

# DC MOTOR

# Introduction

- The Dc machines are of two types namely DC generators and DC motors.
- A DC generators converts mechanical energy into electrical energy whereas a DC motor converts the electrical energy into mechanical energy.
- In order to understand the operating principle of a DC motor, it is necessary to understand how does a current carrying conductor experience a force, when kept in a magnetic field.

- **Force on current carrying conductor:**

- If a straight conductor is placed in the magnetic field produced by a permanent magnet, the current flowing through a conductor in anti clockwise direction.
- Due to the presence of two magnetic fields simultaneously, an interaction between them will take place as shown in fig.(1).

- **Magnitude of Force:**

- The magnitude of the force experienced by the current carrying conductor placed in the magnetic field is given by,

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

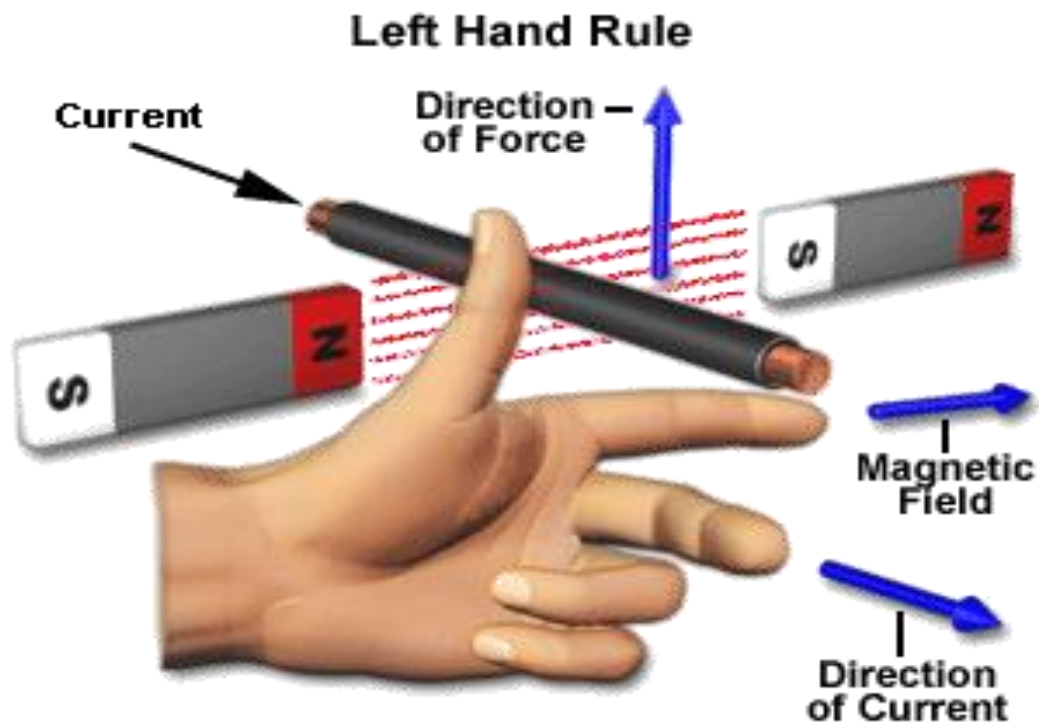
Where B = Flux density produced by Magnet

I = current flowing through conductor

$l$  = Length of the conductor

- **Direction of force:**

- The direction of rotation of a motor depends on the direction of force exerted on the the armature winding and the direction of force experienced by a current carrying conductor is given by Fleming's left hand rule.
- Statement of Fleming's left hand rule:  
It states that if the first three fingers of the left hand are held mutually at right angles to each other and if index finger indicates the direction of the magnetic field, and if middle finger indicates the direction of current flowing through the conductor, then thumb indicates the direction of force exerted on the conductor. This is shown in fig (2).



**Fig.(2):Fleming's left hand rule thumb**

# Windings in DC Machine

- In any dc machines, there are two windings:
  1. Field winding
  2. Armature winding
- Out of these, the field winding is stationary which does not move at all and armature winding is mounted on a shaft. So it can rotate freely.
- Connection of windings for operation as motor:
  - To operate the dc machine as a motor, the field winding and armature winding is connected across a dc power supply.

# DC Motor

- Principle of operation:
  - When current carrying conductor is placed in a magnetic field, it experienced a force.
  - In case of DC motor, the magnetic field is developed by the field current i.e. current flowing in field winding and armature winding plays the role of current carrying conductor
  - So armature winding experienced a force and start rotating.



