# UNIT IV: DC Machines

**Syllabus:**

Construction, working of DC Generator, EMF Equation, types and characteristics of DC generators, Principle of DC motor, Torque Equation of Motor, types of DC Motors, Torque speed characteristic and speed control of DC motor, (Theoretical Concepts only)

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**DC machines**

1. DC Generator

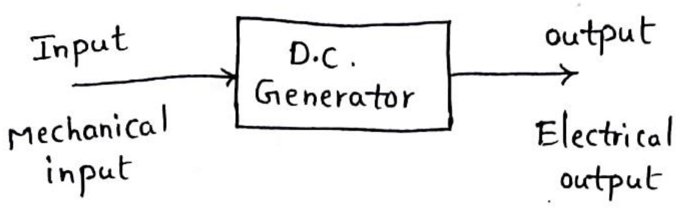


**Fig. 4.1**

2. DC Motor

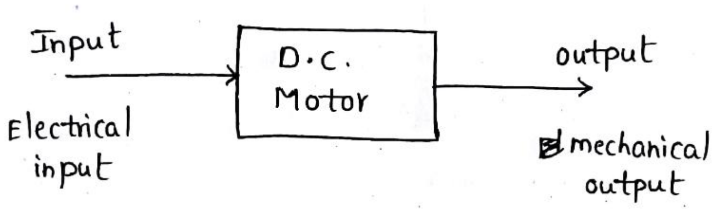


**Fig. 4.2**

DC Generator Converts Mechanical energy into Electrical Energy as shown in **Fig. 4.1.**

DC Motor Converts Electrical energy into Mechanical Energy as shown in **Fig. 4.2.**

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## DC Generator

**Generator Principle:**

**A set conductors being rotated in a steady magnetic field an E.M.F(Electro motive force)is induced in a set of conductors, which will cause a current to flow if the conductor circuit is closed, According to Faradays law's(First law) of electromagnetic induction.**

Therefore, the essential components of a generator are:

(a) A steady magnetic field
(b) Conductor or a group of conductors
(c) motion of conductor w.r.t. magnetic field.

An electric generator is a machine that converts mechanical energy into electrical energy.

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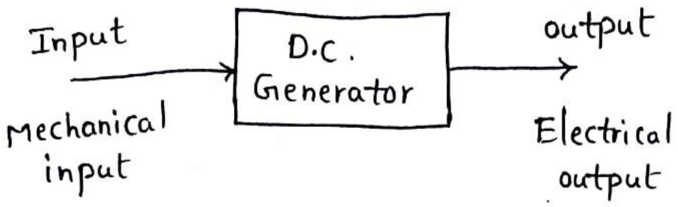


## Simple Loop D.C. Generator or Working of D.C Generator:

Consider a single turn loop ABCD rotating clockwise in a uniform magnetic field with a constant speed as shown in Fig.(4.3). As the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f. induced in these coil sides.

Explanation:

**(i) When the loop is in position no. 1** [See Fig. 4.3], the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

**(ii) When the loop is in position no. 2**, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 2 in Fig. (4.4).

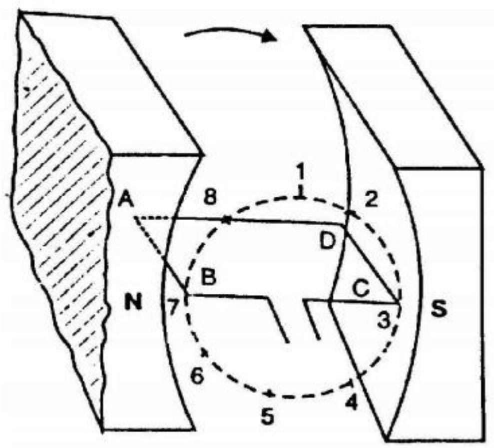


Fig 4.3

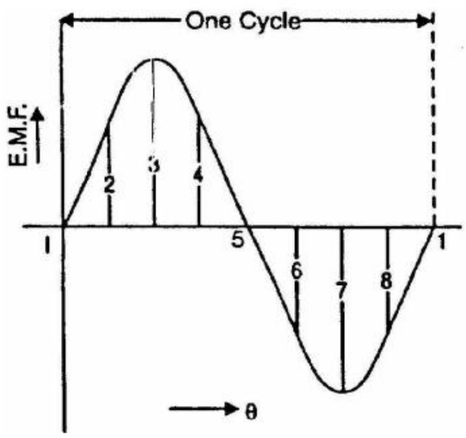


Fig 4.4

**(iii) When the loop is in position no. 3**, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate, the generated e.m.f. is maximum as indicated by point 3 in Fig. (4.4).

**(iv) When the loop is in position 4,** the generated e.m.f. is less because the coil sides are cutting the flux at an angle and, therefore, a low e.m.f. is generated as indicated by point 4 in Fig. (4.4).

**(v) When the loop is in position 5,** the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

**(vi) When the loop is in position 6**, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 6 in Fig. (4.4).

**(vii) When the loop is in position no. 7**, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate, the generated e.m.f. is maximum as indicated by point 7 in Fig. (4.4).

**(viii) When the loop is in position 8,** the generated e.m.f. is less because the coil sides are cutting the flux at an angle and, therefore, a low e.m.f. is generated as indicated by point 8 in Fig. (4.4).

Induced E.M.F $E_g \propto \Phi$ ( Magnetic flux)

$E_g \propto N$ ( Speed of the armature)

$E_g \propto Z$ ( Number of conductors)

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## Construction of D.C Machine or D.C. Generator or D.C. Motor

A DC Machine is a Electro-Mechanical Energy Conversion Device, which can be operated as a DC generator or DC motor. The d.c. generators and d.c. motors have the same general construction. Any d.c. generator can be run as a d.c. motor and vice-versa

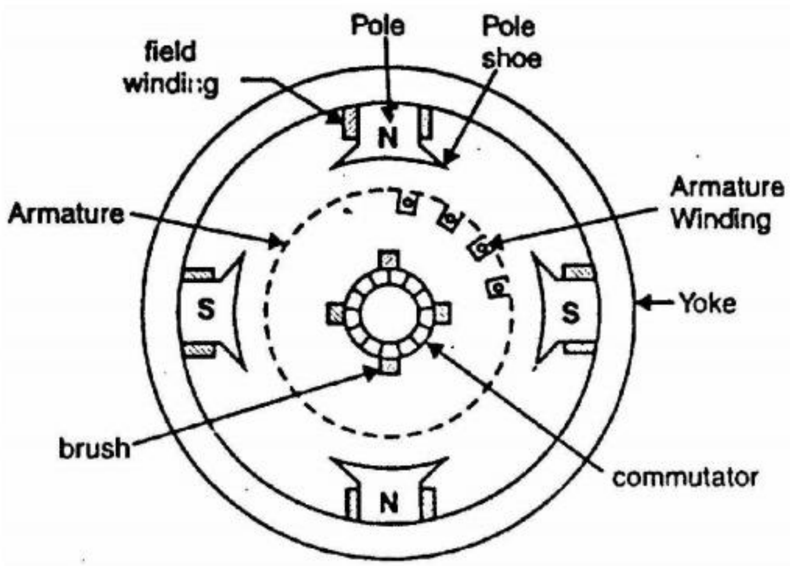


**Fig 4.5**

All d.c. machines have five principal components viz.,

(i) Yoke

(ii) Field system

(iii) Armature core

(iv) Armature winding

(v) Commutator

(vi) Brushes

## (i)Yoke

It is a stationary part.

- The outer frame of a dc machine is called as yoke.
- It is made up of cast **iron** or steel. It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding.
- Poles are joined to the yoke with the help of bolts or welding.

## (ii) Field system

It is a stationary part.

a) Field Poles b) Field winding c) Pole shoe

- The function of the field system is to produce uniform magnetic field.
- It consists of a number of salient poles (of course, even number) bolted to the inside of circular frame (generally called yoke).
- Field coils are mounted on the poles and carry the d.c. exciting current. The field coils are connected in such a way that adjacent poles have opposite polarity. The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame (See Fig. 4.6).
- Practical d.c. machines have air gaps ranging from 0.5 mm to 1.5 mm.

