

## D.C Motors

### principle of operation :-

A machine that converts d.c power into mechanical power is known as a d.c motor. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of this force is given by Fleming's left hand rule and magnitude is given by.

$$F = BIl \text{ Newtons}$$

where,  $F$  = Force exerted on the conductor in Newtons.

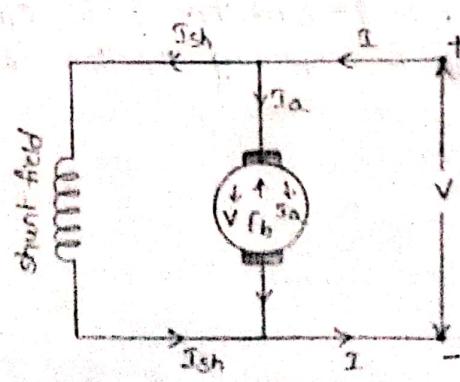
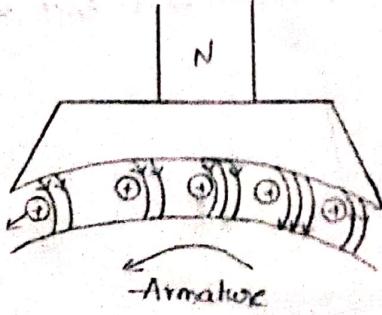
$B$  = Magnetic flux density ( $\text{wb/m}^2$ ).

$I$  = current in the conductor in amperes.

$l$  = length of the conductor.

### Energy conversion in D.C motor:-

Suppose the current is sent through the armature conductors of D.C machine, under north pole in the downward direction, as shown in fig. The conductors will experience a force in the anticlock wise direction. Hence the machine will start rotating anticlockwise, thereby developing a torque which produces mechanical rotation. Then the machine is said to be motoring. As said above the energy conversion is possible only if there is some opposition whose overcoming provides the necessary means for such conversion. In case of d.c motor it is the back emf  $E_b$  which provides necessary operation.

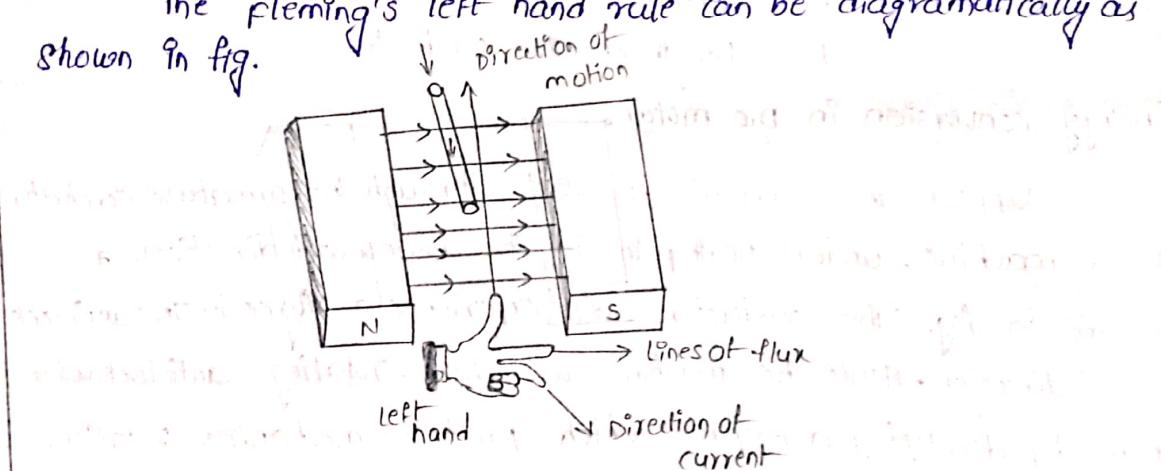


As the motor armature starts rotating dynamically induced emf is produced in the armature conductors, this emf is in direct opposition to the applied voltage. So it is called back emf.  $E_b = \phi N \left( \frac{P}{A} \right)$  volt. The applied voltage  $V$  has to force current through the armature conductors against this back emf  $E_b$ . The electric work done in overcoming this opposition is converted into mechanical energy.

### Fleming's left hand rule :-

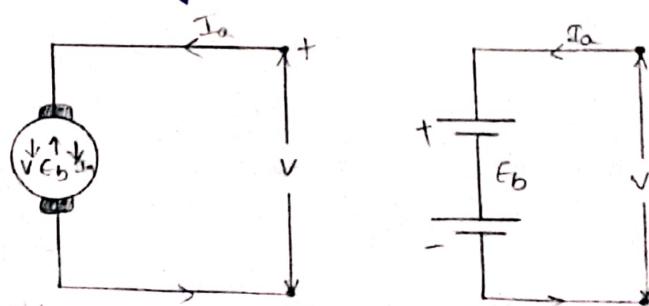
The rule states that, outstretch the three fingers of the left hand namely the first finger, middle finger and thumb such that they are mutually perpendicular to each other. Now point the first finger in the direction of magnetic field and the middle finger in the direction of the current then the thumb gives the direction of the force experienced by the conductor!

The Fleming's left hand rule can be diagrammatically as shown in fig.



### \* Significance of Back emf :-

When the motor armature rotates, the conductors also rotate and cuts the lines of flux. The emf is induced in the conductors according to Faraday's law's of electromagnetic induction. The emf is induced in the conductors is in opposition to the applied voltage. Because of its opposing direction, it is referred to as back emf  $E_b$ .



The rotating armature generating the back emf  $E_b$  is like a battery of emf  $E_b$  put across voltage  $V$  volts.  $V$  has to drive  $I_a$  against opposition of  $E_b$ .

The armature current  $I_a = \frac{V - E_b}{R_a}$  where  $R_a$  is the resistance of armature.

The back emf  $E_b = \frac{\Phi_0 N}{60} \times \left(\frac{P}{A}\right)$  volt.

where  $N$  is in rpm. The Back emf depends on speed of armature. If the speed is high,  $E_b$  will be large and hence  $I_a$  will be small. If the speed is less, then  $E_b$  will be small and hence  $I_a$  will be more and develop more torque. Back emf  $E_b$  makes the motor self regulating so that it draws as much current as is just necessary.

$$\text{Back emf } E_b = V - I_a R_a$$

$$\text{or } V = E_b + I_a R_a \text{ (Voltage equation).}$$

### power equation of a D.C Motor:-

The voltage equation of a.d.c motor is given by,

$$V = E_b + I_a R_a$$

Multiplying both sides of the above equation by  $I_a$  we get,

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

This is called power equation of a.d.c motor.

$VI_a$  = Net electrical power input to the armature measured in watts

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

so difference between  $VI_a$  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  $P_m$ .