# Construction of DC Motor

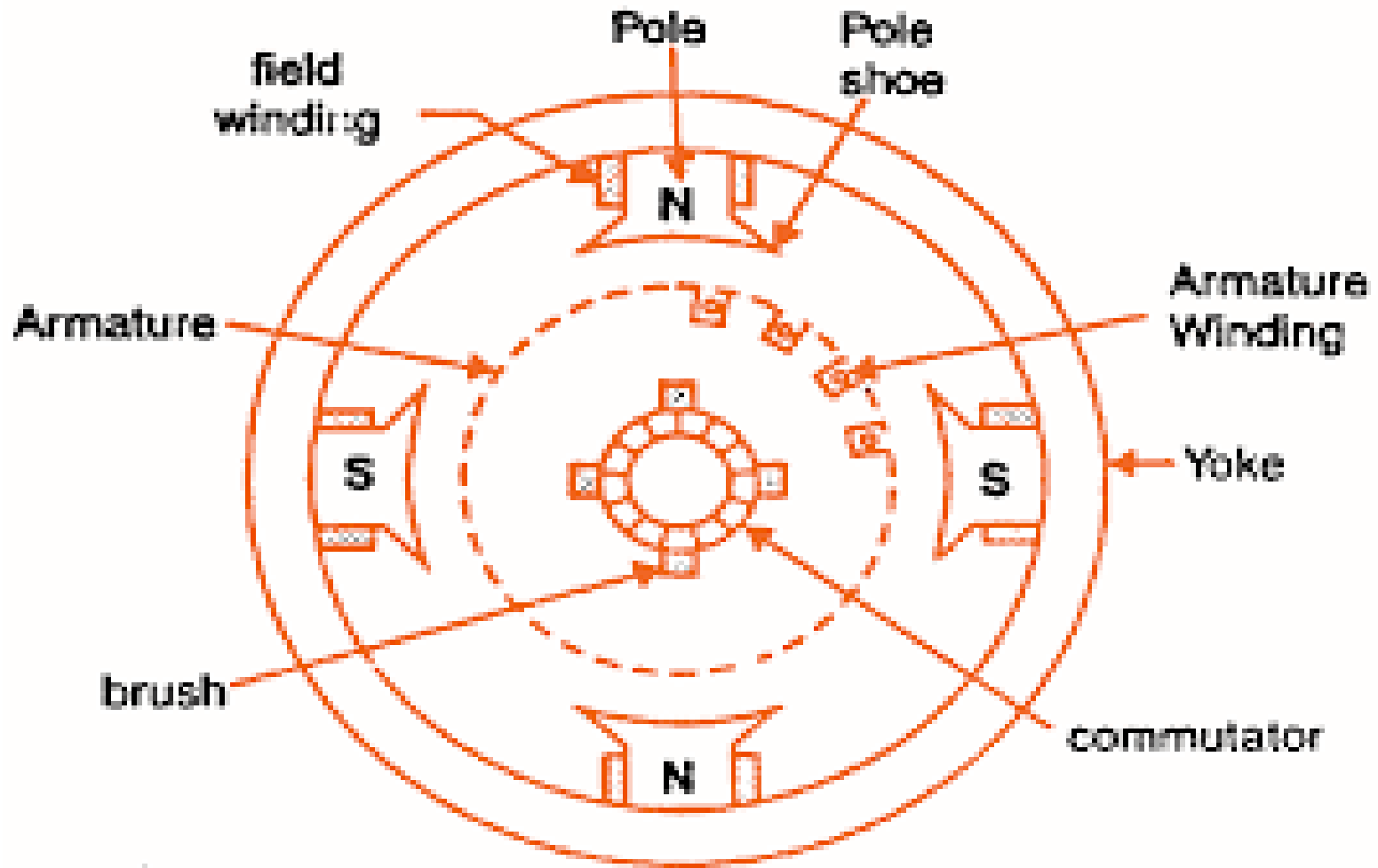


Fig.(1): construction of DC motor

- **Important parts of DC motor:**

- |                  |                               |
|------------------|-------------------------------|
| 1. Yoke          | 4. Armature                   |
| 2. Field winding | 5. Commutator, brushes & gear |
| 3. poles         | 6. Brushes                    |

- 1. Yoke:**

- It acts as the outer support of a DC motor.
- It provides mechanical support for the poles.

## **2. Poles:**

- pole of a dc motor is an electromagnet.
- The field winding is wound over the poles.
- Poles produces magnetic flux when the filed winding is excited.

## **3. Field winding:**

- The coils wound around the pole are called field coils and they are connected in series with each other to form field winding.
- When current passing through the field winding, magnetic flux produced in the air gap between pole and armature.

#### **4. Armature:**

- Armature is a cylindrical drum mounted on shaft in which number of slots are provided.
- Armature conductors are placed in these slots.
- These armature conductors are interconnected to form the armature winding.

#### **5. Commutator:**

- A commutator is a cylindrical drum mounted on the shaft along with the armature core.
- It collects the current from the armature conductors and passes it to the external load via brushes.

## **6. Brushes:**

- Commutator is rotating. So it is not possible to connect the load directly to it.
- Hence current is conducted from the armature to the external load by the carbon brushes which are held against the surface of commutator by springs.

# Back EMF

- When the armature winding of a dc motor starts rotating in the magnetic flux produced by the field winding, it cuts the lines of magnetic flux.
- Hence according to the faraday's laws of electromagnetic induction, there will be an induced emf in the armature winding.
- As per the Lenz's law, this induced emf acts in opposite direction to the armature supply voltage. Hence this emf is called as the back emf and denoted by  $E_b$ .

$$E_b = \frac{NP\phi Z}{60 A}$$

- **Significance of back emf:**

- The presence of back e.m.f. 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.

