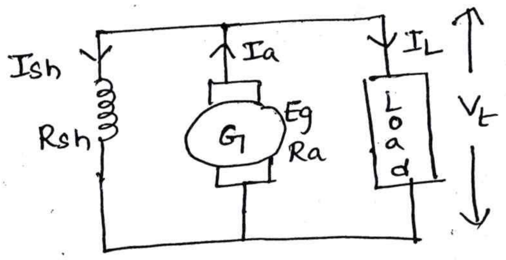
$$= V_t + I_a (R_a + R_{se}) + V_{brushdrop} \quad (\because I_a = I_{se})$$

$$= 500 + 52 (0·05 + 0·03) + 1$$

$$\Rightarrow \boxed{E_g = 505·16 \text{ volts}}$$

→ The resistance of Field circuit of a shunt wound dc generator is 200Ω. when the output of generator is 100 Kw. ~~Calculate~~ The Terminal voltage is 500 V and generated emf is 525 V. calculate : (1) The armature resistance
(2) The value of generated emf when the output is 60 Kw with a Terminal voltage of 520 V.
(II ECE, June 2015).

Sol: case-1: Given.
Shunt resistance $R_{sh} = 200\,\Omega$
output power (or) load power $P_L = 100$ Kw.
Terminal voltage $V_t = 500$ V
generated emf $E_g = 525$ V
armature Resistance $R_a = ?$



$I_a = I_L + I_{sh}$

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

$E_g = V_t + I_a R_a$.

We know $P_L = V_t I_L \Rightarrow I_L = \frac{P_L}{V_t} = \frac{100 \times 10^3}{500} = 200$

$I_L = 200$ A

$I_{sh} = \frac{V_t}{R_{sh}} = \frac{500}{200} = 2.5 \Rightarrow I_{sh} = 2.5$ A

$I_a = I_L + I_{sh} =$
$= 200 + 2.5$
$\boxed{I_a = 202.5 \text{ A}}$

$E_g = V_t + I_a R_a$
$525 = 500 + 202.5(R_a)$
$\Rightarrow R_a = \frac{525 - 500}{202.5} = 0.12$

$\boxed{R_a = 0.12\,\Omega}$

<u>case-2</u>:

output power (or) Load power $P_L = 60$ KW

Terminal votage, $V_t = 520$ V

generated emf $E_g = ?$

$$P_L = V_t I_L \Rightarrow I_L = \frac{P_L}{V_t} = \frac{60 \times 10^3}{520}$$

$$\boxed{I_L = 115.38 \text{ A}}$$

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{520}{200} = 2.6 \text{ A}$$

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

$$= 115.38 + 2.6$$

$$\boxed{I_a = 117.98 \text{ A}}$$

$$E_g = V_t + I_a R_a$$

$$= 520 + 117.98 (0.12)$$

$$\boxed{E_g = 534.15 \text{ Volts}}$$

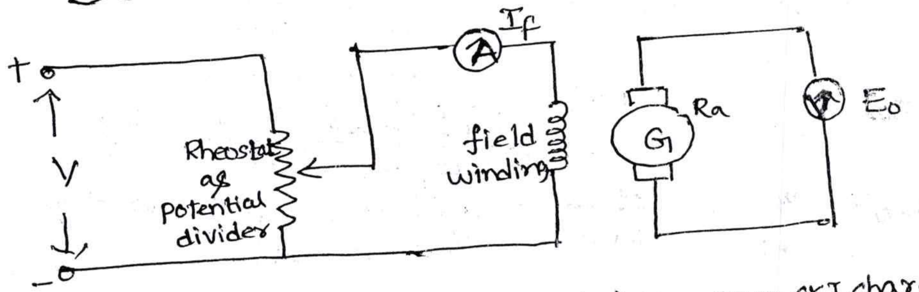
Characteristics of DC Generators :-

DC Generators have following characteristics :

1. Magnetization characteristics (or) No Load characteristics (E_0 Vs I_f)
2. Load characteristics. :- (2a) Internal characteristics
   (2b) External characteristics.

Characteristics of separately Excited DC Generator :-

(1) Magnetization (or) open circuit (or) No load characteristics :



fig(1) :- circuit for obtaing open CKT characteristics

→ Fig(1) shows the circuit for obtaining open circuit characteristics of seperately excited dc generator.

→ The rheostat is used as potential divider and is used to control the field current (I_f)

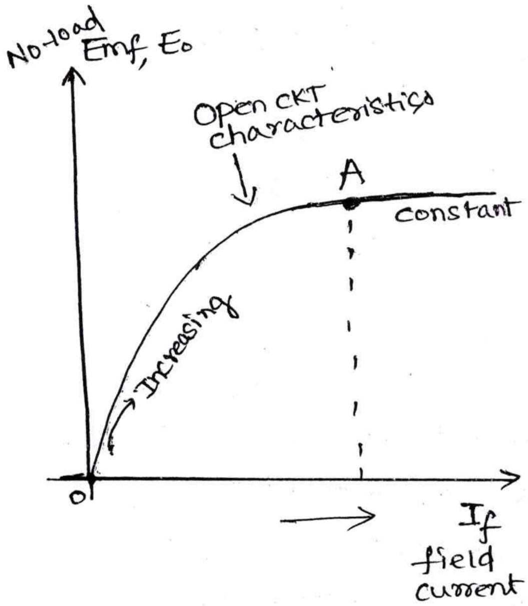


fig :- E_0 versus I_f open circuit characteristics.

→ We have Emf, $E_0 = \frac{P \phi N Z}{60 A}$

→ As I_f is varied, then ϕ changes and hence emf E_0 varies.

→ Fig(2) shows the No load characteristics drawn between E_0 & I_f.

→ From fig(2), As field current I_f increases, flux ϕ increases ($\because \phi \propto I_f$) and hence emf E_0 increases.

→ After point A, saturation occurs when ϕ becomes constant and hence E_0 saturates.

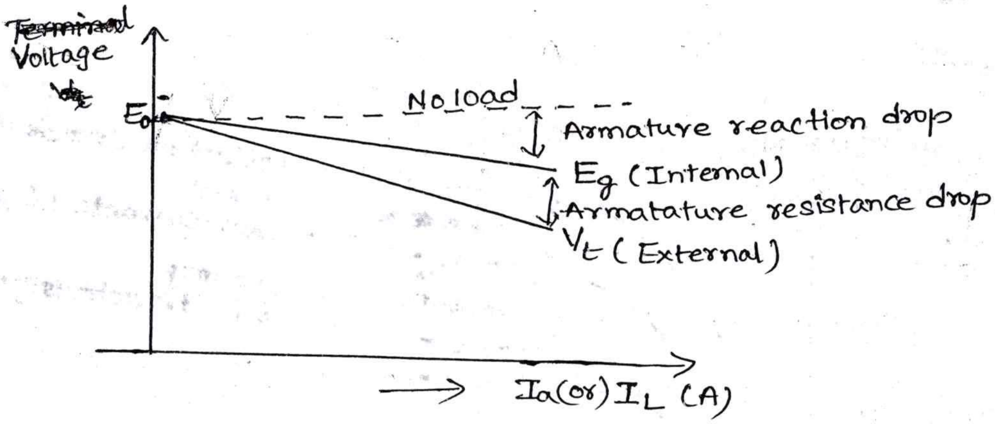
(2) Load characteristics of separately Excited dc generator

→ The graph drawn between Terminal voltage V_t and load current I_L is called External characteristics

→ The graph drawn between ~~Terminal voltage~~ Induced emf E_g and armature current I_a is called Internal characteristics.

→ For separately Excited dc generator, $I_a = I_L$.

→ Fig(3) shows the load characteristics of separately Excited generator.

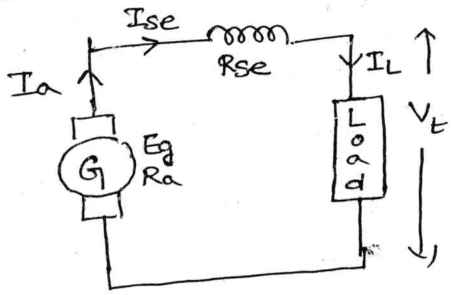


Fig(3): Load characteristics

→ ~~Load~~ characteristics of Dc ~~series~~ Generator:-

Load characteristics of dc series Generator :-

→ consider a dc series generator shown in fig(1)



For series generator $I_a = I_{se} = I_L$

As the load current increases, I_{se} increases.

→ As $\phi \propto I_{se}$, flux ϕ also increases.

As $\phi \propto E_g$, so induced emf E_g increases.

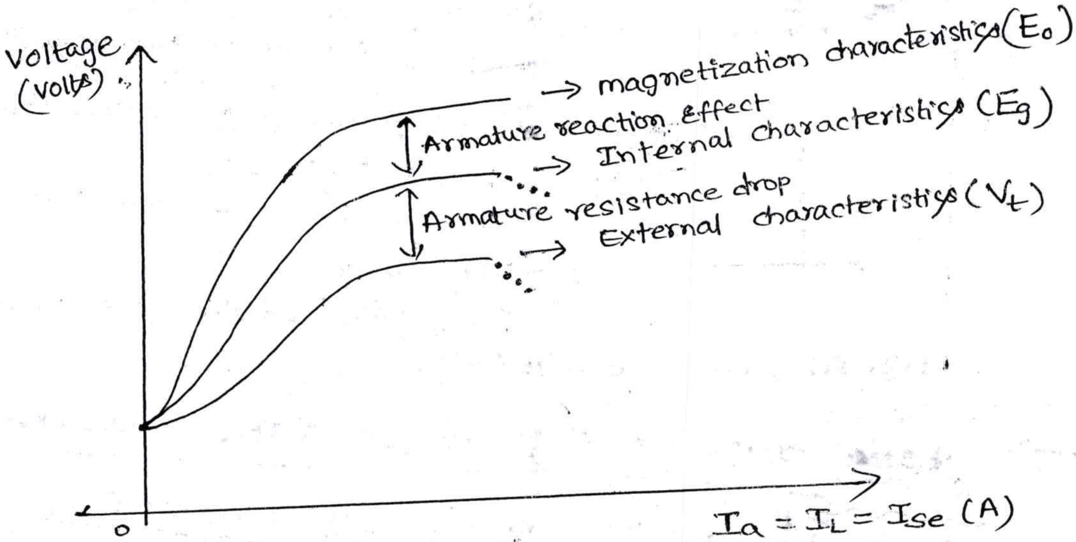
→ Thus the characteristics of E_g versus I_L ($\because I_a = I_L$), which is internal characteristics is of increasing nature, shown in fig(2).