$\therefore$  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,

$$P_m = \text{Gross mechanical power developed} = E_b I_a$$

$$= VI_a - I_a^2 R_a$$

for maximum  $P_m$ ,

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

$$0 = V - \alpha I_a R_a$$

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

substituting in voltage equation,

$$V = E_b + \alpha I_a R_a = E_b + \frac{V}{2}$$

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

### Torque Equation of a DC Motor :-

It is seen that the turning or twisting force about an axis is called torque. Consider a wheel of radius  $R$  meters acted upon by a circumferential force  $F$  newtons as shown in the fig.

The wheel is rotating at a speed of  $N$  r.p.m. Then angular speed of the wheel is,

$$\omega = \frac{2\pi N}{60} \text{ rad/sec.}$$

so workdone in one revolution is

$$w = F \times \text{distance travelled in one revolution}$$

$$= F \times 2\pi R \text{ Joules}$$

And  $P = \text{power developed} = \frac{\text{workdone}}{\text{time}}$

$$= \frac{F \times 2\pi R}{\text{time for 1 rev}} = \frac{F \times 2\pi R}{\left[\frac{60}{N}\right]} = [F \times R] \times \left[\frac{2\pi N}{60}\right]$$

$$P = T \times \omega \text{ watts}$$

where  $T = \text{torque in N-m}$

$\omega = \text{Angular speed in rad/sec.}$

Let  $I_a$  be the gross torque developed by the armature of the motor. It is also called armature torque. The gross mechanical power developed in the armature is  $E_b I_a$ , as seen from the power equation. So if speed of the motor is  $N$  r.p.m. then,

power in armature = Armature torque  $\times \omega$

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

Fig. Shows the connection of a dc shunt motor. The field current  $I_{fh}$  is constant since the field winding is directly connected to the supply voltage  $V$  which is assumed to be constant. Hence the flux in a shunt motor is approximately constant. Due to armature reaction, flux decreases a little but the decrease in flux is usually negligible under normal conditions. Assuming flux to be practically constant we find that  $T_a \propto I_a$ .

Hence, the electrical characteristics is practically a straight line through the origin. shaft torque is shown dotted and is less than  $T_a$ . In a shunt motor a heavy starting load will need a heavy starting current. So shunt motor should never be started on load.

### 2. $N/I_a$ characteristics:-

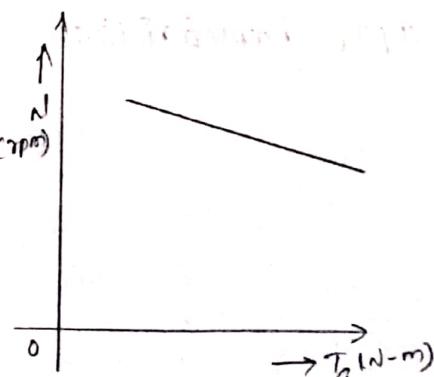
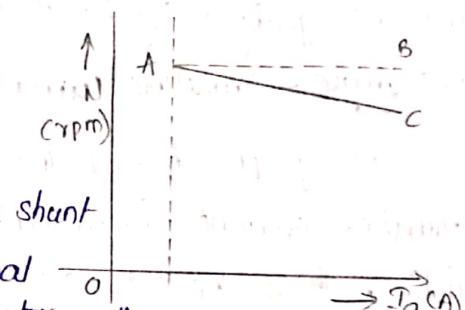
The speed  $N$  of a motor is given by:

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

The flux  $\Phi$  and back emf  $E_b$  in a shunt motor are almost constant under normal conditions. Therefore speed of a shunt motor will remains constant as the armature current varies. Strictly speaking when the load is increased  $E_b = V - I_a R_a$  and  $\Phi$  decreases due to the armature resistance drop and armature reaction respectively. However  $E_b$  decreases slightly more than  $\Phi$  so that the speed of the motor decreases slightly with load. It may be noted that the characteristics does not have a point of zero armature current because a small current is necessary to maintain rotation of the motor at no-load.

### 3. $N/I_a$ characteristics:-

This curve is obtained by plotting the values of  $N$  and  $I_a$  for various armature currents as shown in fig. It may be seen that speed falls some what as the load torque increases.



but  $E_b$  in a motor is given by

$$E_b = \frac{\phi PNz}{60A}$$

$$\therefore \frac{\phi PNz}{60A} \times I_a = T_a \times \frac{2\pi N}{60}$$

$$T_a = \frac{1}{2\pi} \phi I_a \times \frac{Pz}{A}$$

$$\therefore T_a = 0.159 \phi I_a \times \frac{Pz}{A} \text{ N-m}$$

This is the torque equation of a d.c. motor.

### D.C. Motor characteristics:-

The performance of a d.c. motor under various conditions can be judged by the following characteristics.

#### i) Torque - Armature current characteristics ( $T$ vs $I_a$ ) :-

The graph showing the relationship between the torque and the armature current is called a torque-armature current characteristics. These are also called electrical characteristics.

#### ii) Speed - Armature current characteristics ( $N$ vs $I_a$ ) :-

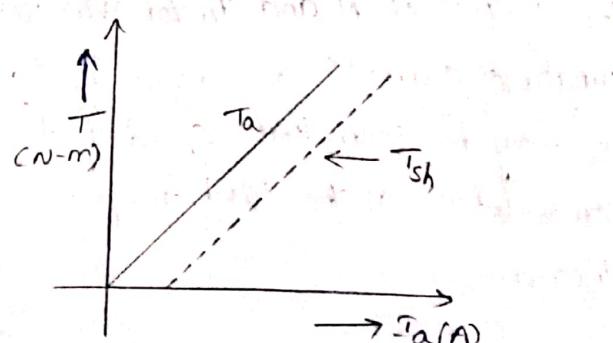
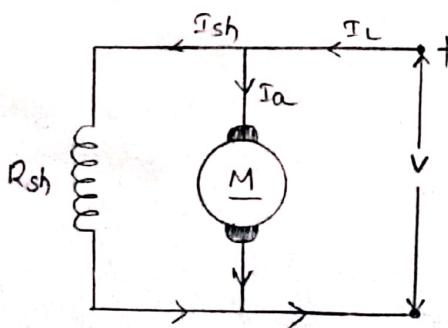
The graph showing the relationship between the speed and armature current characteristics.

#### iii) Speed - Torque characteristics ( $N$ vs $T$ ) :-

The graph showing the relationship between the speed and the torque of the motor is called speed-torque characteristics of the motor. These are also called mechanical characteristics.

