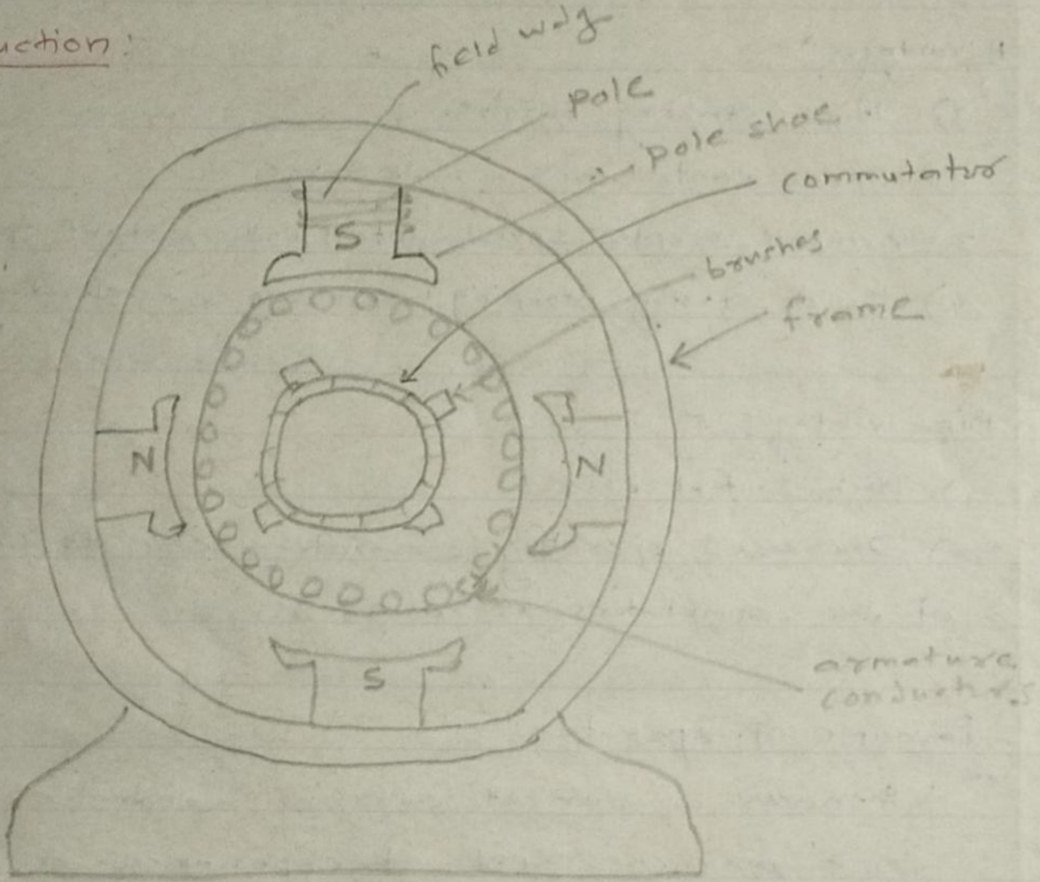
# Direct Current (D.C.) Motor:

## Introduction:

→ The electric motor is a machine which converts electric energy into mechanical energy. It depends for its operation on the force which is known to exist on a conductor carrying current while situated in a magnetic field.

## Construction:




→ Frame is a stationary part of a machine to which poles are fixed. (poles are bolted to its blade plate)

→ Armature: → Armature consists of core & winding
→ Iron is used as a material for core (being magnetic material)

Commutator: → Commutator converts alternating voltage to d.c. voltage (If generator). In motor it will convert pulsating torque to unidirectional torque.

**Brushes :-** To collect current from rotating armature or to feed current to it, brushes are used.

**Applications :-**

D.C. motors find extensive application in;

(i) steel plants (ii) Paper mills
(iii) Textile mills (iv) Printing presses
(v) Cranes (vi) Excavators etc.

**Advantages :-**

1) High starting torque
2) Speed control over a wide range
3) accurate stepless speed control with constant speed
4) Quick starting, stopping, reversing & accelerating

**Disadvantages :-**

1) High Initial cost
2) Increased operating & maintenance costs because of the commutators & brushgear.