→ For high load current saturation occurs, E_g starts decreasing, shown by dotted line in fig(2).

→ As $I_L = I_a$, ~~if~~ I_L increases, drop $I_a(R_a+R_{se})$ increases. then V_t increases. since $V_t = E_g - I_a(R_a+R_{se})$

→ Thus external characteristics V_t versus I_L, is of increasing nature, but below internal characteristics.

→ open circuit characteristics of dc series generator is possible only ~~if~~ by separately exciting the field winding. It is also shown in fig(2).

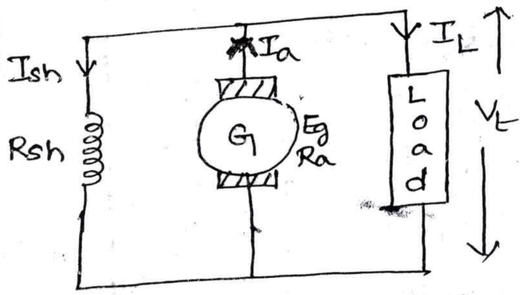


fig(2): characteristics of dc series generator.

Characteristics of Dc shunt generator :-

Load characteristics of dc shunt generator :

consider the dc shunt generator as shown in fig(1) below.

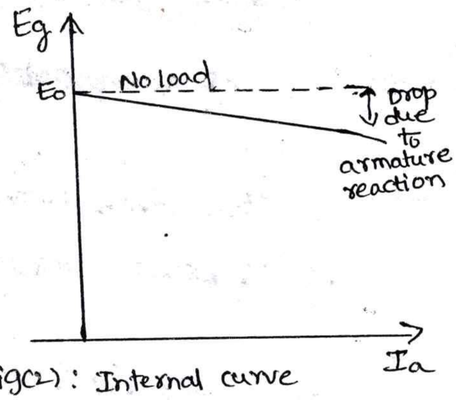


$$I_a = I_L + I_{sh}$$

$$E_g = V_t + I_a R_a$$

Fig(1): Dc shunt generator.

Internal characteristics :-



Fig(2): Internal curve

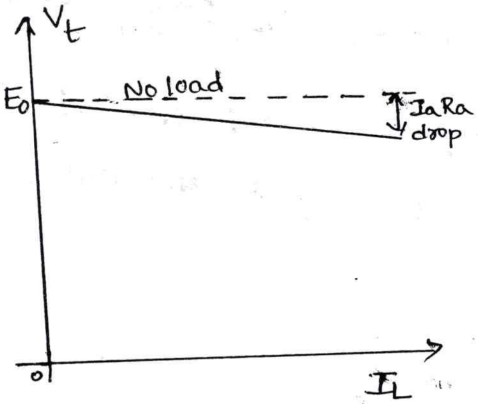
As Load current I_L increases, armature current I_a increases.

As I_a increases armature flux increases.

Due to armature reaction the emf E_g decreases.

Internal characteristics E_g Versus I_a shown in fig(2).

External characteristics :

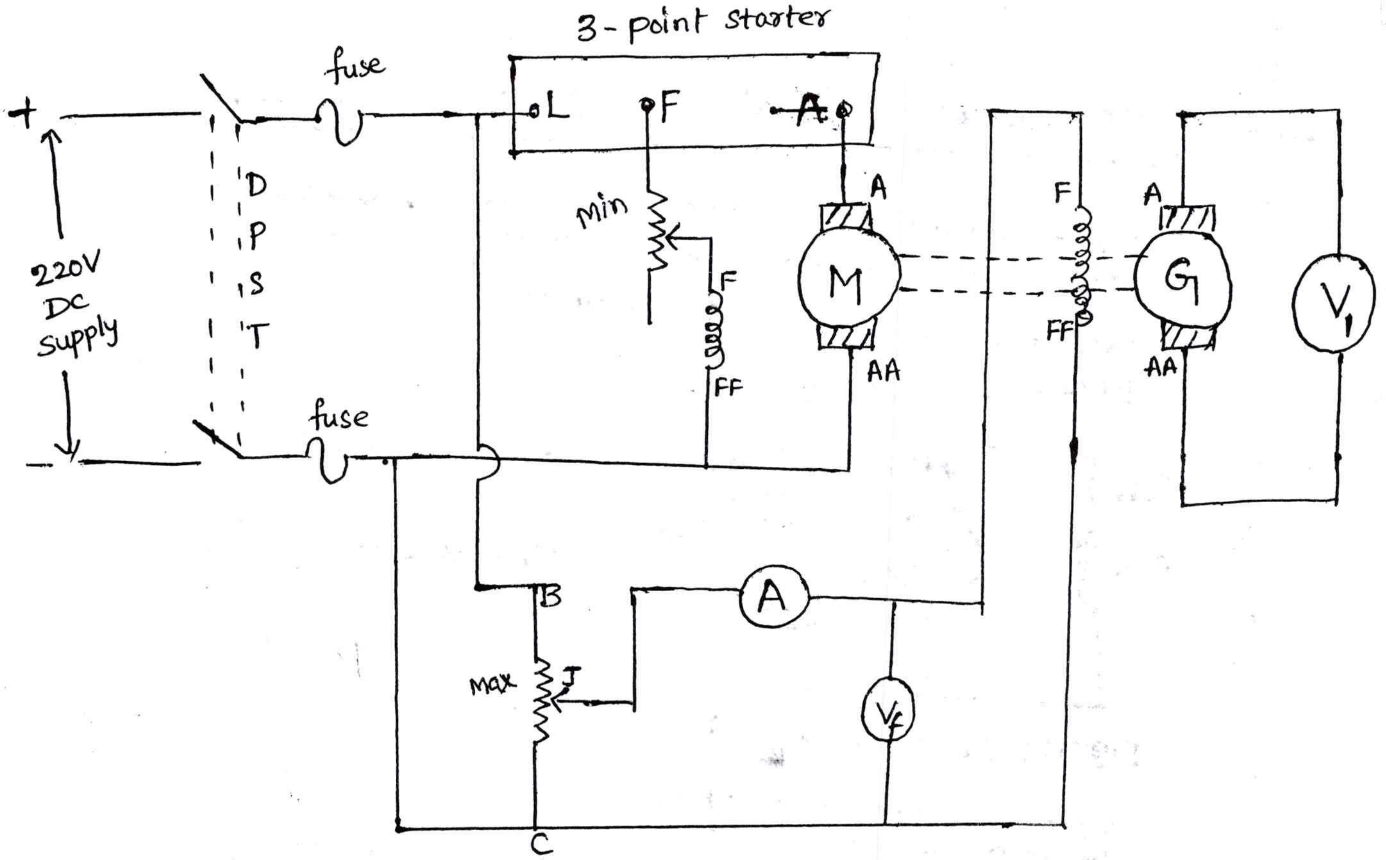


→ As load current I_L increases, I_a increases. Thus drop $I_a R_a$ increases and the terminal voltage $V_t = E_g - I_a R_a$, decreases.

→ External characteristics V_t versus I_L shown in fig(3)

Fig(3): External characteristics

→ Open Circuit Characteristics (OCC) of DC Shunt Generator :-



Fig(1): Circuit for determining OCC of dc shunt generator

→ The circuit diagram for determining the OCC of a separately excited generator is shown in fig(1).

→ The generator is coupled to a dc shunt motor. The field winding (F-FF) of the generator is provided with a separate dc source through a potential divider (BJC)

→ The ammeter connected in series with the field winding reads the excitation current through the field windings. The Voltmeter connected across the armature of the generator reads the Emf generated by the machine.

→ The potential divider connection ensures the variation of field current from zero to any desired Value by adjusting the variable point J from point B to point C.

→ The generator is run at its rated speed and field current I_f is increased from zero value to definite value in steps. At each value of I_f the readings of two voltmeters V_f and V_1 are noted down.

→ I_f is increased until the voltmeter V_1 reads at least 25% more than the rated voltage. After measuring the maximum value I_f is now decreased in steps and the corresponding voltmeters V_f and V_1 readings are again noted down.

→ The average of ~~two~~ readings of the voltmeter V_1 corresponding ascending & descending values of I_f are taken for drawing the open circuit characterstics. as shown in fig (2).

No load emf (E_0) :- By drawing a field resistance line R_{sh}, which passes through origin and cuts the OCC at point 'P'.

The slope of the line is ~~Rsh~~ $\frac{PQ}{OQ}$ will give the resistance of field winding. i.e, $R_{sh} = \frac{PQ}{OQ}$.

The voltage PQ represents the machine can build on no-load.

The intersection point 'P' ~~will determ~~ between the OCC and R_{sh} line

∴ The intersection point 'P' determines the no load emf E_0.

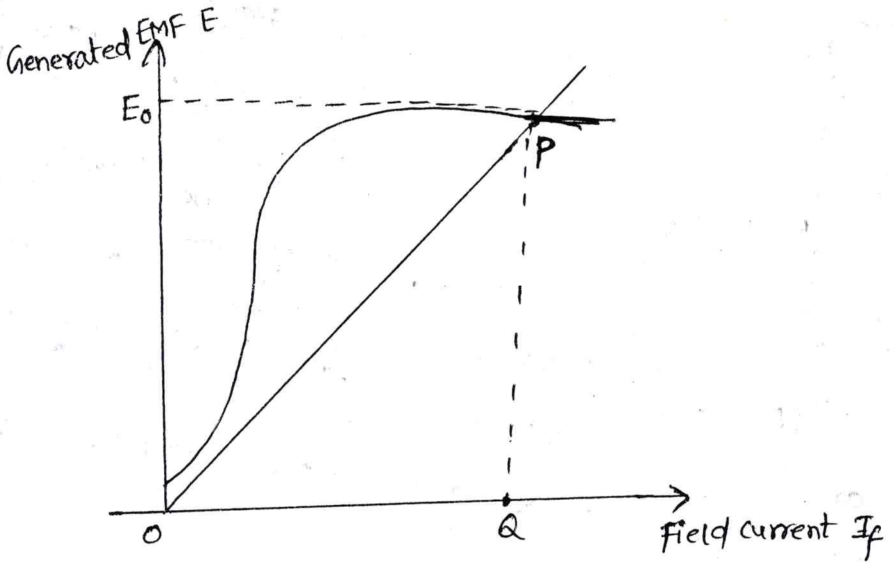


Fig (2): open circuit characteristics (OCC) of shunt generator.

