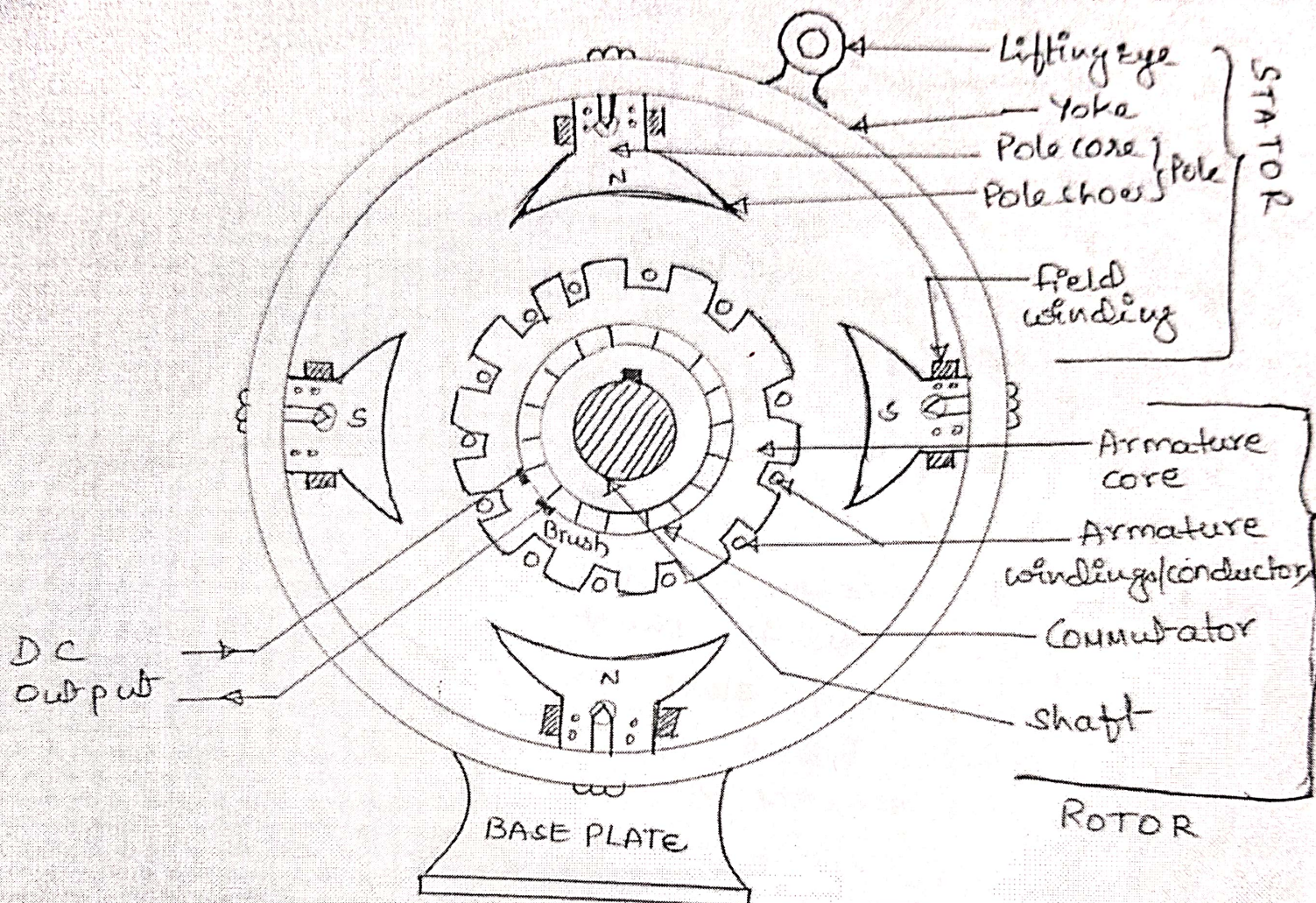


## Module 3) DC MACHINES

### 1) DC GENERATORS



I) STATOR - It is the stationary part of the machine  
In DC Generator Poles are stationary (stator)

i) Yoke - It is the outer cover of the generator.  
 \* It provides protection to the machine from moisture and dust & provides housing to the poles.  
 \* It is made by cast iron for small generators and cast steel for large generators.

ii) Poles - Poles are the electromagnets of DC Generator which provides flux.  
 \* Poles are made up of cast iron & cast steel.  
 \* Poles are laminated to reduce eddy current loss.



a) Pole core : It carries field winding to produce flux.

b) Pole shoe : It enlarges the area of armature core.

iii) Field winding : Field winding is wound on the pole core to carry the current, due to which the poles get excited.

→ The field windings are made up of conducting material like copper & Aluminium.

II) ROTOR : It is the rotating part of the generator. In DC generator Armature acts as rotor.

iv) Armature : a) Armature core b) Armature winding

a) Armature core : is cylindrical in shape which is placed on the shaft.

→ It consists of slots on its periphery which provides house to the armature winding.

→ Armature core is made up of cast iron and laminated to reduce eddy current loss.

b) Armature windings : are placed in the slots.

→ In the windings an emf induces.

→ These windings are made by conducting material like copper.

v) Commutator : It converts AC induced emf into DC emf. It is made up of conducting material; Cu - copper.

vi) Brushes : It collects the DC current from the rotating commutator and gives it to the stationary load.

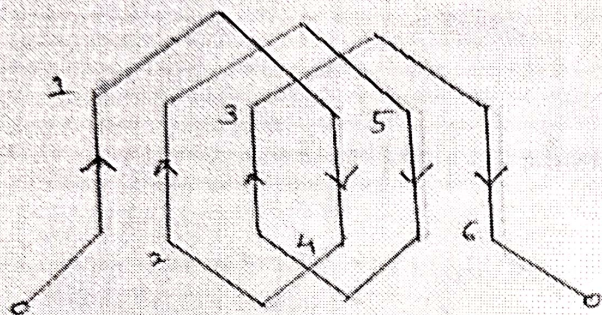
→ It is made up of soft material like carbon.



## Types of Armature winding

There are two types of armature winding  
i) Lap winding      ii) wave winding.

### i) Lap winding



\*> The connections of windings overlap each other as winding proceeds as shown in fig

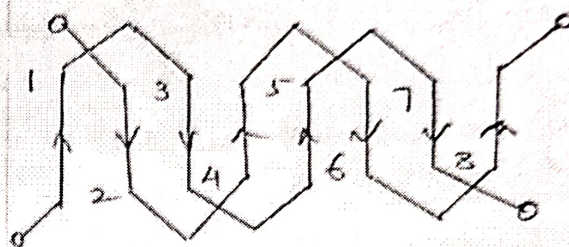
\*> Number of parallel paths  
 $(A) = \text{Number of poles } (P)$   
ie;  $A = P$

\*> Number of brushes  $(B)$   
 $= \text{Number of parallel paths}$   
ie;  $B = A = P$

\*> Preferable for high current low voltage generators

\*> Used for the generators of capacity more than 500 A

### ii) Wave winding



\*> The winding travels ahead like a wave by avoiding overlapping as shown in fig.

\*> Number of parallel paths  
 $(A) = 2$

\*> Number of brushes  $(B) =$   
 $\text{Number of parallel paths}$   
ie;  $B = A = 2$

\*> Preferable for high voltage low current generators.

\*> Used for the generators of capacity less than 500 A



## EMF Equation of DC Generator:

Let  $Z$  = Total number of conductors.

$\phi$  = flux per pole in wb

$N$  = Speed of the armature in rpm

$P$  = Number of poles.

