DC MOTOR

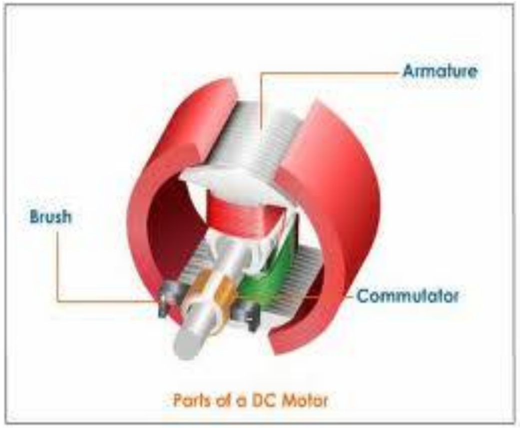
Electrical motor: It is a machine which convert electrical energy into mechanical energy.

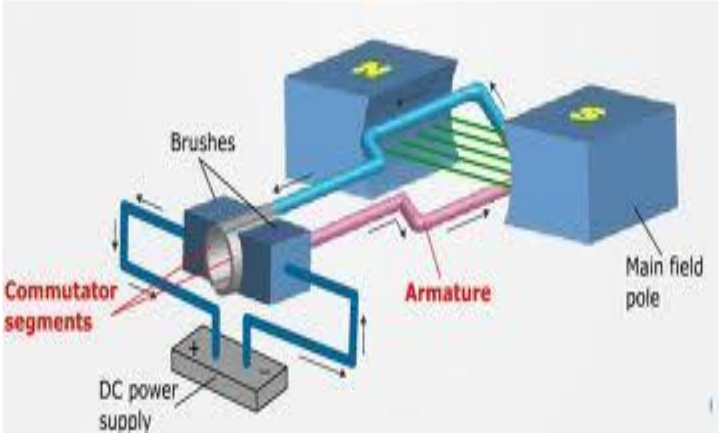
AC Motor: motor that runs on alternating current (AC) electricity.

DC Motor: motor that runs on direct current (DC) electricity.

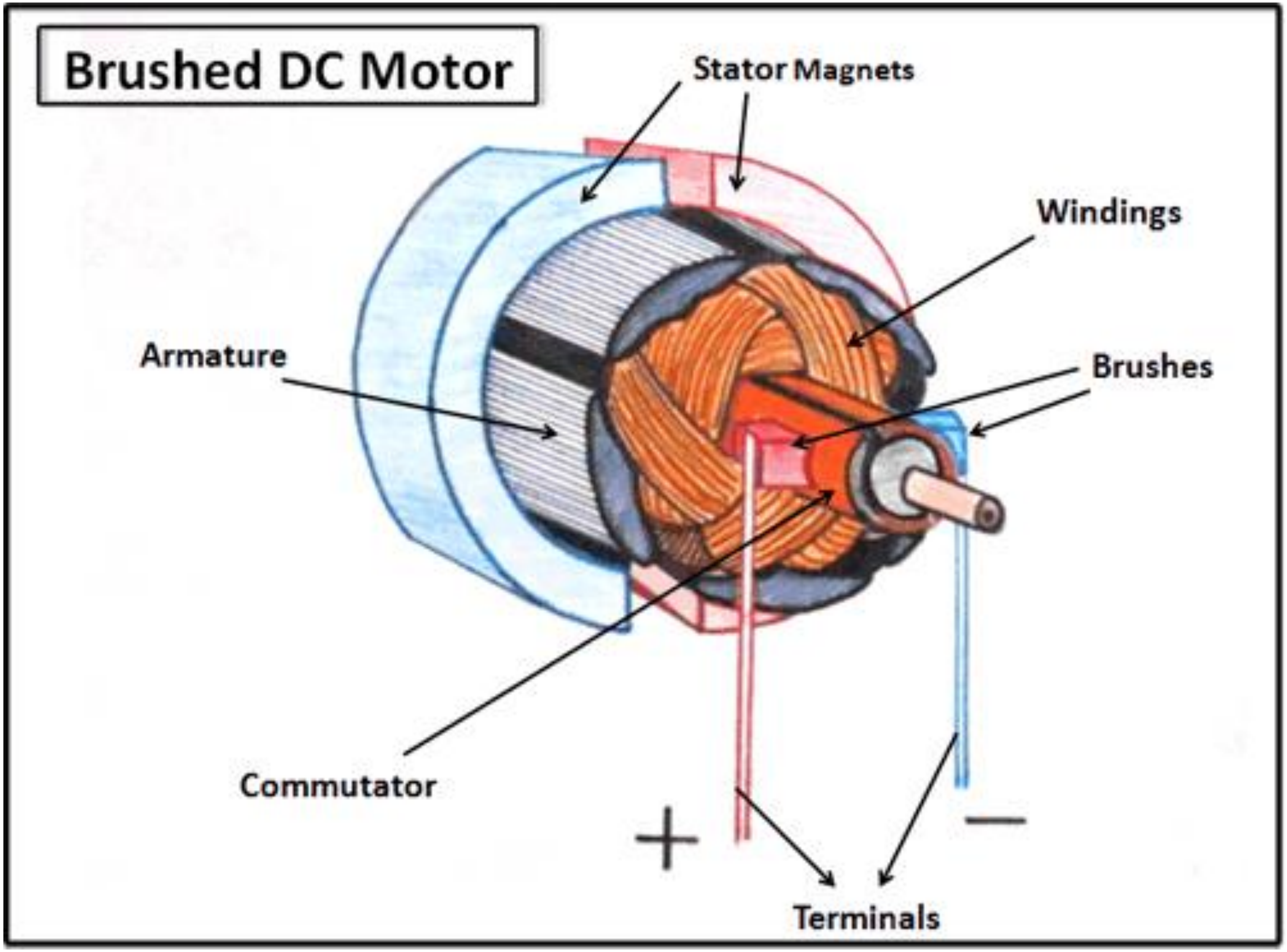
Principle of operation of DC Motor:

When current carrying conductor is placed in a magnetic field it experience a force.