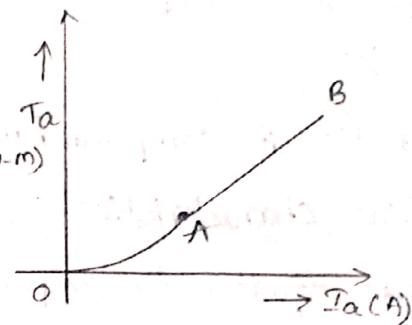
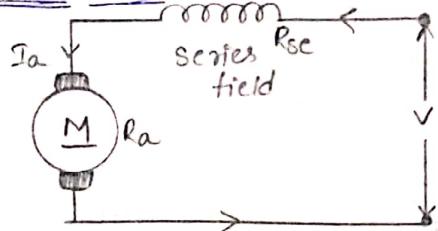
### Characteristics of D.C. shunt motors:-

#### i) $T/I_a$ characteristics:-



## Characteristics of DC Series motor:-

### 1. Td/Ia characteristics:-



We know that  $T_d \propto I_a$  upto magnetic saturation,  $\phi \propto I_a$  so that  $T_d \propto I_a^2$ . After magnetic saturation,  $\phi$  is constant, so that  $T_d \propto I_a$ . Thus upto magnetic saturation, the armature torque is directly proportional to the square of armature current. If  $I_a$  is doubled  $T_d$  is almost quadrupled. Therefore  $T_d/I_a$  curve upto magnetic saturation is a parabola. However after magnetic saturation, torque is directly proportional to the armature current. Therefore  $T_d/I_a$  curve after magnetic saturation is a straight line.

It may be seen that in the initial portion of the curve,  $T_d \propto I_a^2$ , this means that the starting torque of a DC series motor will be very high as compared to a shunt motor.

### 2. N/Ia characteristics:-

The speed  $N$  of a series motor is given by  $N = \frac{E_b}{\phi}$  (rpm); where  $E_b = V - I_a(R_a + R_{se})$ . When the armature current increases, the back EMF  $E_b$  decreases due to  $I_a(R_a + R_{se})$  drop while the flux  $\phi$  increases. However,  $I_a(R_a + R_{se})$  drop is quite small under normal conditions and may be neglected.

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

$\propto \frac{1}{I_a}$  up to magnetic saturation.

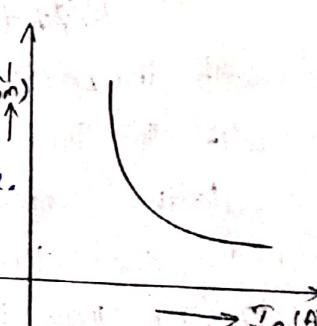
Thus upto magnetic saturation, the  $N/I_a$  curve follows the hyperbolic path as shown in fig. after saturation the flux becomes constant and so does the speed.

### 3. N/Ia characteristics:-

The  $N/I_a$  characteristics of a series motor is shown in fig. It is clear the series motor develops high torque at low speed and vice-versa.

It is because an increase in torque requires an increase in armature current, which is also

the field current. The result is that flux is strengthened and unit  $m$  made.



hence the speed drops. ( $\because N \propto \frac{1}{\phi}$ ). Reverse happens should the torque be low.

### Characteristics of compound motors-

#### 1. Electrical characteristics ( $T/I_a$ ):-

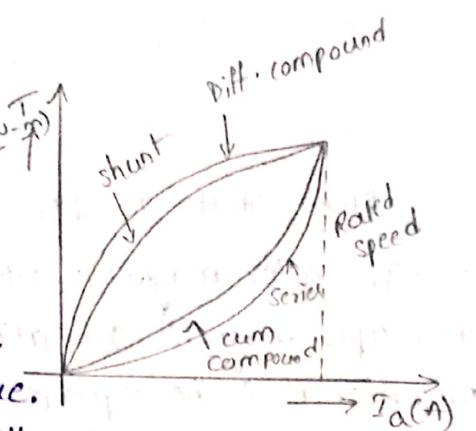
The torque equation for compound motor is

$$T = K \phi I_a$$

$$= K (\phi_{sh} + \phi_{se}) I_a$$

with increase in armature current,  $\phi_{se}$  increases and consequently the torque.

If the shunt field is more stronger than the series field the torque current characteristics approaches as that of shunt motor. And in case series field is stronger than shunt field the torque current characteristics approaches as that of series motor. The comparison of torque current are shown in fig.



In case of differential compound motors since series field opposes the shunt field, the net flux decreases as load is applied to the shunt field motor. The result is, hence there is a decrease in the rate at which the motor torque increases with load. Therefore such motors are not in common use. Another drawback is weakening of flux with increase in load, there is a tendency to speed instability.

#### 2. Speed and armature current characteristics ( $N/I_a$ ):-

for long shunt Compound motor

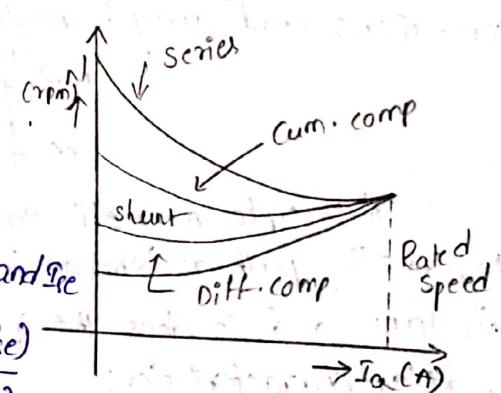
$$V = E_b + I_a (R_a + R_{se})$$

$$\text{and } E_b = K \phi N$$

$$= K (\phi_{sh} + \phi_{se}) N$$

where,  $\phi_{sh}, \phi_{se}$  are flux due to  $I_{sh}$  and  $I_{se}$

$$N = - \frac{E_b}{K(\phi_{sh} + \phi_{se})} = \frac{V - I_a (R_a + R_{se})}{K(\phi_{sh} + \phi_{se})}$$



With increase in  $I_a$ ,  $\phi_{se}$  increases and  $V - I_a (R_a + R_{se})$  decreases. Thus with the increase in  $I_a$  the speed drops at faster rate in cumulative compound motor than in shunt motor. If the shunt field the curve tends to shunt motor curve and if series field is stronger than shunt field it tends to series field curve. The comparison of characteristics is shown in fig.

### 3. Speed Torque characteristics (N/I) :-

Speed torque characteristics is also known as mechanical characteristics and is derived from speed-current and torque current characteristics. It is seen that an increase in torque increases the armature current and also the flux, at the same time decreasing the speed rapidly in armature of compound motor. The decrease is more predominant than that compared with shunt motor. Therefore the speed torque characteristics approaches the shunt motor characteristics if the shunt field is stronger. If the series flux is stronger than shunt flux speed torque characteristic approaches the series motor characteristics. Depending upon the relative strength of shunt and series fields the speed torque can occupy any position as shown in the fig.