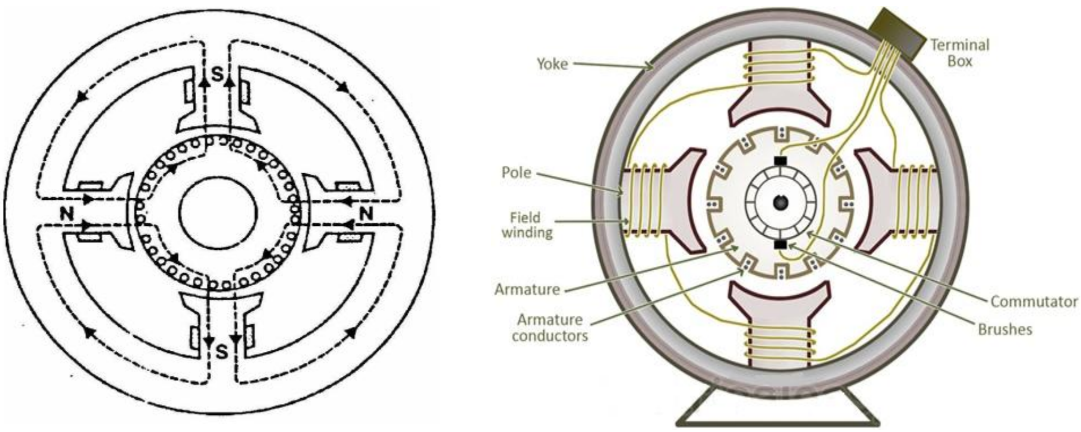


**Fig 4.6**

## (iii) Armature core

It is a rotating part.

- The armature core is keyed to the machine shaft and rotates between the field poles.
- Conductors are placed on armature slots.
- It consists of slotted soft-iron laminations (about 0.4 to 0.6 mm thick) that are stacked to form a cylindrical core as shown in Fig (4.7).

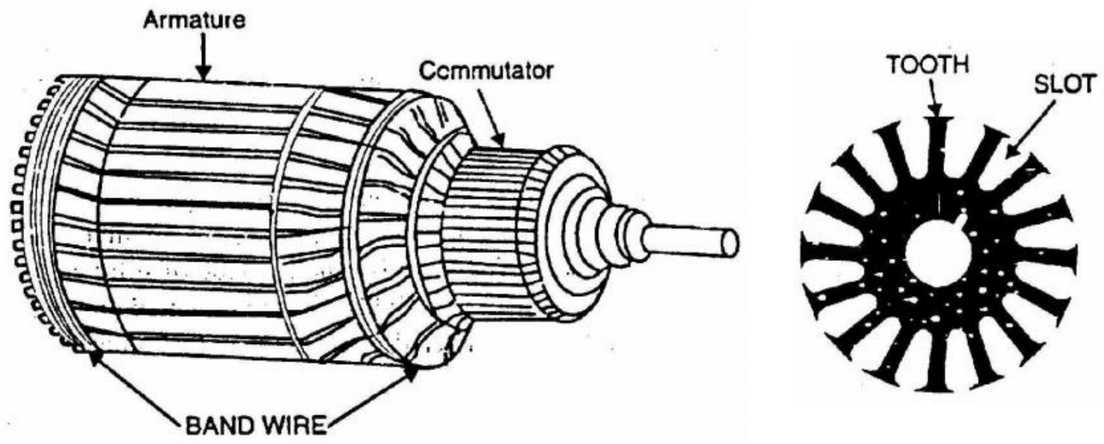


**Fig 4.7**

## (iv) Armature winding

It is a rotating part.

- The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding.
- This is the winding in which "working" e.m.f. is induced.
- The armature conductors are connected in series-parallel; the conductors being connected in series so as to increase the voltage and in parallel paths so as to increase the current.
- there are two types of armature winding in a d.c. machine viz.,
  (a) Lap winding
  (b) Wave winding.

## (v) Commutator

It is a rotating part.

Which converts AC to DC and DC to AC

- A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes.
- The commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine (See Fig 4.8).
- The armature conductors are soldered to the commutator segments in a suitable manner to give rise to the armature winding.

- Great care is taken in building the commutator because any eccentricity will cause the brushes to bounce, producing unacceptable sparking. The sparks may bum the brushes and overheat and carbonise the commutator.

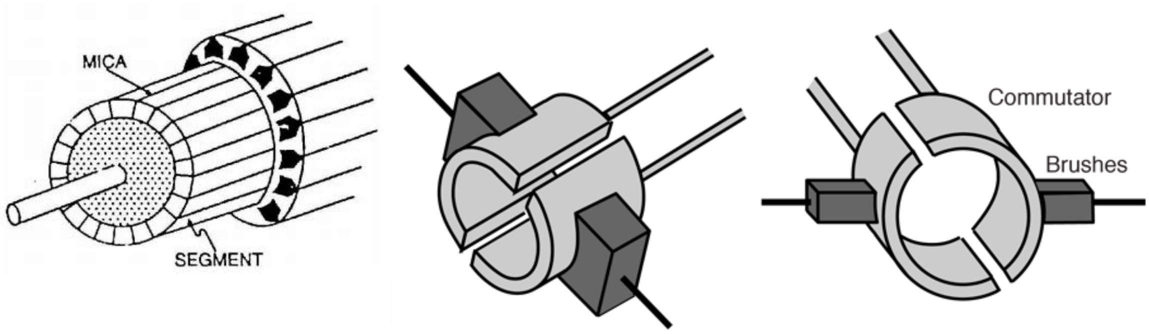


**Fig 4.8**

## (vi) Brushes

It is a stationary part.

- The purpose of brushes is to ensure electrical connections between the rotating commutator and stationary external load circuit.
- The brushes are made of carbon and rest on the commutator.
- The brush pressure is adjusted by means of adjustable springs (See Fig. 4.9).
- If the brush pressure is very large, the friction produces heating of the commutator and the brushes. On the other hand, if it is too weak, the imperfect contact with the commutator may produce sparking.

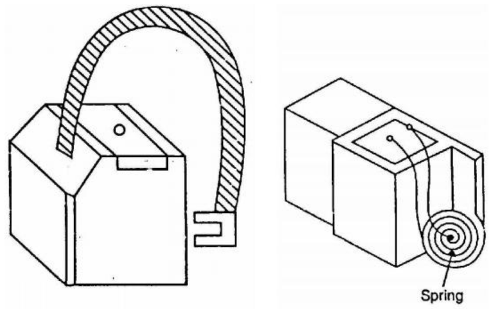


**Fig 4.9**

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## E.M.F. Equation of a D.C. Generator

Derive an expression for the e.m.f. generated in a d.c. generator.

Let $\Phi$= flux/pole in Wb
Z = total number of armature conductors
P = number of poles

N = speed of armature in r.p.m.
A = number of parallel paths A =2 ... for wave winding
= P ... for lap winding

Eg = e.m.f. of the generator = e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature,

$$d\,\Phi = P\,\Phi \text{ webers}$$

Time taken to complete one revolution,

$$dt = 60/N \text{ second}$$

e.m.f generated/conductor = $\dfrac{d\Phi}{dt} = \dfrac{P\Phi}{60/N} = \dfrac{P\Phi N}{60}$ Volts

e.m.f. of generator,
Eg = e.m.f. per parallel path
= (e.m.f generated/conductor) X No. of conductors in series per parallel path

= $\dfrac{P\Phi N}{60} X \dfrac{Z}{A}$

$$\mathbf{Eg} = \boldsymbol{\frac{\Phi Z N}{60} X \frac{P}{A}\ Volts}$$

where A = 2 for-wave winding

= P ... for lap winding

NOTE: Induced E.M.F $E_g \propto \Phi$ ( Magnetic flux)

$E_g \propto N$ ( Speed of the armature)

$E_g \propto Z$ ( Number of conductors)

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## Types of D.C. Generators

Generators are generally classified according to their methods of field excitation.

D.C. generators are divided into the following two classes:
(1) Separately excited d.c. generators
(2) Self-excited d.c. generators

(a) Series generator;
(b) Shunt generator;
(c) Compound generator

(i) Short shunt compound generator
(ii) Long shunt compound generator

**(1) Separately Excited D.C. Generators**

A d.c. generator whose field magnet winding is supplied from an independent external d.c. source (e.g., a battery etc.) is called a separately excited generator.

The voltage output depends upon the speed of rotation of armature and the field current. The greater the speed and field current, greater is the generated e.m.f.

