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# Unit-2 DC Motors

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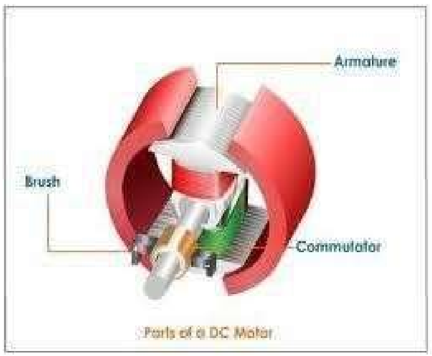
# DC MOTOR

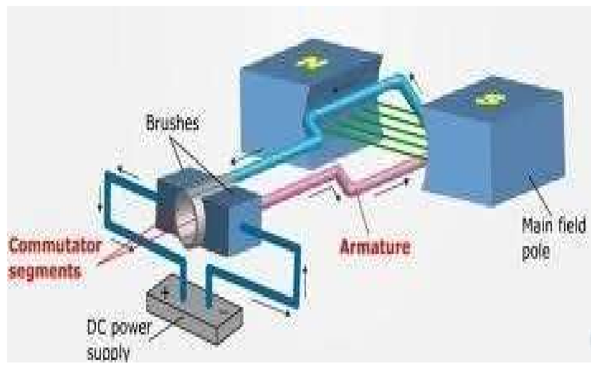
Motor: It is a machine which converts electrical energy into mechanical energy.

# Principle of operation of DC Motor:

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

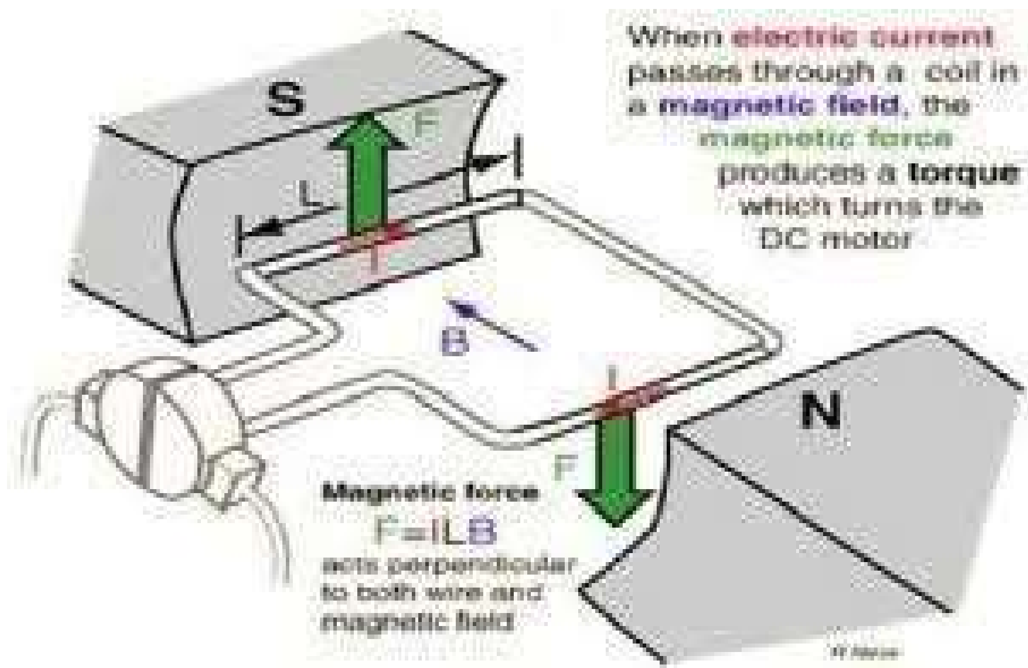



Parts of a DC Motor




The direction of force is given by Fleming's Left Hand Rule

# Force acting on the armature conductor(Lorentz force):

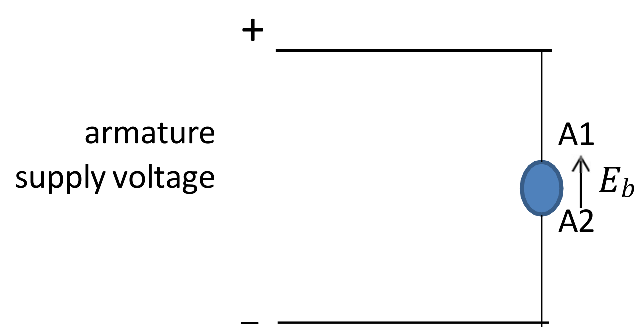


## Back emf:

- 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



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# Significance of Back EMF

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The presence of **back emf** makes the d.c. motor a *self-regulating machine* i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load.