DC MOTORS

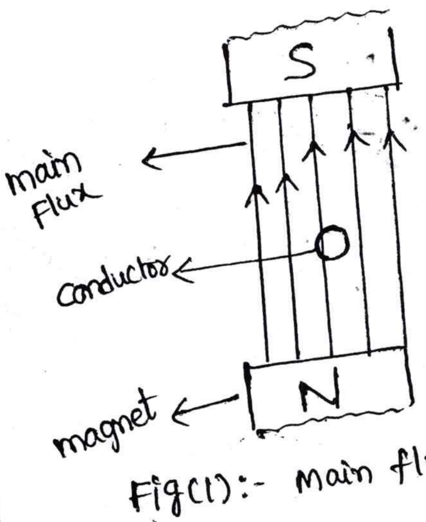
2 → **Principle and operation of a DC motor :-** ✓

→ **Principle :** The principle of operation of a dc motor can be stated as "when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force".

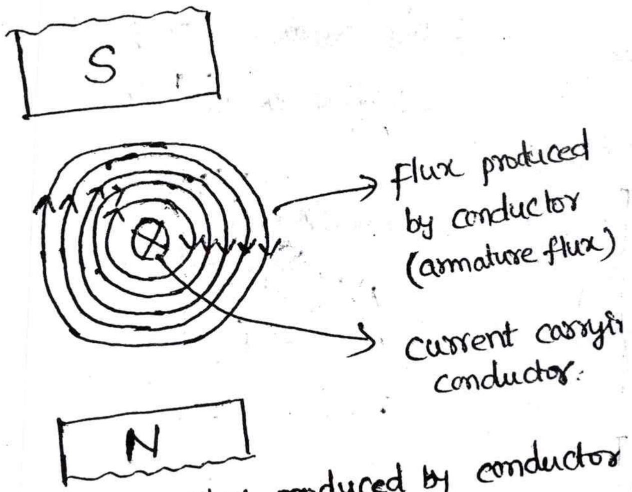
→ **Operation of dc motor :-** consider a single conductor placed in magnetic field as shown in Fig (1). The magnetic field is produced by a permanent magnet but in a practical dc motor it is produced by field winding when it carries a current.

→ Now this conductor is excited by a separate supply so that it ~~current~~ carries a current in a particular direction. consider that it carries a current away from an observer as shown in Fig(2).

→ Any current carrying conductor produces its own magnetic field around it hence this conductor also produces its own flux around. For the direction of current considered, the direction of flux around a conductor is clockwise.



Fig(1):- Main flux produced by magnets.



Fig(2): Flux produced by conductor

Now there are two fluxes present,

1) The flux produced by permanent magnet called Main flux shown in fig(1)

2) The flux produced by current carrying conductor called armature flux shown in fig(2).

→ These two fluxes are shown in Fig(3).

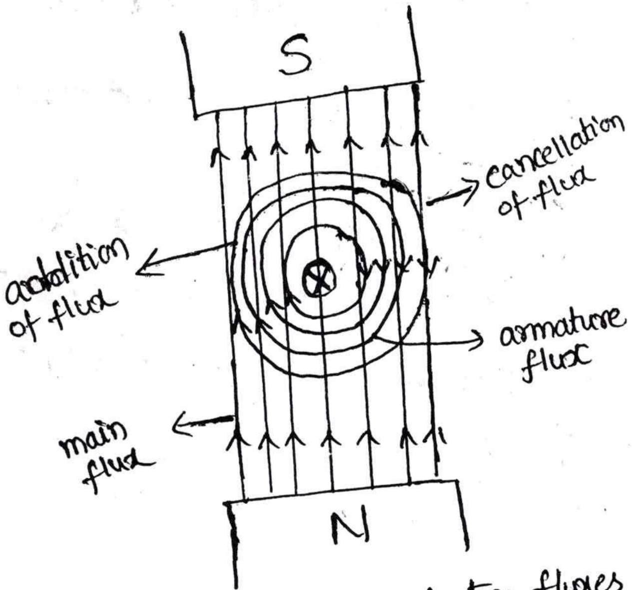
→ From this, it is clear that on one side of conductor both the fluxes are in the same direction. In this case, on left side of conductor there is gathering of flux lines as the two fluxes help (or add) each other.

→ on the right side of conductor, the two fluxes are in opposite direction and hence try to cancel each other.

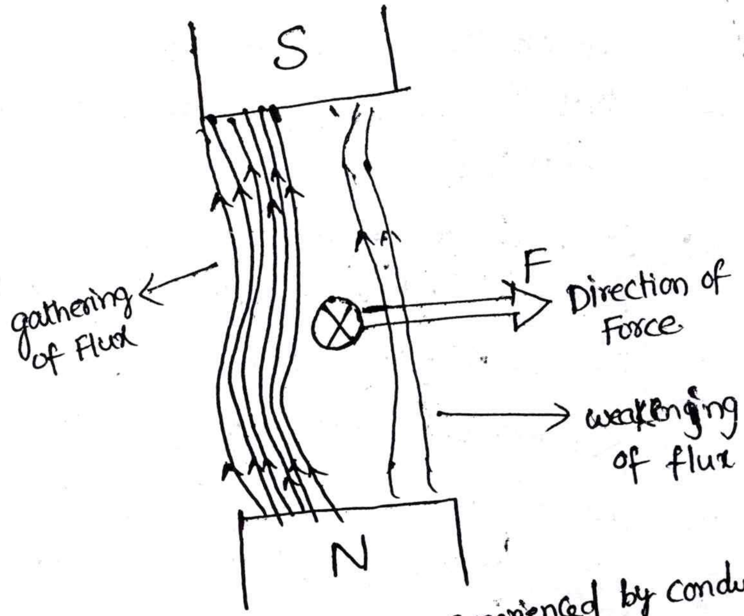
→ Due to this, density of flux lines on rightside gets weakend.

→ So on the left, there exist high flux density area while on the right of the conductor there exists low flux density area as shown in Fig(4).

→ This flux distribution around the conductor acts like a stretched rubber band under tension. There exists a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e, from left to right for the case considered as shown in Fig(4).



Fig(3): Interaction of two fluxes



Fig(4):- Force experienced by conductor in motor

The magnitude of force experienced by conductor is given by $F = BIl$ newtons

The direction of force i.e, the direction of rotation of motor can be determined by Flemming's Left hand rule.

→ Direction of rotation of motor :-

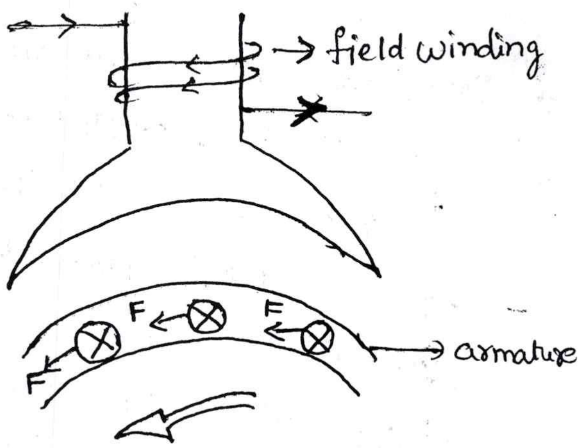


Fig : Torque Exerted on armature

The magnitude of force experienced by the conductor in motor is given by

$F = BIl$ newtons

where B = Flux density

I = magnitude of current passing through conductor

l = length of the conductor.

The direction of force i.e, the rotation direction of motor is determined by Flemmings Left hand rule.] 2

→ Significance of Back EMF :-

→ when the armature rotates, the conductors rotate due to motor action and cuts flux and therefore inducing Emf according to Faradays law of Electromagnetic Induction.

→ This induced Emf in the armature always acts in the opposite direction of the supply voltage. This is according to the Lenz's law which states that the direction of induced emf is always so as to oppose the cause producing it.

→ In a dc motor, Electric input i.e, supply voltage is the cause and hence this induced emf opposes the supply voltage.

→ This Emf tries to setup a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor.

→ so as this emf always opposes the supply voltage it is called Back EMF (or) counter EMF and denoted as E_b.

→ The Back EMF E_b is given as $E_b = \dfrac{P\phi NZ}{60A}$ volts

where ϕ = flux in weber

P = No. of poles

N = Speed in rpm

Z = No. of conductor.

A = No. of parallel paths.

4

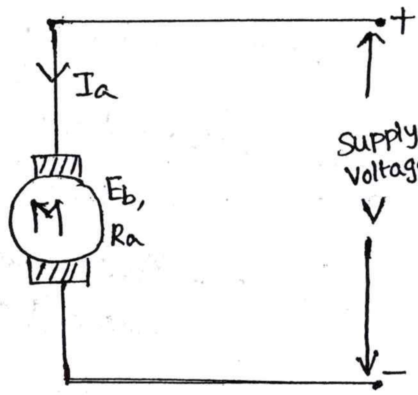
→ Voltage Equation of a dc Motor :-

→ In case of generator, generator emf has to supply armature resistance drop and remaining part is avaiable across the load as a Terminal voltage.

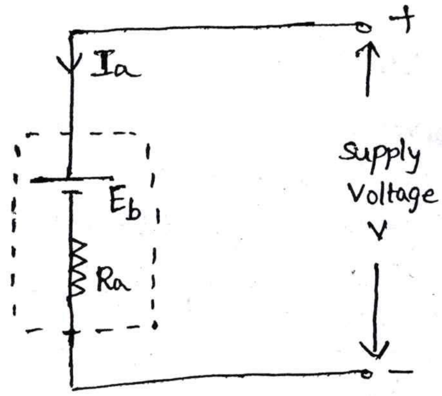
→ But in case of dc motor, supply voltage V has to overcome backemf E_b which is opposing 'V' and also various drops as armature resistance drop $I_a R_a$, brush drop etc.