1. When the motor is running on no load, small torque is required to overcome the friction and windage losses. Therefore, the armature current  $I_a$  is small and the back e.m.f. is nearly equal to the applied voltage.

2. If the motor is suddenly loaded, the first effect is to cause the armature to slow down. Therefore, the speed at which the armature conductors move through the field is reduced and hence the back e.m.f.  $E_b$  falls. The decreased back e.m.f. allows a larger current to flow through the armature and larger current means increased driving torque. Thus, the driving torque increases as the motor slows down. The motor will stop slowing down when the armature current is just sufficient to produce the increased torque required by the load.



3. If the load on the motor is decreased, the driving torque is momentarily in excess of the requirement so that armature is accelerated. As the armature speed increases, the back e.m.f.  $E_b$  also increases and causes the armature current  $I_a$  to decrease. The motor will stop accelerating when the armature current is just sufficient to produce the reduced torque required by the load. It follows, therefore, that back e.m.f. in a d.c. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the Load requirement.

# Voltage Equation of a DC Motor

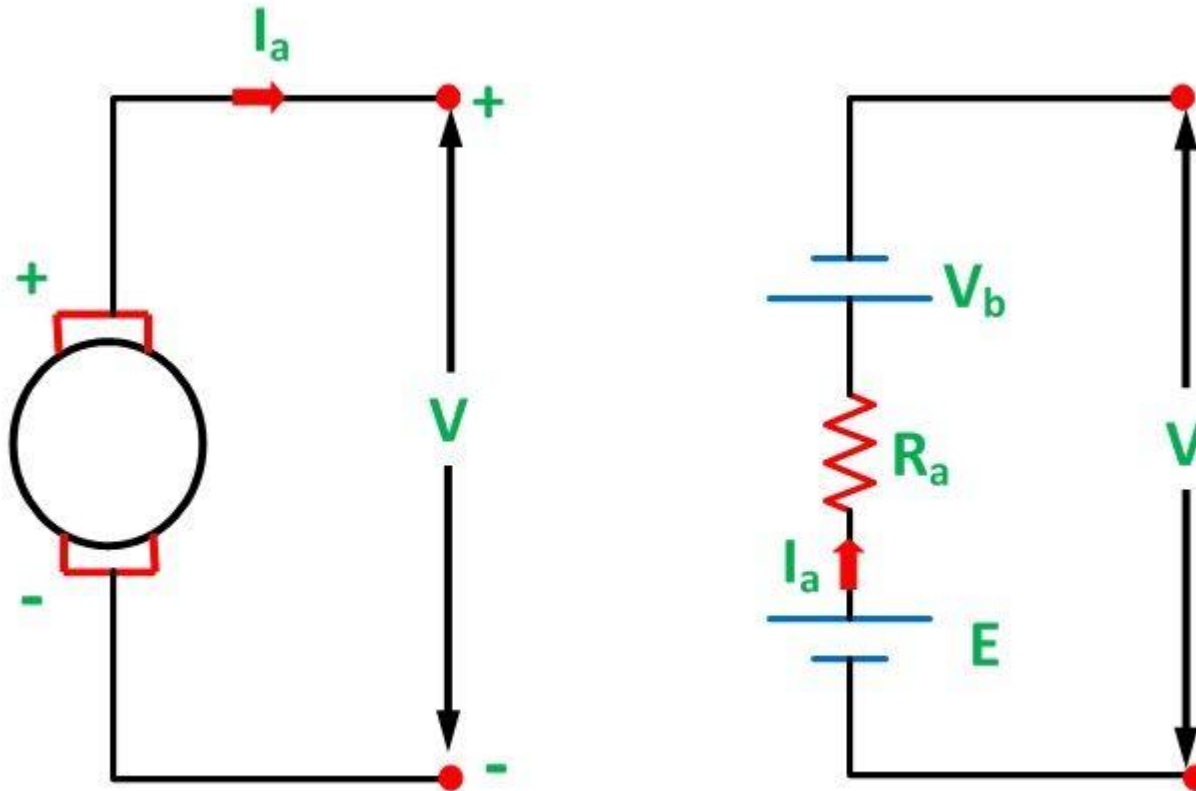


Fig.(1):Equivalent circuit of DC motor

- As shown in fig.(1), the armature supply voltage  $V$  has to overcome the opposition posed by the back emf  $E_b$  and some other voltage drops such as brush drop and the voltage drop across  $R_a$ .
- From fig.(1), we can write that,