#### Applications of Motors:-

S.NO	Types of motor	Characteristics	Applications.
1.	shunt motor	Approximately constant speed, Adjustable speed. Medium starting Torque (upto 1.5 F1 torque).	for driving constant speed line shafting, belt centrifugal pumps. Machine tools. Blowers and Fans Reciprocating pumps.
2.	series motor	variable speed, Adjustable varying speed. High starting torque.	for traction work (i.e.) electric locomotives. Rapid transit systems. Trolley cars, etc. cranes and hoists, conveyors.
3.	cumulative compound	variable speed, Adjustable varying speed, high starting torque.	for shears, punches. Elevators, conveyors, heavy planers, Rolling mill, Ice machines.
4.	Differential compound motor	<ul style="list-style-type: none"> <li>Motor speed remains almost constant.</li> <li>speed increases with increase in load.</li> <li>Some times speed is stability.</li> </ul>	These are not in common use, limited application for experimental and research work.

## • Armature Reaction

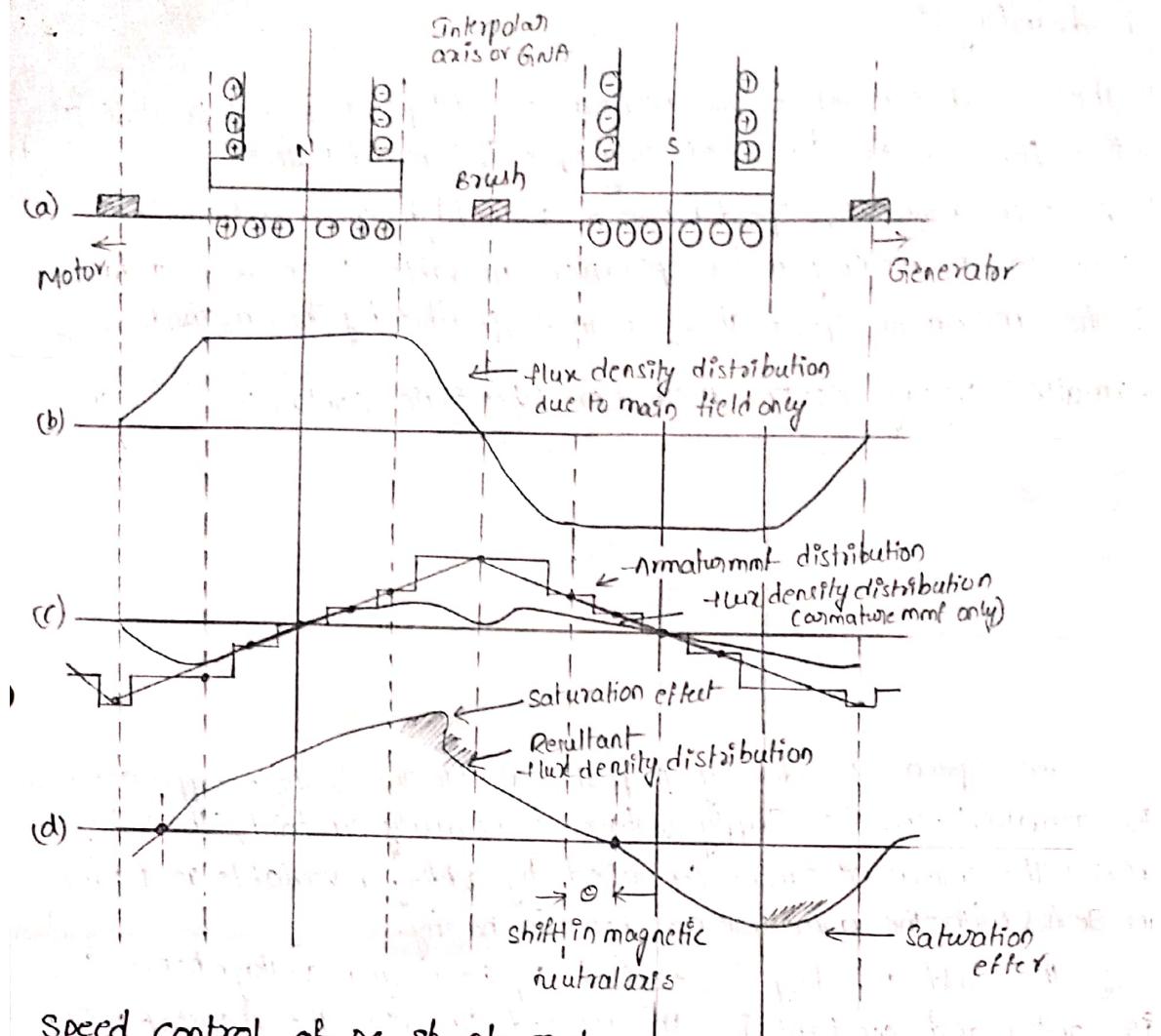
As we have discussed in chapter 3, the armature reaction is nothing but the effect of flux produced by armature conductors on the distribution of main-flux due to the field poles.

In case of all the d.c. machines it can be seen that armature m.m.f is approximated by a symmetrical triangular waveform with axis as interpolar axis. Thus armature m.m.f and field m.m.f are displaced in space by  $90^\circ$ , this will cause distortion in main field flux which is called cross magnetizing effect of armature reaction. The armature m.m.f lags behind field m.m.f with respect to the direction of rotation in case of motors and vice-versa in case of generators.

The fig. shows the developed form indicating distribution of main field flux, armature flux and the respective m.m.f's. The armature m.m.f is zero at the pole centers and maximum at interpolar axis. Assuming air gap to be uniform then the distribution of flux due to armature current only is shown in fig. It is observed that flux density in the interpolar region is very large owing to large reluctance offered by long air paths in this region.

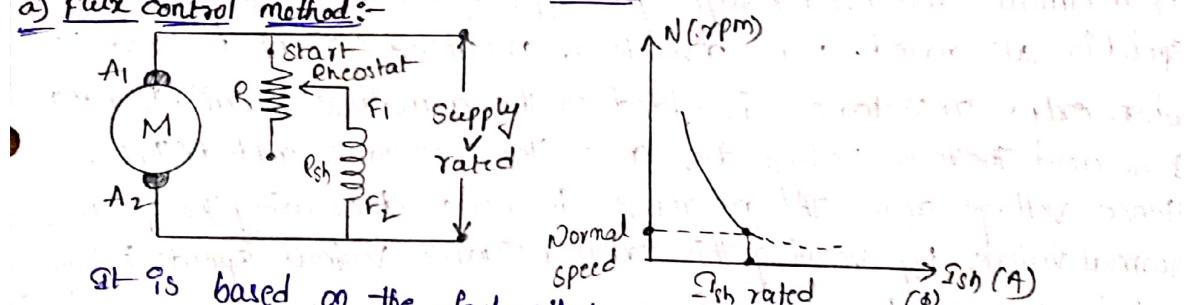
The flux density distribution due to main field poles is shown in fig. The total flux in air gap is due to resultant of the field and armature m.m.f's. Thus resultant flux density can be found by adding the two flux density curves shown in the fig. The resultant flux density curve is shown in fig.