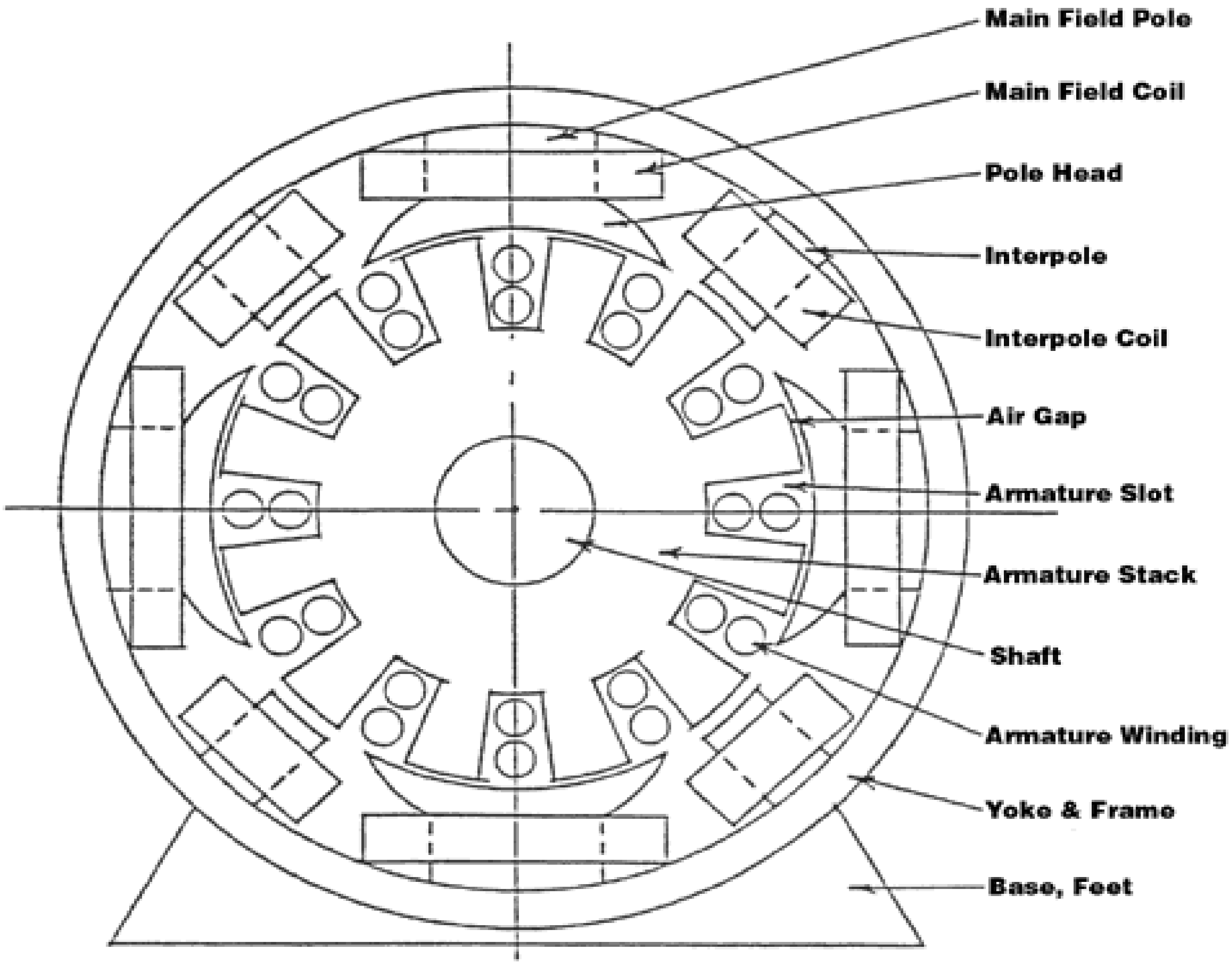




Construction of DC Motor:



Construction of DC Motor:

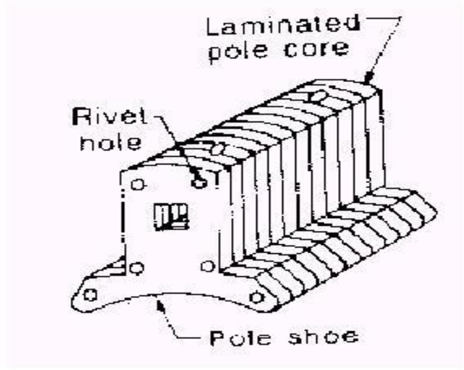


Function of each part of DC Motor:

Yoke:

- It is outer cover of dc motor also called as frame.
- It provides protection to the rotating and other part of the machine from moisture, dust etc.
- Yoke is an iron body which provides the path for the flux to complete the magnetic circuit.
- It provides the mechanical support for the poles.
- Material Used: low reluctance material such as cast iron, silicon steel, rolled steel, cast steel etc.

Poles, and pole core:



- Poles are electromagnet, the field winding is wound over it.
- It produces the magnetic flux when the field winding is excited.
- The construction of pole is done using the lamination of particular shape to reduce the power loss due to eddy current.

pole shoe:

- Pole shoe is an extended part of a pole. Due to its typical shape, it enlarges the area of the pole, so that more flux can pass through the air gap to armature.
- Material Used: low reluctance magnetic material such as cast steel or cast iron is used for construction of pole and pole shoe.

Field winding:

- The coil wound on the pole core are called field coils.
- Field coils are connected in series to form field winding.
- Current is passed through the field winding in a specific direction, to magnetize the poles and pole shoes. Thus magnetic flux is produce in the air gap between the pole shoe and armature.
- Field winding is also called as Exciting winding.
- Material Used for copper conductor is copper.
- Due to the current flowing through the field winding alternate N and S poles are produced.

Armature core:

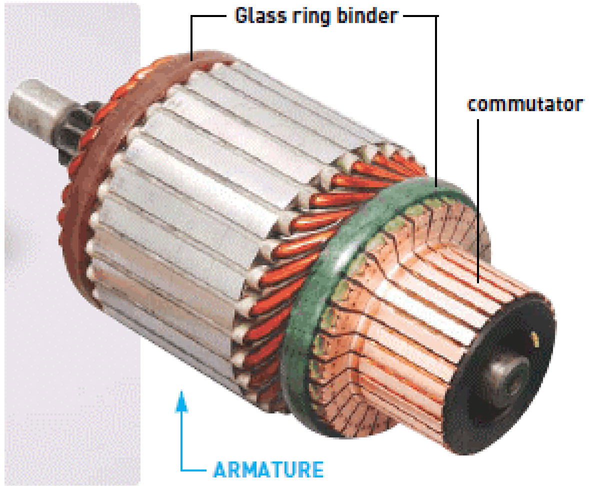
- Armature core is a cylindrical drum mounted on the shaft.
- It is provided with large number of slots all over its periphery and it is parallel to the shaft axis.
- Armature conductors are placed in these slots.
- Armature core provides low reluctance path to the flux produced by the field winding.
- Material used: high permeability, low reluctance cast steel or cast iron material is used.
- Laminated construction of iron core is used to minimize the eddy current losses.