$A$  = Number of parallel paths.

$$\Rightarrow \text{EMF induced/conductor} = \frac{\text{flux cut by the conductor in 1 revolution}}{\text{Time for 1 revolution}}$$

$$\text{ie; } E/\text{conductor} = \frac{d\phi}{dt} \quad \text{--- (1)}$$

$$\Rightarrow d\phi = \phi \times P \quad \text{--- (2)}$$

$$\Rightarrow dt = \frac{60}{N} \text{ seconds} \quad \text{--- (3)}$$

$$\left\{ \begin{array}{l} \text{for } N \text{ rev} \stackrel{u}{=} \text{sec} \rightarrow 60 \text{ sec} \\ \text{1 rev} \stackrel{u}{=} \rightarrow ? \end{array} \right.$$

Substitute eq<sup>n</sup> (2) & (3) in (1)

$$\Rightarrow \text{(1)} \Rightarrow E/\text{conductor} = \frac{\phi \times P}{\frac{60}{N}} = \frac{\phi P N}{60} \text{ volts} \quad \text{--- (4)}$$

$$\Rightarrow E/\text{parallel path} = E/\text{conductor} \times \frac{\text{No. of conductors}}{\text{1 path}}$$

$$\therefore E = \frac{\phi P N}{60} \times \frac{Z}{A} \text{ volts} \quad \text{--- (5)}$$

$\Rightarrow$  for lap winding

$$A = P$$

$$\text{(5)} \Rightarrow E = \frac{\phi N Z}{60} \text{ volts} \quad \text{--- (5)}$$

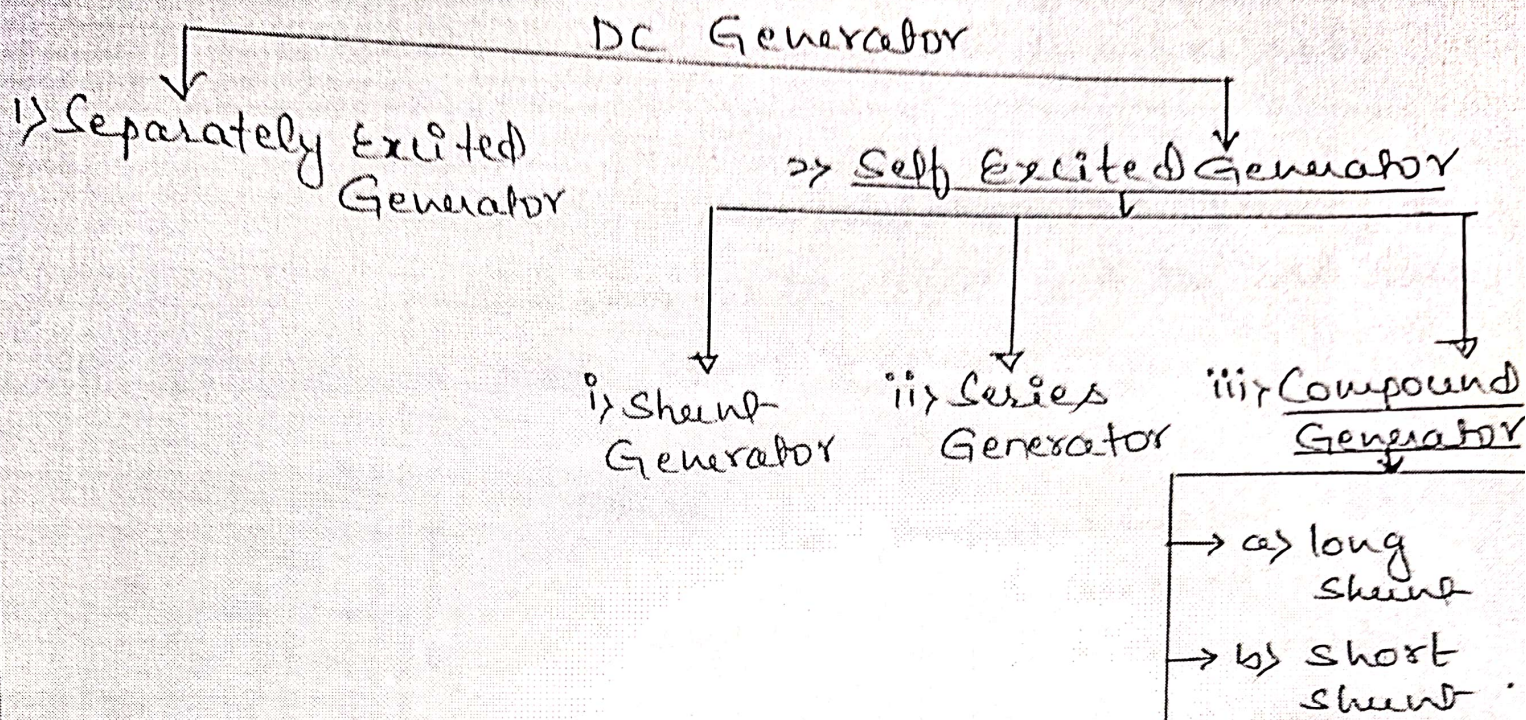
$\Rightarrow$  for wave winding

$$A = 2$$

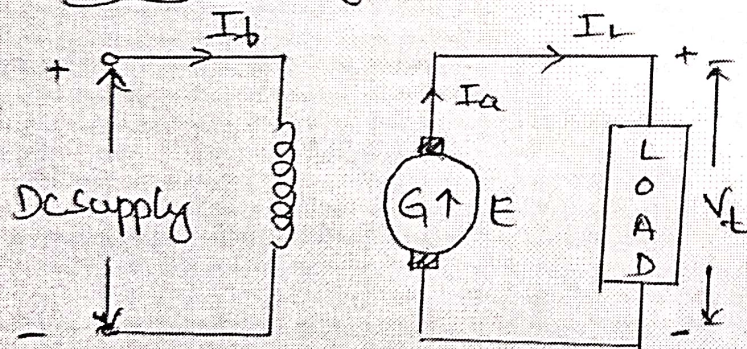
$$E = \frac{\phi P N Z}{120} \text{ volts}$$



# Types of DC Generator



## 1) Separately Excited DC Generator:



Where:

- $I_f$  - field current (A)
- $I_a$  - Armature current (A)
- $I_L$  - Load current (A)
- $V_t$  - Terminal voltage (V)
- $E$  - Induced emf (V)

In separately excited DC generator the field winding is excited or supplied by external DC source as shown in fig above.

$$I_a = I_L$$

$$E = V_t + I_a R_a + V_b \quad \text{where}$$

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

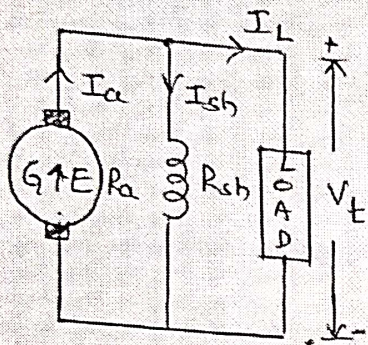
where  $V_b$  - voltage drop across the brushes.



## 2) Self Excited DC Generator:

\*> When the field winding is supplied from the armature of the generator itself is known as self excited DC Generator.

i) DC Shunt Generator: When the <sup>field</sup> armature winding is connected in parallel with the armature and the load then the generator is called shunt generator.



Where

$I_a$  - Armature current (A)

$I_L$  - Load current (A)

$I_{sh}$  - Shunt field current (A)

$R_a$  - Armature resistance ( $\Omega$ )

$R_{sh}$  - Shunt field resistance ( $\Omega$ )

$V_t$  - Terminal voltage (V)

$V_b$  - Voltage drop across brush (V)

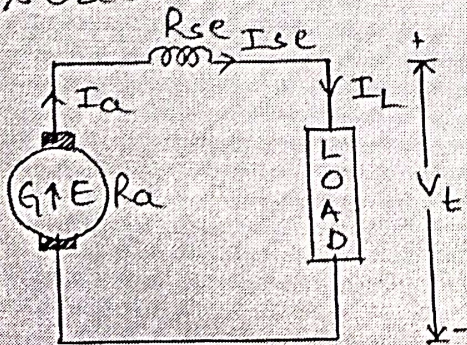
$E$  - Induced emf (V)

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

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

$$E = V_t + I_a R_a + V_b \quad \& \quad E = \frac{\Phi P N Z}{60 A}$$

ii) DC Series Generator: The field winding is connected in series with the armature and load as shown in fig



Where

$I_a$  - Armature current (A)

$I_{se}$  - Series field current (A)

$I_L$  - Load current (A)

$R_a$  - Armature resistance ( $\Omega$ )

$R_{se}$  - Series field resistance ( $\Omega$ )

$V_t$  - terminal voltage (V)

$V_b$  - Voltage drop across brush (V)

$E$  - Induced emf (V)

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

$$E = V_t + I_a R_a + I_{se} R_{se} + V_b$$

$$\& \quad E = V_t + I_a (R_a + R_{se}) + V_b$$

$$\& \quad E = \frac{\Phi P N Z}{60 A}$$



## Applications of Various types of DC Generators

1) Separately Excited DC Generator

Appl<sup>n</sup> : \*

- \*> Electroplating
- \*> Electro-refining of materials.