Thus armature reaction will cause distortion in main field flux density distribution curve. The MNA will be shifted by some angle so the brushes are also shifted by same angle as they lie along MNA. In case of motors it is observed that the brushes are shifted backwards opposite to the direction of rotation. So that they will lie along MNA.



### Speed control of dc shunt motor:-

#### a) flux control method:-



It is based on the fact that by varying the flux,  $\phi$ , the motor speed ( $N \propto \frac{1}{\phi}$ ) can be changed and hence the name flux control method. In this method, a variable resistance known as shunt field rheostat is placed in series with shunt field winding as shown in fig.

The shunt field rheostat reduces the shunt field current  $I_{sh}$  and hence the flux  $\phi$ . By using flux control method, the speed of the motor can be raised above the normal speed. Generally this method permits to increase the speed in the ratio 2:1. wider speed ranges tend to produce instability and poor commutation.

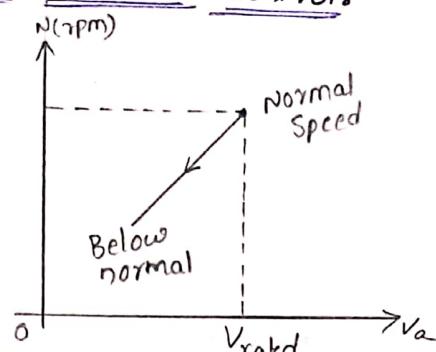
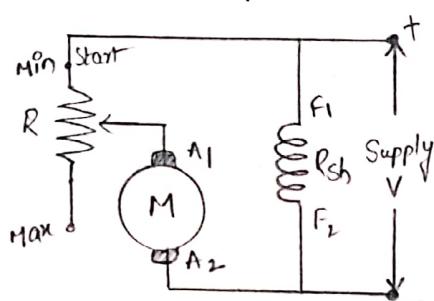
#### Advantages:-

1. It provides relatively smooth and easy control.
2. Speed control above rated speed is possible.

### Disadvantages:-

1. The speed control below normal rated speed is not possible as flux can be increased only upto its rated value.
2. As flux reduces, speed increases. But high speed affects the commutation making motor operation unstable. So there is a limit to the maximum speed above normal, possible by this method.

### \* Armature voltage control method or Rheostatic control:-



The speed is directly proportional to the voltage applied across the armature. As the supply voltage is normally constant, the voltage across the armature can be controlled by adding a variable resistance in series with the armature as shown in the fig.

The field winding is excited by the normal voltage hence  $I_{sh}$  is rated and constant in this method. Initially the rheostat position is minimum and rated voltage gets applied across the armature, so speed is rated. For a given load, armature current is fixed. So when extra resistance is added in the armature circuit,  $I_a$  remains same and there is voltage drop across the resistance added ( $I_a R$ ). Hence voltage across the armature decreases, decreasing the speed below normal value. By varying this extra resistance various speeds below rated value can be obtained.

So for a constant load torque, the speed is directly proportional to the voltage across the armature. The relationship between speed and voltage across the armature is shown in the fig.

### Advantages of Rheostatic Control:-

1. Easy and smooth speed control below normal is possible.
2. In potential divider arrangement, rheostat can be used as a starter.

### Disadvantages:-

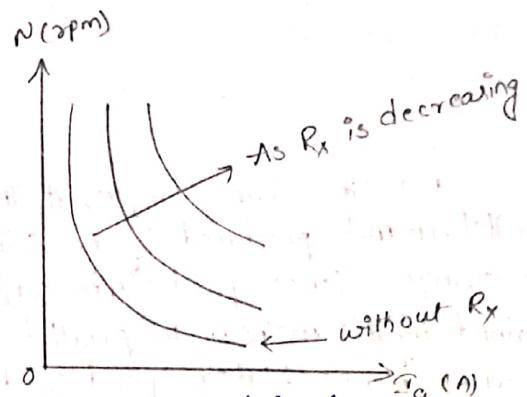
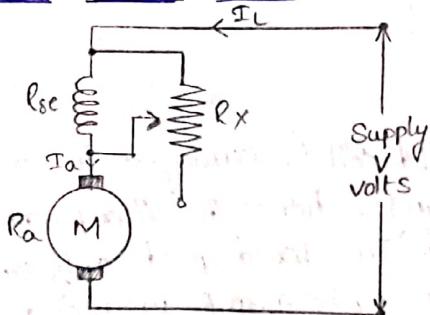
1. Speed above rated is not possible by this method.
2. Due to large power losses, the method is expensive, wasteful and less efficient.
3. The method needs expansive heat dissipation arrangements.

## \* Speed control of DC Series motor:-

### a) flux control Method:-

The various methods of flux control in a D.C series motor are explained below.

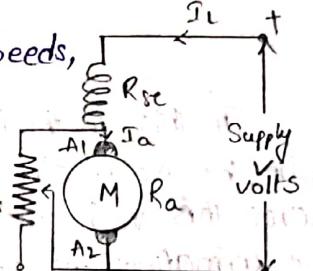
#### 1. Field Diverter method:-



In this method a variable resistance called field diverter is connected in parallel with series field winding, as shown in fig. Its effect is to shunt some portion of the line current from the series field winding, thus weakening the field and increasing the speed [ $N \propto \frac{1}{\phi}$ ]. The lowest speed obtainable is that corresponding to zero current in the diverter. lowest speed obtainable is the normal speed of the motor. This method can provide speeds above the normal speed. This method is used for traction work.