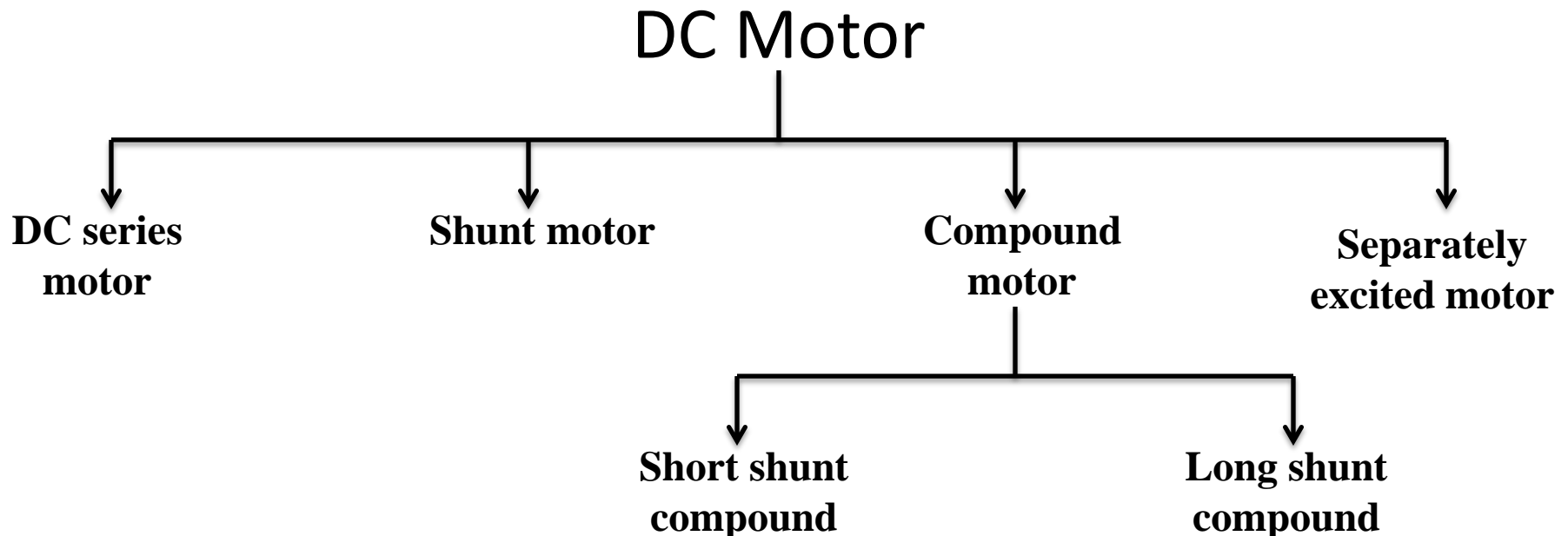
$$V = E_b + I_a R_a + V_b \quad \text{.....(1)}$$

- But voltage drop across brushes is negligible.

$$\therefore V = E_b + I_a R_a \quad \text{.....(2)}$$

# Types of DC Motors

- Depending on the way of connecting the armature and field windings of a d.c. motors are classified as follows:



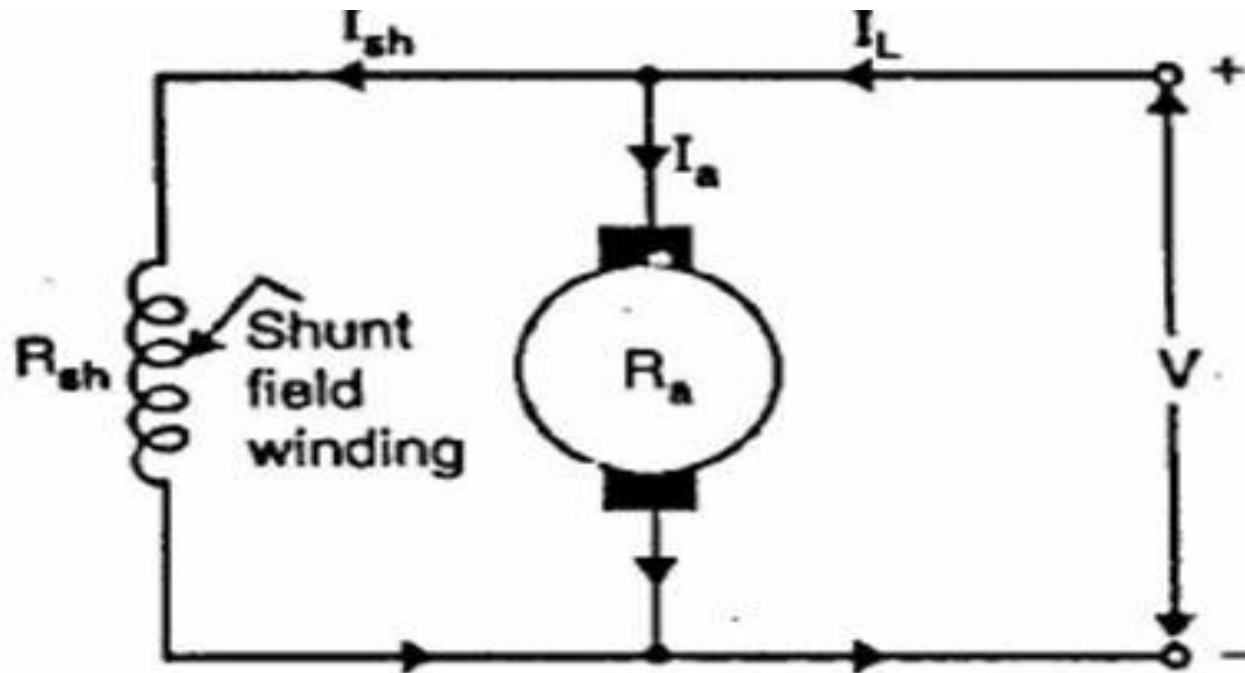
# DC Shunt Motor

- In DC shunt type motor, field and armature winding are connected in parallel as shown in fig.(1), and this combination is connected across a common dc power supply.
- The resistance of shunt field winding ( $R_{sh}$ ) is always much higher than that of armature winding ( $R_a$ ).
- This is because the number of turns for the field winding is more than that of armature winding.