2) Self Excited DC Generator

i) DC shunt Generator

Appl<sup>n</sup> : \*

- \*> Boosters Battery charging
- \*> Ordinary lighting purpose

ii) DC Series Generator

Appl<sup>n</sup> : \*

- \*> Boosters
- \*> Welding generator
- \*> Arc lamps

iii) ~~DC~~ Compound Generator.

Appl<sup>n</sup> : \*

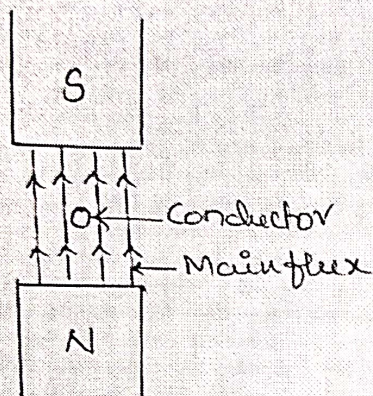
- \*> Domestic lighting
- \*> Electric Arc welding.



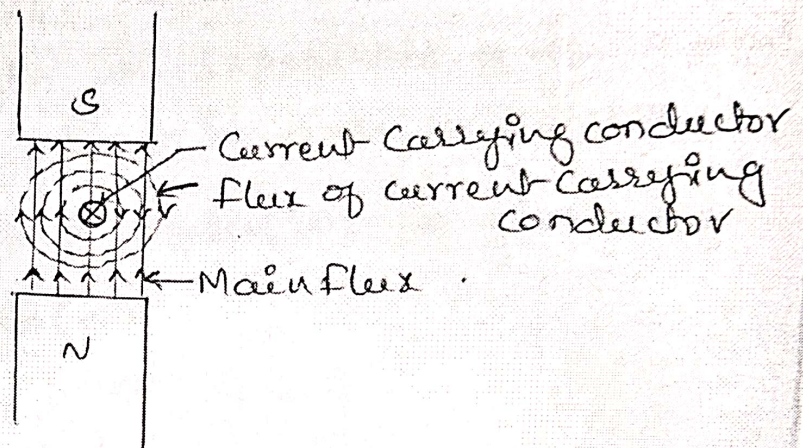
## 2> DC Motors

Working principle of DC motor :

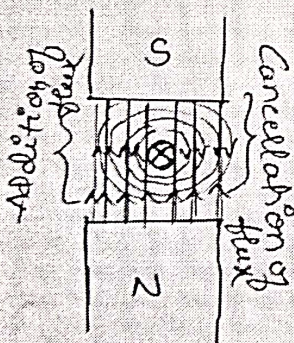
"Whenever a current carrying conductor is placed in a magnetic field it will experience a mechanical force (torque)".



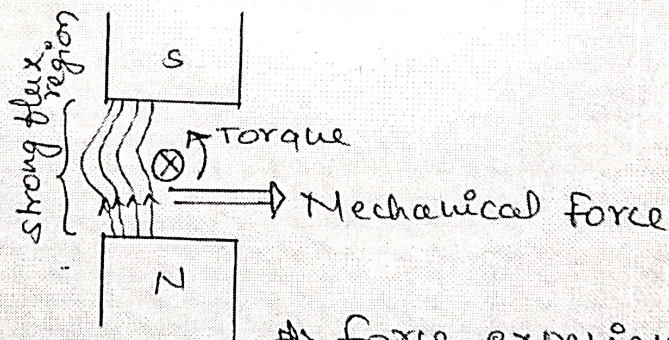
a) Conductor in a magnetic field.



b) flux produced by a current carrying conductor



c) Interaction of two fluxes



d) force experienced by the conductor

fig a:- In a dc motor field winding produces a magnetic field and armature conductor carries the current. as shown in fig a.

fig b:- The dc supply is given to the conductor through commutator. Now the current-carrying conductor produces the flux as shown in fig b.



Fig c:- Now the two fluxes will interact as shown in fig c at one side the fluxes will add and at other side they will cancel

Fig d:- Hence at one side the flux region becomes very strong and acts as stretched rubber band, it will push the conductor in opposite direction as shown in fig d. Hence the conductor  
Hence the conductor will experience a mechanical force and rotates about its axis called torque.

The force experienced by a conductor is given by

$$F = B l I \text{ Newtons (N)}$$



## Back emf in a DC Motor:

In a  $\phi$ c motor after motoring action the generating action takes place and an emf gets induced in it which opposes the cause of production of it. i.e; the supply voltage hence known as back emf.

The construction of DC Generator and DC Motor is same hence the equation for the back emf is same as generator emf equation.

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

## Significance of Back emf.

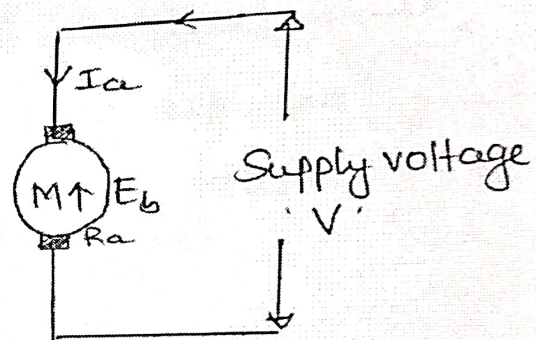
$$E_b = \frac{\phi P N Z}{60 A} \text{ volts}$$

$$\therefore E_b \propto N \text{ --- (1)}$$

$$V = E_b + I_a R_a$$

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

$$\therefore I_a \propto (V - E_b) \text{ --- (2)}$$



Case i):- When load on the motor increases.

\* As load increases the speed ( $N$ ) of the motor decreases.

\* From eq<sup>n</sup> (1) the back emf ( $E_b$ ) also reduces.

\* As back emf reduces from eq<sup>n</sup> (2) it is clear that the net voltage ( $V - E_b$ ) increases.

Hence the armature current ( $I_a$ ) also increases.

\* Therefore motor draws more current from the supply as load on the motor increases.



- Case ii) :- When load on the motor decreases.
- \*> As load reduces the speed ( $N$ ) of the motor increases.
  - \*> As speed of the motor increases from eq<sup>n</sup>. (1) it is clear that the back emf ( $E_b$ ) also increases.
  - \*> from eq<sup>n</sup>. (2) we can see that as back emf increases the net voltage across the armature ( $V - E_b$ ) decreases, hence the armature current also decreases.
  - \*> Therefore motor draws less current from the supply as load on the motor decreases.

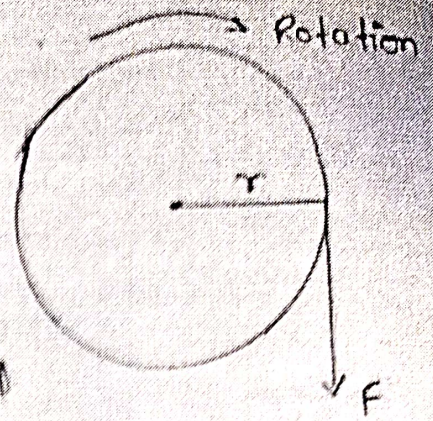
From above two cases it is clear that the back emf helps the DC motor to act as regulating machine to satisfy the load demand.



## Torque Equation of a DC Motor :-

"The turning or twisting force about an axis is called torque"

Consider the armature of a DC motor of radius  $r$  meters and  $F$  be the force acting tangential to the surface of the armature as shown in fig above.



→ The torque exerted on the armature

$$T_a = F \times r \text{ N-m} \quad \text{--- (1)}$$

→ The armature rotates at a speed of  $N$  rpm.  
∴ Angular speed is

$$\omega = \frac{2\pi N}{60} \text{ rad/sec} \quad \text{--- (2)}$$

→ The work done in one revolution

$$W = \text{Force} \times \text{Distance} = F \times 2\pi r \text{ joules} \quad \text{--- (3)}$$

→ Power developed by the armature

$$P = \frac{\text{Work done}}{\text{Time}} = \frac{F \times 2\pi r}{\frac{60}{N}}$$

$$P = (F \times r) \frac{2\pi N}{60}$$

$$P = T_a \times \omega \text{ watts} \quad \text{--- (4)}$$

Wkt- ∴  $P = E_b \times I_a$  &  $E_b = \frac{\phi P N Z}{60 A}$

$$\therefore \textcircled{4} \Rightarrow E_b \times I_a = T_a \times \omega$$

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

$$\therefore T_a = 0.159 \phi I_a \frac{P Z}{A} \text{ N-m} \quad \text{--- (5)}$$



## Types of DC Motors

DC Motor .