**Principle of operation :-**

"Whenever a current carrying conductor is placed in a magnetic field, it experiences a force whose direction is given by Flemings left hand rule"

**Back or Counter emf :-**

In a d.c. motor when the armature rotates, the conductors on it cut the lines of force of magnetic field in which they revolve, so that an e.m.f. is induced in the armature as in a generator. The induced emf acts in opposition to the current in machine & ∝ to the applied voltage, so that it is customary to refer to this voltage as the 'back emf'.

$$\underline{E_b = K \cdot \phi \cdot N}$$

## Torque development in a motor:—

When the field of a machine is excited & a potential difference is impressed upon the machine terminals, the current in the arm. winding reacts with the air-gap flux to produce a turning moment or torque which tends to cause the armature to revolve

Let $T_a$ be the torque developed in N-m by the motor armature running at N rpm

Power developed = work done per second

$= T_a \times 2\pi N$ watts —— (i)

Electrical equivalent of mechanical power developed by the armature

$= E_b \cdot I_a$ watts —— (ii)

Equating (i) & (ii)

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

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

In generator,
$E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$
same is $E_b$ in motor

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

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

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

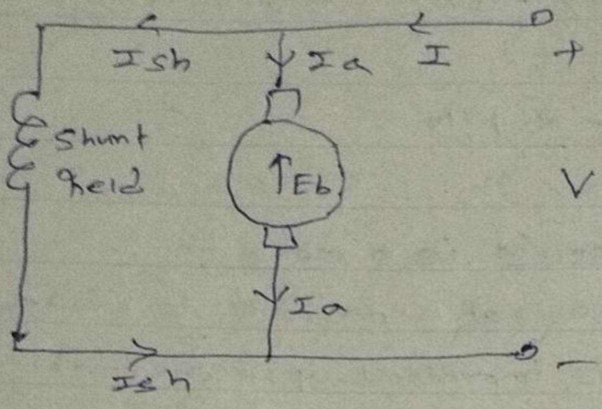
$$= 0.159 Z \phi P \times \frac{I_a}{A} \text{ const.}$$

$$\therefore \boxed{T \propto \phi \cdot I_a}$$

Series motors,
$\phi \propto I_a$
$T \propto I_a^2$

Shunt motor
$\phi$ is constant
$T \propto I_a$

## Mechanical Power developed by motor armature:




The voltage V applied across the motor armature has to (i) overcome back emf $E_b$

& (ii) supply the armature ohmic drop $I_aR_a$

$$V = E_b + I_aR_a$$

This is known as voltage eqn. of a motor multiplying both sides by $I_a$, we get.

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

Here $V \cdot I_a$ = electrical input to the armature

$E_b \cdot I_a$ = electrical equivalent of mechanical power $P_m$ developed in armature,

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

The power available at the pulley for doing useful work is somewhat less than the mechanical power developed by the armature. This is evident since there are certain mechanical losses (such as bearing & windage friction & iron losses) that must be supplied by the driving power of the motor.

**Shaft Torque** :- Torque developed by arm. is gross torque whole of this torque is not available at the pulley since certain % of $T_a$ is lost in overcoming friction & iron windage losses. $T_{sh}$ is shaft torque. Horse power obtained using shaft torque is called brake horse power (BHP)

$$BHP = T_{sh} \times 2\pi N / 735.5$$

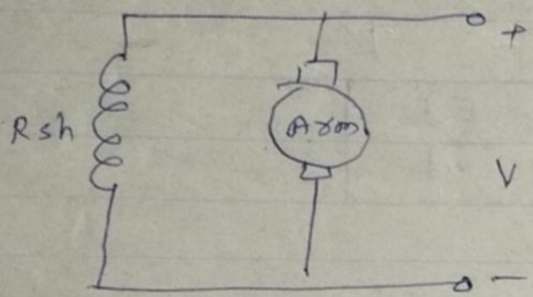
$$T_{sh} = 9.55 \times \frac{P_{out}}{N}$$

## Types of D.C. motors

There are three main types of D.C. motors characterized by the connection of the field wdg. in relation to the armature. These are:

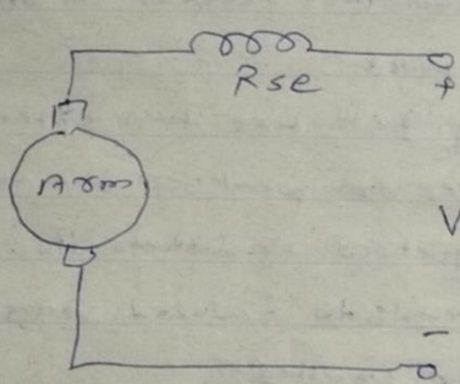
1. Shunt wound motor or shunt motor, in which field wdg. is connected in llel with the armature
2. Series motor, in which field wdg. is connected in series with the armature
3. compound motor, which has two field wdg.s one connected in llel & other in series with armature

### Shunt wound motor :—

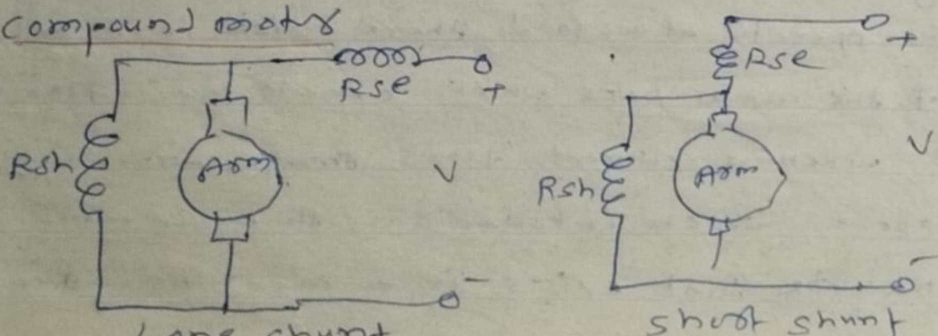



→ flux is const
→ back emf constant
→ speed is constant
⟹ constant speed motor

### Series wound motor :-




### compound motor



## Speed of a d.c. motor:-

we know that

$$V = E_b + I_a R_a$$

$$E_b = V - I_a R_a$$

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

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

but $V - I_a R_a = E_b$.

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

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

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

ope
res

## Characteristics of series motor:

① $T_a/I_a$ characteristic :-

We have seen that $T_a \propto \phi . I_a$

as field winding also carries armature current,

$$\phi \propto I_a$$

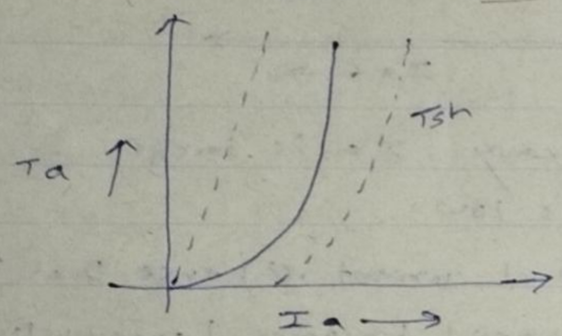
$$\therefore T_a \propto \phi . I_a$$

$$\propto I_a . I_a \propto I_a^2$$

$$\underline{T_a \propto I_a^2}$$

→ At light loads $I_a$ & hence $\phi$ is small. But as $I_a$ increases $T_a$ increases as the square of current.

Hence $T_a/I_a$ curve is a parabola.




→ After saturation $\phi$ is almost independent of $I_a$ hence $T_a \propto I_a$ only. So characteristic becomes a straight line.

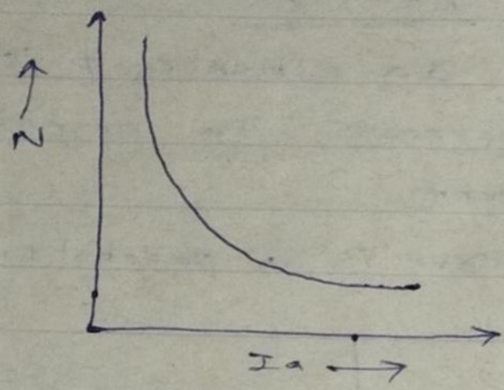
The shaft torque $T_{sh}$ is less than armature torque due to stray losses.