→ Fig(1) shows Back emf in dc motor

Fig(2) shows Equivalent circuit of motor.



Fig(1): Back Emf in a dc motor



Fig(2): Equivalent circuit of motor

Hence the voltage equation of dc motor is given by

$$V = E_b + I_a R_a + V_{brush\ drop}$$

Neglecting the brush drop, the generalized voltage eqn is

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

where V = applied (or) supply Voltage

E_b = Back EMF

I_a = armature current

R_a = armature Resistance.

power Equation of a DC motor :-

The voltage Equation of a dc motor is given by,

$$V = E_b + I_a R_a.$$

multiplying both sides of above Eqn by I_a we get

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

This Equation is called power Equation of a dc motor.

This Equation is called power Equation measured in watts.

$V \cdot I_a$ = Net Electrical power input to the armature measured in watts.

$I_a^2 R_a$ = power loss due to resistance of the armature called Armature Copper loss.

$$V I_a - I_a^2 R_a = E_b I_a.$$

so difference between $V I_a$ and $I_a^2 R_a$ i-e, input − losses gives the output of the armature.

so $E_b I_a$ is called Electrical Equivalent of gross mechanical power developed by the armature. This is denoted as P_m.

∴ power input to the armature − Armature Copper loss = Gross Mechanical Power developed in the armature.

Condition For Maximum Power :

For a motor from power equation it is Known that

Gross Mechanical power developed = $E_b I_a$.

$$P_m = \text{Gross Mechanical power}$$

$$P_m = V I_a - I_a^2 R_a.$$

For maximum P_m,

$$\frac{d P_m}{d I_a} = 0$$

$$\frac{d P_m}{d I_a} \Rightarrow \frac{d}{d I_a}\left[V I_a - I_a^2 R_a\right] = 0$$

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

$$V = 2 I_a R_a.$$

$$I_a = \frac{V}{2 R_a} \quad \text{i-e,} \quad I_a R_a = \frac{V}{2}.$$

Substituting in voltage Equation, $V = E_b + I_a R_a$

$$V = E_b + \underbrace{I_a R_a}$$

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

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

$$\Rightarrow \boxed{E_b = \frac{V}{2}} \rightarrow \text{condition for Maximum Power.}$$

Problems :-

1) A 220V dc motor has an armature resistance of 0.75Ω. It is drawing an armature current of 30 A, driving a certain load. Calculate the induced Emf in the motor under this condition?

Sol: Given Supply voltage $V = 220$ V, armature resistance $R_a = 0.75\Omega$, armature current $I_a = 30$ A., Induced Emf $E_b = ?$

For a motor, We have, $V = E_b + I_a R_a$

$E_b = V - I_a R_a$

$E_b = 220 - 30(0.75) = 197.5$ V

The induced emf is called back emf in a motor.

2) A 4 pole dc motor has lap connected armature winding. The flux per pole is 30 mwb. The no. of armature conductors is 250. when connected to 230V dc supply it draws an armature current of 40A. calculate the back emf and the speed at which motor is running. Assume armature resistance is 0.6Ω.

Sol: Given ~~Poles~~ $P = 4$; No. of parallel paths $= A = P = 4$ as lap connected,

No. of conductors $Z = 250$

supply voltage $V = 230$V, armature current $I_a = 40$A,

flux $\phi = 30$ mwb $= 30 \times 10^{-3}$ wb ;

armature resistance $R_a = 0.6\Omega$.

We have, $V = E_b + I_a R_a$

$230 = E_b + 40(0.6) \Rightarrow E_b = 206$ V.

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

~~206ea~~ $N = \frac{206 \times 60 \times 4}{4 \times 30 \times 10^{-3} \times 250} = 1648$ rpm.

Speed $N = 1648$ rpm.

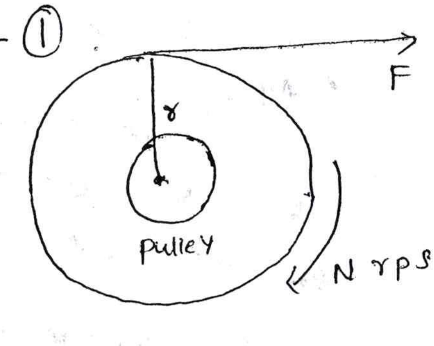
Torque :-

By the Term torque is meant the Turning or Twisting moment of force about an axis. It is measured by the product of force and the radius at which this force acts.

consider a pulley of radius r metre acted upon by a circumferential force of F Newton which causes it to rotate at N rpm. (fig (1))

Then Torque $T = F \times r$ Newton-metre (N-m) — (1)

where $F = BIL$. Newton.



fig(1).

work done by this force in one revolution

= Force x distance (circumference)

= $F \times 2\pi r$ Joule — (2)

power developed = $F \times 2\pi r \times N$ Joule / second (or) Watt

= $(F \times r) \times 2\pi N$ W. — (3)

Now, $2\pi N$ = angular velocity ω in radian/second and

$\therefore$ power developed = $T \times \omega$ watt (or) $P = T\omega$ watt. — (4)

Moreover, if N is in rpm, then

$\omega = 2\pi N / 60$ rad/sec.

$P = \frac{2\pi N}{60} \times T$ (or) $P = \frac{2\pi}{60} . NT = \frac{NT}{9.55}$ — (5)

Armature Torque of a motor:-

let T_a be the torque developed by the armature of a motor running at 'N' rps.. If T_a is in N-m. then — (6)

power developed = $T_a \times 2\pi N$, watt

we also know that Electrical power converted in to mechanical power in the armature = $E_b I_a$ watt. — (7)

from Eq (6) & (7), we get $T_a \times 2\pi N = E_b I_a$. — (8)

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

we have $T_a \times 2\pi N = \phi Z N \times \left(\frac{P}{A}\right) \times I_a$

$$T_a = \frac{1}{2\pi} \cdot \phi Z I_a \frac{P}{A} \quad N-m$$

$$T_a = 0.159 \times \phi Z I_a \times \frac{P}{A} \quad N-m.$$

Note: from the above eqn, for the Torque $T_a \propto \phi I_a$.

a) In case of series motor, ϕ is directly proportional to I_a. bcoz field windings carry full armature current.

$\therefore \quad T_a \propto I_a^2. \qquad (\because \phi \propto I_a)$

b) for shunt motors, ϕ is practically constant hence $T_a \propto I_a$.

As seen from eqn (8),

$$T_a = \frac{E_b I_a}{2\pi N} \quad N-m$$ ~~in~~ where 'N' in rps.

If N is in rpm then

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

$$T_a = 9.55 \times \frac{E_b I_a}{N} \quad N-m$$

Shaft Torque:

The whole of the armature torque, as calculated above is not available for doing useful work bcoz a certain percentage of it is reqd for supplying iron & friction losses in the motor.

The torque which is available for doing useful work is known as shaft Torque T_{sh}. It is so called bcoz it is available at the shaft.

The motor o/p is given by output $= T_{sh} \times 2\pi N$ ~~watt~~; where T_{sh} = is in N-m, N is in rps

$$T_{sh} = \frac{\text{output in watts}}{2\pi N} \quad N-m \text{ in rps}$$

$$= \frac{\text{output in watts}}{2\pi N / 60} \quad N-m \text{ in rpm.}$$

$$T_{sh} = \frac{60}{2\pi} \times \frac{\text{output}}{N} = 9.55 \frac{\text{output}}{N} \quad N-m$$

The difference $T_a - T_{sh}$ is known as Lost torque, and is due to Iron and friction losses of the motor.

Note:- The value of back Emf can be found from

i) The Eqn $E_b = V - I_a R_a$

ii) The formula $E_b = \phi Z N \times \frac{P}{A}$ volt

→ A dc motor takes an armature current of 110A at 480V. The armature circuit resistance is 0.2Ω. The machine ~~flows~~ has 6 poles and the armature is lap connected with 864 conductors. The flux per pole is 0.05 wb. Calculate i) the speed & ii) The gross torque developed by the armature.

Sol:

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

$\phi = 0.05\ wb, \quad Z = 864.$

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

$$458 = \frac{0.05 \times 864 \times N}{60} \times \frac{6}{6} \Rightarrow N = 636\ rpm.$$

$$T_a = 0.159 \times 0.05 \times 864 \times 110 \times \frac{6}{6} = 756.3\ N\text{-}m.$$

→ A 250V, 4 pole wave wound dc series motor has 782 conductors in an armature. It has armature and series field resistance of 0.75Ω. The motor takes a current of 40A. Estimate its speed and gross torque developed if it has a flux per pole of 25 mwb.

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

$$E_b = V - I_a R_a = 250 - 40 \times 0.75 = 220V.$$

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

$$\Rightarrow 220 = 25 \times 10^{-3} \times \frac{782 \times N}{60} \times \frac{4}{2} \Rightarrow N = 337\ rpm$$

$$T_a = 0.159 \times \phi Z I_a \times \frac{P}{A}$$

$$= 0.159 \times 25 \times 10^{-3} \times 782 \times 40 \times \frac{4}{2} = 249\ N\text{-}m$$

→ A dc shunt machine develops an ac emf of 250V at 1500 rpm. Find its torque and mechanical power developed for an armature current of 50 A.

Sol: Mechanical power developed in the arm. $= E_b I_a = 250 \times 50$

$= 12\,500 \text{ W}$

Torque $T_a = 9.55 \dfrac{E_b I_a}{N} = \dfrac{9.55 \times 250 \times 50}{1500} = 79.6 \text{ N-m}.$

→ Determine developed torque and shaft torque of 220V, 4 pole series motor with 800 conductors wave connected supplying a load of 8.2 Kw. by taking 45A from the mains. The flux per pole is 25mwb. and its armature ckt resistance is 0.6Ω.