Armature winding:

- Armature conductor is placed in a armature slots present on the periphery of armature core.
- Armature conductor are interconnected to form the armature winding.
- When the armature winding is rotated using a prime mover, it cuts the magnetic flux lines and voltage gets induced in it.
- Armature winding is connected to the external circuit (load) through the commutator and brushes.
- Material Used: Armature winding is suppose to carry the entire load current hence it should be made up of conducting material such as copper.

Commutator:

- It is a cylindrical drum mounted on the shaft along with the armature core.
- It is made up of large number of wedge shaped segments of hard-drawn copper.
- The segments are insulated from each other by thin layer of mica.



- Armature winding are tapped at various points and these tapping are successively connected to various segments of the commutator.

Function of commutator:

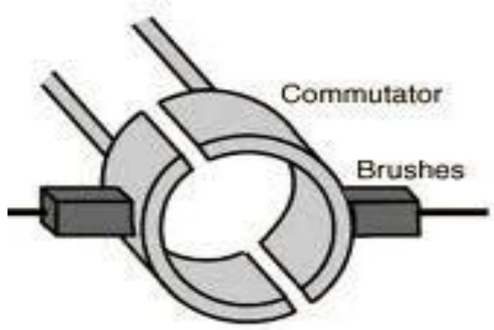
- It converts the ac emf generated internally into dc
- It helps to produce unidirectional torque.

Material Used: it is made up of copper and insulating material between the segments is mica.

Brushes:

- Current are conducted from the armature to the external load by the carbon brushes which are held against the surface of the commutator by springs.
- Function of brushes: To collect the current from the commutator and apply it to the external load in generator, and vice versa in motor.
- Material Used:

Brushes are made of carbon and they are rectangular in shape.



Action of commutator:

Back emf:

- When the armature winding of dc motor is start rotating in the magnetic flux produced by the field winding, it cuts the lines of magnetic flux and induces the emf in the armature winding.
- According to Lenz's law (*The law that whenever there is an induced electromotive force (emf) in a conductor, it is always in such a direction that the current it would produce would oppose the change which causes the induced emf.*), this induced emf acts in the opposite direction to the armature supply voltage. Hence this emf is called as back emfs.

$$E_b = \frac{N \emptyset Z}{60} \frac{P}{A} \text{ Volts}$$

N= speed in rpm

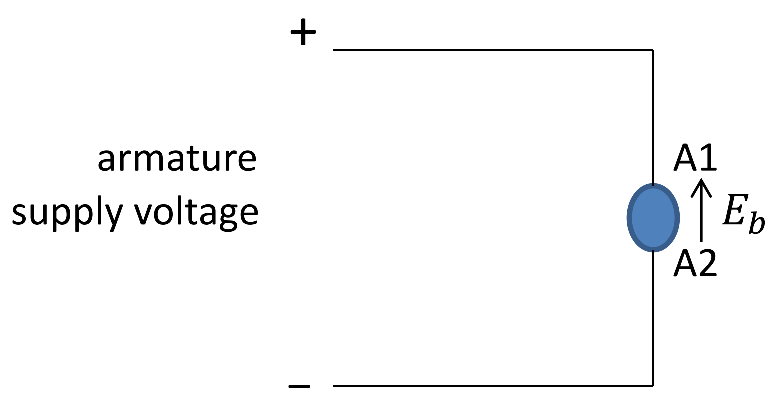
$\emptyset$= flux per pole

Z= no of conductors

P=no of pole pairs

A=area of cross section of conductor

E_b= back emf



Voltage and Power equation of DC Motor:

$$V = Eb + IaRa$$

If we multiply the above equation by Ia, we will get

$$VIa = EbIa + Ia^2Ra$$

$VIa = electrical\ power\ supplied\ to\ the\ motor$
$EbIa = electrical\ equivalent\ of\ the\ mechanical\ power\ produced\ by\ the\ motor$
$Ia^2Ra = power\ loss\ taking\ place\ in\ armature\ winding$
Thus,

$$EbIa = VIa - Ia^2Ra$$

=input power-power loss

thus, $EbIa$= Gross mechanical power produce by the motor

= Pm

Torque equation of DC Motor:

$mechanical\ power\ required\ to\ rotate\ the\ shaft\ on$

$mechanical\ side = T\omega$………………………………………… 1

T = Torque in Newton-meter

ω= angular velocity in radian /second

$gross\ mechanical\ power\ produce\ by\ the\ motor\ on$

$electrical\ side = EbIa$………………………………………… 2

Eb = back emf in volts

Ia = armature current in ampere

equating eqnuation 1 and 2, we get

$$EbIa = T\omega \quad \text{………………………………………… } 3$$

$\omega = \frac{2\pi N}{60}$ .... $\left\{ \frac{2\pi N}{60} \right.$ = Speed in rpm

And $Eb = \frac{N\emptyset ZP}{A60}$

Thus, equation (3) become

$$\frac{N\emptyset ZP}{A60} Ia = T \frac{2\pi N}{60}$$

$$T = \frac{P\emptyset ZIa}{2\pi A} = \frac{0.159P\emptyset ZIa}{A} = \left(\frac{0.159PZ}{A}\right) \emptyset Ia$$

$P, Z \ and \ A$ are constant, hence we can say

$$T \propto \emptyset \ Ia$$

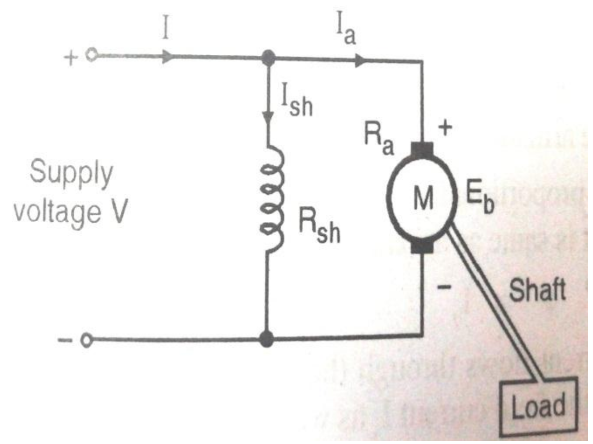
Thus torque produce by the DC Motor is proportional to the main field flux Ø and armature current Ia