⟹ So we conclude that (prior to magnetic saturation) on heavy loads a series motor exerts a torque proportional to the square of the arm. current. Hence in cases where huge starting torque is required for accelerating heavy masses quickly as in hoists & electric trains etc series motors are used.

② N/Ia characteristic :-

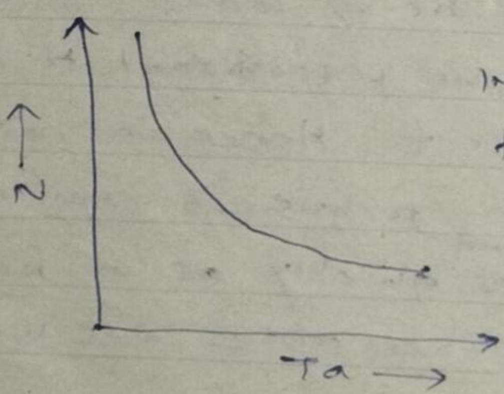
Variation of speed can be deduced from formula $N \propto \frac{E_b}{\phi}$.

Change in Eb for various load currents is small & hence may be neglected for the time being.
With increased Ia, $\phi$ also increases
Hence speed varies inversely as arm. current Ia




→ When load is heavy, Ia is large.
Hence speed is low
→ But when load current & hence Ia falls to a small value, speed becomes dangerously high
⇒ Hence a series motor should never be started without some mechanical load on it ~~or~~ otherwise it may develop excessive speed & get damaged due to heavy centrifugal forces so developed.

③ N/Ta characteristic :-




When speed is high, torque is low & vice-versa

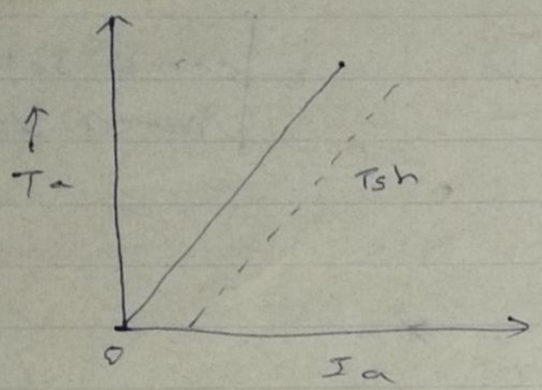
## Characteristic of shunt motors:-

1) Ta/Ia characteristic:-

Assuming $\phi$ to be practically constant

$$T_a \propto I_a$$

Hence electrical characteristic is practically a straight line through the origin.



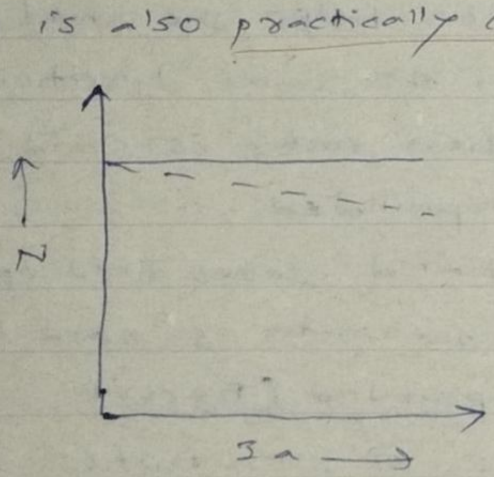

→ Since a heavy starting load will need a heavy starting current, shunt motor should never be started on heavy load.

(2) N/Ia characteristic:-

If $\phi$ is assumed constant then

$$N \propto E_b$$

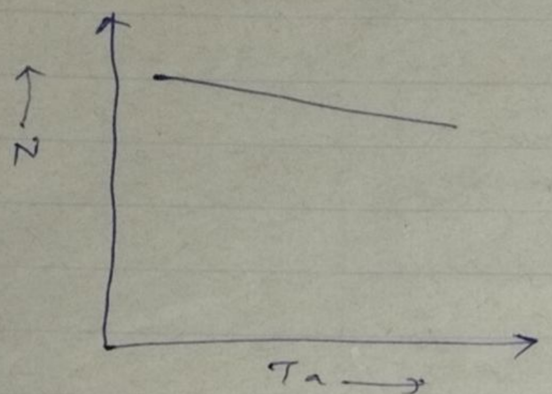
As $E_b$ is also practically constant, speed is constant




But strictly speaking both $E_b$ & $\phi$ decreases with increasing load. However $E_b$ decreases slightly more that $\phi$ so that one the whole, there is some decrease in speed.