Sol: Developed Torque (or) gross torque is the same thing as armature torque

$T_a = 0.159\, \phi Z I_a \times \dfrac{P}{A} = 0.159 \times 25 \times 10^{-3} \times 800 \times 45 \times \dfrac{4}{2}$

$= 286.2 \text{ N-m}$

$E_b = V - I_a R_a = 220 - 45 \times 0.6 = 193 \text{ V}$

$E_b = \phi Z N \dfrac{P}{A} \Rightarrow 193 = 25 \times 10^{-3} \times 800 \times N \times \dfrac{4}{2}.$

$N = 4.825 \text{ rps}.$

$\therefore T_{sh} = \dfrac{\text{O/P in watts}}{2\pi N} = \dfrac{8.2 \text{ kW}}{2\pi \times 4.825} = \dfrac{8200}{2\pi \times 4.825}$

$T_{sh} = 270.5 \text{ N-m}$

→ A 220 V dc shunt motor runs at 500 rpm. when the armature current is 50A. Calculate the speed if the torque is doubled. Given that $R_a = 0.2\,\Omega$.

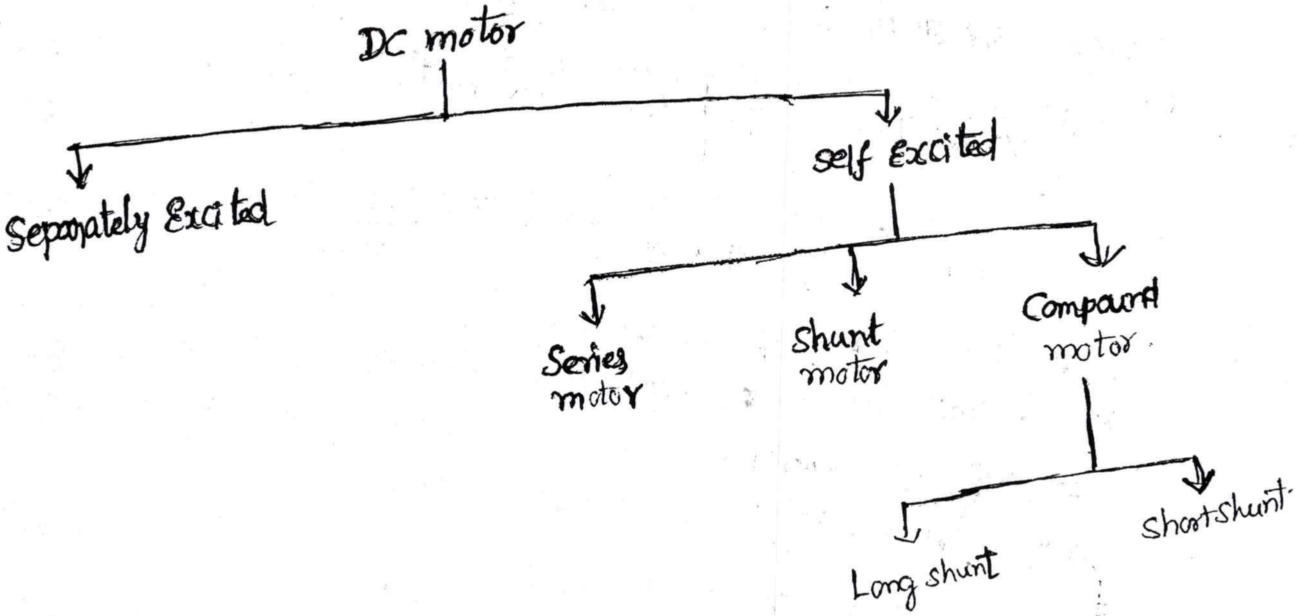
Sol. we know ~~that the~~ $T_a \propto \phi I_a$, but for shunt motor ϕ is constant

so $T \propto I_a$.

$T_{a1} \propto I_{a1}$ and $T_{a2} \propto I_{a2} \Rightarrow \dfrac{T_{a2}}{T_{a1}} = \dfrac{I_{a2}}{I_{a1}}.$

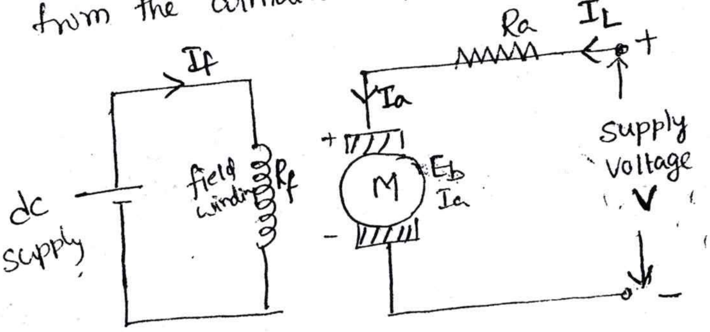
$\therefore \dfrac{2 \cancel{T_a}}{\cancel{T_a}} = \dfrac{I_{a2}}{I_{a1}} \Rightarrow 2 = \dfrac{I_{a2}}{I_{a1}} \Rightarrow 2 = \dfrac{I_{a2}}{50} \Rightarrow I_{a2} = 100 \text{ A}.$

Types of DC motors



1) Separately Excited motor :-

The field winding is supplied power from a Separate dc source and not from the armature of that motor



Here $I_L = I_a$

$$V = E_b + I_a R_a$$

2) Self Excited motors :-

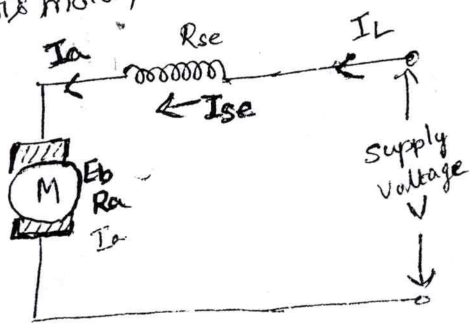
The field is supplied power from the armature.

This is classified in to 3 types of motor.

i) Series motor ii) shunt motor iii) compound motor.

i) Series motor :-

In this motor, field winding is in series with the armature



Let R_{se} be the series field Resistance

I_L be the total current drawn from the supply.

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

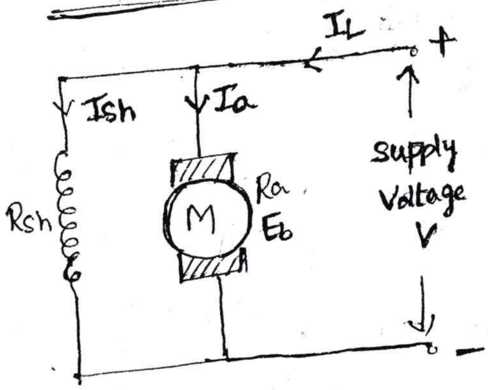
$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

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

In series motor ~~field winding~~, entire armature current is passing through the series field winding. So flux produced is proportional to the armature current.

$\boxed{\phi \propto I_{se} \propto I_a}$ for series motor

ii) <u>Shunt motor</u>:- In this type, field winding is connected in parallel with the armature.



let R_{sh} be the resistance of shunt field winding
R_a be the resistance of armature winding
The total current drawn from the supply is denoted as I_L.

$I_L = I_a + I_{sh}$. $\Rightarrow$ $I_a = I_L - I_{sh}$

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

$V = E_b + I_a R_a + V_{brush}$

V_{brush} is generally neglected

$V = E_b + I_a R_a$.

Here, flux produced by the field winding is proportional to the current passing through it. i-e, I_{sh}

$\phi \propto I_{sh}$.

iii) <u>Compound motor</u>:-

In this motor, the field winding has both series and shunt field windings.

Again this is classified in to Two types of motors.

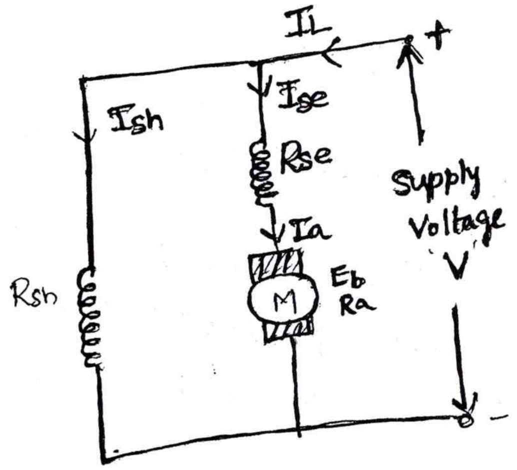
a) ~~Differ~~ Cumulative Compound b) Differential Compound

a) <u>Cumulative Compound</u>: If series field flux ~~oppos~~ is in the same direction as shunt field flux, i-e, helps each other then that it is cumulative compound. $\boxed{\phi_T = \phi_{se} + \phi_{sh}}$

b) ~~Cumulat~~Differential Compound: If series field flux opposes the shunt field flux then that it is differential compound. $\boxed{\phi_T = \phi_{se} \sim \phi_{sh}}$

~~Basd~~ Again cumulative and differential compounds are classified as i) short shunt compound & ii) Long shunt compound.

i) Long shunt Compound :- In this type, shunt field winding is connected across the combination of armature and the series field winding as shown in fig.



here Rsh // (Ra+Rse)

Let Rse, the resistance of Series field winding
Rsh be the resistance of Shunt field winding
Total current drawn from supply is I_L

So $I_L = I_{se} + I_{sh}$.

but $I_{se} = I_a$.

$\Rightarrow I_L = I_a + I_{sh}$.

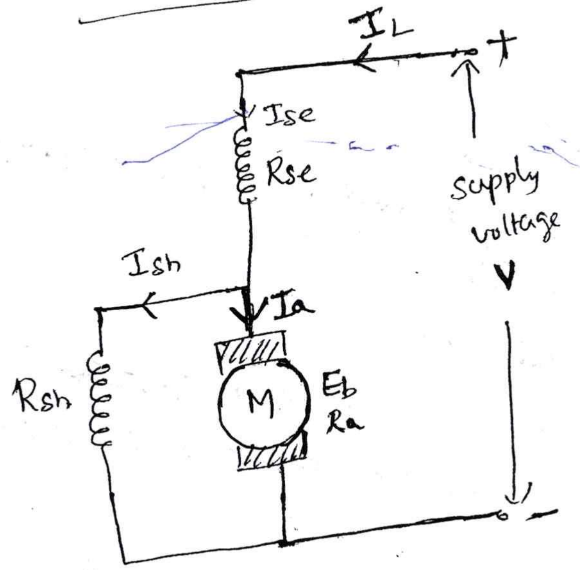
$I_{sh} = \frac{V}{R_{sh}}$.