Types of DC Motor:

- Classification of the d.c. motor depends on the way of connecting the armature and field winding of a d.c. motor:

1. DC Shunt Motor
2. DC Series Motor
3. DC Compound Motor
   - Short shunt compound
     - Cumulative compound motor
     - Differential compound motor
   - long shunt compound
     - Cumulative compound motor
     - Differential compound motor

DC Shunt Motor:



- In dc shunt motor the armature and field winding are connected in parallel across the supply voltage
- The resistance of the shunt winding R_{sh} is always higher than the armature winding R_a
- Since V and R_{sh} both remains constant the I_{sh} remains essentially constant, as field current is responsible for generation of flux.

  thus $\emptyset \propto I_{sh}$

- So shunt motor is also called as constant flux motor.

Torque and Speed equation of DC Shunt Motor:

As we have seen for dc motor

$$T \propto \emptyset\, Ia$$

But for dc shunt motor :$\emptyset \propto Ish$

And Ish is constant , thus $\emptyset$ is also constant

So torque in dc shunt motor is

$$T \propto Ia$$

For dc motor

$$Eb = \frac{N\emptyset ZP}{A60}$$

Z , P, A, $\emptyset$ and 60 are constants

Thus, $N \propto Eb \propto (V - IaRa)$

Characteristics of DC Shunt Motor:

To study the performance of the DC shunt Motor various types of characteristics are to be studied.

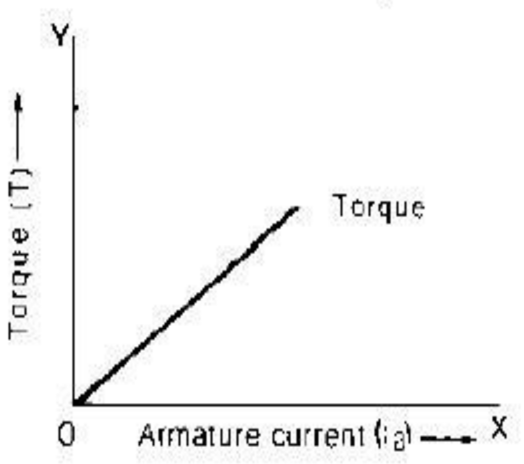
1. Torque Vs Armature current characteristics.
2. Speed Vs Armature current characteristics.
3. Speed Vs Torque characteristics.

Torque Vs Armature current characteristics of DC Shunt motor

This characteristic gives us information that, how torque of machine will vary with armature current, which depends upon load on the motor.

$$T \propto Ia$$

Thus,



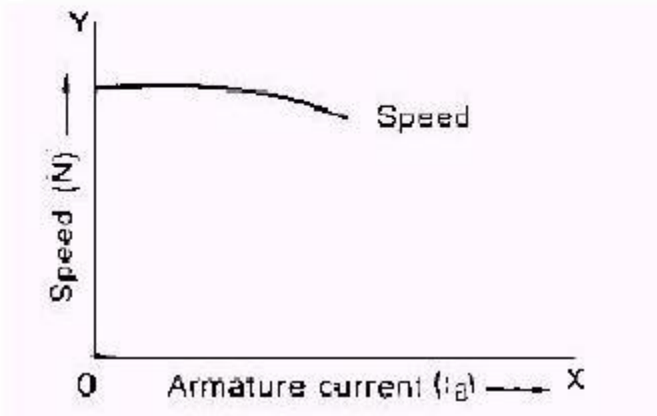
Speed Vs Armature current characteristics of DC Shunt Motor

The back emf of dc motor is $Eb = \frac{N\emptyset ZP}{A60} = V - IaRa$

$$\text{Therefore} \quad N = \frac{(V - I_a R_a)\ 60\ A}{\phi PZ} = \frac{K(V - I_a R_a)}{\phi}$$

where K = 60A/ ZP and it is constant. In dc shunt motor, when supply voltage V is kept constant the shunt field current and hence flux per pole will also be constant.

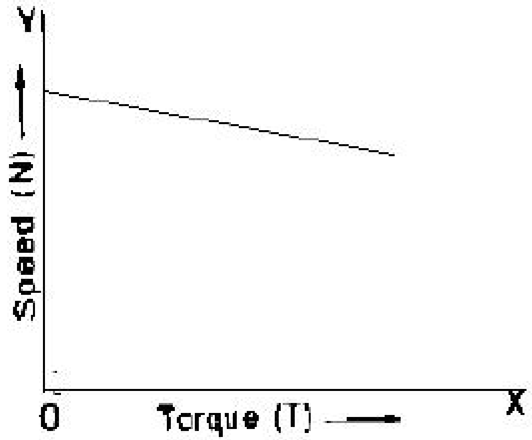
$$\therefore N \propto V - Ia\,Ra$$



- Therefore shunt motor is considered as constant speed motor.

Speed Vs Torque characteristics of DC Shunt motor

- From the above two characteristics of dc shunt motor, the torque developed and speed at various armature currents of dc shunt motor may be noted.
- If these values are plotted, the graph representing the variation of speed with torque developed is obtained.
- This curve resembles the speed Vs current characteristics as the torque is directly proportional to the armature current.



Applications of DC shunt Motor:

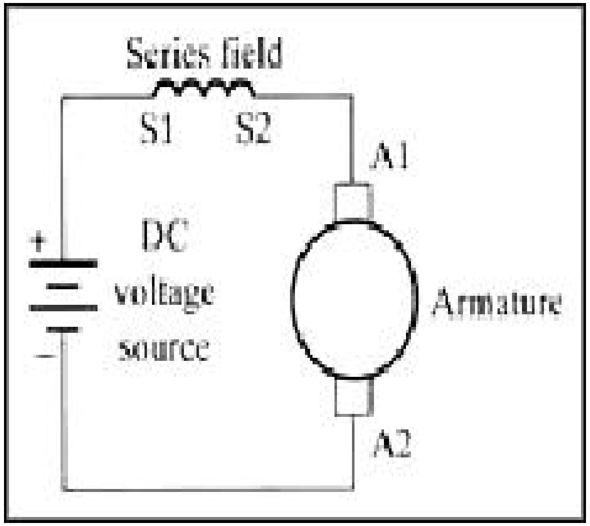
These motors are constant speed motors, hence used in applications requiring constant speed.