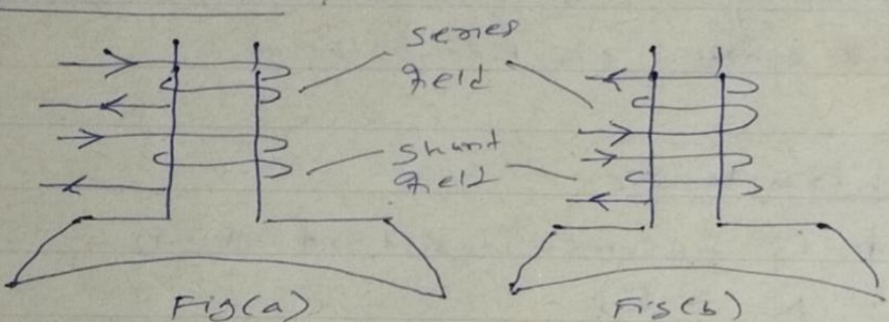
Due to constant speed, shunt motors are suitable for driving shafting, machine tools, lathes, wood-working machines & other purposes where constant speed is required.

3) N/Ta characteristic:-




can be deduced from (1) & (2) above.

Compound motors:-

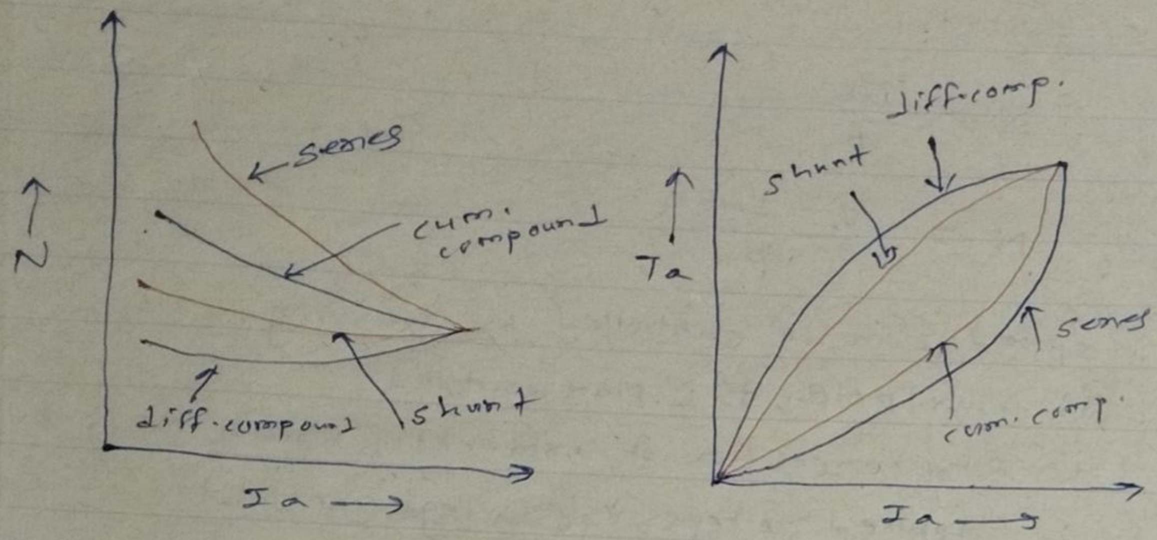



Fig(a) Fig(b)

If series excitation helps the shunt excitation i.e series flux is in the same direction [Fig(a)] as shunt flux then motor is said to be cumulatively compounded.

If on the other hand, series field opposes the shunt field, then the motor is said to be differentially compounded [Fig(b)].

The characteristics of such motors lie in between those of shunt & series motors




(a) Cumulative-compound motors:-

Such machines are used where series chara. are reqd. & where in addition the load is likely to be removed totally such as in some types of coal cutting machines or for driving heavy machine tools which have to take sudden cuts quite often. Due to shunt wdg.. speed will not become excessively high.