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

but as $I_{se} = I_a$

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

ii) Short shunt Compound :- In this type, shunt field is connected only in parallel with armature and the series field is connected in series with this combination shown in fig.



here Rsh // Ra

Here $I_{se} = I_L$.

$I_L = I_{sh} + I_a$.

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

but $I_{se} = I_L$

$\Rightarrow V = E_b + I_L R_{se} + I_a R_a$.

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

$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}} = \frac{E_b + I_a R_a}{R_{sh}}$

Applications of DC motors :--

Instead of Just stating the applications, the behaviour of the various characteristics like speed, starting torque etc which makes the motor more suitable for the applications is also stated. in the table.

Type of motor	characteristics	Applications.
Shunt	Speed is fairly constant and medium starting torque.	1) Blowers and fans 2) Centrifugal and reciprocating pumps 3) Lathe machines 4) machine tools 5) milling machines 6) Drilling machines
series	High starting torque. No load condition is dangerous. variable speed.	1) cranes 2) Hoists, Elevators 3) Trolleys 4) Conveyors 5) Electric locomotives.
Cumulative compound	High starting torque No load condition is allowed.	1) Rolling mills 2) punches 3) shears 4) Heavy planers 5) Elevators.
Differential Compound	Speed increases as load increases	Not suitable for any practical application

Comparison of between generators and motor :-

DC Generator :-

→ Generator is one which converts mechanical Energy in to Electrical energy

→ It works on the principle of Faradays laws of Electromagnetic Induction. That whenever a conductor cuts a magnetic field, an Emf is induced.

→ The magnitude of Emf induced is given by

$$E_g = N \frac{d\phi}{dt}$$

→ The direction of induced Emf is given by Flemming Right hand rule.

→ The machine operating as generator is driven by some external driving force and DC output is obtained.

DC Motor :-

→ Motor is one which Converts Electrical Energy in to Mechanical Energy.

→ It works on the principle of Faradays laws of Electromagnetic induction that If a ~~conductor~~ Current carrying conductor is placed in magnetic field, it experiences a force.

→ The magnitude of force Experienced on conductor is given by

$$F = BIL \text{ newtons}$$

→ The direction of force is given by Flemming left hand rule.

→ The machine operating as motor is supplied by Electric Current and mechanical rotation is obtained.

→ Here the back Emf opposes the supply voltage.

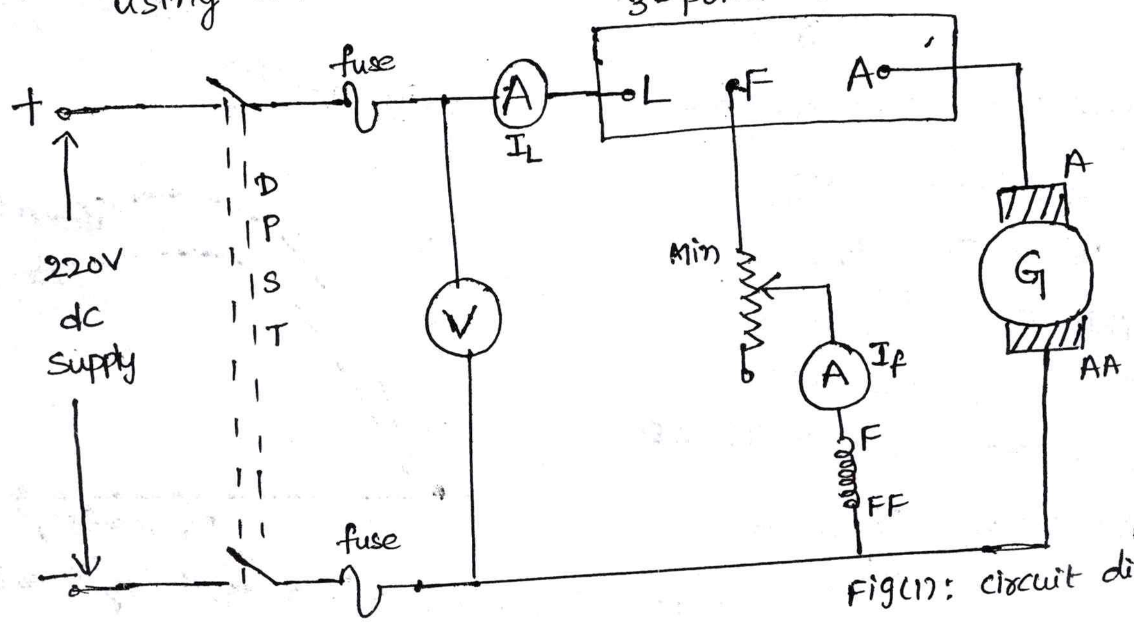
Swinburne's Test (or) No load Test :-

→ This is indirect method of testing of dc motors, in which flux remains practically constant.

→ with out actually loading the motor, the losses and efficiency at different loads can be found out.

→ The motor is run on No load at its rated voltage. Adjust the speed of motor to the rated speed with the help of shunt field rheostat as shown in fig.

→ The No load current I_L and field current I_f are noted down by using ammeters.



Fig(1): circuit diagram

Tabular column :

V	I_{Lo}	I_f

No load Input current $= I_{Lo}$

Shunt field current $= I_f$.

supply voltage $= V$.

No-load motor I/p power $= V I_{Lo}$ watt.

$I_{ao} = I_{Lo} - I_{sh}$

variable losses $= I_{ao}^2 R_a$

Constant losses W_c = Iron loss + Mechanical loss + shunt field cu. loss

(∵ I/p power = O/p power + Total losses

I/p power = O/p power + Constant losses + variable losses

I/p power = constant losses + $I_{ao}^2 R_a$.

constant loss = I/p power $- I_{ao}^2 R_a$)

$\therefore$ Constant losses $\Rightarrow W_c = V I_{L0} - I_{a0}^2 R_a$.

(1) when running as motor :-

motor Input power $= V I_L$.

armature current $\Rightarrow I_a = I_L - I_{sh}$

constant losses $= W_c$

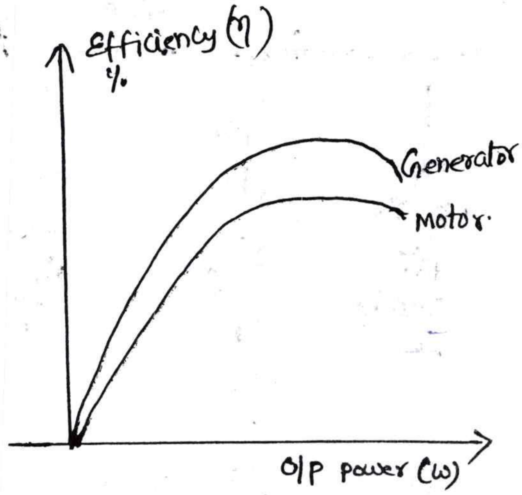
Total losses = constant loss + variable loss

$= W_c + I_a^2 R_a$

motor output power ~~efficiency η~~ $\Rightarrow$ I/P power − Total losses

Efficiency $\eta = \frac{\text{output}}{\text{Input}} \times 100$.

Fig (2): efficiency curves



(2) when running as Generator :-

Generator O/P power $= V I_L$.

$I_a = I_L + I_{sh}$

Armature Copper loss $= I_a^2 R_a$.

Total losses $\Rightarrow W_c + I_a^2 R_a$

I/P power = O/P power + Total losses

Generator Efficiency $\eta = \frac{O/P}{I/P} \times 100$

Advantages :- 1) since constant losses are known the efficiency can be estimated at any load.

2) This method is simple and less expensive.

3) The motor is not required to be loaded.

Disadvantages :- 1) As it is a no-load test, it cannot be performed on a series motor.

2) This method does not give any idea of the temperature rise under full load.

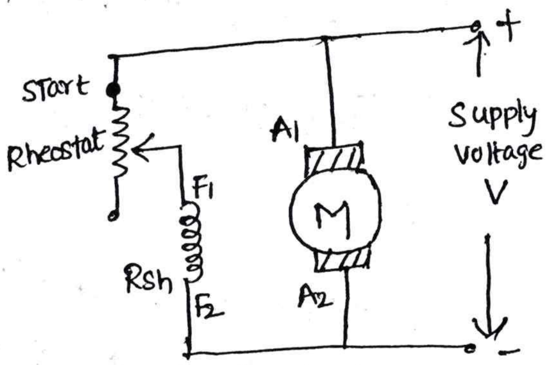
3) As it is noload test, it is difficult to find whether there will be satisfactory commutation at full load.

4) In this method, efficiency is predetermined only by approximate since it does not take into account the variations in stray losses.

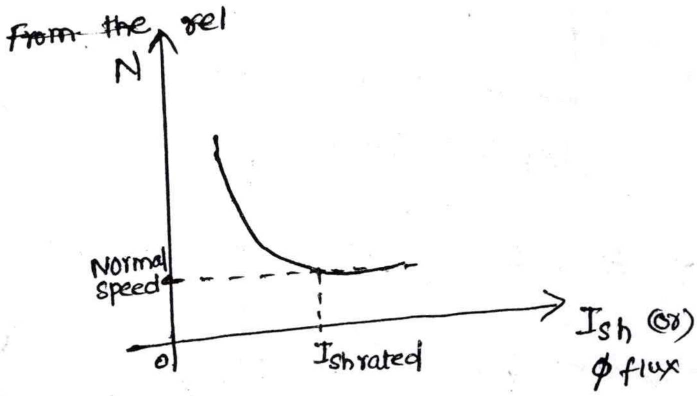
Speed control of DC shunt motor :-

1) Flux control method
2) Armature voltage control method.

1) Flux control method (or) Field control method :-



Fig(1): Flux control method



Fig(2): N versus Ish(ϕ).

→ From the relation $N \propto \frac{E_b}{\phi}$, the speed is inversly proportional to flux. The flux is dependent on current through shunt field winding.