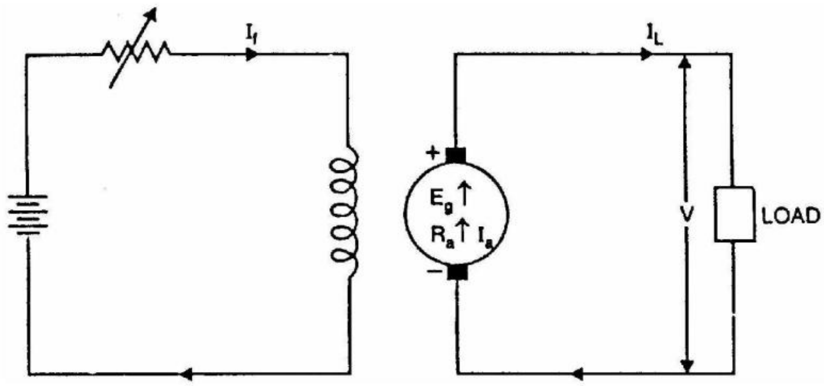


**Fig 4.10**

Apply KVL to right side circuit in fig 4.10

**e.m.f. of the generator $E_g = V_L + I_aR_a$**

Armature current, $I_a = I_L$

Electric power developed $P_d = E_gI_a$

Power delivered to load $P_L = V_LI_a$

## (2)Self-Excited D.C. Generators

A D.C. generator whose field magnet winding is supplied current from the output of the generator itself is called a self-excited generator.

There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely;
(a) Shunt generator
(b) Series generator
(c) Compound generator

i) Short shunt compound generator
(ii) Long shunt compound generator

## (a) Shunt generator

In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it.

The shunt field winding has many turns of fine wire having high resistance. Therefore, only a part of armature current flows through shunt field winding and the rest flows through the load.

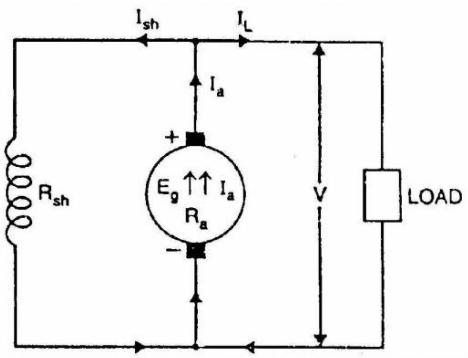


**Fig 4.11**

Apply KVL to the circuit shown in fig 4.11

**e.m.f. of the generator $E_g = V_L + I_a R_a$**

According to KCL, Armature current, $I_a = I_L + I_{sh}$

Shunt field current, $I_{sh} = V/R_{sh}$

Electric power developed $P_d = E_g I_a$

Power delivered to load $P_L = V_L I_L$

$R_{sh}$—Shunt field resistance

Shunt field winding have more number of turns and thin wire

### (b) Series generator

In a series wound generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as the load.

Since the field winding carries the whole of load current, it has a few turns of thick wire having low resistance.

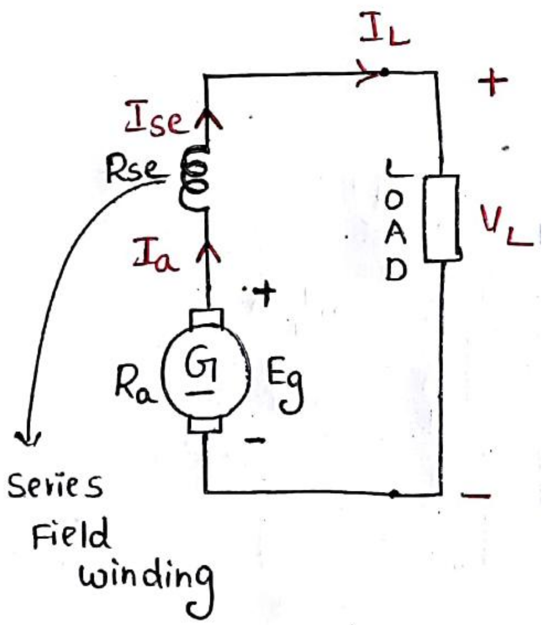


**Fig 4.12**

Apply KVL to the circuit shown in fig 4.12

**e.m.f. of the generator $E_g = V_L + I_a (R_a+R_{se})$**

Armature current, $I_a = I_{se} = I_L$

Electric power developed $P_d= E_gI_a$

Power delivered to load $P_L= V_LI_L$

$R_{se}$—Series field resistance

Series field winding have more less of turns and thick wire

Applications: Boosters

### (c) Compound generator

In a compound-wound generator, there are two sets of field windings on each pole—one is in series and the other in parallel with the armature.

### (i) Short shunt compound generator

In which only shunt field winding is in parallel with the armature winding.

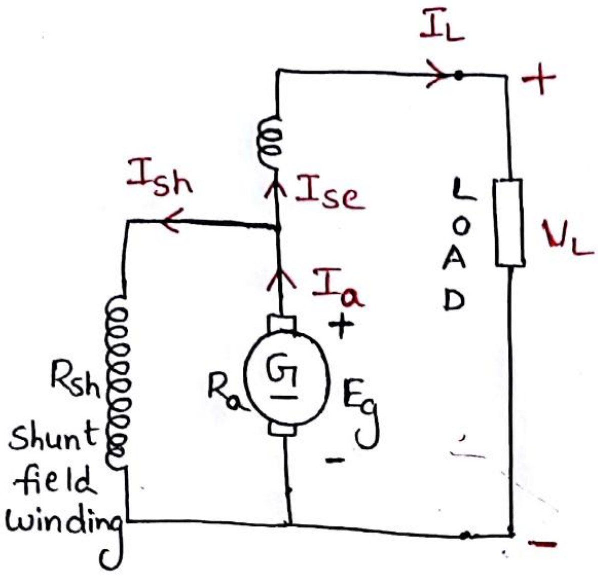


**Fig 4.13**

Apply KVL to the circuit shown in Fig 4.13

**e.m.f. of the generator $E_g = V_L + I_a R_a + I_{se}R_{se}$**

Series field current, $I_{se} = I_L$

Apply KCL to the circuit

Armature Current $I_a = I_{se} + I_{sh}$

Apply KVL to the circuit

$$-V + I_{se}R_{se} + I_{sh}R_{sh} = 0$$

Shunt field current, $I_{sh} = \frac{V_L + I_{se}R_{se}}{R_{sh}}$

Power developed in armature = $E_g I_a$

Power delivered to load = $V_L I_L$

### (ii) Long shunt compound generator

In which shunt field winding is in parallel with both series field and armature Winding.

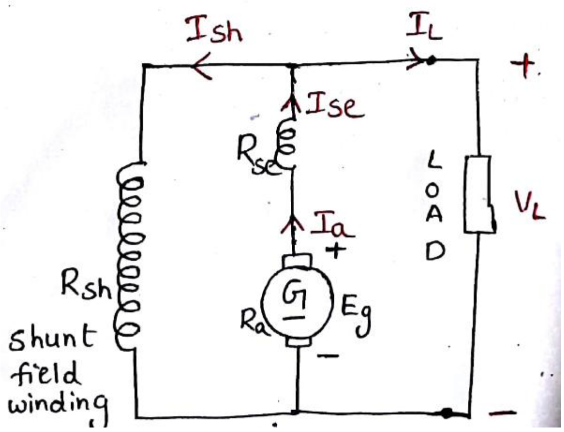


**Fig 4.14**

Series field current, $I_{se} = I_a = I_L + I_{sh}$

Shunt field current, $I_{sh} = V/R_{sh}$

Apply KVL to the circuit in Fig 4.14

**e.m.f. of the generator $E_g = V + I_a\,(R_a + R_{se})$**

Power developed in armature = $E_g I_a$

Power delivered to load = $V_L\, I_L$

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## Characteristics of DC generators

Important characteristics of a d.c. generator:

1. Open Circuit Characteristic (O.C.C.) ($E_g$ versus $I_f$)
2. Internal or Total characteristic ($E_g$ versus Ia)
3. External characteristic ($V_L$ versus $I_L$)

### Characteristics of a Separately Excited D.C. Generator

### 1. Open Circuit Characteristic

The field winding of the d.c. generator (series or shunt) is disconnected from the machine and is separately excited from an external d.c. source as shown in Fig. 4.15.