$Ia=(V-E_b)/R_a$

# Voltage and Power equation of DC Motor:

$$V = E + IR$$

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

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

$VIa = electrical\ power\ supplied\ to\ the\ motor$

$EbIa = electrical\ equivalent\ of\ the\ mechanical\ power\ produced\ by\ the\ motor$

$Ia^2Ra = power\ loss\ taking\ place\ in\ armature\ winding$

Thus,

$$E_b I_a = VI_a - {I_a}^2 R_a$$

$$= input\ power\text{-}power\ loss$$

thus,

$EbIa$= Gross mechanical power produce *by the motor*

$= P_m$

# n for Maximum Power

The gross mechanical power developed by a motor is

$$P_m = VI_a - I_a^2 R_a$$

Differentiating both sides with respect to $I_a$ and equating the result to zero, we get

$$P_m = VI_a - I_a^2 R_a$$

$$\frac{\mathrm{d}P_m}{\mathrm{d}I_a} = V - 2I_a R_a = 0$$

$$\therefore I_a R_a = \frac{V}{2}$$

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

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

Thus maximum efficiency of a dc motor occurs when back EMF is equal to half the applied voltage.

# t Points

- Thus gross mechanical power developed by a motor is maximum when back EMF is equal to half the applied voltage.

- This condition is, however, not realized in practice, because in that case current would be much beyond the normal current of the motor.

- Moreover, half the input would be wasted in the form of heat and taking other losses (mechanical and magnetic) into consideration, the motor efficiency will be well below 50 percent.

# quation of DC Motor:

$$Mechanical\ power\ required\ to\ rotate\ the\ shaft\ on\ mechanical\ side = T\omega \text{------------------------------}1$$

T = Torque in Newton-meter

$\omega$= angular velocity in radian /second

$$gross\ Mechanical\ power\ produce\ by\ the\ motor\ on\ electrical\ side = E_b I_a \text{------------------------------------------------}2$$

$E_b$ = back emf in volts

Ia = armature current in ampere

equating equation 1 & 2

$E_b I_a = T_\omega$

60 ..................................

$$\frac{2\pi N}{60}$$ = 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

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

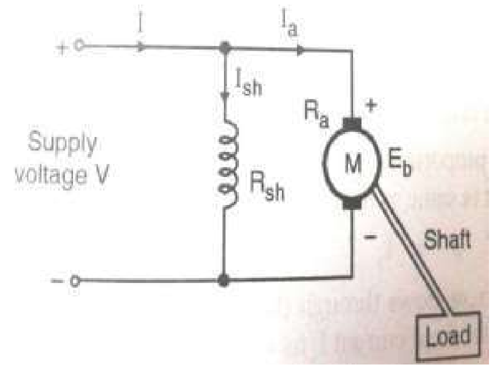
Thus torque produce by the DC Motor is proportional to the main field flux Ø and armature current $Ia$

# 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.

# d Speed equation of DC Shunt Motor:



As we have seen for dc motor

$$T \propto \emptyset Ia$$

But for dc shunt motor :$\emptyset \propto Is$□

And $Is$□ 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.

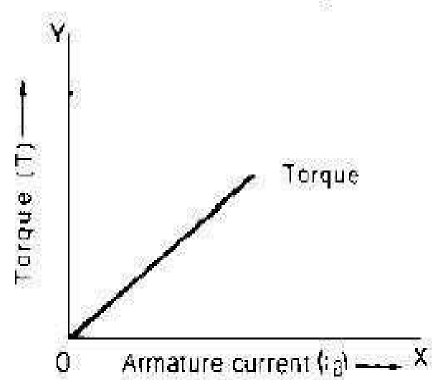
1. Torque Vs Armature current characteristics.
2. Speed Vs Armature current characteristics.
3. Speed Vs Torque characteristics.

# 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,



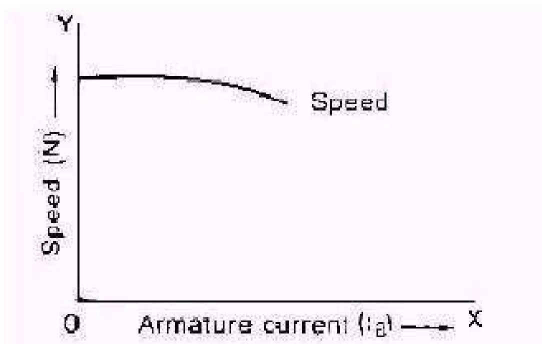
# Speed vs Armature current characteristics of DC Shunt Motor

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

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

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.