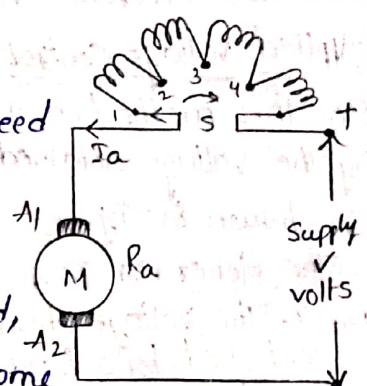
#### 2. Armature Diverter method:-

In order to obtain speeds below the normal speeds, a variable resistance called armature diverter is connected in parallel with the armature as shown in fig. The diverter shunts some of the line current,  $R_x$ , thus reducing the armature current. Now for a given load, if  $I_a$  is decreased, the flux  $\phi$  must increase ( $\because N \propto \frac{1}{\phi}$ ). Since  $N \propto \frac{1}{\phi}$ , the motor speed, is decreased. By adjusting the armature diverter,  $\phi$ , any speed lower than the normal speed can be obtained.



#### 3. Tapped field method:-

In this method, the flux is reduced and speed is increased by decreasing the number of turns of the series field winding as shown in fig.

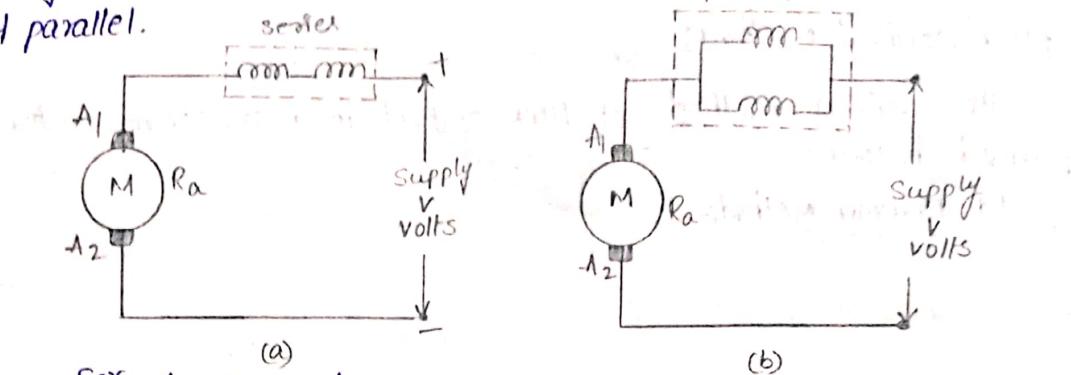


With full field the motor runs at minimum speed, which can be raised in steps by cutting out some of the series turns. This method is often used in electric traction.

#### 4. Series-parallel connection of field:-

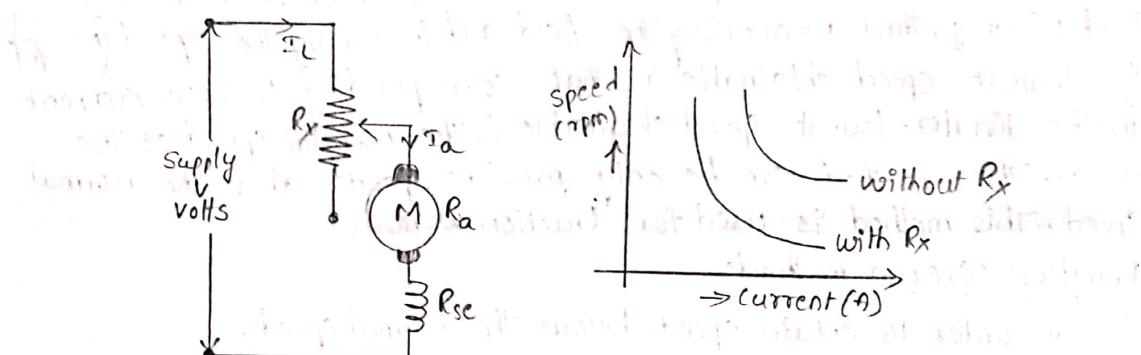
In this method, the field coil is divided into various parts. These parts can then be connected in series or parallel as per the requirement.

The fig (a) and (b) show the two parts of field coil connected in series and parallel.



For the same torque, if the field coil is arranged in series or parallel, m.m.f produced by the coils changes, hence the flux produced also changes. Hence speed can be controlled. Some fixed speeds only can be obtained by this method. In parallel grouping, the m.m.f produced decreases, hence higher speed can be obtained by parallel grouping. The method is generally used in case of fan motors.

#### \* Rheostatic control:-



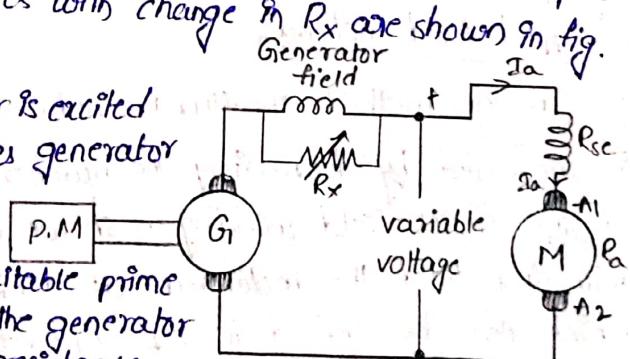
In this method, a variable resistance ( $R_x$ ) is inserted in series with the motor circuit. As this resistance is inserted, the voltage drop across this resistance ( $I_a R_x$ ) occurs. This reduces the voltage across the armature. As speed is directly proportional to the voltage across the armature, the speed reduces. The arrangement is shown in the fig. As entire current passes through  $R_x$ , there is large power loss. The speed vs. armature current characteristics with change in  $R_x$  are shown in fig.

#### K Applied voltage control:-

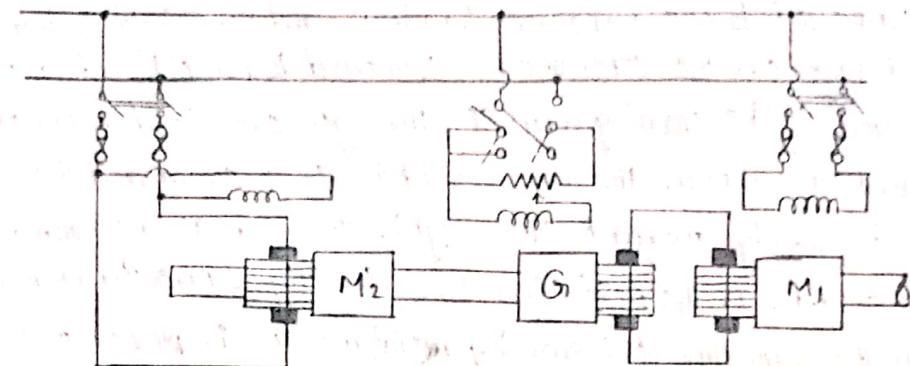
In this method, a series motor is excited by the voltage obtained by a series generator as shown in fig.

The Generator is driven by a suitable prime mover. The voltage obtained from the generator is controlled by a field diverter resistance connected across series field winding of the generator.