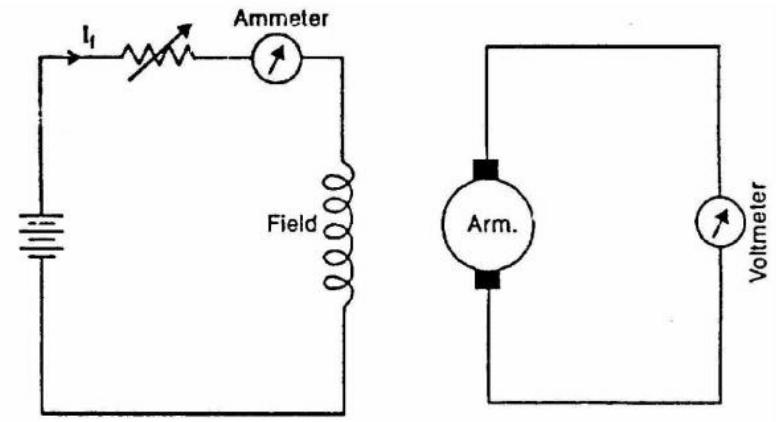



**Fig 4.15**

The generator is run at fixed speed. The field current ($I_f$) is increased from zero in steps and the corresponding values of generated e.m.f ($E_0$) read off on a voltmeter connected across the armature terminals. On plotting the relation between $E_0$ and $I_f$, we get the open circuit characteristic as shown in Fig. 4.16.

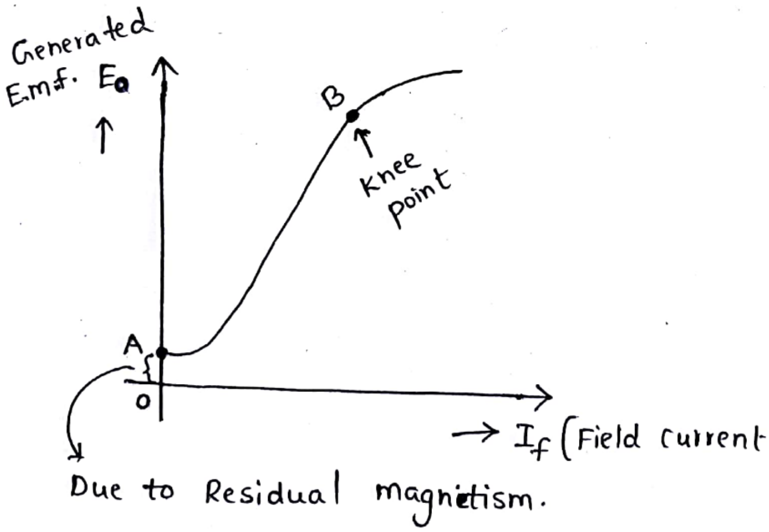



**Fig 4.16**

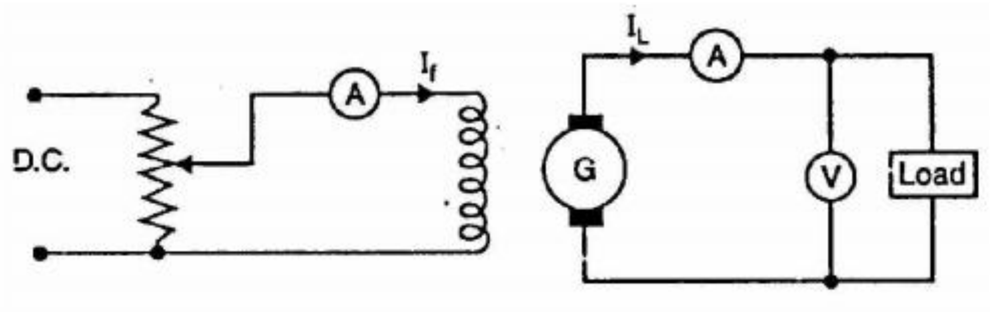
Knee point: The point at which saturation starts.

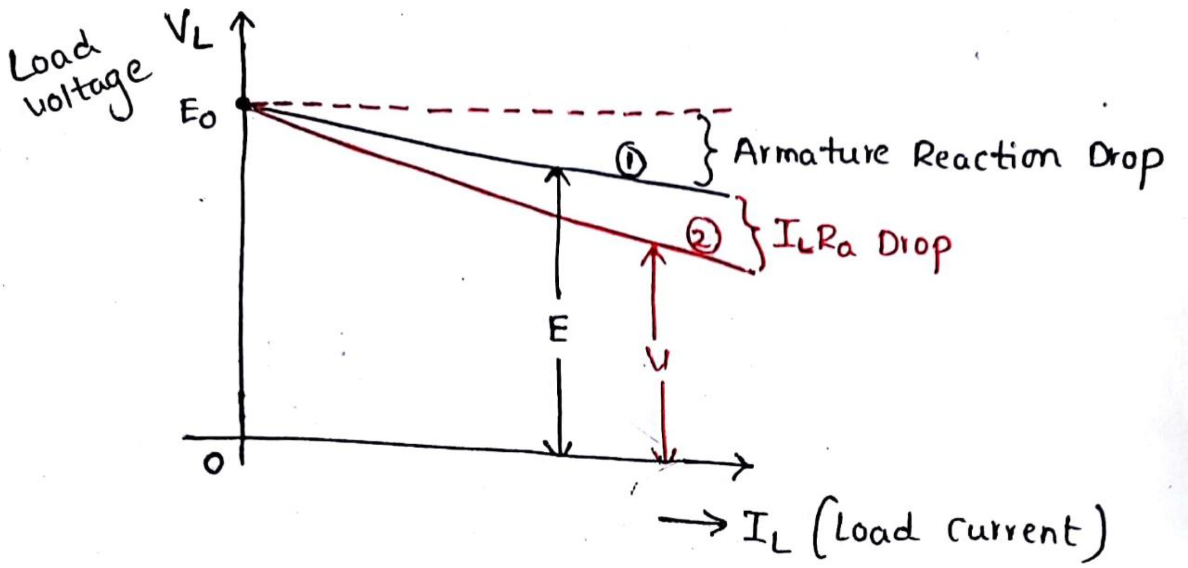
### 2. Internal and External Characteristics

The external characteristic of a separately excited generator is the curve between the terminal voltage ($V_L$) and the load current $I_L$ in Fig 4.17(Curve 2).

As the load current increases, the terminal voltage falls due to two reasons:
(a) The armature reaction

(b) There is voltage drop across armature resistance ($= I_L R_a = I_a R_a$).




Curve 1-- Internal characteristics
Curve 2-- External characteristics
**Fig 4.17**

The internal characteristic can be determined from external characteristic by adding $I_L R_a$ drop to the external characteristic.

# DC Motor

Referring to the Fig 4.2, DC Motor Converts Electrical energy into Mechanical Energy.

## Working Principle of DC Motor

## Principle

"whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force". The direction of this force is given by Fleming's left-hand rule and its magnitude is given by F = BIL. Where, B = magnetic flux density, I = current and L = length of the conductor within the magnetic field.

**Fleming's left hand rule:** If we stretch the first finger, second finger and thumb of our left hand to be perpendicular to each other, and the direction of magnetic field is represented by the first finger, direction of the current is represented by the second finger, then the thumb represents direction of the force experienced by the current carrying conductor.

## Working

Consider that the armature has only one coil which is placed between the magnetic field shown below in the Fig 4.18. When the DC supply is given to the armature coil the current starts flowing through it. This current develops their own field around the coil. Fig 4.19 shows the field induces around the coil. Where MNA is the Magnetic Neutral Axis.

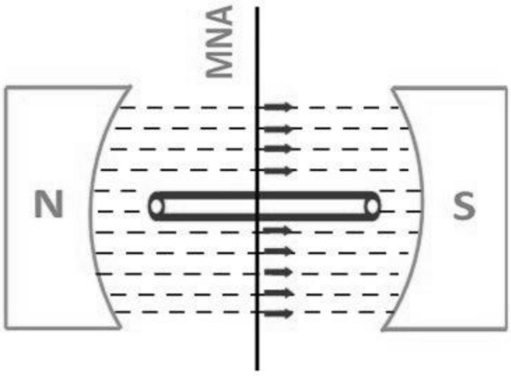



**Fig 4.18**

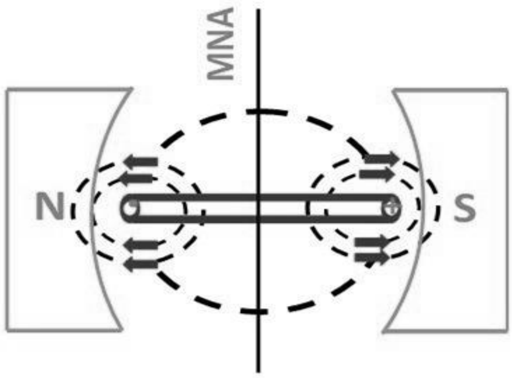



**Fig 4.19**

By the interaction or superimposing both Fig 4.18 and 4.19 of the fields (produces by the coil and the magnet), resultant field develops across the conductor. The resultant field tends to regain its original position, i.e. in the axis of the main field. The field exerts the force at the ends of the conductor, and thus the coil starts rotating shown in the Fig 4.20.