(b) Differentially compound motors:-

Since series field opposes the shunt field the flux is decreased as load is applied to the motor. This results in the motor speed remaining almost constant

Such motors are not in common use.

## Speed control of D.C. motors

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

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

∴ speed can be controlled by varying:

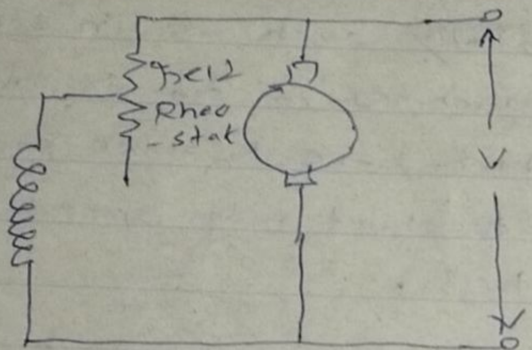
(i) Flux/pole, $\phi$ [Flux control]

(ii) Resistance $R_a$ of arm. ckt. [Rheostatic control]

(iii) Applied voltage, V (voltage control)

## Speed control of shunt motors:

(i) Flux control method:




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

→ by decreasing flux, speed can be increased & vice-versa

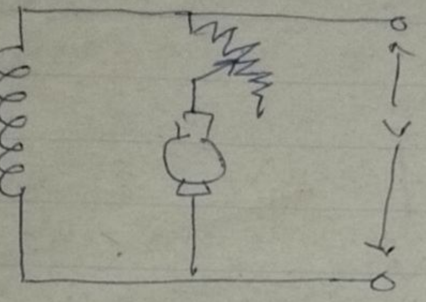
→ flux can be changed by changing $I_{sh}$ with the help of rheostat

→ $I^2R$ loss is more ($I_{sh}$ relatively small, hence rheostat has to carry more current)

(ii) Armature or Rheostatic control:

This method is used when speeds below no load speed are reqd.

→ A variable rheostat is inserted in series with arm. ckt.



(iii) Voltage control method:

Ward - Leonard method ⇒ old method.

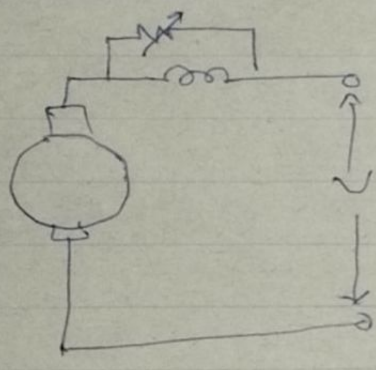
Read from book

Speed control of series motors:

(i) Flux control method:

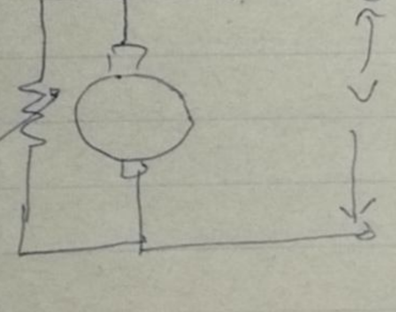
Variation of flux of series motor can be brought about by:

(a) Field diverters:



Series wdg. shunted by variable resistance known as field diverter

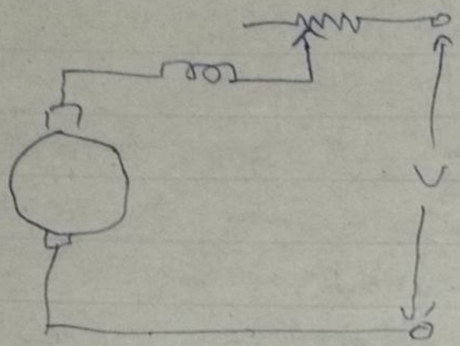
(b) Armature diverter:



A diverter across arm. can be used for giving speeds lower than normal speed.

(ii) variable resistance in series with motor:

By increasing resistance in series with arm voltage applied across arm. terminals can be decreased.