As  $E \propto \phi$ , the flux change is achieved, gives the variable voltage at the output terminals. Due to the change in the supply voltage, the various speeds of the d.c series motor can be obtained.



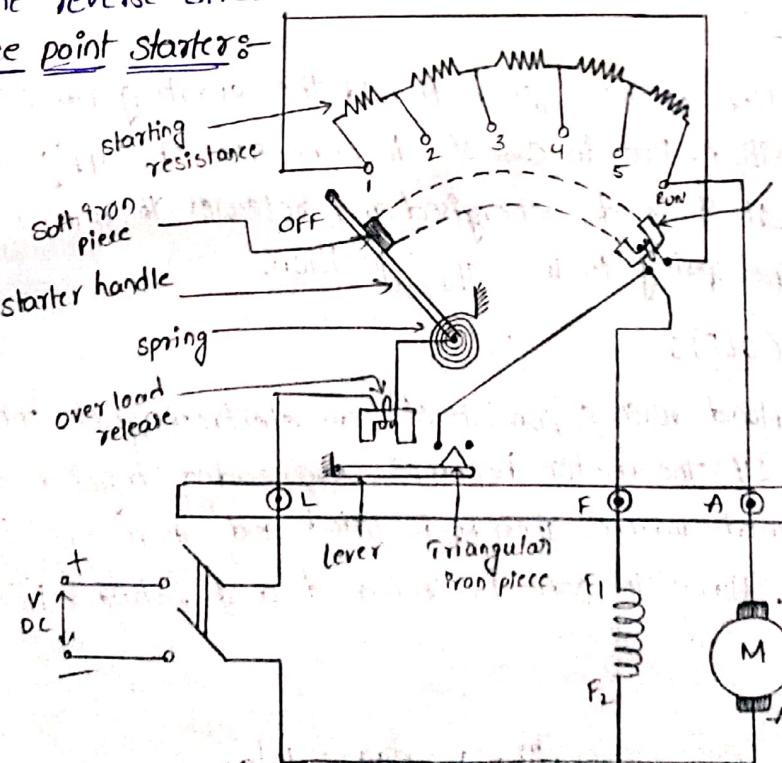
## \* Ward - Leonard Speed control Method;



Both the methods mentioned above have certain disadvantages. These can be eliminated in the ward-leonard method of speed control as given in fig.

The armature of the main motor, the speed of which is to be controlled is fed directly from a DC generator which is driven by a prime mover driven at constant speed. The prime mover may be a DC, or AC motor. The field of the main motor MM is permanently connected to the DC supply. The output of the generator is directly fed to the main motor. The generator output can be varied from zero to its rated value by varying its field current through the potential divider ABC. The direction of the current through the generator field can be changed in direction, thus varying the main motor speed from zero to its rated speed. By reversing the direction of the generator field current by means of the potential divider, the speed of the motor can be varied from its maximum rated value in one direction to the same maximum value in the reverse direction.

## \* Three point starters



The internal wiring diagram of a starter is shown in fig. The 3 terminals of the starting box are marked L, F and A. One line is directly connected to one armature terminal and one field terminals which are tied together. The other line is connected to point 'L' which is further connected to the starting arm SR, through over load release M.

To start the motor, the main switch is first closed and the starting arm is slowly moved to the right. As soon as the arm makes contact with stud no. 1. The field circuit is directly connected across the line and at the same time full starting resistance  $R_s$  is placed in series with the armature. The starting current drawn by the armature =  $\frac{V}{R_a + R_s}$ . As the arm is further moved, the starting resistance is gradually cutout and the arm reaches running position. Then all resistance is cutout. The arm moves over various studs against a strong spring which tends to restore it to off position. A soft iron piece 'p' is attached to the arm which is in full 'ON' position is attracted and held by an electromagnet energised by the shunt current. It is known as NO-VOLTAGE release or Hold 'ON' coil.

As the arm is moved from stud no. 1 to last stud. The field current has to travel back through the portion of the starting resistance that has been cutout of the armature circuit. This results in slight decrease of shunt current. This defect can be overcome by using a brass arc connected to stud no 1. The field circuit is completed through this arc so that field current does not pass through the starting resistance.

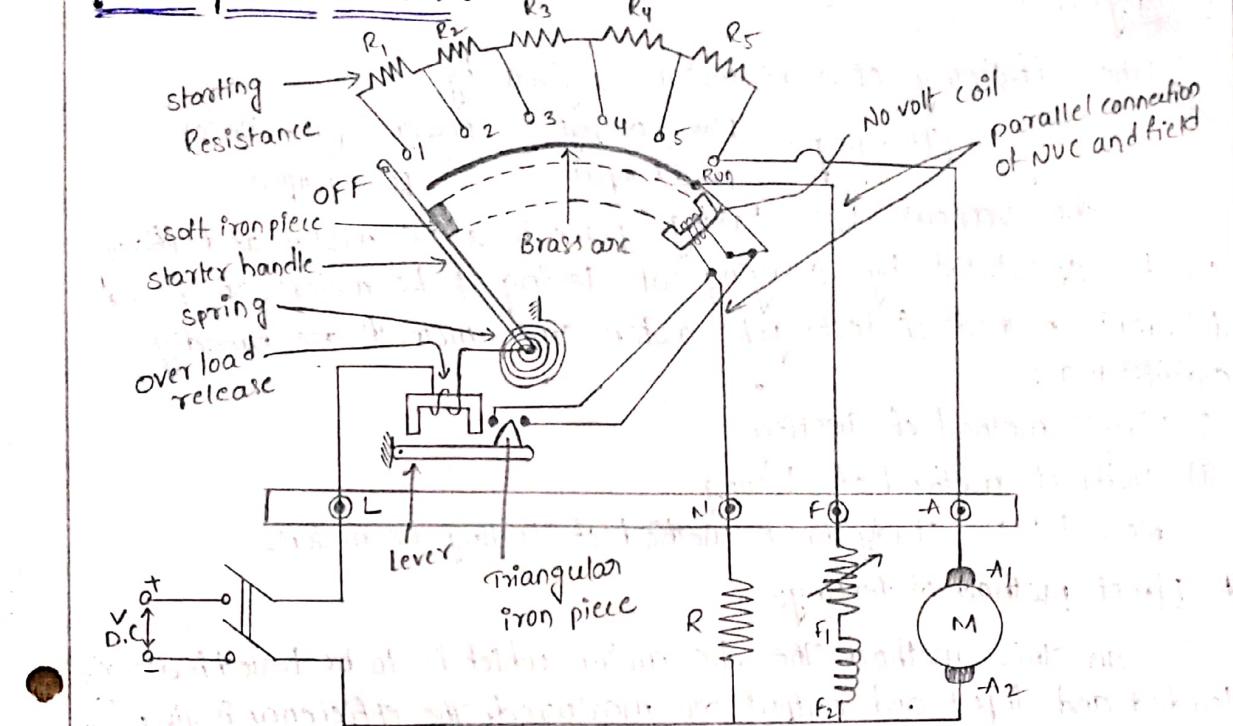
#### Hold ON coil (NVR):-

The function of this coil is to hold the starting arm (SR) in full running position. But in case of disconnection of supply or break in field circuit it is de-energised and releases the arm which is pulled back by the spring to the 'off' position.