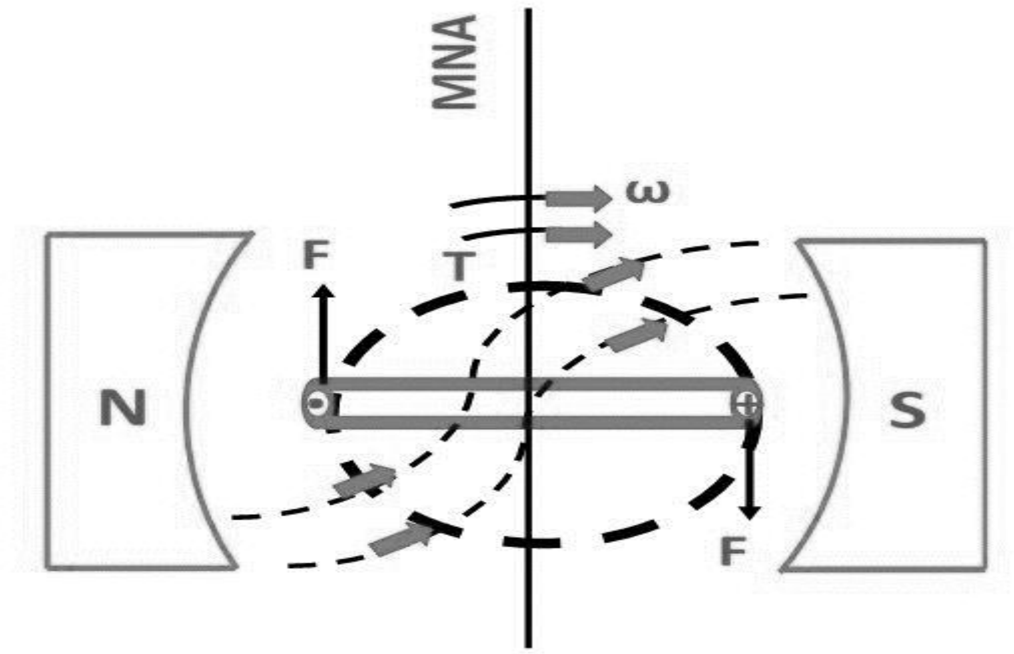



Fig 4.20

Therefore the torque acts on the armature, torque is nothing but an twisting force acts on the armature.

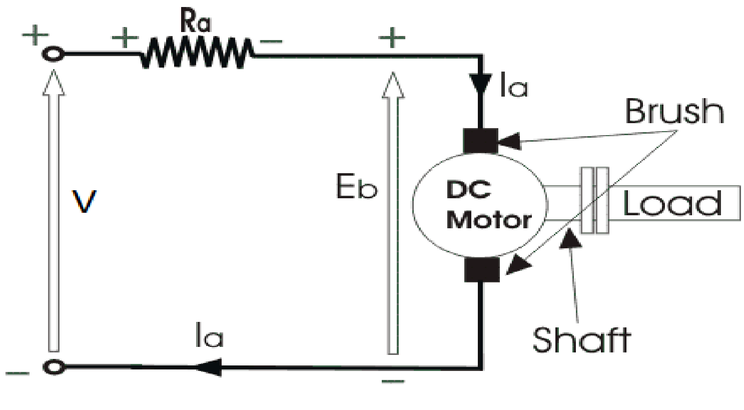



Fig 4.21

## Back EMF or Counter EMF

When the motor armature rotates, the armature conductors will cut the flux and an EMF is induced.

The direction of this induced EMF is opposite to the applied voltage (V) shown in Fig 4.21. so, it is called Back emf or Counter emf ($E_b$). Basically it gets generated by the generating action so the magnitude is generated emf equation.

$$\textbf{Eg or } E_b = \frac{\Phi Z N}{60} X \frac{P}{A} \text{ Volts}$$

Where the terms $E_b$ is Back EMF

We can write $E_b = V - I_aR_a$ from the Fig 4.21 by Applying KVL

Where $R_a$ = Armature Resistance

$I_a$ = Armature Current

The effective mechanical power is $E_b * I_a$

Significance of Back EMF

The significance of Back Emf is, it acts as a governor i.e it makes motor self regulating. So that it draws much current as necessary.

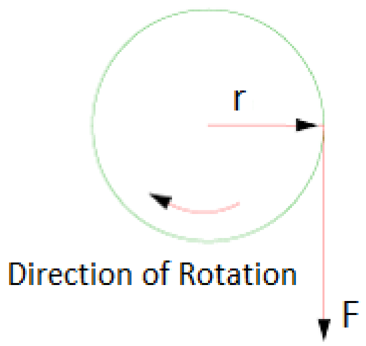
## Torque Equation of DC Motor

Torque is defined as the force acting or twisting or tuning about an axis

Consider a force F acting circumferentially on a pulley of radius R.

The equation of torque is given by,

$T = F * R$ N-m




Work done by the force in one revolution,

W.D = F x $2\pi r$ Joules

Power developed in the process is W.D/ Sec

Therefore, W.D/Sec = $F * 2\pi r * \frac{N}{60}\frac{J}{Sec}\, or\, Watt$

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

$$= T * \omega$$

The mechanical power Pm is related to the electromagnetic torque $T_g$ as,

$P_m = T_g * w$ …….. (1)

and the true effective mechanical power that is required to produce the desired torque of DC machine is given by,

$$P_m = E_b * I_a \ldots\ldots (2)$$

Equating (1) and (2)

$T_g * w = E_b * I_a$ …… (3)

Now for simplifying the torque equation of DC motor we substitute.

$$E_b = \frac{\Phi ZN}{60} X \frac{P}{A} \ldots\ldots (4)$$

Where, P is no of poles,

φ is flux per pole,

Z is no. of conductors,

A is no. of parallel paths,

and N is the speed of the DC motor.

Hence $w = \frac{2\pi N}{60}$ ...... (5)

Substituting equation (4) and (5) in equation (3), we get

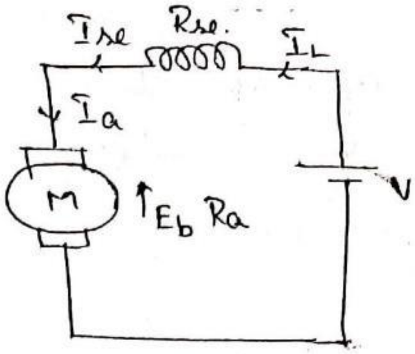
$$\therefore \; \boldsymbol{T_g} = \frac{\boldsymbol{PZ\varphi I_a}}{\boldsymbol{2\pi A}} \textbf{ N-m}$$

## Types of DC Motor

A Direct Current Motor, DC is named according to the connection of the field winding with the armature. Mainly there are two types of DC Motors. First, one is Separately Excited DC Motor and Self-excited DC Motor.

- Series Motor
- Separately Excited DC Motor or Shunt Motor
- Compound Motor – i. Long shunt Motor ii. Short Shunt Motor

## Series Motor




$R_{se}$ is very small &

It is made of small number of turns having large cross sectional area.

By using KCL

Current $I_L = I_a = I_{se}$

Using KVL

Voltage $V = E_b + I_a R_a + I_{se} R_{se} + B.D$

$= E_b + I_a(R_a + R_{se}) + B.D$ (brush drop)

Power $P = V I_L$

$$\boxed{\phi \propto I_{se} \propto I_a}$$

where $I_a$ - Armature current

$I_L$ - Load current

$I_{se}$ - Series current

B.D - Brush drop

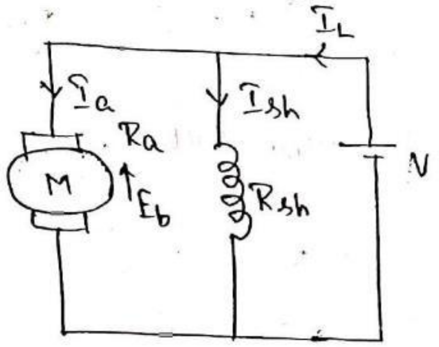
$R_a$ - Armature Resistance

$R_{se}$ - Series Resistance.

V - Applied Voltage.

$\phi$ - Flux.

## Shunt Motor




$R_a \rightarrow$ Armature Resistance.

$R_{sh} \rightarrow$ Shunt field wdg. or Shunt Resistance

The value of $R_a$ is very small while $R_{sh}$ is quite large. Hence shunt field winding has more no of turns with less cross sectional area.