- i) DC shunt Motor    ii) DC series Motor    iii) DC compound Motor .

→ a) long shunt  
→ b) short shunt .

### i) DC shunt Motor :

The field winding of the motor is in parallel with the armature and load.

Where :  $I_a$  - Armature current (A)

$I_L$  - Line current (A)

$I_{sh}$  - Shunt field current (A)

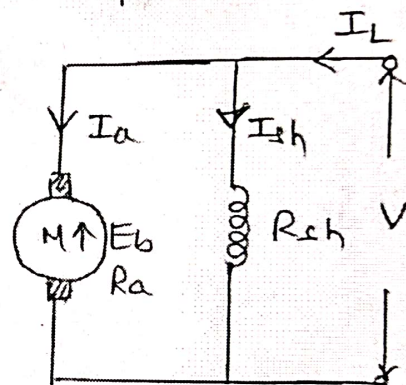
$R_a$  - Armature resistance ( $\Omega$ )

$R_{sh}$  - Shunt-field resistance ( $\Omega$ )

$V$  - Supply voltage (V)

$E_b$  - Back emf (V)

$V_b$  - Voltage across the brush (V)



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

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

$$V = E_b + I_a R_a + V_b$$

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



## ii) DC Series Motor :

The field winding is in series with the armature and the load.

Label:

$I_a$  - Armature current (A)

$I_L$  - Line current (A)

$I_{se}$  - Series field current (A)

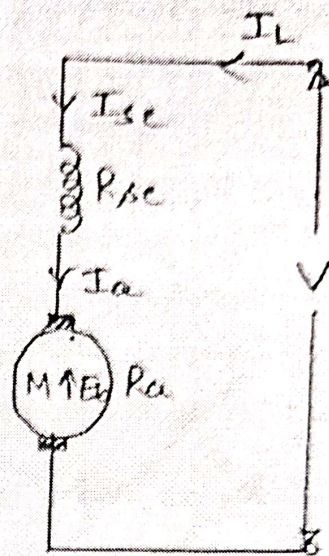
$R_a$  - Armature resistance ( $\Omega$ )

$R_{se}$  - Series field resistance ( $\Omega$ )

$V$  - Supply voltage (V)

$E_b$  - Back emf (V)

$V_b$  - Voltage across the brush (V)



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

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

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

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

## Applications of DC Motors

i) DC Shunt Motors:

Appl<sup>n</sup>s: Pumps, fans, drilling machine etc.

ii) DC Series Motors:

Appl<sup>n</sup>s: Trolleys, cranes, conveyors, vacuum cleaners etc.

iii) DC Compound Motors:

Appl<sup>n</sup>s: Printing Press, Rolling Mills, Elevators etc.



## Characteristics of DC motor

i) DC Shunt Motor : Flux ( $\phi$ ) is constant.  
It is a medium torque, constant speed motor.

ii) Torque Vs Armature Current ( $T_a / I_a$ ) : (Medium torque)

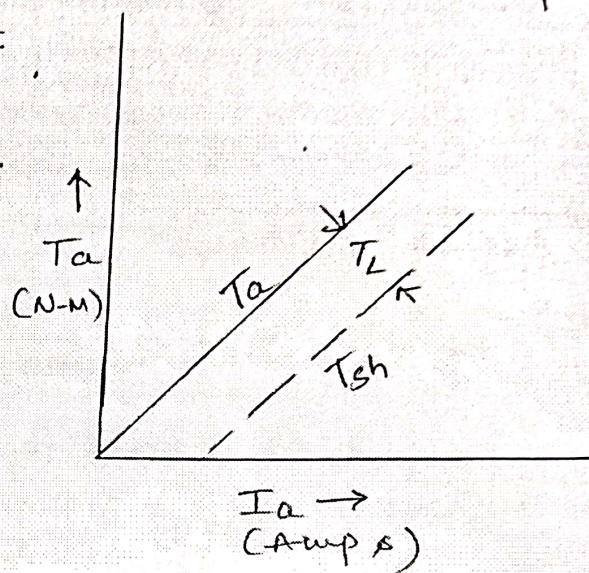
Wkt!  $T_a = 0.159 \phi I_a \frac{PZ}{A}$

In above eqn.

$\phi, P, Z \text{ \& } A$  are constant.

$\therefore T_a \propto I_a$

Hence the characteristic is a straight line passing through the origin as shown in fig.



The Shaft torque ( $T_{sh}$ ) is always less than the armature torque ( $T_a$ ) due to Mechanical loss ( $T_L$ )

From the characteristic it is clear that a DC shunt motor has medium torque hence does not suit for very large loads.

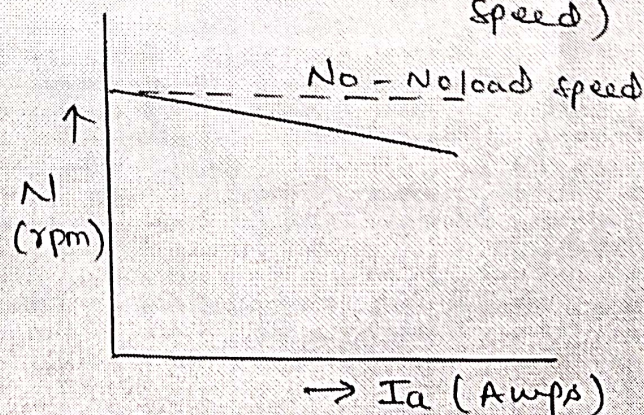
iii) Speed Vs Armature Current ( $N / I_a$ ) : (Constant speed)

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

$\therefore E_b \propto N$

and  $E_b = V - I_a R_a$

$\therefore N \propto V - I_a R_a$



As load increases,  $I_a R_a$  increases

hence  $V - I_a R_a$  decrease and Speed

also decreases. But the drop  $I_a R_a$  is very small compared to  $V$  hence the decrease in the speed is also small as shown in fig.



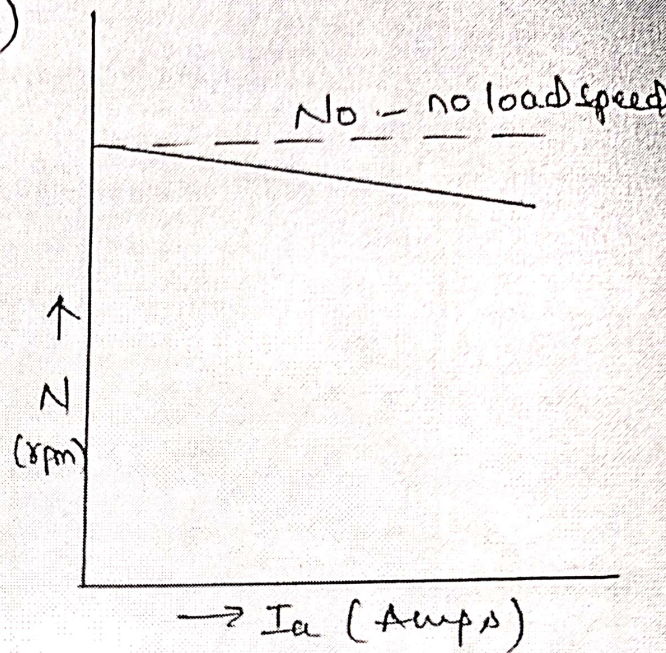
### iii) Speed $V_s$ Torque ( $N/T_a$ )

W14-1:  $T_a \propto I_a$ .

Hence the speed  $V_s$  torque characteristic is same as speed  $V_s$  Armature current as shown in fig.

The change in speed from No load to full load is very small.

From the above three characteristics it is concluded that the DC shunt motor is a medium torque and constant speed motor.





27 DC Series Motor : It is a high torque, variable speed motor. (Its starting torque is very high)

∴ Torque Vs Armature current ( $T_a / I_a$ ) :

Wkt :

$$T_a = 0.159 \phi I_a \frac{PZ}{A}$$

In above eq<sup>n</sup>  $P, Z$  &  $A$  are constant.