Like:

1) Lathe machine
2) Drilling machine
3) Grinders
4) Blowers
5) Compressors

DC Series Motor:

- In this type of DC motor the armature and field windings are connected in series.
- the resistance of the series field winding Rs is much smaller than the armature resistance Ra
- The flux produced is proportional to the field current but in this $I_f = I_a$ thus $\emptyset \propto Ia$



- Thus flux can never become constant in dc series motor as load changes I_f and I_a also gets changed
- Thus dc series motor is not a constant flux motor.

Torque and Speed equation of DC Series Motor:

As we have seen for dc motor

$$T \propto \emptyset\, Ia$$

But for dc series motor as $I_{f=}I_a$ $thus\ \emptyset \propto Ia$

So torque in dc series motor is

$$T \propto Ia^2$$

For dc motor

$$Eb = \frac{N\emptyset ZP}{A60}$$

Z , P, A and 60 are constants

Thus,$N \propto \frac{Eb}{\emptyset} \propto \frac{(V-IaRa)-I_sR_s}{\emptyset} = \frac{V-Ia(Ra+R_s)}{\emptyset}$....... as Ia=I_s

for dc series motor

Characteristics of DC Series Motor:

To study the performance of the DC series Motor various types of characteristics are to be studied.

1. Torque Vs Armature current characteristics.
2. Speed Vs Armature current characteristics.
3. Speed Vs Torque characteristics

Torque Vs Armature current characteristics of DC Series motor

- Torque developed in any dc motor is

$$T \propto \emptyset Ia$$

- In case of a D.C. series motor, as field current is equal to armature current, and for small value of I_a

$$\emptyset \propto I_a$$

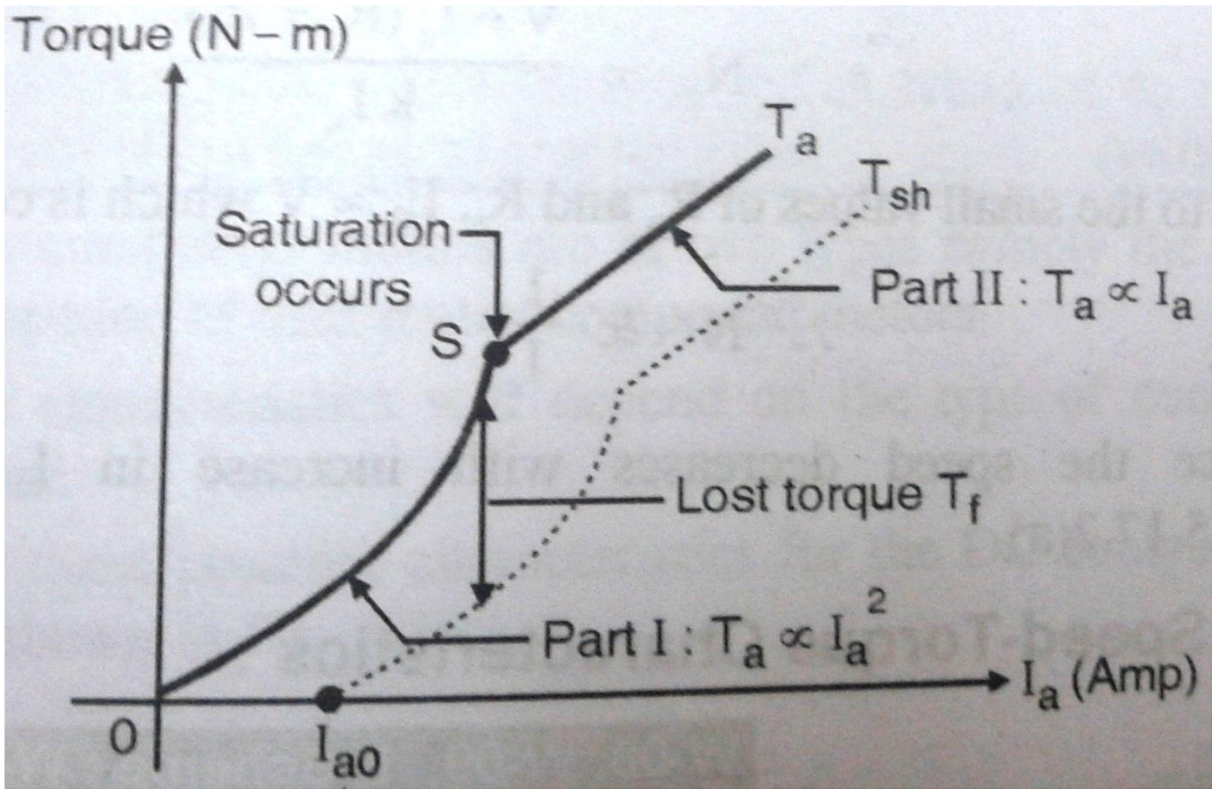
- Therefore the torque in the dc series motor for small value of I_a

$$T \propto Ia^2$$

- When I_a is large the Ø remains the constant due to saturation, thus torque is directly proportional to armature current for large value of I_a

$$T \propto I_a$$

- Thus Torque Vs Armature current characteristics begin to raise parabolically at low value of armature current and when saturation is reached it become a straight line as shown below.