Using KCL

$I_L = I_a + I_{sh}$

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

by using KVL

$$V = E_b + I_a R_a + B.D$$

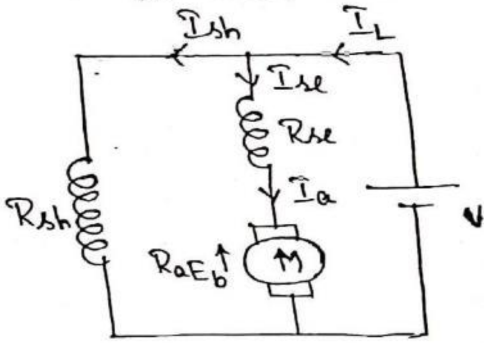
$$P = V I_L$$

$\boxed{\phi \propto I_{sh}}$ flux produced by field wdg is proportional to the current passing through it.

## Compound Motor

Mixing of both series & shunt field wdg. is compound Motor; These are Two types. (i) Long Shunt Motor (ii) Short Shunt Moto

(i) Long shunt




by using KCL

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

$$I_L = I_{se}.$$

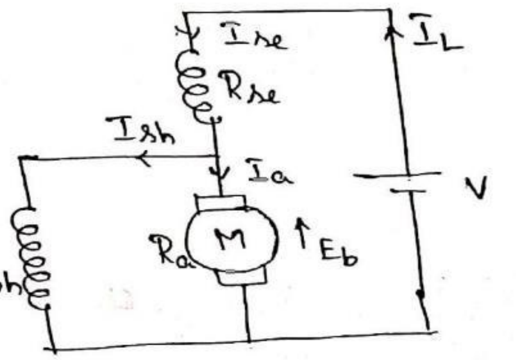
$$I_{sh} = \frac{V}{R_{sh}}$$

by using KVL

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

$$P = V I_L$$

Short shunt




$$I_L = I_{se}$$

Using KCL

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

Using KVL

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

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

$$P = VI_L$$

## Speed of DC Motor

We know that.

Back emf $E_b = V - I_a R_a$ —

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

$$\frac{\phi Z N}{60} \times \frac{P}{A} = V - I_a R_a.$$

$$N = \frac{V - I_a R_a}{\phi} \times \frac{60A}{PZ}$$

$$= \frac{E_b}{\phi} \times K$$

Where k is constant $k = \frac{60A}{PZ}$.

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

## Speed Relations

If a DC Motor has initial values of speed, flux, back emf as $N_1, \phi_1, E_{b1}$ & final values $N_2, \phi_2, E_{b2}$ Then.

$$N_1 \propto \frac{E_{b_1}}{\phi_1} \qquad N_2 \propto \frac{E_{b_2}}{\phi_2}.$$

(i) for a shunt motor, flux practically constant $(\phi_1 = \phi_2)$

$$\frac{N_1}{N_2} = \frac{E_{b_1}}{E_{b_2}}$$

(ii) for a Series motor, flux $\phi \propto I_a$.

$$\frac{N_1}{N_2} = \frac{E_{b_1}}{E_{b_2}} \times \frac{I_{a_2}}{I_{a_1}}$$

## Characteristics of DC Motor

There are Three imp Characteristics.

(i) Torque & Armature current characteristics $(T_a / I_a)$.

(ii) Speed & Armature current characteristic $(N / I_a)$.

(iii) Speed & Torque Characteristic $(N / T_a)$.

### $T_a / I_a$

It is a curve b/w armature torque & armature current. It is also known as Electrical characteristics.

### $N / I_a$

It is a curve b/w speed & armature current.

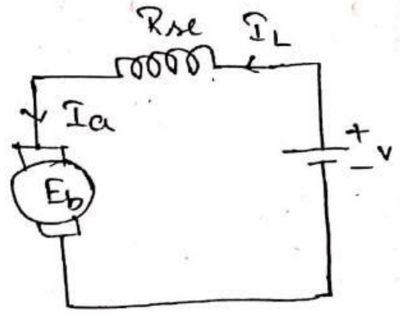
### $N / T_a$

It is a curve b/w speed & armature Torque.

It is also known as mechanical characteristics.

from this characteristic we can say which motor is selected for a particular Application.

## Series Motor




The current through field Wdg & Armature is same.

if the mechanical load ↑'s → $I_a$ ↑'s hence, the flux ↑'s with increase in $I_a$ & vice versa.

Load ↑ ⟶ $I_a$ ↑ ⟶ $\phi$ ↑.

Load ↓ ⟶ $I_a$ ↓ ⟶ $\phi$ ↓.

(i) $T_a / I_a$ Characteristic

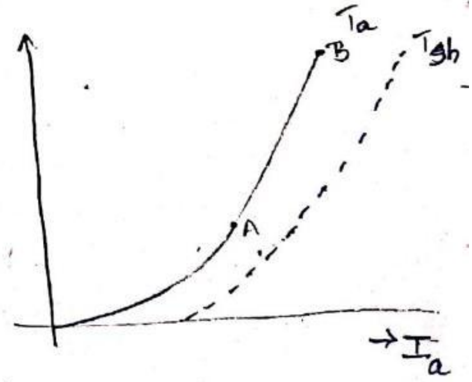
$T_a \propto \phi I_a$.

upto magnetic saturation, $\phi \propto I_a$, so that $T_a \propto I_a^2$

After magnetic saturation, $\phi$ is constant sothat $T_a \propto I_a$

upto magnetic saturation curve is parabola,

After the saturation $T_a \propto I_a$ so curve is linear.



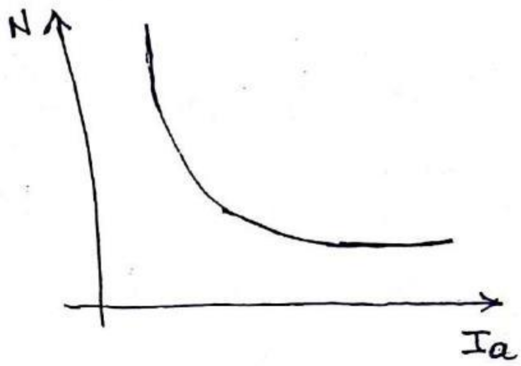
Since $T_a \propto I_a^2$, for small amount armature current high Torque is obtained.

So, Series motors are suitable for the applications which demand high starting Torque.

ii) $N / I_a$ characteristic

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

$$\propto \frac{V - I_a(R_a + R_{se})}{\phi}$$




When $I_a \uparrow$'s $\rightarrow E_b \downarrow \rightarrow \phi \uparrow$

$E_b \downarrow$ due to $I_a(R_a + R_{se})$. however drop is quite small under normal conditions may be neglected

Now, $N \propto \frac{1}{\phi}$

$\propto \frac{1}{I_a}$ $\quad (\because \phi \propto I_a)$

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

This is why series motor never start at No load.

$I_a \uparrow \rightarrow N \downarrow$ vice versa.

hence series motor is variable speed motor.

Used in Traction, cranes, conveyors etc

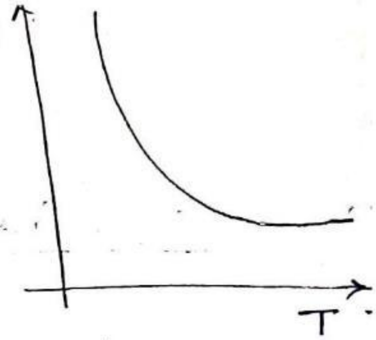
(iii) N | Ta characteristic

$$T_{sh} \propto \frac{o/p}{N}.$$

(or)

$$T \propto I_a^2 \quad \& \quad N \propto \frac{1}{I_a}$$

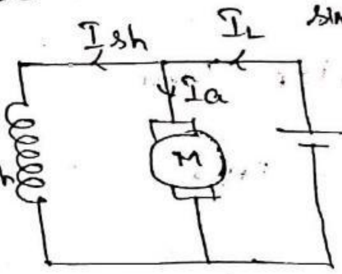
$$\text{Now, } N \propto \frac{1}{\sqrt{T}}$$




⇒ Torque ↓'s → ~~load~~ Speed ↑'s.

on no load, Torque is very less and hence speed increases dangerously.

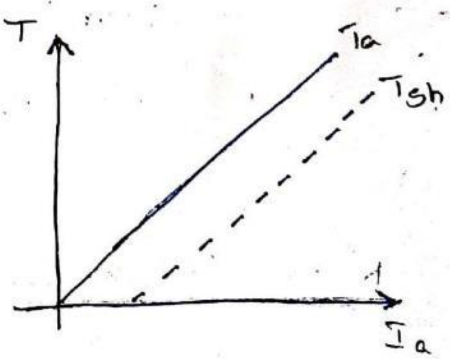
Shunt Motor or separately excited DC motor's i.e both are having similar char




The field current Ish is constant, since it is directly connected to supply voltage V which is assumed to be constant.

hence the $\phi$ is constant.