- The field current  $I_{sh}$  always remains constant. Since  $V$  and  $R_{sh}$  both are constant. Hence flux produced also remains constant. Because field current is responsible for generation of flux.

$$\therefore \phi \propto I_{sh}$$

- This is why the shunt motor is also called as the constant flux motors.



**Fig.(1):DC shunt motor schematic diagram**

# DC Series Motor

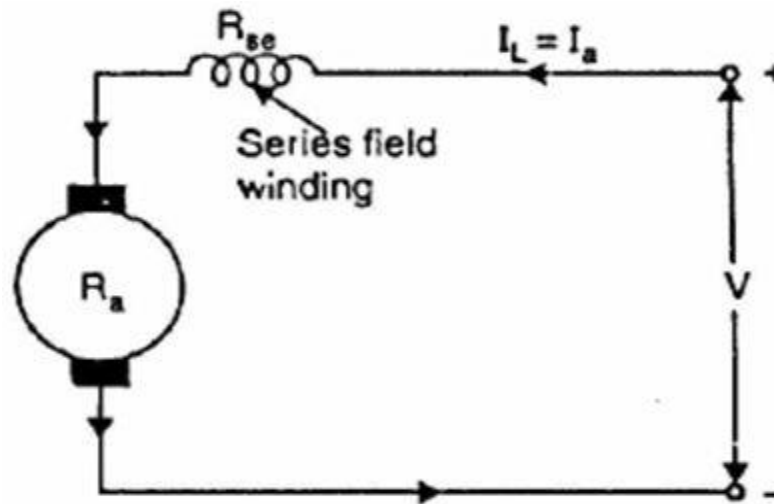
- In DC series motor, the armature and field windings are connected in series with each other as shown in fig.(1).
- The resistance of the series field winding ( $R_s$ ) is much smaller as compared to that of the armature resistance ( $R_a$ ).
- The flux produced is proportional to the field current. But in series motor, the field current is same as armature current.

$$\therefore \phi \propto I_a \quad \text{or}$$

$$\therefore \phi \propto I_s$$



- The armature current  $I_a$  and hence field current  $I_s$  will be dependent on the load.
- Hence in DC series motor the flux does not remain constant.