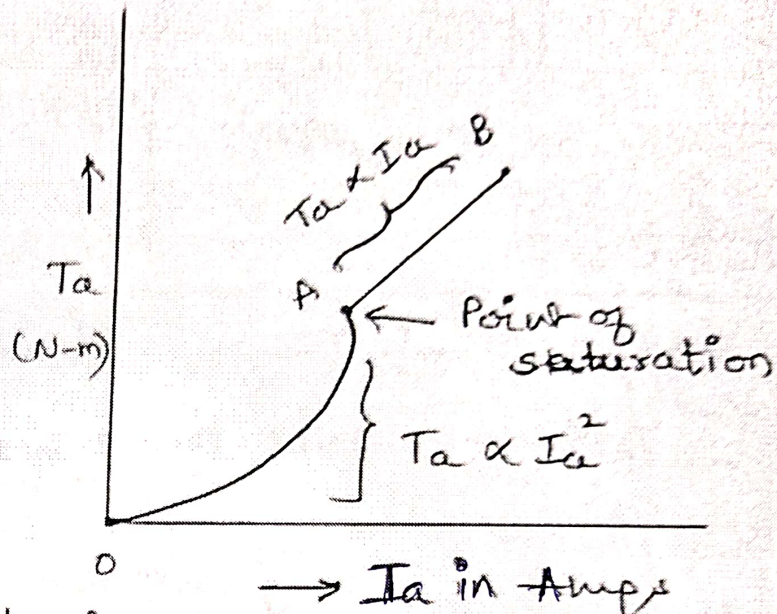
$$T_a \propto \phi I_a$$

$$\text{but } \phi \propto I_a$$

$$\therefore T_a \propto I_a^2 \text{ till point A}$$

after point A  $\phi$  is constant.

$$\therefore T_a \propto I_a \text{ — (2)}$$



∴ From the above eq<sup>n</sup>s and characteristic it is clear that till point A the flux ( $\phi$ ) varies according to the load, hence  $T_a \propto I_a^2$  and the curve OA is a parabola (OA) in fig.

∴ Point A is called saturation point, after this point the poles get saturated hence the flux ( $\phi$ ) becomes constant. Therefore  $T_a \propto I_a$  and the curve is a linear curve (AB) in fig.

∴ From this it is clear that the starting torque of DC series motor is very high hence can be used for heavy loads.



## ii) Speed $V_s$ Armature Current ( $N/I_a$ ) :-

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

In above eq<sup>n</sup>  $P, Z \& A$  are constant.

$$\therefore E_b \propto N \phi$$

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

$$\phi \propto I_a \quad \& \quad E_b \propto (V - I_a R_a - I_a R_{se})$$

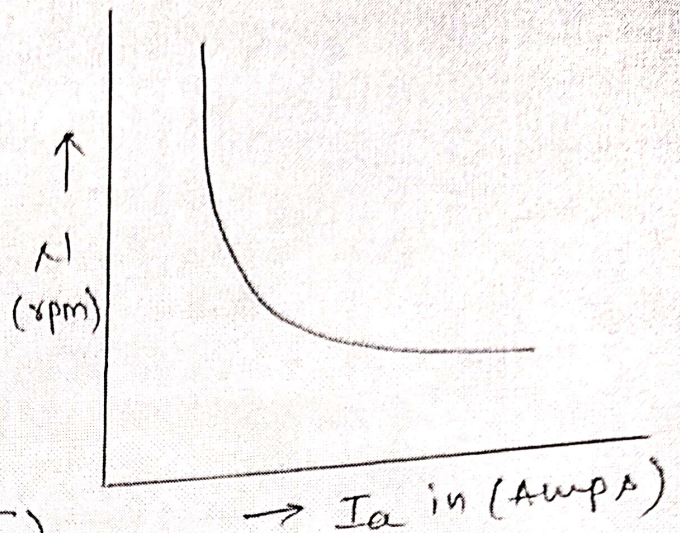
the values of  $R_a \& R_{se}$  is very small hence neglected.

$\therefore E_b \cong V$  which is constant.

①  $\Rightarrow N \propto \frac{1}{I_a}$  ie; the speed is inversely proportional to the armature current.

\* So, as load increases, the armature current also increases and speed decreases and vice-versa.

\* From the curve it is observed that the speed varies over a wide range hence a dc series motor is a variable speed motor.



## iii) Speed $V_s$ Torque ( $N/T_a$ ) :-

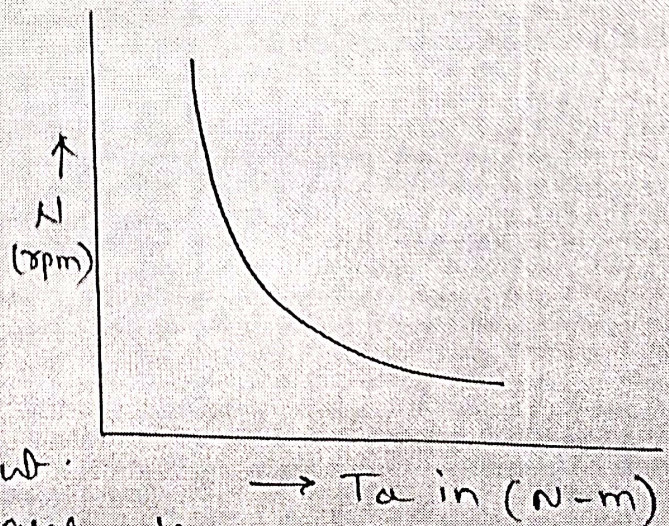
Wkt!  $T_a \propto I_a^2$

and  $N \propto \frac{1}{I_a}$

$$\therefore N \propto \frac{1}{\sqrt{T_a}}$$

Hence the Speed versus Torque curve is same as Speed  $V_s$  Armature Current.

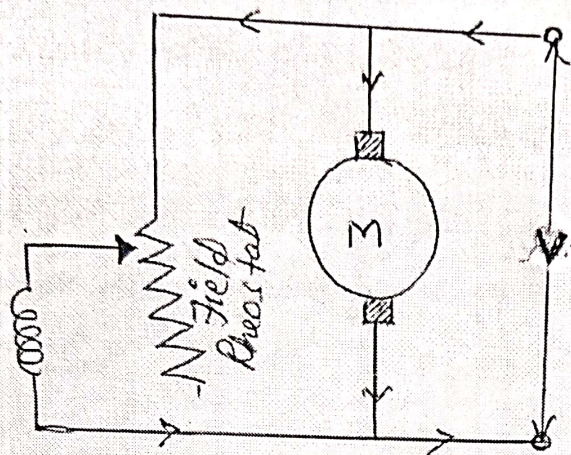
ie; for smaller values of torque, the speed is very large and vice-versa.





# Speed Control of DC Motor

- i) DC Shunt Motor ;  $E_b = V - I_a R_a$  &  $E_b = \frac{\phi N Z}{60} \left( \frac{P}{A} \right)$   
 ii) field control  $\approx$  flux control Method .



$$N = \frac{V - I_a R_a}{Z \phi} \left( \frac{A}{P} \right) \text{ rps}$$

$$N = K \frac{V - I_a R_a}{\phi} \text{ rps.}$$

ie;  $N \propto \frac{1}{\phi}$

By decreasing the flux the speed can be increased and vice versa. Hence this method is named as flux or field control method.

The flux of a d.c motor can be changed by changing  $I_{sh}$  with the help of shunt field rheostat as shown in fig above.

Since  $I_{sh}$  (shunt field current) is relatively small, shunt field rheostat has to carry only a small current, which means  $I^2 R$  loss is small, so that rheostat is small in size. Hence this method is very efficient.