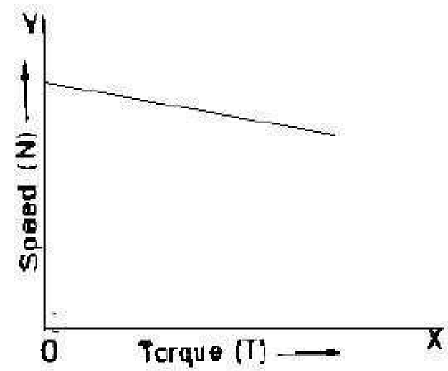
$$\therefore\ N \propto V - Ia\,Ra$$




- Therefore shunt motor is considered as constant speed motor.

# 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:

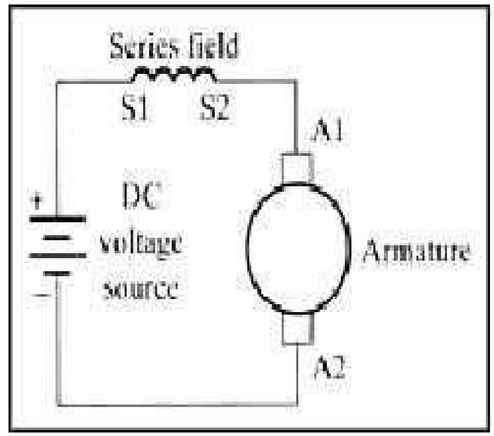
These motors are constant speed motors, hence used in applications requiring constant speed.

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

  $I_f = I$ 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 $I_{f=}I_a$ but$\emptyset \propto Ia$

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

## 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 $I_a$

$$\emptyset \propto I_a$$

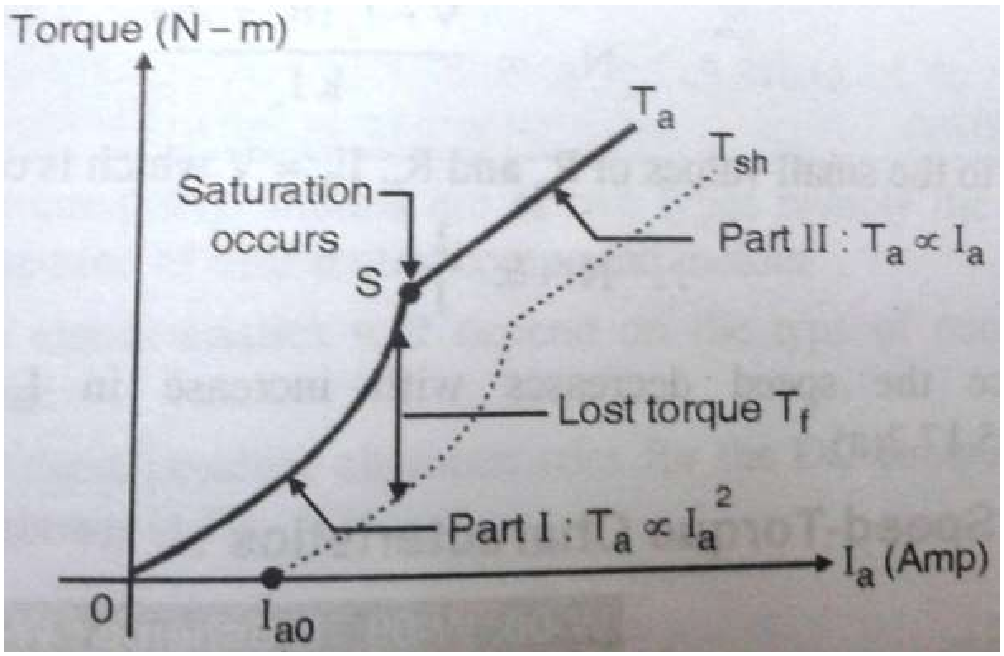
- Therefore the torque in the dc series motor for small value of $I_a$

$$T \propto Ia^2$$

- When $I_a$ is large the $\emptyset$ 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.



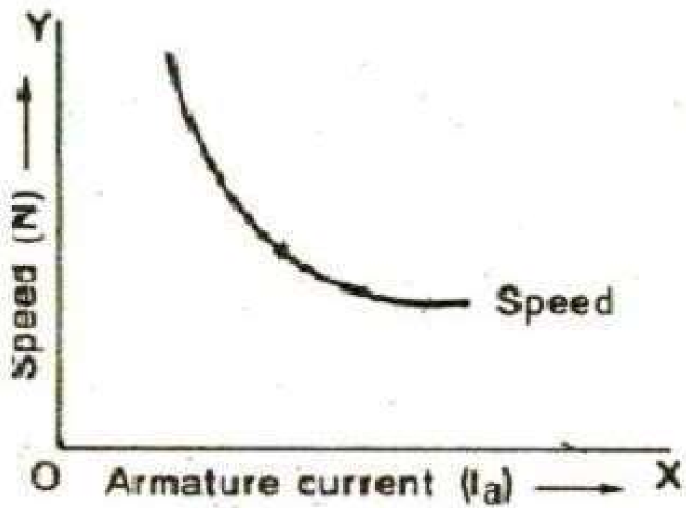
# Speed Vs Armature current characteristics of DC Series Motor