→ The Flux can be controlled by adding Rheostat in series with shunt field winding.

→ At beginning rheostat kept at minimum indicated as START in Fig(1).

→ The supply voltage & current through field winding are at rated values. Hence the speed is also rated speed called normal speed.

→ Then rheostant R is increased, due to which Ish decreases, decreasing flux ϕ produced.

→ As $N \propto \frac{1}{\phi}$, the speed of motor increases beyond its rated speed.

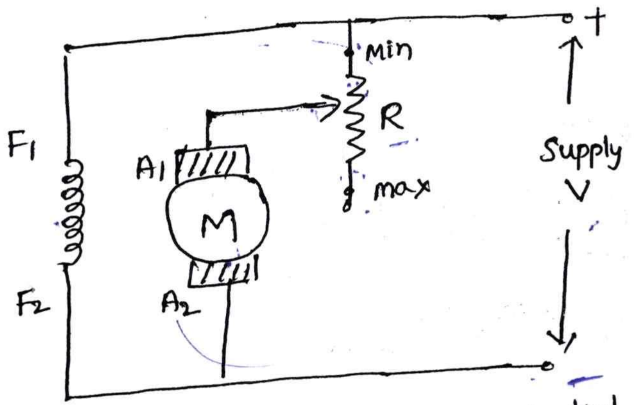
→ Thus by this method, speed control above rated speed is possible.

→ Fig(2) shows N−Ish(ϕ) curve and its nature is rectangular hyperbola.

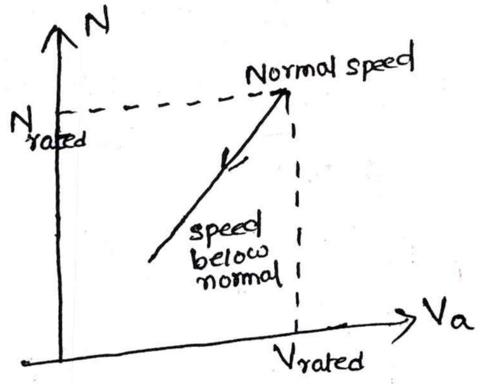
↳ Advantages:
1) It provides smooth & easy control
2) speed control above rated speed is possible.
3) It is economical & efficient.

↳ Disadvantages:
1) speed control below rated speed is not possible.
2) At high speed, commutation makes motor operation unstable.

2) → Armature Voltage control method (or) Rheostatic control :-



Fig(3): Armature voltage control method



Fig(4): N versus V_a (armature voltage)

→ From the relation, $N \propto \frac{E_b}{\phi} \Rightarrow N \propto \frac{V - I_a R_a}{\phi}$.

→ The speed is directly proportional to voltage applied across armature.

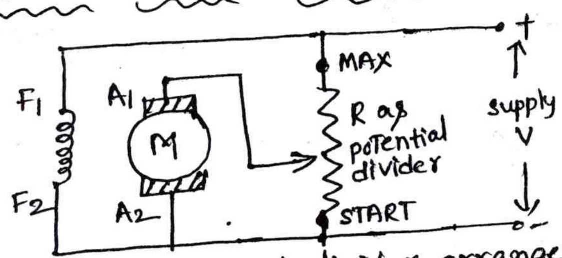
→ As supply voltage is constant, voltage across armature can be controlled by adding a variable Rheostat, in series with armature, as shown in fig(3).

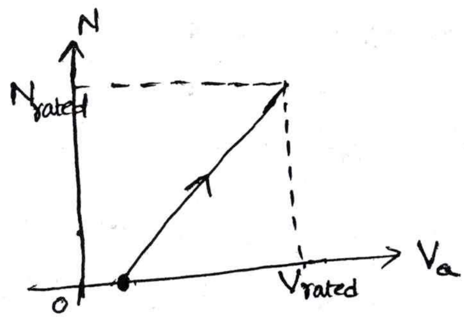
→ Supply voltage V & current I_{sh} are in rated values. Initially rheostat position is minimum and speed is also rated.

→ As rheostat increases, ~~volt~~ I_a remains same & voltage drop $I_a R$ increases. Hence speed decreases, decreasing the speed below normal value. as armature voltage $(V_a - I_a R_a)$ decreases.

→ But speed upto zero is not possible by this method. So it is modified as potential divider method.

(2b) Potential divider control :-





Fig(5): Potential divider arrangement

→ Here Rheostat used as potential divider. when Rheostat in 'start', zero speed is obtained

→ By this arrangement speeds below rated speed are controlled and speeds upto zero is possible. As Rheostat is moving towards from START to Maximum position. Speed increase from zero speed to rated speed.

Advantages:- 1) speed below rated speed is possible.

Disadvantages:- 1) speed above rated speed is not possible
2) Due to large power loss, the method is Expensive, less efficient.

Efficiency :- Efficiency (η) is defined as ratio of output power to Input power.

$$\text{Efficiency } \eta = \frac{\text{O/P power}}{\text{I/P power}} \times 100$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100.$$

I/p power = output power + Total losses

I/P power. = output power + P_{Iron} + P_{cu}

Losses in a DC Machines

The various losses in a dc machine, whether it is a generator or motor, are classified in to three groups. as:

1) Iron loss (or) core losses (or) magnetic loss
2) copper losses (or) I^2R loss (or) ohmic loss
3) Mechanical losses.

1) **Copper losses :-** The copper losses are those losses, takes place due to current flowing in a winding.

There are basically Two windings in a dc machine namely, armature winding & field winding.

The various copper losses are given as.

(i) armature copper loss = $I_a^2 R_a$.

where I_a = armature current, R_a = armature resistance.

(ii) shunt field copper loss = $I_{sh}^2 R_{sh}$.

where I_{sh} = shunt field current

R_{sh} = shunt field resistance.

Series field copper loss = $I_{se}^2 R_{se}$

where R_{se} = series field winding resistance

I_{se} = series field current.

2) Iron losses or Core losses :-

These losses are also called magnetic losses. These losses include i) hysterisis loss and ii) Eddy current loss

→ The hysterisis loss is proportional to the frequency and the maximum flux density B_m in the air gap and is given by,

Hysterisis loss = $\eta B_m^{1.6} f V$ watts.

where η = steinmetz hysterisis coefficient

V = Volume of core in m^3.

f = frequency of magnetic reversals.

This loss is basically due to reversal of magnetisation of the armature core.

→ The eddy current loss exists due to eddy currents. when armature core rotates, it cuts magnetic flux and emf gets induced in the core. This induced emf sets up eddy current which cause the power loss.

This loss is given by,

Eddy current loss = $K B_m^2 f^2 t^2 V$. watts.

where K = constant

t = Thickness of each lamination.

V = Volume of core

f = frequency of magnetic reversals.

→ The hysterisis loss is minimized by selecting the core material having low hysterisis coefficient. while the eddy current loss is minimized by selecting the laminated construction for the core.

→ These losses are almost constant for the dc machines.

3) Mechanical losses :- These losses consists of friction and windage losses. some power is required to overcome mechanical friction and wind resistance at the fault. This loss is nothing but the friction and windage loss. These mechanical losses are also constant for a dc machine.

→ The magnetic and mechanical losses together are called stray losses.

→ For the shunt and compound dc machines where field current is constant field copper losses are also constant. Thus stray losses along with constant field copper losses are called constant losses. while the armature current is dependent on the load and thus armature copper losses are called variable losses.

Thus for a dc machine,

Total losses = constant losses + variable losses

The power flow and Energy transformation diagrams at various stages, which takes place in a dc machine are represented diagramatically shown in fig (a) and fig (b).

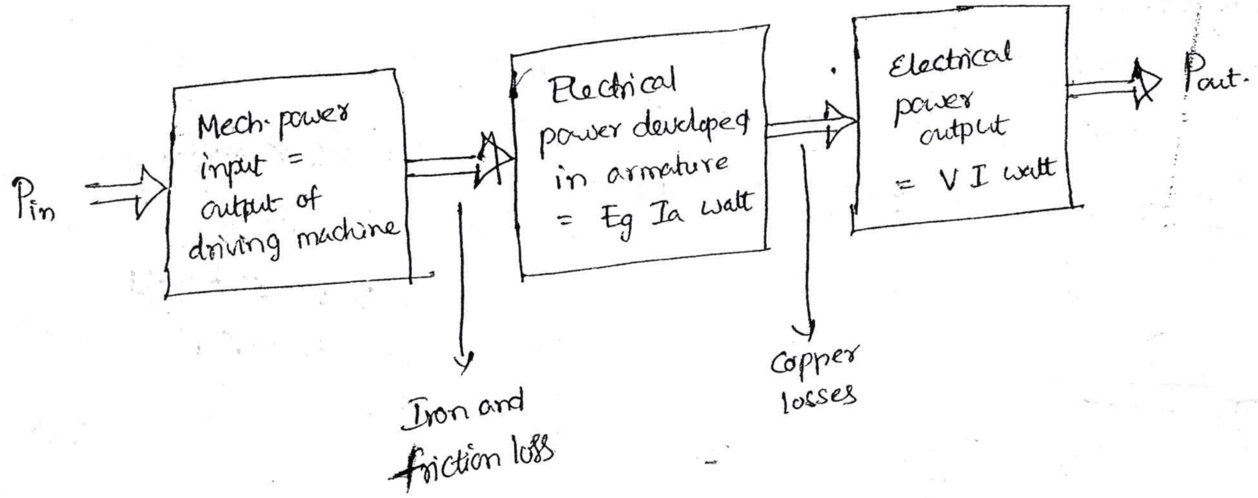


fig (a): Generator.