## Electronic speed control methods:-

All power electronics converters used methods will come under electronic speed control.

## Brushless D.C. motors:

> Conventional D.C. motors rely on mechanical commutation
- These motors have two principle problems
> First, they require periodic maintenance to repair & replace brushes
> Secondly, electric arcs produced by the mechanical commutator brush arrangement limit the operating speed & voltage of the motor

⇒ A motor that retains the characteristics of a D.C. motor but eliminates the commutator & the brushes is called a brushless d.c. motor (BLDC)

→ These motors use electronic commutators
→ An electronic commutator consists of thyristors & transistors & perform the function of its mechanical counterpart.

## Advantages:-

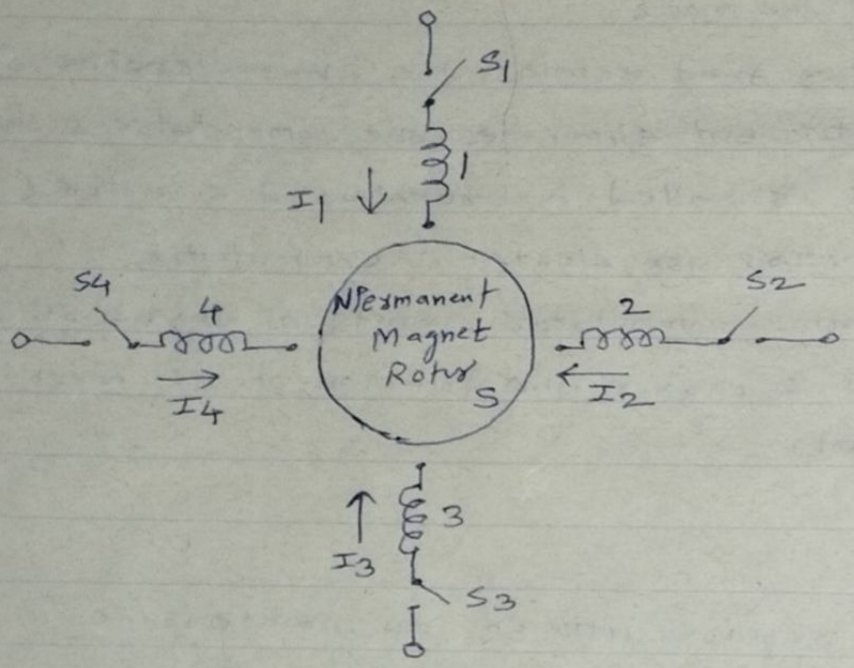
(i) They require little or no maintainance.
(ii) They have a longer operating life
(iii) There is no arcing in these motors so that possibility of explosion is eliminated.
(iv) These are generally more efficient than conventional D.C. motors
(v) They can be used in situations where combustible fluids & gases are present
(vi) They are very reliable & their efficiencies may exceed 75%
(vii) They are capable of rotating at speeds greater than 40,000 rpm.

## Disadvantages:

(i) For the same output power, they are more expensive than the conventional d.c. motors

(ii) They have greater overall size because additional equipment is reqd. for electronic commutation.

## Operating Principle:




→ A brushless D.C. motor consists of a multiphase winding wound on a non-salient stator & a permanent magnet (PM) rotor.

→ Direct voltage or alternating voltage is applied to the individual phase windings through a sequential switching operation to achieve the necessary commutation to impart rotation of the motor. The switching is done electronically using power transistors or thyristors

## Operation:

→ If winding 1 is energised, the PM rotor alligns with the magnetic field produced by winding 1.

→ When winding 1 is switched off & winding 2 is turned on, the rotor is made to rotate to line up with the magnetic field of winding 2

→ Thus by applying voltage to individual phase winding through a sequential switching circuitary, the motor rotation can be achieved

→ The control of the magnitude & the rate of switching of the phase currents essentially determine the speed-torque characteristic of a BLDC.

Applications:

→ Brushless D.C. motors are very popular in the biomedical & aerospace fields

→ Due to the high reliability & low maintenance requirement, these motors are used as artificial heart pump motors

→ In the aerospace industry, these are used in satellites, gyroscopes & robot systems

→ Other applications include video recorders, tape transport systems & disc drive motors