**Fig.(1):DC series motor schematic diagram**

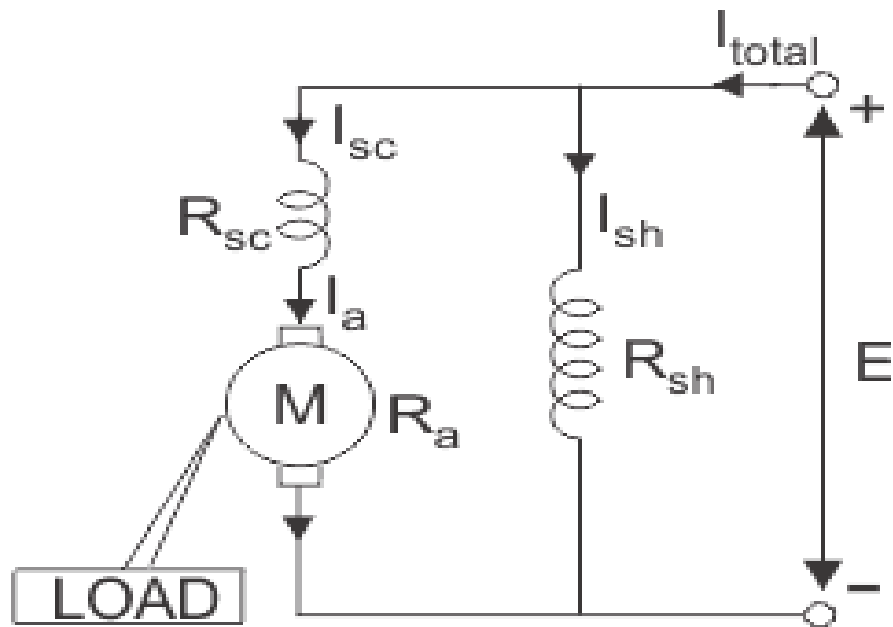
# DC Compound Motor

## 1. Long Shunt Compound Motor:

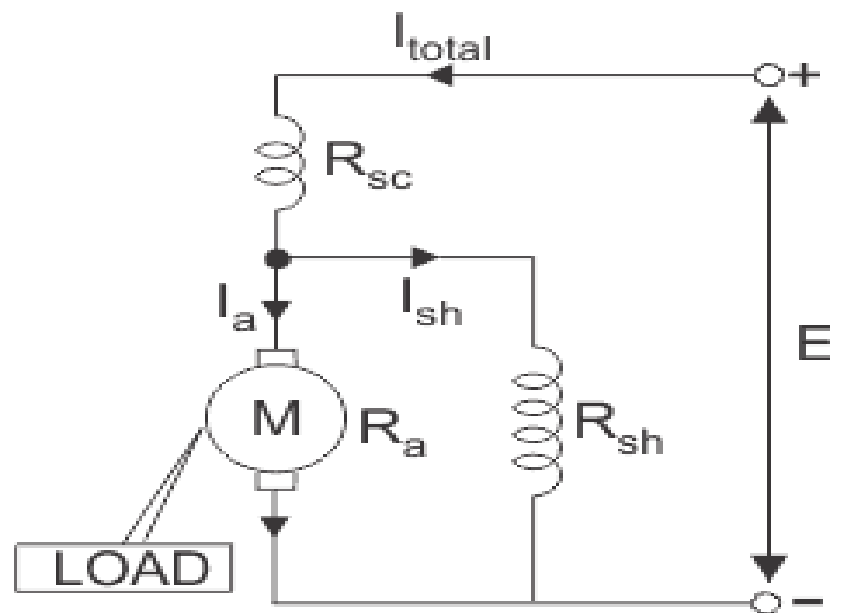
- As shown in fig.(1), in long shunt dc motor, shunt field winding is connected across the series combination of the armature and series field winding.

## 2. Short Shunt Compound Motor:

- In short shunt compound motor, armature and field windings are connected in parallel with each other and this combination is connected in series with the series field winding. This is shown in fig.(2).
- The long shunt and short shunt compound motors are further classified as **cumulative and differential compound motors**



**Fig.(1): Long shunt compound dc motor**



**fig.(2):Short shunt compound dc motor**

# Torque & Speed Equations

- **Torque equations:**

- Torque produced by a motor will always be proportional to the air gap flux  $\phi$  and the current flowing through the armature winding ( $I_a$ ).
- That means  $T \propto \phi I_a$
- The flux is produced by the field current hence  $\phi$  will be proportional to field current. That means,

$$\phi \propto I_{\text{field}}$$

- hence torque produced by a dc motor is proportional to the product of  $I_a$  and  $I_{\text{field}}$ . That means,

$$T \propto I_a I_{\text{field}} \quad \dots\dots\dots(1)$$

- For various types of dc motors the expression for field current will be different. We will substitute them into eq.(1) to get the torque equations.

## 1. Torque equation of DC shunt motor:

- For DC shunt motor  $I_{\text{field}} = V / R_{\text{sh}} = \text{constant}$
- Hence the flux  $\phi$  is constant.

$$\therefore T \propto I_a \quad \dots\dots\dots(2)$$

- Hence in dc shunt motor, torque is proportional to only to the armature current.

## 2. Torque equation DC series motor:

- For DC series motor, the field current is equal to the armature current i.e.  $I_{\text{field}} = I_a$ .

- Hence  $T \propto I_a I_a$

$$\therefore T \propto I_a^2 \quad \dots\dots\dots(3)$$

- Hence in dc series motor, torque is proportional to the square of armature current.

- **Speed Equations:**

- We know that the expression for the back emf is,

- But P, Z and 60A are constants. Therefore we can write that,

$$E_b \propto \phi N \quad \dots\dots(4)$$

$$E_b = \frac{NP\phi Z}{60 A}$$

- Therefore the speed can be expressed as,

$$N \propto E_b / \phi \quad \dots\dots(5)$$

$$N = k E_b / \phi \quad \dots\dots\dots(6)$$

- But  $V = E_b + I_a R_a$

$$\therefore E_b = V - I_a R_a \quad \dots\dots\dots(7)$$

- Substituting eq.(7) into eq.(5) we get,

$$N \propto (V - I_a R_a) / \phi \quad \dots\dots\dots(8)$$

- Since  $\phi \propto I_{\text{field}}$ , we can write,

$$N \propto (V - I_a R_a) / I_{\text{field}} \quad \dots\dots\dots(9)$$

## 1. DC shunt motor:

➤ For dc shunt motor, the flux  $\phi$  is constant.