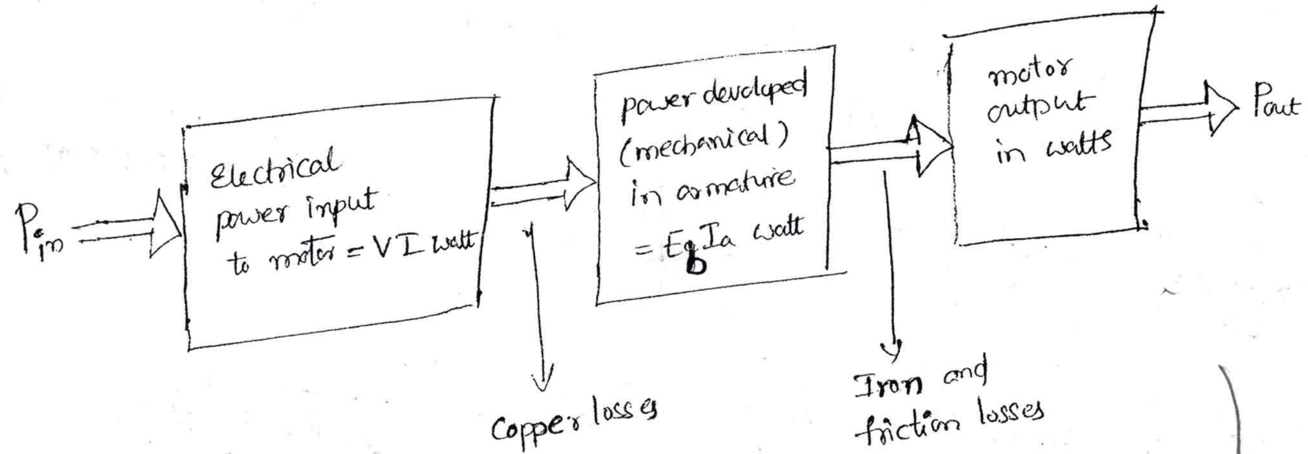


fig (b) = Motor.

A 6 pole dc motor has a wave connected with 87 slots, each slot containing 6 conductors. The flux per pole is 20 mwb and the armature has a resistance of 0.13 Ω when the motor is connected to 240 V supply and the armature draws a current of 80 A driving a load of 15 kW. Calculate i) Speed ii) Armature torque iii) Shaft torque.

Given Pole $P = 6$.

No. of parallel path $A = 2$; for wave connected.

No. of conductors $Z =$ slots × (conductors / slot)

$Z = 87 \times 6 = 522$

flux $\phi = 20$ mwb

armature resistance $R_a = 0.13\ \Omega$

supply (or) applied voltage $V = 240$ V

armature current $I_a = 80$ A.

output power $P_{out} = 15$ kW.

We have the voltage eqn for motor is, $V = E_b + I_a R_a$

$\Rightarrow E_b = V - I_a R_a$

$= 240 - 80 \times 0.13$

$= 229.6$ V

i) Speed:

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

$$N = \frac{E_b \times 60 \times A}{P \phi Z} = \frac{229.6 \times 60 \times 2}{6 \times 20 \times 10^{-3} \times 522} = 439.846 \text{ rpm}$$

Speed, $N = 439.846$ rpm.

ii) armature torque

$$T_a = \frac{E_b I_a}{\left(\frac{2\pi N}{60}\right)} = \frac{229.6 \times 80}{\left(\frac{2\pi \times 439.846}{60}\right)} = 398.7786 \text{ N-m}$$

iii) shaft torque

$$T_{sh} = \frac{P_{out}}{\omega} = \frac{P_{out}}{\left(\frac{2\pi N}{60}\right)} = \frac{15 \times 10^3}{\left(\frac{2\pi \times 439.846}{60}\right)}$$

$= 325.657$ N-m

29.

A 250V, 4 pole shunt motor has two circuit armature winding with 500 conductors. The armature resistance is 0.25Ω, field resistance is 125Ω. and the flux per pole is 0.02 wb. Neglect armature reaction. Find the speed and torque developed if the motor ~~runs~~ draws 14 A from the mains.

Sol: Given $V = 250V$, Pole $P = 4$.

No. of parallel path $A = P = 2$ for two circuit armature (wave)

No. of conductors $Z = 500$

Armature resistance $R_a = 0.25\Omega$.

Shunt field resistance $R_{sh} = 125\Omega$.

flux $\phi = 0.02$ wb.

$I_L = 14$ A.

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2A$$

$$I_a = I_L - I_{sh} = 14 - 2 = 12A.$$

Armature torque $T_a = \frac{1}{2\pi} \phi I_a \frac{PZ}{A} = \frac{1}{2\pi} \times 0.02 \times 12 \times \frac{4 \times 500}{2}$

$$T_a = 38.1972 \text{ N-m}$$

$$E_b = V - I_a R_a = 250 - 12 \times 0.25 = 247 V.$$

$$E_b = \frac{P \phi N Z}{60 A} \Rightarrow N = \frac{E_b \times 60 \times A}{P \times \phi \times Z} = \frac{247 \times 60 \times 2}{4 \times 0.02 \times 500}$$

Speed, $N = 741$ rpm

→ The armature of a 6-pole lap wound, dc shunt motor takes a current of 350 A, at a speed of 400 rpm. The flux/pole is 75 mwb. and the no. of armature conductors is 1200. calculate the Brake Horse Power if 3% of the torque is lost in friction windage and iron losses.

Sol: Given Pole $P = 6$

No. of parallel path $A = P = 6$ for lap connected.

armature current $I_a = 350$ A.

speed $N = 400$ rpm.

flux $\phi = 75$ mwb $= 75 \times 10^{-3}$ wb.

No. of conductors $Z = 1200$.

Problems

→ A 250V, dc shunt machine has line current of 80A. It has armature and field resistance of 0.1Ω and 125Ω respectively. Calculate the power developed in armature when running as i) Generator and ii) motor.

Sol:- ~~V=250~~ Given ~~supply voltage~~ $V = 250V$.

Line current $I_L = 80A$

armature Resistance $R_a = 0.1\Omega$

Field resistance (or) shunt resistance $R_{sh} = 125\Omega$.

~~i) For a generator~~ For a shunt machine, $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2A$

$I_{sh} = 2A$.

~~$I_a = I_L + I_{sh}$~~
~~$= 80 +$~~

i) For a generator :-

$I_a = I_L + I_{sh}$.

$= 80 + 2$

$= 82 A$

$E_g = V + I_a R_a$.

$= 250 + 82(0.1)$

$= 258.2 V$

P_a = power developed in armature

$P_a = E_g I_a$

$= 258.2 \times (82)$

$P_a = 21.1724 KW$

ii) For a motor :-

$I_L = I_a + I_{sh}$.

$I_a = I_L - I_{sh}$

$= 80 - 2$

$= 78 A$

$E_b = V - I_a R_a$

$= 250 - 78(0.1)$

$= 242.2 V$

P_a = power developed in armature

$P_a = E_b I_a$

$= 242.2 \times 78$

$P_a = 18.8916 KW$.

→ A 230V dc shunt motor takes 32 A at full load. Find the back emf on full load if $R_a = 0.2\,\Omega$ and $R_{sh} = 115\,\Omega$ respectively.

Sol: Given $V = 230\,V$.

$I_L = 32\,A$

$R_a = 0.2\,\Omega$.

$R_{sh} = 115\,\Omega$

For a shunt motor, $I_{sh} = \frac{V}{R_{sh}} = \frac{230}{115} = 2\,A$.

and $I_L = I_a + I_{sh}$

$\Rightarrow I_a = I_L - I_{sh} = 32 - 2 = 30\,A$

$I_a = 30\,A$.

$\Rightarrow E_b = V - I_a R_a = 230 - 30 \times 0.2 = 224\,V$

$E_b = 224\,V$ //

→ A 220V dc shunt motor draws a no load armature current of 2.5 A when running at 1400 rpm. Determine its speed when taking an armature current of 60 A and armature reactions weakens the flux by 3%.

Assume $R_a = 0.1\,\Omega$.

Sol: Given $V = 220\,V$, $I_{ao} = 2.5\,A$, $N_o = 1400$ rpm,

$I_{a1} = 60\,A$.

$\phi_1 = \phi_o - 0.03\,\phi_o = 0.97\,\phi_o$.

$E_{bo} = V - I_{ao} R_a = 220 - 2.5 \times 0.1 = 219.75\,V$.

$E_{b1} = V - I_{a1} R_a = 220 - 60 \times 0.1 = 214\,V$.

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

$\Rightarrow \frac{N_o}{N_1} = \frac{E_{bo}}{E_{b1}} \times \frac{\phi_1}{\phi_o}$

$\Rightarrow N_1 = \frac{N_o \times E_{b1} \times \phi_o}{E_{bo} \times \phi_1} = \frac{1400 \times 214 \times \cancel{\phi_o}}{219.75 \times 0.97\,\cancel{\phi_o}}$

$N_1 = 1405.533$ rpm //

Armature torque $T_a = 0.159\,\phi\, I_a \dfrac{PZ}{A} = 0.159 \times 75\times10^{-3} \times 350 \times \dfrac{6\times1200}{6}$

$= 5008.5$ N-m.

we have $T_{lost} = T_a - T_{sh}$.

$T_{sh} = T_a - T_{lost}$

$= T_a - (3\%\, T_a)$

$T_{sh} = \dfrac{P_{out}}{\omega} \Rightarrow P_{out} = \cancel{T_{sh}\times\omega} = 5008.5 - \left(\dfrac{3}{100} * 5008.5\right)$

$T_{sh} = 4858.245$

$P_{out} = T_{sh} \times \omega \Rightarrow 4858.245 \times \dfrac{2\pi N}{60}$

$= 203.5016$ KW.

we have, 1 Brake Horse Power $= 735.5$ W

$BHP = \dfrac{P_{out}\text{ in W}}{735.5} = \dfrac{203.5016\times10^3}{735.5} = 276.684$ BHP.

→ A 4 pole 250V, series motor has a wave connected armature with 1254 conductors. The flux per pole is 22 mwb. when the motor is taking 50A. Iron and friction losses amount to 1.0 kw. Armature resistance is 0.2 Ω. and series field resistance is 0.2 Ω. calculate i) The speed ii) The BHP iii) shaft torque iv) Efficiency at this load.

sol: Given Pole $P = 4$.

$V = 250$ V.

No. of parallel path $A = 2$ for wave connected.

No. of conductors $Z = 1254$.

flux, $\phi = 22$ mwb.

armature current, $I_L = I_a = 50$ A as series motor

armature resistance $R_a = 0.2\,\Omega$.

series field resistance $R_{se} = 0.2\,\Omega$.