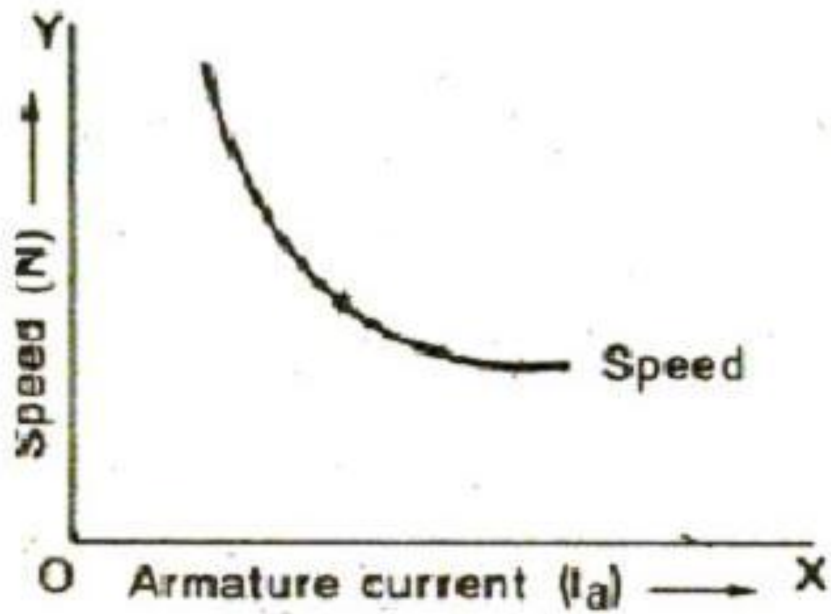
Speed Vs Armature current characteristics of DC Series Motor

Consider the following equation:

$$N = \frac{K(V - IaRa)}{\emptyset}$$

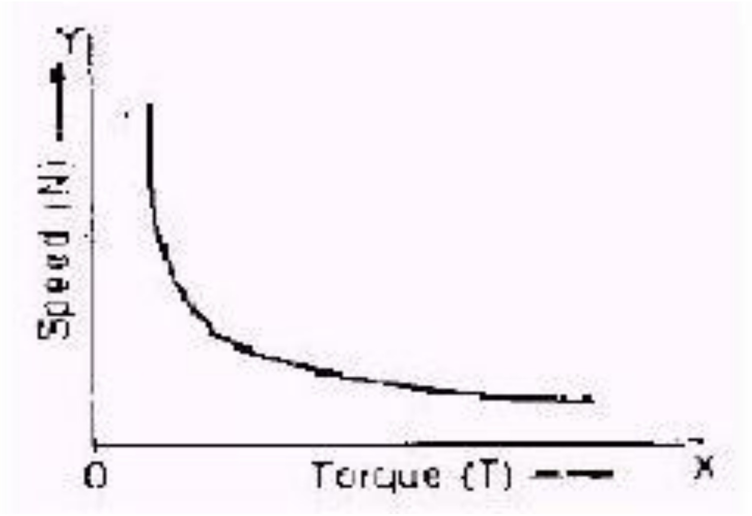
When supply voltage V is kept constant, speed of the motor will be inversely proportional to flux. In dc series motor field exciting current is equal to armature current which is nothing but a load current. Therefore at light load when saturation is not attained, flux will be proportional to the armature current and hence speed will be inversely proportional to armature current. Hence speed and armature current characteristics is hyperbolic curve upto saturation.

- As the load increases the armature current increases and field gets saturated, once the field gets saturated flux will become constant irrespective of increases in the armature current. Therefore at heavy load the speed of the dc series motor remains constant.
- This type of dc series motor has high starting torque.



Speed Vs Torque characteristics of DC Series motor

- The Speed Vs Torque characteristics of dc series motor will be similar to the Speed Vs Armature current characteristics it will be rectangular hyperbola, as shown in the fig.



Applications of DC series Motor-

These motors are useful in applications where starting torque required is high and quick acceleration. Like:

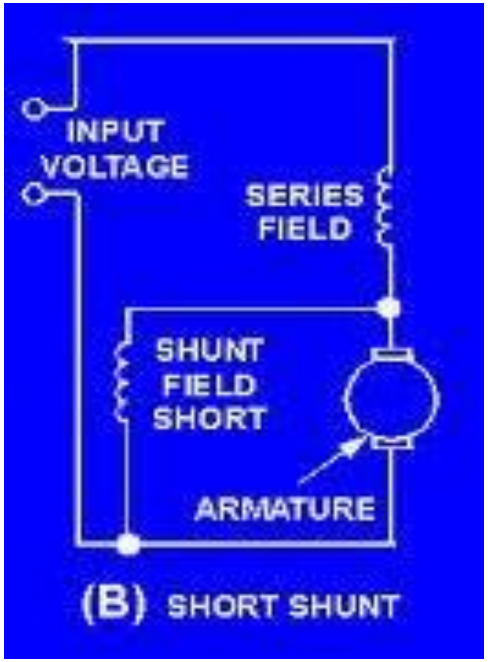
1) Traction
2) Hoists and Lifts
3) Crane
4) Rolling mills
5) Conveyors

DC Compound Motor:

- The DC compound motor is a combination of the series motor and the shunt motor. It has a series field winding that is connected in series with the armature and a shunt field that is in parallel with the armature. The combination of series and shunt winding allows the motor to have the torque characteristics of the series motor and the regulated speed characteristics of the shunt motor. Several versions of the compound motor are:
- Short shunt Compound Motors
- Long shunt Compound Motors

Short shunt compound motor:

- When shunt field winding is connected in parallel with armature like dc shunt motor and this assembly is connected in series with the series field winding then this type of motor is called as short shunt compound motor.

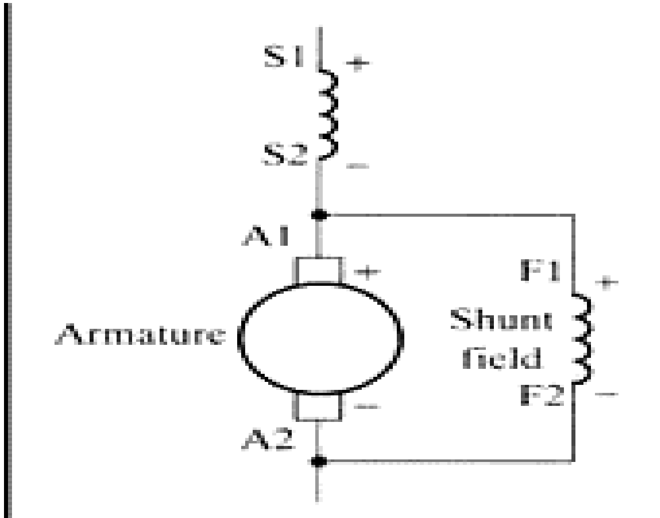


- Depending on the polarity of the connection short shunt motor is classified as:

1. Cumulative compound motor.
2. Differential compound motor.

Cumulative compound motor (short shunt):

- Figure shows a diagram of the cumulative compound motor. It is so called because the shunt field is connected so that its coils are aiding the magnetic fields of the series field and armature.
- In this figure that the top of the shunt field is positive polarity and that it is connected to the positive terminal of the armature.