#### Over Load Release (OLR):-

The overload release consists of an electromagnet connected in the supply line. If the motor becomes overloaded beyond a certain predetermined value, then M is lifted and short circuits the electromagnet. Hence the arm is released and returns to 'off' position.

## \* Four-point Starter



The basic difference between three point and four point starter is the connection of NVC. In three point, NVC is in series with the field winding while in four point starter. NVC is connected independently across the supply through the fourth terminal called 'N' in addition to the 'L', 'F' and 'A'.

Hence any change in the field current does not affect the performance of the NVC. Thus it is ensured that NVC always produce a force which is enough to hold the handle in 'RUN' position, against force of the spring, under all the operating conditions. Such a current is adjusted through NVC with the help of fixed resistance  $R$  connected in series with the NVC using fourth point 'N' as shown in fig.

### \* Comparison Between 3-point and 4-point starter:

S.No	3-point Starter	4-point starter
1.	This starter is used for D.C. Shunt motor.	This is used for DC compound motor.
2.	Terminals exist for shunt field only.	Terminals exist for shunt, and series field, also.
3.	N.V coil is short circuited through an auxiliary magnet.	N.V coil is directly connected to supply through high resistance.
4.	3-point exists for main, shunt and armature.	4-point exists for main, shunt, series and armature.

## \* Testing of D.C. motors:-

The efficiency of a d.c motor is given by

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}} = \frac{\text{power input} - \text{losses}}{\text{power input}}$$

The various losses taking place in a d.c motor and efficiency can be calculated by carrying out testing of d.c motors. There are different methods of testing d.c motors. These methods are broadly classified as:

- i) Direct method of testing.
- ii) Indirect method of testing.

Now let us study direct method of testing d.c motors.

## \* Direct Method of testing:-

In this method the d.c motor which is to be tested is actually loaded and input and output are measured. The efficiency is given by.

$$\text{Efficiency, } \eta = \frac{\text{output}}{\text{input}}$$

Generally this method is employed to small motors. The motor is loaded by means of a brake applied to the water cooled pulleys.

The main drawback of this method is that the accuracy in determining the mechanical power output of the motor is limited. Alternately it is difficult to provide full load for the large capacity motor.

## \* Indirect method of Testing:-

In these methods the motor is not loaded directly but the losses and efficiency at different loads can be estimated. Out of the different methods available for testing of d.c motors, Swinburne's test and Hopkinson's test are commonly used in practice on shunt-motors. Since series motors cannot be started without load, the no load tests cannot be performed on d.c series motors.

## Losses in a D.C Machine:-

The various losses in a d.c machine whether it is a motor or a generator are classified into three groups as:

1. copper losses
2. Iron or core losses
3. Mechanical losses.

## 1) Copper losses:-

The copper losses are the losses taking place due to the current flowing in a winding. There are basically two windings in a d.c machine namely armature winding and field winding. The copper losses are

proportional to the square of the current flowing through these windings. Thus the various copper losses can be given by,

$$\text{Armature copper loss} = I_a^2 R_a$$

where

$R_a$  = armature winding resistance.

$I_a$  = armature current.

$$\text{Shunt field copper loss} = I_{sh}^2 R_{sh}$$

where

$R_{sh}$  = shunt field winding resistance

$I_{sh}$  = shunt field current.

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

where

$R_{se}$  = series field winding resistance

$I_{se}$  = series field current.

### Iron or core losses:-

These losses are also called magnetic losses. These losses include hysteresis loss and eddy current losses.

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

where

$\eta$  = Steinmetz hysteresis co-efficient.

$V$  = Volume of core in  $m^3$ .

$f$  = frequency of magnetic reversals.

$$\text{Eddy current loss} = k B_m^2 f^2 t^2 V \text{ watts.}$$

where

$k$  = constant.

$t$  = thickness of each lamination

$V$  = volume of core.

$f$  = frequency of magnetic reversals.

### Mechanical losses:-

These losses consist of friction and windage losses. The magnetic and mechanical losses are called stray losses. For the shunt and compound d.c machines where field current is constant, field copper losses are also constant.

Thus for a d.c machine,

$$\text{Total losses} = \text{constant losses} + \text{variable losses.}$$

## Efficiency of a D.C. Machine :-

for a d.c machine, its overall efficiency is given by,

$$\% \eta = \frac{\text{Total output}}{\text{Total input}} \times 100$$

Let

$P_{\text{out}}$  = total output of a machine.

$P_{\text{in}}$  = total input of a machine

$P_{\text{cu}}$  = variable losses

$P_i$  = constant losses

then

$$P_{\text{in}} = P_{\text{out}} + P_{\text{cu}} + P_i$$

$$\% \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100 = \frac{P_{\text{out}}}{P_{\text{out}} + \text{losses}} \times 100$$

$$\therefore \% \eta = \frac{P_{\text{out}}}{P_{\text{in}} + P_{\text{cu}} + P_i} \times 100$$

## Condition for Maximum efficiency:-

In case of d.c generator the output is given by

$$P_{\text{out}} = VI$$

$$P_{\text{cu}} = \text{variable losses} = I_a^2 R_a = I^2 R_a$$

$$I_a = I \quad (\text{neglecting shunt field current})$$

$$\% \eta = \frac{VI}{VI + I^2 R_a + P_i} \times 100 = \frac{1}{1 + \left( \frac{R_a}{V} + \frac{P_i}{VI} \right)} \times 100$$

The efficiency is maximum, when the denominator is minimum.

According to Maxima-minima theorem,

$$\frac{d}{dI} \left[ 1 + \left( \frac{R_a}{V} + \frac{P_i}{VI} \right) \right] = 0$$

$$\frac{R_a}{V} - \frac{P_i}{VI^2} = 0$$

$$I^2 R_a - P_i = 0$$

$$I^2 R_a = P_i = P_{\text{cu}}$$

Thus for the maximum efficiency, the condition is

$$\text{variable losses} = \text{constant losses}$$

let us study now the various methods of testing the d.c. motors from the losses and efficiency point of view.