- ii) Armature control or Rheostatic Control Method :-

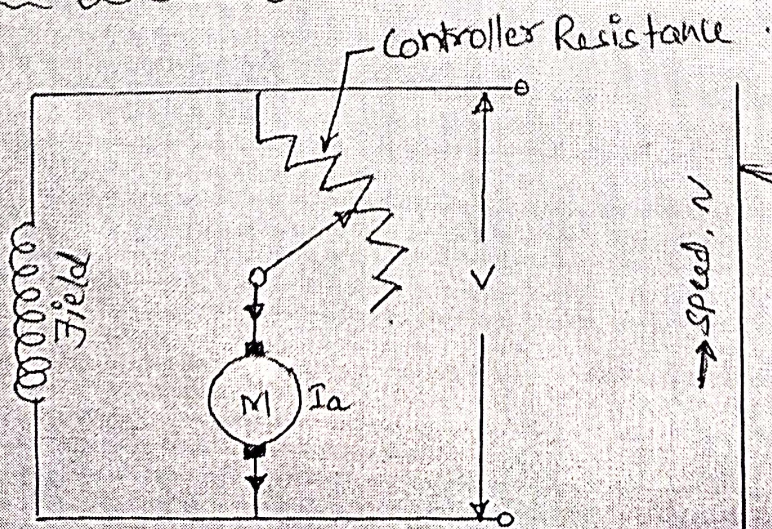


fig (a) circuit diagram

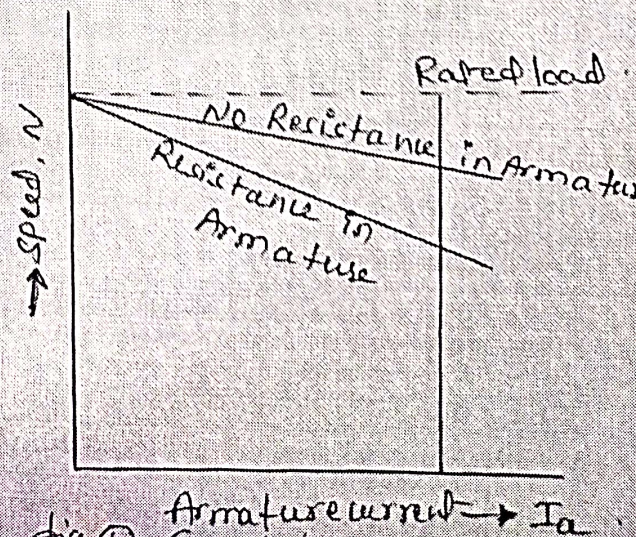


fig (b) Armature current  $\rightarrow I_a$



This method is used when speeds below the no-load speed are required. As the supply voltage is normally constant the voltage across armature is varied by inserting a variable rheostat called as controller resistance in series with the armature circuit as shown in fig. (a)

As controller resistance is increased the voltage across the armature is decreased, thereby decreasing the armature speed.

From the speed/armature current characteristic shown in fig. (b), it is seen that greater the resistance in the armature circuit, greater is the fall in the speed.

The advantages of this method are

- \* Constant field current and torque: with the armature control method, the field current and torque remains constant throughout the application.

- \* Fast and simple speed variation;

The disadvantages of armature controlled method are.

- \* Higher initial cost

- \* Low energy efficiency

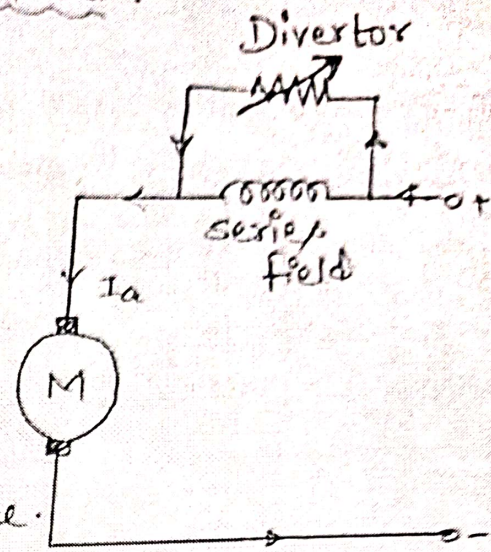


## 2) DC Series Motor

1) field control & flux control method :

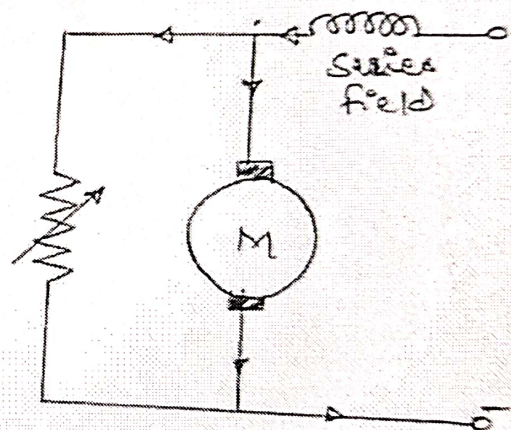
### a) field Divertor

The series windings are shunted by a variable resistance known as field divertor shown in fig. Any desired amount of current can be passed through the divertor by adjusting its resistance. Hence the flux can be decreased and consequently, the speed of the motor increased.



### b) Armature Divertor

A divertor (variable resistance) across the armature can be used for giving speed lower than the normal speed as shown in fig. For a given constant load torque, if  $I_a$  is reduced due to armature divertor, the flux  $\phi$  must increase. ( $\because T_a \propto \phi I_a$ ). This results in an increase in current taken from the supply which increases the flux and fall in speed  $\therefore N \propto \frac{I}{\phi}$ .



The variation in speed can be controlled varying the divertor resistance.



## Numericals of DC Generator

A 4 pole, 1500 rpm dc generator has a lap wound armature having 24 slots with 10 conductors per slot. If the flux per pole is 0.04 wb, calculate the emf generated in the armature. What would be the generated emf if the wdg is wave connected?

Given.

Lap ~~A~~  $A = P$

$$P = 4$$

$$N = 1500 \text{ rpm}$$

$$\text{Slots} = 24$$

$$\text{cond/slot} = 10$$

$$\phi = 0.04 \text{ wb}$$

Find:

i)  $E = ?$  Lap connected.

ii)  $E' = ?$  if wave connected  
ie;  $A = 2$

Sol:

i) wkt ~~Lap~~  $A = P$

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

$$E = \frac{0.04 \times 1500 \times 240}{60}$$

$$E = 240 \text{ V}$$

wkt

$$Z = \text{slots} \times \text{cond/slot}$$

$$Z = 24 \times 10$$

$$Z = 240$$

ii) wkt ~~Wave~~  $A = 2$

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

$$= \frac{0.04 \times 1500 \times 4 \times 240}{60 \times 2}$$

$$E = 480 \text{ V}$$



2

A 4 pole lap connected DC Gen. has 60 armature conductors and runs at 1200 rpm. This generator has a field flux of 0.24 wb in the calculator is independent of the above DC Gen.

Find speed at which it should be driven to produce the same emf when connected in wave.

Sol<sup>n</sup> Given Lap  $A = P$

$$P = 4$$

$$Z = 60$$

$$N = 1200 \text{ rpm}$$

$$\phi_T = 0.24 \text{ wb}$$

Wkt

$$\phi_T = \phi \times P$$

$$\therefore \phi = \frac{\phi_T}{P} = \frac{0.24}{4} = 0.06 \text{ wb}$$

Wkt  $\therefore$  Lap  $A = P$

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

$$E = \frac{0.06 \times 1200 \times 60}{60}$$

$$E = 720 \text{ V}$$

Wkt  $\therefore$  wave  $A = 2$  &  $E = 720 \text{ V}$

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

$$\therefore N = \frac{60 A E}{\phi P Z} = \frac{60 \times 2 \times 720}{0.06 \times 4 \times 60}$$

$$N = 600 \text{ rpm}$$



A shunt-gen supplies a load of 10 kW at 200 V, through a pair of feeders of total resistance of  $0.05 \Omega$ . The armature resistance is  $0.1 \Omega$ . The shunt-field resistance is  $100 \Omega$ . Find the terminal v/p & the generated emf.

Given: Shunt-gen

$$P = 10 \text{ kW} = 10 \times 10^3 \text{ W}$$

$$V_L = 200 \text{ V}$$

$$R_f = 0.05 \Omega$$

$$R_a = 0.1 \Omega$$

$$R_{sh} = 100 \Omega$$

Find:-

$$i) V_t = ?$$

$$ii) E = ?$$

Wkt:-

$$P = V_L \times I_L$$

$$I_L = \frac{P}{V_L} = \frac{10,000}{200}$$

$$I_L = 50 \text{ A}$$

Pract:-

$$V_t = V_L + I_L R_f = 200 + 50 \times 0.05$$

$$V_t = 202.5 \text{ V}$$

Wkt:-

$$E = V_t + I_a R_a$$

Wkt:-

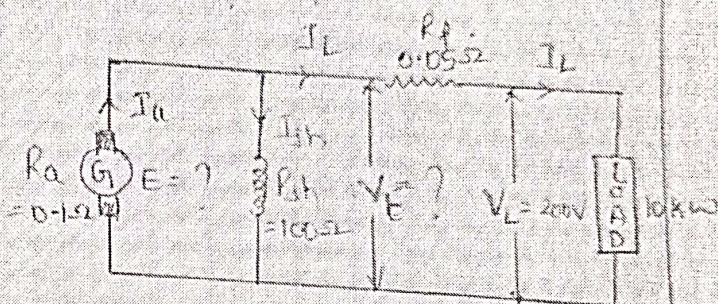
$$I_a = I_L + I_{sh}$$

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{202.5}{100} = 2.025 \text{ A}$$

$$\therefore I_a = 50 + 2.025 = 52.025 \text{ A}$$

$$\therefore E_g = 202.5 + 52.025 \times 0.1$$

$$E_g = 207.7025 \text{ V}$$





A 4 pole generator with wave wound armature 51 slots, each having 24 conductors. The flux per pole is 0.01 wb. At what speed must the armature rotate to give an induced emf of 220V? What will be the % developed if the wdg is lap and the armature rotates at the same speed?