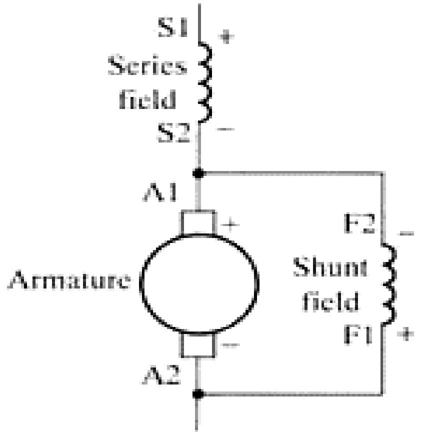


(a) Cummulative compound dc motor (short shunt)

- The cumulative compound motor is one of the most common DC motors because it provides high starting torque and good speed regulation at high speeds. Since the shunt field is wired with similar polarity in parallel with the magnetic field aiding the series field and armature field, it is called cumulative. When the motor is connected this way, it can start even with a large load and then operate smoothly when the load varies slightly.
- You should recall that the shunt motor can provide smooth operation at full speed, but it cannot start with a large load attached, and the series motor can start with a heavy load, but its speed cannot be controlled. The cumulative compound motor takes the best characteristics of both the series motor and shunt motor, which makes it acceptable for most applications.

Differential Compound Motor (short shunt):

Differential compound motors use the same motor and windings as the cumulative compound motor, but they are connected in a slightly different manner to provide slightly different operating speed and torque characteristics. Figure shows the diagram for a differential compound motor with the shunt field connected so its polarity is reversed to the polarity of the armature. Since the shunt field is still connected in parallel with only the armature, it is considered a short shunt.

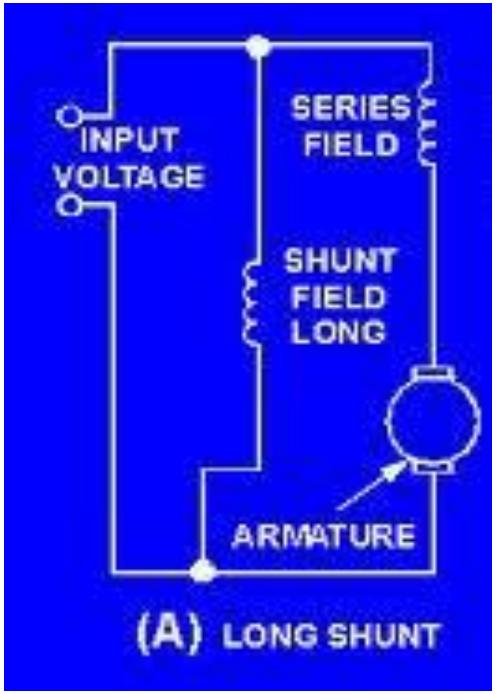


(b) Differential compound dc motor (short shunt)

In the above diagram you should notice that Fl and F2 are connected in reverse polarity to the armature. In the differential compound motor the shunt field is connected so that its magnetic field opposes the magnetic fields in the armature and series field. When the shunt field's polarity is reversed like this, its field will oppose the other fields and the characteristics of the shunt motor are not as pronounced in this motor. This means that the motor will tend to overspeed when the load is reduced just like a series motor. Its speed will also drop more than the cumulative compound motor when the load increases at full rpm. These two characteristics make the differential motor less desirable than the cumulative motor for most applications.

Long shunt compound motor:

- when the shunt field is connected in parallel with both the series field and the armature then this type of motor is called as long shunt compound motor.
- Depending on the polarity of connection of shunt field winding, series field winding and armature, long shunt motor is classified as:



1. Cumulative Compound Motor.
2. Differential Compound Motor.

Cumulative Compound Motor (long shunt):

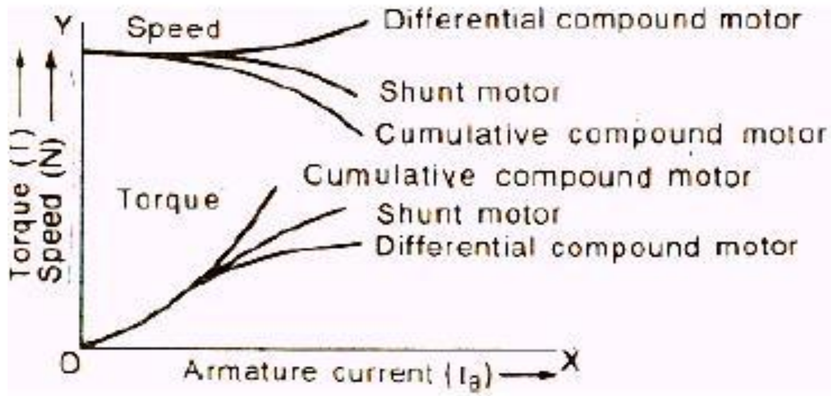
Characteristics of DC compound Motor:

To study the performance of the DC compound Motor various types of characteristics are to be studied.

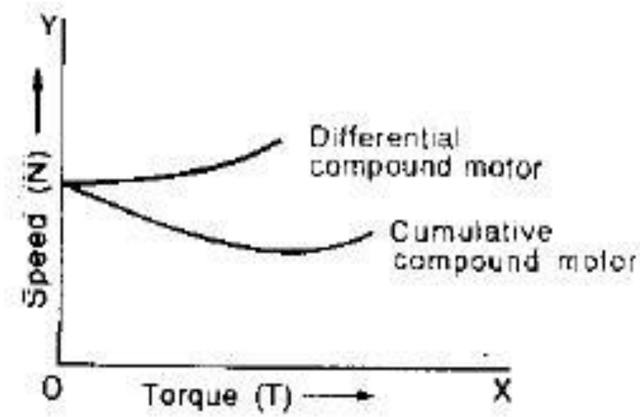
1. Torque Vs Armature current characteristics.
2. Speed Vs Armature current characteristics.
3. Speed Vs Torque characteristics

- In dc compound motors both shunt and series field acting simultaneously.
- In cumulative compound motor series field assist the shunt field.
- In such motors when armature current increases the field flux increases.
- So for given armature current the torque developed will be greater and speed lower when compared to a dc shun motor.
- In differential compound motor series field opposes the shunt field, therefore when armature current decreases the field flux decreases, so for given armature current the torque developed will be lower and speed greater when compare to the dc shunt motor.