$$\therefore N \propto (V - I_a R_a) \quad \dots\dots(10)$$

## 2. DC series motor:

➤ For dc series motor  $I_{\text{field}} = I_a$ . Therefore

$$N \propto (V - I_a R_a - I_s R_s) / I_a \quad \dots\dots\dots(11)$$

$$\text{where } E_b = V - I_a R_a - I_s R_s$$

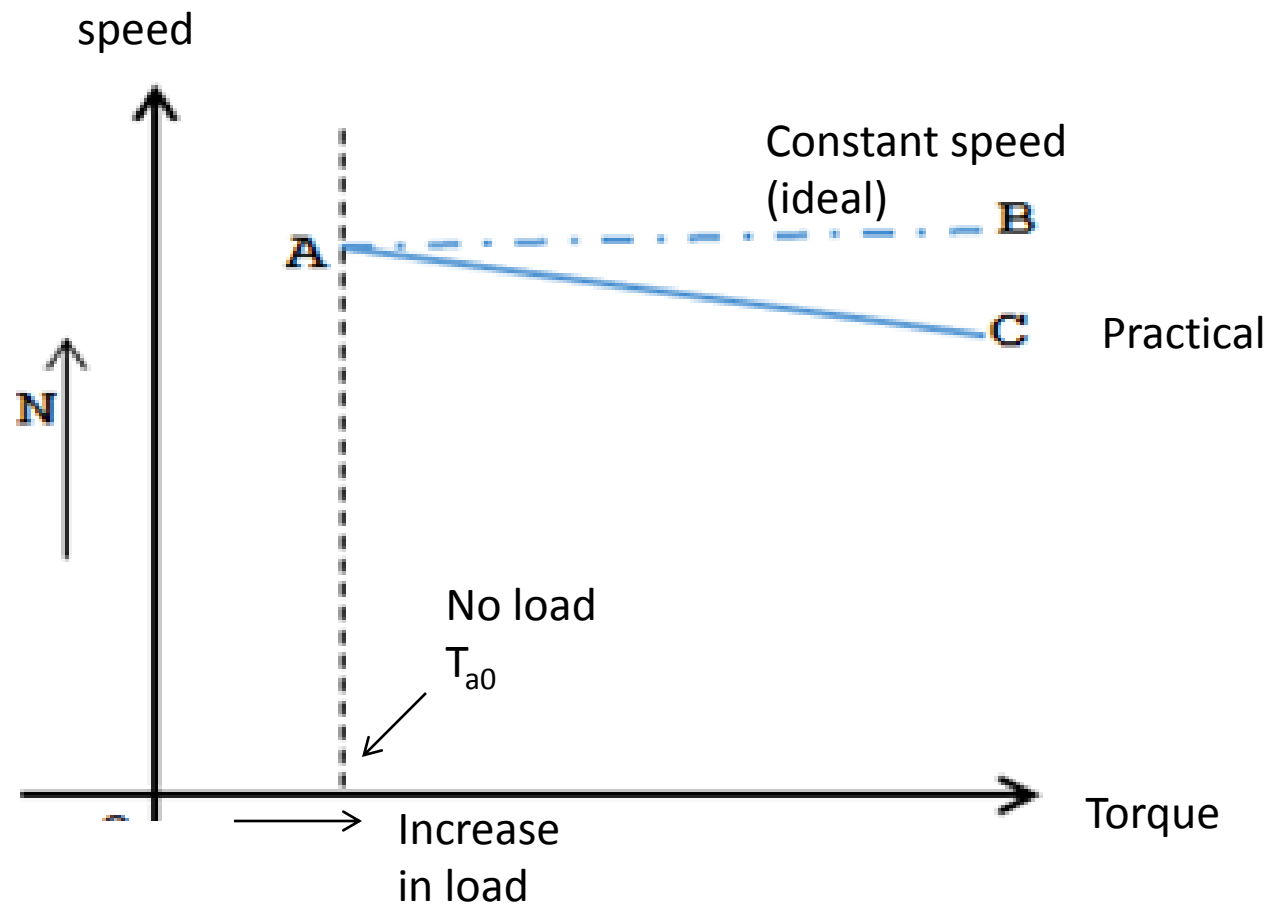
# Torque-speed characteristics

## 1. DC shunt motor:

- The torque-speed characteristics of dc shunt motor is as shown in fig.(1).
- At no load, the torque produced by the motor is  $T_{a0}$  and the motor rotates at the no load speed  $N_0$ .
- As the load increased, the torque requirement also increase. To generate the required amount of torque, the motor has to draw more armature current.



- And more armature current can be drawn if the speed decreases.
- Therefore, as the load increases, torque will also increase and the speed decreases.
- However the reduction in speed is not significant as the load is increased from no load to full load. Therefore practically the dc shunt motor is called as a constant speed motor.



**Fig.(1):speed-torque characteristics of dc shunt motor**

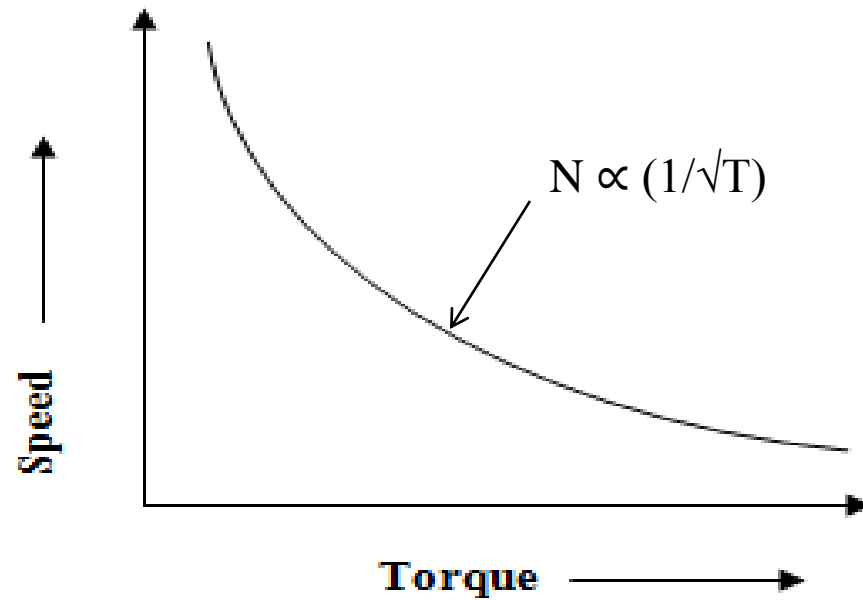
## 2. DC series motor:

- The speed –torque characteristics of DC series motor is as shown in fig.(2).
- We know that

$$N \propto 1/ I_a \text{ and } T \propto I_a^2$$

$$N \propto 1/\sqrt{T} \text{ and } I_a \propto \sqrt{T}$$

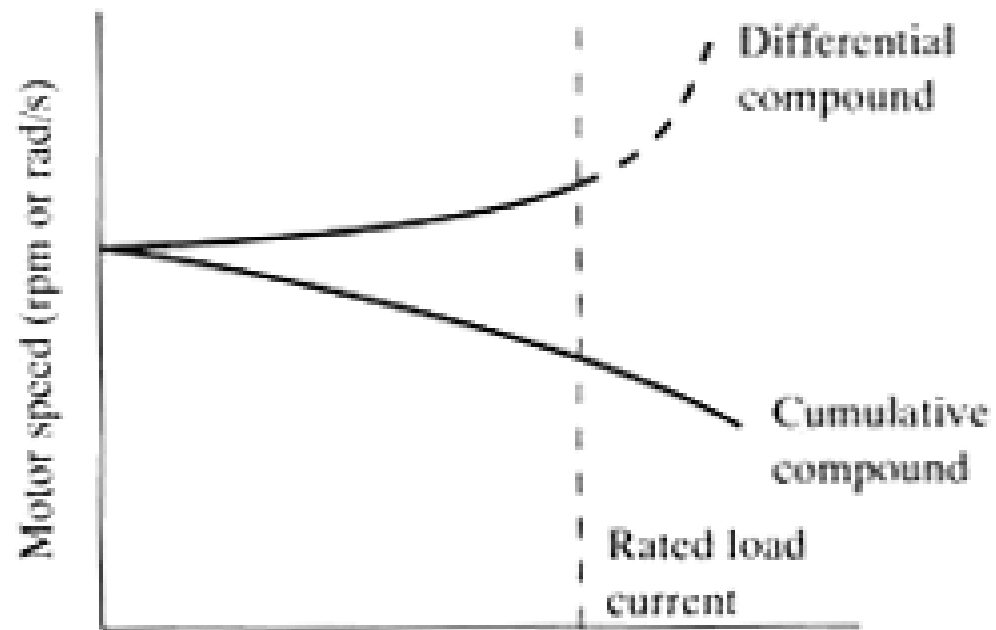
- This shows that the speed decreases with increase in the value of torque.



**Fig.(2): speed-torque characteristics of dc series motor**

### 3. DC compound motor:

- The torque- speed characteristics of the DC compound motor is as shown in fig.(3).
- It is combination of characteristics of DC series and DC shunt motor.
- The exact shape of these characteristics is dependent on the precise effects of series and shunt field winding.



**Fig.(3): speed torque characteristics of dc compound motor**

# **Applications of DC Motor**

## **1. Shunt motor applications:**

- i. Various machine tools such as lathe machines, drilling machines, milling machines etc.
- ii. Printing machines
- iii. Paper machines
- iv. Centrifugal and reciprocating pumps
- v. Blowers and fans etc.

## **2. Series motor applications:**

- i. Electric trains
- ii. Diesel-electric locomotives
- iii. Cranes
- iv. Hoists
- v. Trolley cars and trolley buses
- vi. Rapid transit systems
- vii. Conveyers etc.



### **3. Cumulative compound motor applications:**

- i. Elevators
- ii. Rolling mills
- iii. Planers
- iv. Punches
- v. Shears

### **4. Differential compound motors applications:**

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

# Specifications of DC Motor

- Some of important specifications of a DC motor:
  1. Output power in horse power(H.P.)
  2. Rated voltage
  3. Type of field winding
  4. Excitation voltage
  5. Base speed in RPM
  6. Current
  7. Frame size
  8. Rating

- **Typical specifications of DC series motor:**

<b>Sr. No.</b>	<b>Specifications/Rating</b>	<b>Value</b>
1.	Output power in horse power	3HP
2.	Rated voltage	230V
3.	Type of field winding	Series
4.	Excitation voltage	230V
5.	Insulation	B
6.	Base speed	1000RPM
7.	Current	11Amp
8.	Frame size	132 S
9.	Rating	Continous
10.	S.R.Number	840858