Consider the following equation:

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

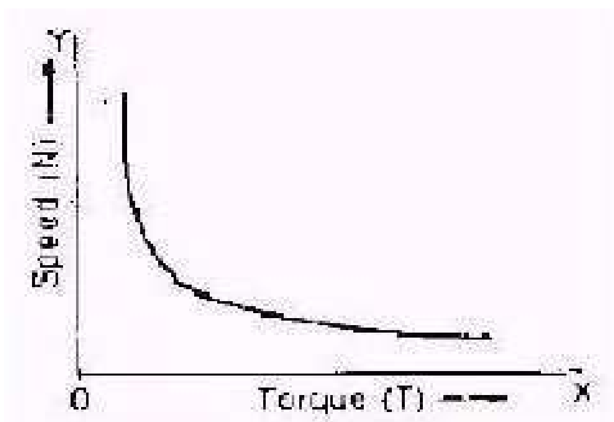
When supply voltage V is kept constant, speed of the motor will be inversely proportional to flux. In dc series motor field exciting current is equal to armature current which is nothing but a load current. Therefore at light load when saturation is not attained, flux will be proportional to the armature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

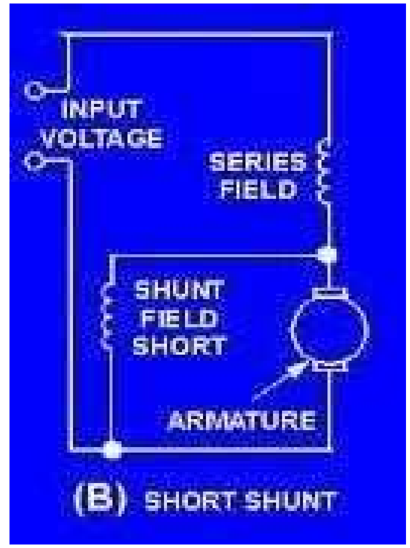
These motors are useful in applications where starting torque required is high and quick acceleration. Like:

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:

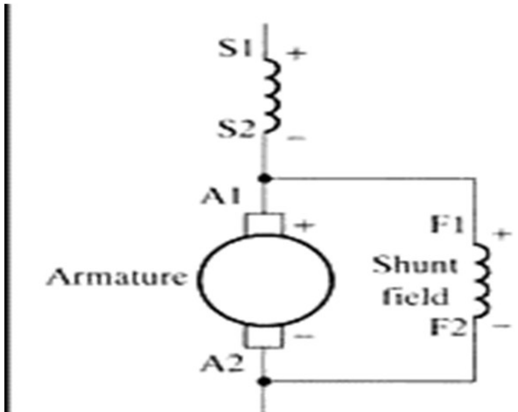



- When shunt field winding is connected in parallel with armature like dc shunt motor and this assembly is connected in series with the series field winding then this type of motor is called as short shunt compound motor.
- Depending on the polarity of the connection short shunt motor is classified as:

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.

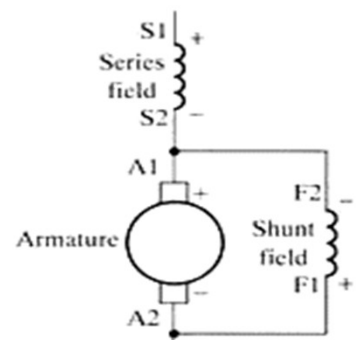



(a) Cummulative compound dc motor (short shunt) ulative compound motor is one of the most common DC motors because it provides high starting torque and good speed regulation at high speeds. Since the shunt field is wired with similar polarity in parallel with the magnetic field aiding the series field 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.

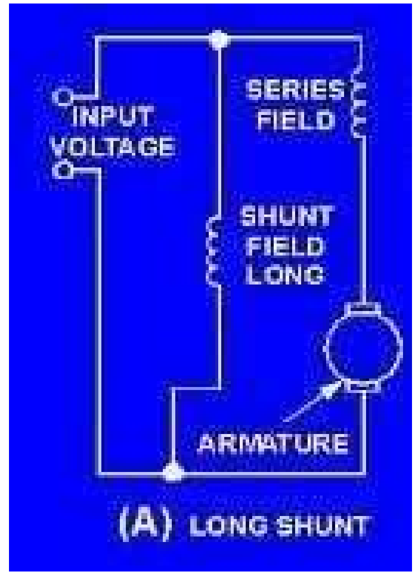
# Differential Compound Motor (short shunt):

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) e 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.

# 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