Torque Vs Armature current and Speed Vs Armature current characteristics of dc compound motors



Speed Vs Torque characteristics are compared with that of shunt motor.



Applications of DC Compound Motor:

Cumulative Compound Motor:

- These motors have high starting torque.
- They can be operated even at no loads as they run at a moderately high speed at no load.
- Hence cumulative compound motors are used for the following applications.

1. Elevators
2. Rolling mills
3. Punches
4. Shears
5. planers

Applications of DC Compound Motor:

Differential Compound Motor:

- The speed of these motors increases with increases in the load which leads to an unstable operation.
- Therefore we can not use this motor for any practical applications.

Speed Control of DC Motor:

- The speed equation of dc motor is

$$N \propto \frac{Eb}{\emptyset} \propto \frac{(V - IaRa)}{\emptyset}$$

- But the resistance of armature winding or series field winding in dc series motor are small.
- Therefore the voltage drop $IaRa$ or $Ia(Ra + R_s)$ across them will be negligible as compare to the external supply voltage V in above equation.
- Therefore $N \propto \frac{V}{\emptyset}$, since V>>>> $IaRa$
- Thus we can say

1. Speed is inversely proportional to flux Ø.
2. Speed is directly proportional to armature voltage.
3. Speed is directly proportional to applied voltage V.

So by varying one of these parameters, it is possible to change the speed of a dc motor

Armature voltage control method:

Field current control method:

Reversal of Direction of Rotation:

- The direction of the magnetic flux in the air gap depends on the direction of the field current.
- And the direction of the force exerted on the armature winding depends on the direction of flux and the direction of armature current.
- Thus in order to reverse the direction of dc motor, we have to reverse the direction of force.
- This can be achieved either by changing the terminals of the armature or the terminals of the field winding.

Need of Starter:

We know that, $V = E_b + I_a R_a$.............for a dc shunt motor

and $V = E_b + I_a(R_a + R_s)$....for a dc series motor

Hence the expression for I_a are as follows:

$$I_a = \frac{V - E_b}{R_a} \text{........................ for dc shunt motor}$$

$$I_a = \frac{V - E_b}{(R_a + R_s)} \text{..................for dc series motor}$$

At the time of starting the motor, speed N=0 and hence the back emf E_b=0. Hence the armature current at the time of starting is given by,

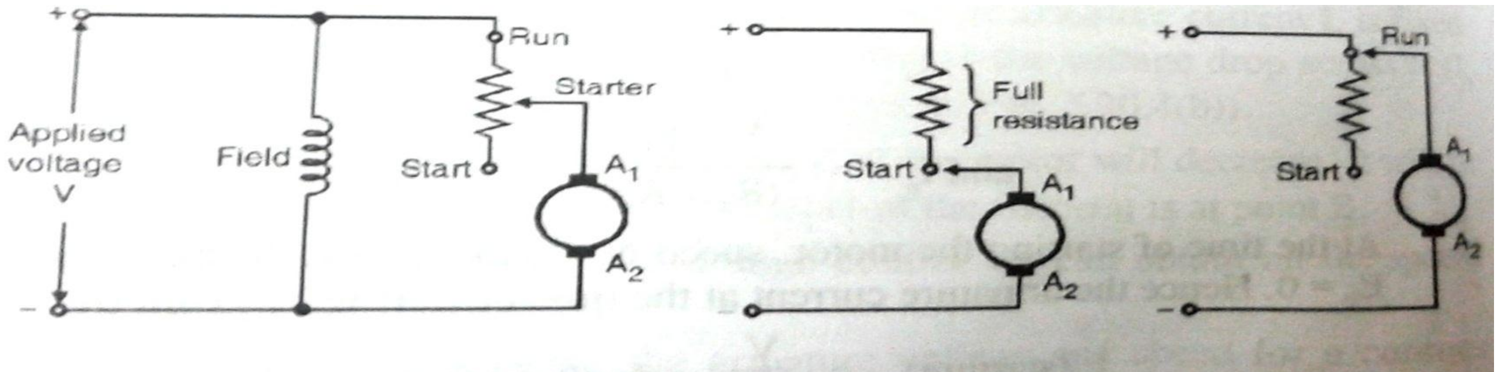
$$I_{a(starting)} = \frac{V}{R_a} \text{............for dc shunt motor}$$

$$I_{a(starting)} = \frac{V}{(R_a + R_s)} \text{......for dc series motor}$$

- Since the the values of R_a and $R_s$are small, the starting currents will be tremendously large if the rated voltage is applied at the time of starting.
- The starting current of the motor can be 15 to 20 times higher than the full load current.
- Due to high starting current the supply voltage will fluctuate.
- Due to excessive current, the insulation of the armature winding may burn.
- The fuses will blow and circuit breakers will trip.
- For dc series motors the torque $\mathrm{T} \propto {I_a}^2$. So an excessive large starting torque is produced. This can put a heavy mechanical stress on the winding and shaft of the motor resulting in the mechanical damage to the motor.
- So to avoid all these effects we have to keep the starting current of motor below safe limit. This is achieved by using starter.

Principle of starter:

- Starter is basically a resistance which is connected in series with the armature winding only at the time of starting the motor to limit the starting current.
- The starter of starter resistance will remain in the circuit only at the time of starting and will go out of the circuit or become ineffective when the motor speed upto a desire speed.



(a) Principle of starter (b) At the time of starting (c) Under normal operating condition

- At the time of starting, the starter is in the start position as shown in fig. so the full starter resistance appears in series with the armature. This will reduce the starting current.
- The starter resistance is then gradually cut off. The motor will speed up, back emf will be developed and it will regulate the armature current. The starter is not necessary then.
- Thus starter is pushed to the Run position as shown in fig under the normal operating condition. The value of starter resistance is zero in this position and it does not affect the normal operation.

Types of starter:

1. Three point starter
2. Four point starter

Classes of Insulation:

Class	Material	Temperature (max value)
Y	Cotton fabric and silk but not impregnated in dielectric	90◦C
A	Same as above but it is impregnated in some dielectric	105◦C
E	Synthetic organic films	120◦C
B	Glass fibres, Mica, Asbestos fibres bound together	130◦C
F	Above material but with impregnations	155◦C
H	Above material combined with silicon binding and impregnation	180◦C
C	Above material with ceramic or quartz wth or without binding agent	More than 180◦C

Force acting on the armature conductor(Lorentz force):