(i) T | Ia characteristic




$$T_a \propto \phi I_a.$$

$\because \phi$ is constant

$$T_a \propto I_a.$$

So characteristic is straight line from origin.

but shaft torque is less since due to armature reaction.

From the characteristic, it is clear that very large current is required to start a heavy load.

∴ Shunt motor should not be started on heavy load.

$T_a \rightarrow$ Armature Torque

$T_{sh} \rightarrow$ Shaft Torque.

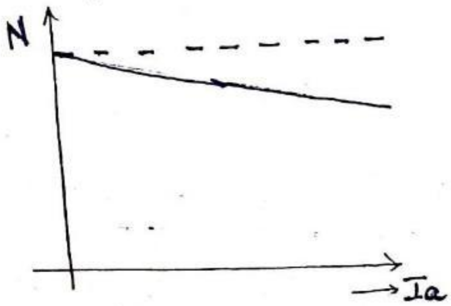
(ii) $N / I_a$ Characteristic

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

∵ $E_b$, $\phi$ is constant, ∴ speed will remain constant

But, when load is increased $E_b$ will decrease due to armature reaction so speed of motor decreases slightly

$$N \propto V - I_a R_a \quad (\because \phi \text{ const})$$



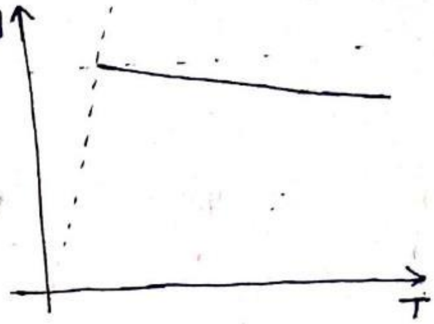

Hence shunt motor is a constant speed motor. Used in wood working M/c's, pumps, lathes etc.

(iii) $N / T_a$ Characteristic

$$T \propto I_a \quad \& \quad N \propto \frac{E_b}{\phi}$$

$\phi$ constant

$N \propto \frac{1}{T}$




speed is constant, Though torque changes from no load to full load.

## Compound motors

It has both series & shunt field.

The shunt field is always stronger than the series field.

Two types.

(i) Cumulative → series field aids shunt field

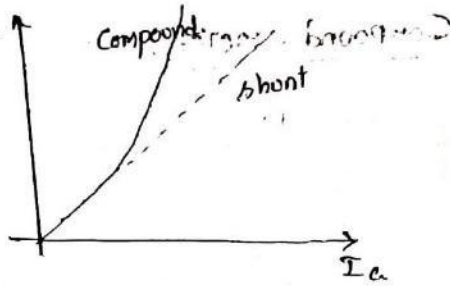
(ii) Differential → Series field opposes shunt field.

Differential compound motors are rarely used due to their poor Torque characteristics. & heavy loads.

Cumulative motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

(i) $T_a | I_a$

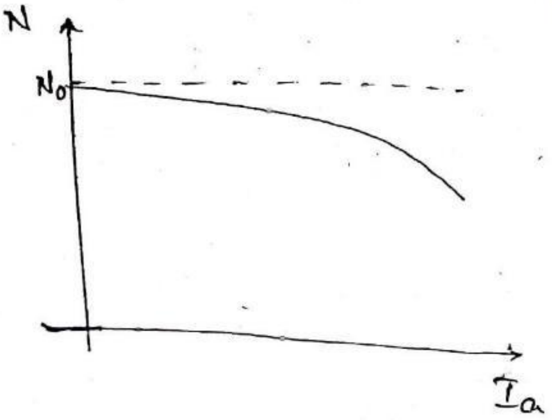
As load Increases, series field increases but shunt field strength ~~increases~~ remains Constant. Therefore, total flux is increased & the armature Torque ($\because T_a \propto \phi I_a$). So, the torque of cumulative compound motor is greater than shunt motor.




(ii) $N | I_a$

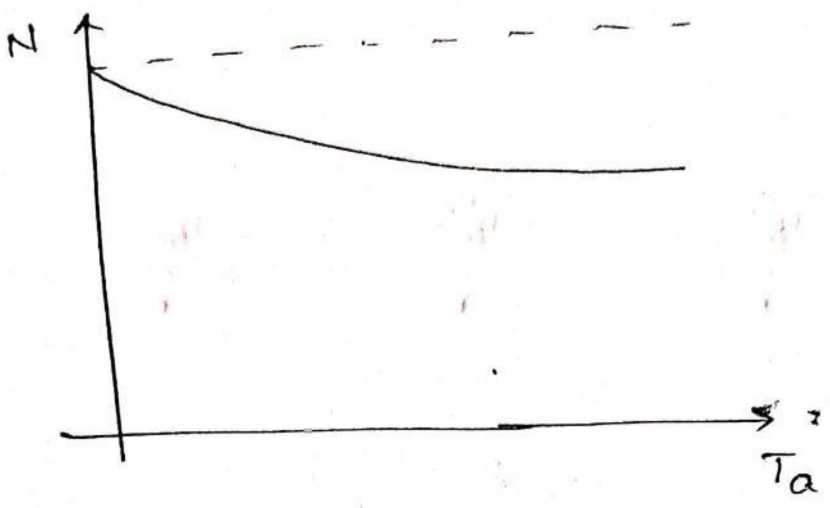
As load increases, the flux per pole also increases. Therefore, the speed $\left(N \propto \frac{1}{\phi}\right)$ of the motor falls as load increases.

$N_0 \rightarrow$ No load Speed.




(iii) $N | T_a$

For a given armature current, the torque of a cumulative compound motor is more than that of a shunt motor but less than that of a series motor.


N
$T_a$

## Speed control of DC Motors

### factors affecting the Speed of DC Motor

The speed of DC motor is given by

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

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

but the value of $R_a$ & series field resistance $R_{se}$ is very small, The drop $I_a R_a$ & $I_a(R_a + R_{se})$ is very small compared to applied voltage

Hence, the equation $\boxed{N \propto \frac{V}{\phi}}$

The factors affecting the speed is

(i) By varying the flux per pole ($\phi$). This is know as flux control Method.

(ii) By varying the resistance of armature, ~~or voltage~~ is called armature control M/d.

(or)

Changing the applied voltage called voltage control

To change the speed as per the requirements, it is not possible to increase the voltage or currents beyond certain limit. These limits are called ratings of motor.

## Speed control of DC Series Motor

Speed control of DC series motor can be obtained by (i) flux control M/d.

(ii) Armature resistance control M/d.

### Flux Control Method

In this M/d the flux produced by the series motor is varied & hence the speed. The variation of flux is achieved by

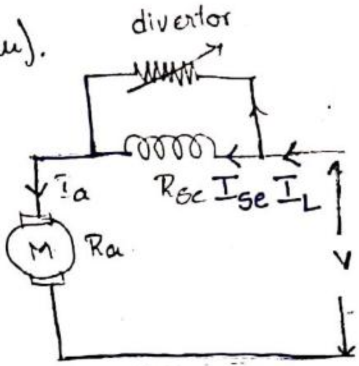
(i) Field Diverter Method

(ii) Armature Diverter Method.

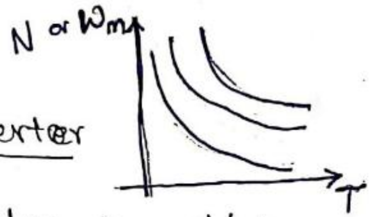
### i) Field Diverter Method

In this M/d, a variable resistance is connected in parallel with series field winding.

Its effect is to shunt some portion of the line current from the series field, weaking the field & Increasing the speed ($\because N \propto 1/\phi$). The lowest speed obtainable is that corresponding to zero current in the diverter (i.e diverter is open).

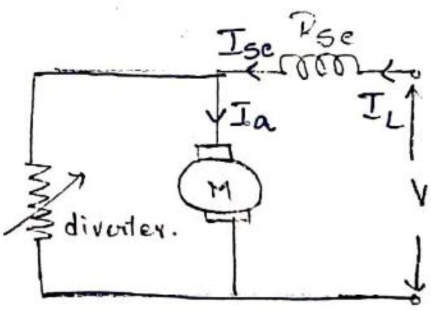



This M/d can only provide speeds above the Normal Speed.