Q.1. Given: wave  $A = 2$

$$P = 4$$

$$\text{slots} = 51$$

$$\text{cond/slot} = 24$$

$$\phi = 0.01 \text{ wb}$$

$$E = 220 \text{ V}$$

Find:-

i)  $N = ?$  wave connected

ii)  $E = ?$  lap connected.

Wkt:-

$$Z = \text{slots} \times \text{cond/slot} = 51 \times 24 = 1224$$

i) Wkt:- wave  $A = 2$

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

$$N = \frac{60 A E}{\phi P Z} = \frac{60 \times 2 \times 220}{0.01 \times 4 \times 1224}$$

$$N = 539.2156 \text{ rpm}$$

ii) Wkt:- Lap:  $A = P$  &  $N = 539.2156 \text{ rpm}$

$$E = \frac{\phi P N Z}{60 A} = \frac{\phi N Z}{60} = \frac{0.01 \times 539.2156 \times 1224}{60}$$

$$E = 110 \text{ V}$$



A D.C. generator connected series gen has armature resistance of  $0.5 \Omega$  & series field resistance of  $0.03 \Omega$ . It drives a load of  $50 \text{ A}$ . It has 6 turns/coil & total 540 coils on the armature and is driven at  $1500 \text{ rpm}$ . Calculate the terminal v/t at the load. Assume 4 poles, lap type wdg, flux per pole as  $2 \text{ mwb}$  and total brush drop as  $2 \text{ V}$ .

Sol:

Given: Lap:  $A = P$

$$R_a = 0.5 \Omega$$

$$R_{se} = 0.03 \Omega$$

$$I_L = 50 \text{ A}$$

$$\text{Turns/coil} = 6$$

$$\text{Total coil} = 540$$

$$N = 1500 \text{ rpm}$$

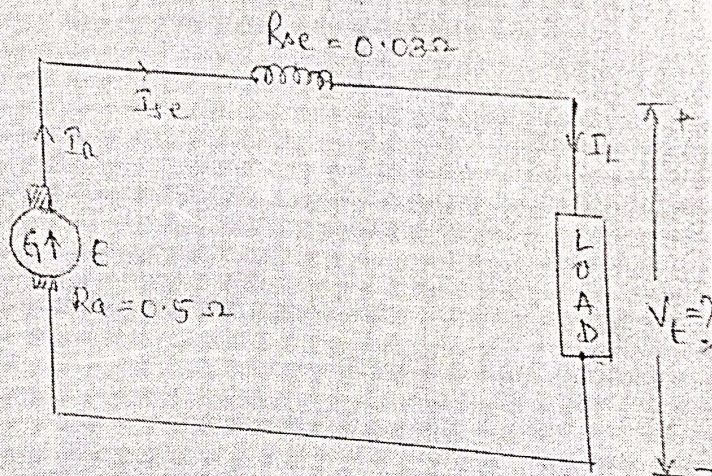
$$P = 4$$

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

$$V_{\text{brush}} = 2 \text{ V}$$

Find:

$$V_L = ?$$



Wkt:  $Z = 2 \times \text{Turns}$

$$\text{Turns} = \text{coil} \times \text{Turns/coil} = 540 \times 6 = 3240$$

$$\therefore Z = 2 \times 3240 = 6480$$

Wkt: Lap  $A = P$

$$E = \frac{\phi P N Z}{60 A} = \frac{\phi N Z}{60} = \frac{2 \times 10^{-3} \times 1500 \times 6480}{60} = 324 \text{ V}$$

Wkt:  $E = V_L + I_a(R_a + R_{se}) + V_{\text{brush}}$

$$\therefore I_a = I_{se} = I_L = 50 \text{ A}$$

$$\therefore V_L = E - I_a(R_a + R_{se}) - V_{\text{brush}}$$

$$V_L = 324 - 50(0.5 + 0.03) - 2$$

$$\boxed{V_L = 295.5 \text{ V}}$$



## DC Motor

①

Find the useful flux per pole on no-load of a 250V, 6 pole shunt motor having a two ckr connected armature winding with 220 conductors. At normal working temperature, the overall armature resistance including brushes is  $0.2 \Omega$ . The armature ckt is  $13.3 \text{ A}$  at the no-load speed of  $908 \text{ rpm}$ .

Given:  $V = 250 \text{ V}$ ,  $P = 6$ ,  $Z = 220$ ,  $R_a = 0.2 \Omega$ ,

$I_a = 13.3 \text{ A}$ ,  $N = 908 \text{ rpm}$

$A = 2$   $\therefore$  two ckr connected armature wdg means wave connected.

Find  $\phi = ?$

Sol:-

Wkt:-  $E_b = \frac{\phi P N Z}{60 A}$   $\therefore \phi = \frac{60 A E_b}{P N Z}$  — ①

Wkt:-  $V = E_b + I_a R_a \therefore E_b = V - I_a R_a$   
 $= 250 - (13.3 \times 0.2)$

$$E_b = 247.34 \text{ V}$$

$$\therefore \text{①} \Rightarrow \phi = \frac{60 \times 2 \times 247.34}{6 \times 908 \times 220} = 24.76 \times 10^{-3} \text{ wb}$$

$\phi = 24.76 \text{ mwb}$



A 240V, 4 pole, shunt motor running at 1000 rpm gives 15 HP with an armature c/f. of 50 A & field c/f. of 1.0 A. The armature <sup>winding</sup> is wave-connected and has 540 conductors. Its resistance is  $0.1 \Omega$  & drop of each brush is 1V. Find as  
 a) Useful torque b) Total torque c) Useful flux/pole  
 d) Rotational torque losses.

Given:  $V = 240V$   $I_a = 50A$   
 $P = 4$   $I_{sh} = 1A$   
 $N = 1000 \text{ rpm}$   $R_a = 0.1 \Omega$   
 $P_{out} = 15 \text{ HP}$   $Z = 540$   
 $A = 2$   $V_{brush} = 1V \text{ per brush.}$   
 (Wave connected)

a) work :- Useful torque / Shaft torque  $T_{sh}$

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

$$T_{sh} = \frac{15 \times 735.5 \times 60}{2\pi \times 1000} = 105.35 \text{ N-m}$$

(1 HP = 735.5 W)

$$T_{sh} = 105.35 \text{ N-m}$$

b) work :- Total torque / Armature torque  $T_a$

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

but-

$$E_b = V - I_a R_a = 240 - (50 \times 0.1) = 233V$$

$$\therefore T_a = \frac{233 \times 50 \times 60}{2\pi \times 1000} = 111.2493 \text{ N-m}$$

$$T_a = 111.2493 \text{ N-m}$$



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

$$\phi = \frac{60 \times 2 \times 233}{1 \times 1000 \times 540} = 12.99 \times 10^{-3} \text{ wb}$$

$$\boxed{\phi = 12.99 \text{ mwb}}$$

$$d) \text{ w/h } \quad \text{lost torque} = \frac{\text{Rotational losses}}{\omega}$$

$$\therefore \text{Rotational losses} = \text{lost torque} \times \omega$$

$$= (T_a - T_{sh}) \times \frac{2\pi N}{60}$$

$$= (111.2493 - 105.35) \times \frac{2\pi \times 1000}{60}$$

$$\boxed{\text{Rotational losses} = 617.77 \text{ watts}}$$

- ⑤ A 500V shunt motor has 4 poles & wave connected with 492 conductors. The flux per pole is 0.05 wb. Calculate the speed & the developed torque. The armature & shunt field resistances are 0.1  $\Omega$  & 250  $\Omega$ .