(ii) Armature diverter

In order to obtain speeds below the Normal speed, a variable resistance is connected in parallel with the armature. The diverter shun some of the line current, thus reducing the armature current. if $I_a$ is decreased, the flux $\phi$ must increase. ($N \propto 1/\phi$), the motor speed is decreased vice versa.

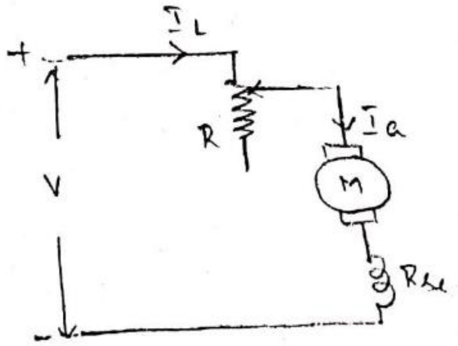


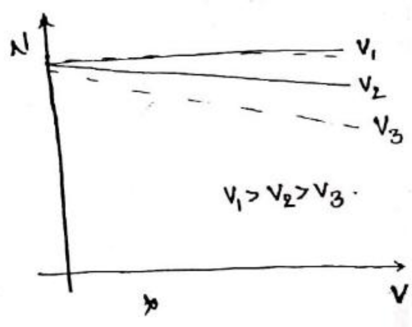
Armature Resistance M/d.

## Armature Resistance Control M/d

In this M/d, a variable resistance is connected in series with the Motor. As this resistance is varied, the voltage drop occurs. This reduces voltage across the armature. hence ($N \propto V$) the speed reduces. Vice versa.

By changing the value of variable resistance, any speed below the Normal speed can be obtained.



## Speed control of Dc Shunt Motor

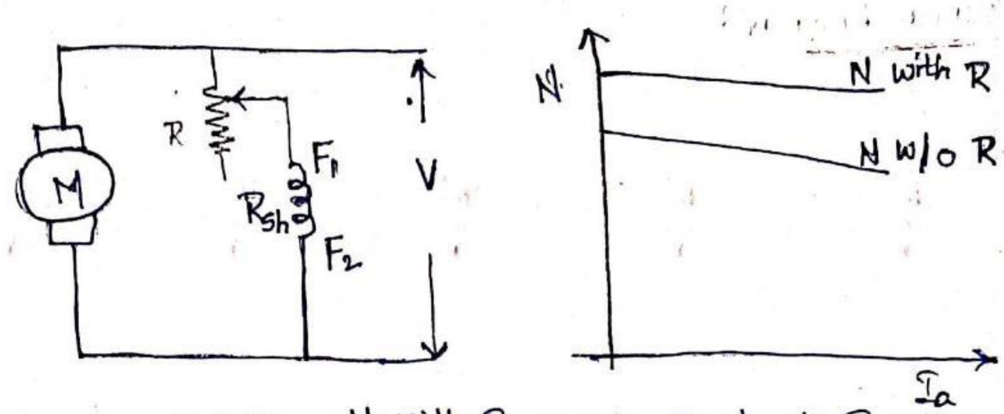
Speed control of DC shunt motor can be obtained by

(i) flux control M/d

(ii) Armature Resistance control M/d.

### (i) flux control M/d

It is based on varying flux $\phi$, The flux is dependent on the current through the shunt field winding. Thus flux can be controlled by adding a rheostat in series to the shunt field wdg ∴ hence by varying rheostat, flux changes, speed changes. When Resistance is at minimum, the voltage is rated value, the flux is rated value hence speed decreases $\left(N \alpha \frac{1}{\phi}\right)$ vice versa.

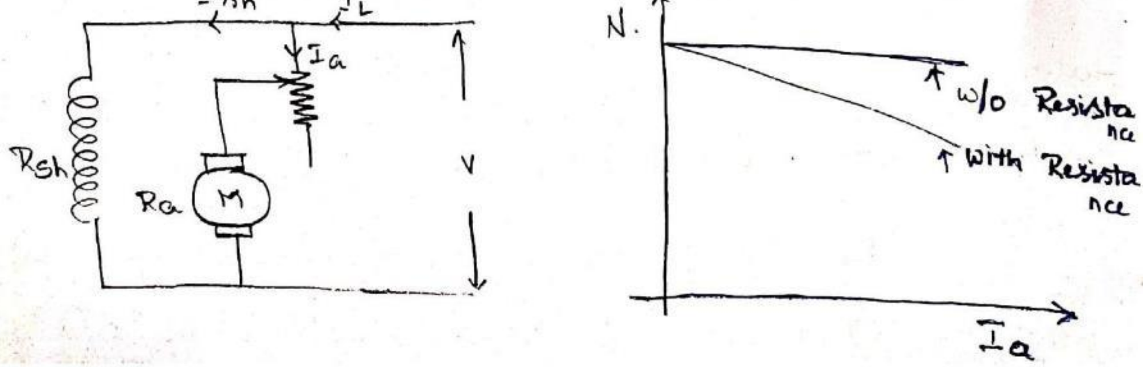



N with R Mean's Speed with Resistance
N w/o R Means Speed without Resistance

(ii) Armature Control M/d

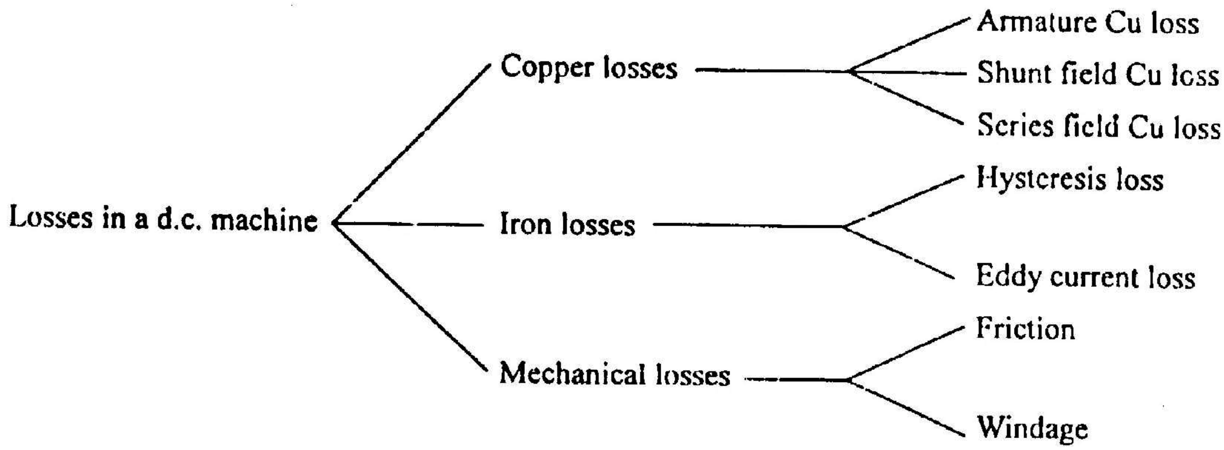
This M/d is based on varying the Voltage available across the armature, & hence the speed of the Motor can be changed. This is done by inserting a variable Resistance.

Initially the Rheostat position is minimum & rated voltage gets applield across the armature hence speed is also rated. When extra resistance is added in series to armature & there is a voltage drop across armature. Hence voltage decreases, speed decreases. below the normal speed.



## Losses in a D.C. Machine

The losses machine (generator or motor) be divided into three classes viz (i) copper losses (ii) iron or core losses and (iii) mechanical losses.




### 1. Copper losses

These losses occur due to currents in the various windings of the machine.

(i) Armature copper loss = $I_a^2 R_a$

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

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

### 2. Iron or Core losses

These losses occur in the armature of a machine and are due to the rotation of armature in the magnetic field of the poles.

### 3. Mechanical losses

These losses are due to friction and windage.
(i) friction loss e.g., bearing friction, brush friction etc.
(ii) windage loss i.e., air friction of rotating armature.

## Constant and Variable Losses

The losses in a d.c. generator (or d.c. motor) may be sub-divided into (i) constant losses (ii) variable losses.

### (i) Constant losses

Those losses in a d.c. generator which remain constant at all loads are known as constant losses. The constant losses in a d.c. generator are:
(a) iron losses
(b) mechanical losses
(c) shunt field losses

### (ii) Variable losses

Those losses vary with load are called variable losses.

The variable losses in a d.c. generator are:

(a) Copper loss in armature winding

(b) Copper loss in series field winding

$$\text{Total losses} = \text{Constant losses} + \text{Variable losses}$$