Given:-  $V = 500\text{V}$

$$P = 4$$

$$A = 2 \text{ (wave connected)}$$

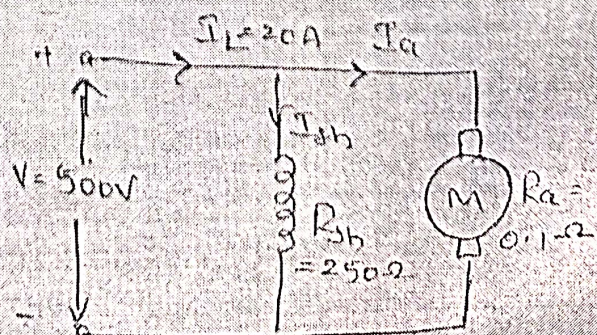
$$Z = 492$$

$$\phi = 0.05 \text{ wb}$$

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

$$R_a = 0.1 \Omega$$

$$R_{sh} = 250 \Omega$$



Find i)  $N = ?$

ii)  $T_a = ?$



ii) Wkt:-  $E_b = \frac{\phi P N Z}{60 A}$   $\therefore N = \frac{60 A E_b}{\phi P Z}$  — (1)

Wkt:-  $E_b = V - I_a R_a$  — (2)

Wkt:-  $I_a = I_L + I_{sh}$  — (3)

Wkt:-  $I_{sh} = \frac{V}{R_{sh}} = \frac{500}{250} = 2 \text{ A}$

(3)  $\Rightarrow I_a = 20 - 2 = 18 \text{ A}$

(2)  $\Rightarrow E_b = 500 - (18 \times 0.1) = 498.2 \text{ V}$

(1)  $\Rightarrow N = \frac{60 \times 2 \times 498.2}{0.05 \times 4 \times 492} = 607.56 \text{ rpm}$

$N = 607.56 \text{ rpm}$

iii) Wkt:-  $T_a = 0.159 \phi I_a \left[ \frac{Z P}{A} \right]$

$= 0.159 \times 0.05 \times 18 \times \frac{492 \times 4}{2}$

$T_a = 140.8164 \text{ N-m}$

soln (3)



The field C/P in a d.c. shunt m/c machine is 2 A & the line C/P is 20 A at 200 V. Calculate

i) The generated emf when working as generator

ii) Torque N-m when running at 1500 rpm as motor

Take the armature resistance as  $0.5 \Omega$ .

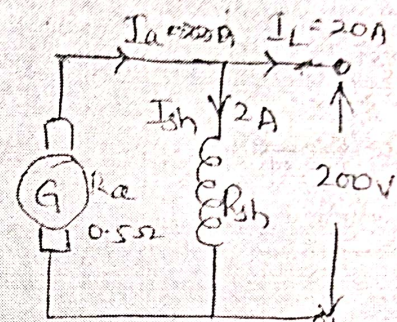
i) As Generator:

$$E_g = V_t + I_a R_a$$

$$I_a = I_L + I_{sh} = 20 + 2 = 22 \text{ A}$$

$$\therefore E_g = 200 + (22 \times 0.5) = 200 + 11$$

$$E_g = 211 \text{ V}$$



ii) As Motor: Given:  $N = 1500 \text{ rpm}$

$$\text{Wkt } T_a = \frac{E_b I_a}{\omega}$$

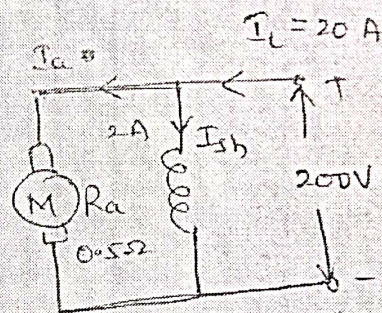
$$E_b = V - I_a R_a$$

$$I_a = I_L - I_{sh} = 20 - 2 = 18 \text{ A}$$

$$E_b = 200 - (18 \times 0.5) = 191 \text{ V}$$

$$\therefore T_a = \frac{E_b I_a}{\frac{2\pi N}{60}} = \frac{E_b I_a 60}{2\pi N} = \frac{191 \times 18 \times 60}{2\pi \times 1500}$$

$$T_a = 21.887 \text{ N-m}$$





- ⑤ A 4 pole, 250V series motor has wave connected armature with 1254 conductors. The flux per pole is 22 mwb when the motor is taking 50 A. The armature and series field coil resistances are  $0.3\Omega$  &  $0.2\Omega$ . Calculate the speed & torque of the motor and also the power developed in watts.

Given :-

$$P = 4, V = 250V, Z = 1254, \phi = 22 \times 10^{-3} \text{ wb}$$

$$I_L = 50A, R_a = 0.3\Omega, R_{se} = 0.2\Omega, A = 2 \text{ (wave connected)}$$

Find :- i)  $N = ?$  ii)  $T_a = ?$  iii)  $P = ?$

is Wkt :

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

$$N = \frac{60 A E_b}{\phi P Z} \quad \text{--- (1)}$$

Wkt :-

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

$$E_b = 250 - 50(0.2 + 0.3) = 225V$$

$$\therefore N = \frac{60 \times 2 \times 225}{22 \times 10^{-3} \times 4 \times 1254} = 244.6716 \text{ rpm}$$

$$N = 244.6716 \text{ rpm}$$

ii) Wkt :-  $T_a = 0.159 \phi I_a \left[ \frac{P Z}{A} \right]$

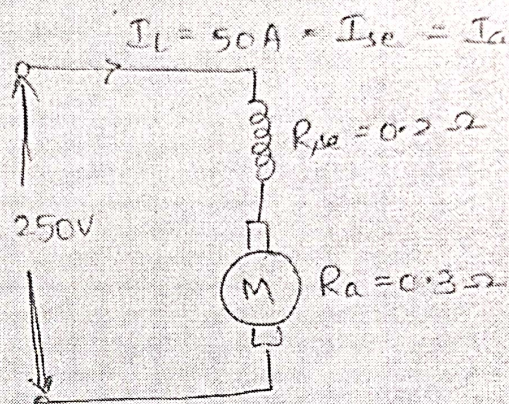
$$= 0.159 \times 22 \times 10^{-3} \times 50 \left[ \frac{4 \times 1254}{2} \right]$$

$$T_a = 438.65 \text{ Nm}$$

iii) Wkt :-  $P = T_a \times \omega = T_a \times \frac{2\pi N}{60}$

$$P = 438.65 \times 2\pi \times 244.6716 / 60$$

$$P = 11239.068 \text{ W} \approx 11.239 \text{ kW}$$





A 4 pole DC shunt motor takes 22 A from 220V supply. The armature and field resistance are respectively  $0.5\Omega$  and  $100\Omega$ . The armature is lap connected with 300 conductors. If the flux per pole is  $20\text{mwb}$ . Calculate the speed & gross torque.

Given:-  $P = 4$ ,  $I_L = 22\text{ A}$ ,  $V = 220\text{ V}$ ,  $R_a = 0.5\Omega$  &  $R_{fh} = 100\Omega$ ,  $A = P = 4$  (lap connected)  
 $Z = 300$ ,  $\phi = 20 \times 10^{-3}\text{ wb}$ .

Find:- i)  $N = ?$  ii)  $T_a = ?$

Wkt:-

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

$$\therefore N = \frac{60 A E_b}{\phi P Z} = \frac{60 E_b}{\phi Z} \quad (\because A = P)$$

Wkt:-  $E_b = V - I_a R_a$  &  $I_a = I_L - I_{sh}$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{100} = 2.2\text{ A}$$

$$\therefore I_a = 22 - 2.2 = 19.8\text{ A}$$

$$\therefore E_b = 220 - (19.8 \times 0.5) = 210.1\text{ V}$$

$$\therefore N = \frac{60 \times 210.1}{20 \times 10^{-3} \times 300} = 2101.8\text{ rpm}$$

$$\boxed{N = 2101.8\text{ rpm}}$$

ii) Wkt:-  $T_a = 0.159 \phi I_a \frac{P Z}{A} = 0.159 \phi I_a Z$

$$T_a = 0.159 \times 20 \times 10^{-3} \times 19.8 \times 300$$

$$\boxed{T_a = 18.89\text{ Nm}}$$

