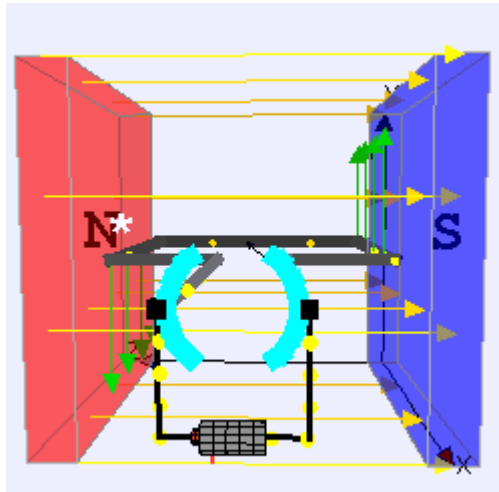


## DC Motor

### Working Principle Of A DC Motor

A motor is an electrical machine which converts electrical energy into mechanical energy. The **principle of working of a DC motor** is that "*whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force*". The direction of this force is given by Fleming's left hand rule and its magnitude is given by  $F = BIL$ . Where, B = magnetic flux density, I = current and L = length of the conductor within the magnetic field.

**Fleming's left hand rule:** If we stretch the first finger, second finger and thumb of our left hand to be perpendicular to each other AND direction of magnetic field is represented by the first finger, direction of the current is represented by second finger then the thumb represents the direction of the force experienced by the current carrying conductor.



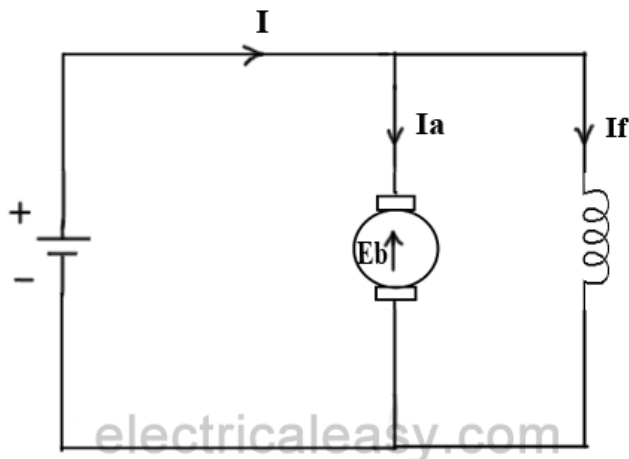
Animation: Working of DC Motor  
(credit: Lookang)

Above animation helps in understanding the **working principle of a DC motor**. When armature windings are connected to a DC supply, current sets up in the winding. Magnetic field may be provided by field winding (electromagnetism) or by using permanent magnets. In this case, current carrying armature conductors experience force due to the magnetic field, according to the principle stated above. Commutator is made segmented to achieve unidirectional torque. Otherwise, the direction of force would have reversed every time when the direction of movement of conductor is reversed the magnetic field.

### Back EMF

According to fundamental laws of nature, no energy conversion is possible until there is something to oppose the conversion. In case of generators this opposition is provided by magnetic drag, but in case of dc motors there is back emf.

When the armature of the motor is rotating, the conductors are also cutting the magnetic flux lines and hence according to the Faraday's law of electromagnetic induction, an emf induces in the armature conductors. The direction of this induced emf is such that it opposes the armature current ( $I_a$ ). The circuit diagram below illustrates the **direction of the back emf** and armature current. Magnitude of **Back emf** can be given by the emf equation of DC generator.



### Significance Of Back Emf:

Magnitude of back emf is directly proportional to speed of the motor. Consider the load on a dc motor is suddenly reduced. In this case, required torque will be small as compared to the current torque. Speed of the motor will start increasing due to the excess torque. Hence, being proportional to the speed, magnitude of the back emf will also increase. With increasing back emf armature current will start decreasing. Torque being proportional to the armature current, it will also decrease until it becomes sufficient for the load. Thus, speed of the motor will regulate.

On the other hand, if a dc motor is suddenly loaded, the load will cause decrease in the speed. Due to decrease in speed, back emf will also decrease allowing more armature current. Increased armature current will increase the torque to satisfy the load requirement. Hence, presence of the **back emf makes a dc motor 'self-regulating'**.

### Types Of DC Motors

DC motors are usually classified on the basis of their excitation configuration, as follows -

- Separately excited (field winding is fed by external source)
- Self excited -
  - Series wound (field winding is connected in series with the armature)
  - Shunt wound (field winding is connected in parallel with the armature)
  - Compound wound -
    - Long shunt
    - Short shunt

### Characteristics Of DC Motors

Generally, three characteristic curves are considered important for DC motors which are, (i) Torque vs. armature current, (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of DC motor. These characteristics are determined by keeping the following two relations in mind.

$$T_a \propto \phi \cdot I_a \text{ and } N \propto E_b / \phi.$$

These above equations can be studied at - emf and torque equation of dc machine. For a DC motor, magnitude of the back emf is given by the same emf equation of a dc generator i.e.  $E_b = P\phi NZ / 60A$ . For a machine, P, Z and A are constant, therefore,  $N \propto E_b / \phi$

## Characteristics Of DC Series Motors

### Torque Vs. Armature Current ( $T_a$ - $I_a$ )

This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to the product of armature current and field flux,  $T_a \propto \phi \cdot I_a$ . In DC series motors, field winding is connected in series with the armature, i.e.  $I_a = I_f$ . Therefore, before magnetic saturation of the field, flux  $\phi$  is directly proportional to  $I_a$ . Hence, before magnetic saturation  $T_a \propto I_a^2$ . Therefore, the  $T_a$ - $I_a$  curve is parabola for smaller values of  $I_a$ .

After magnetic saturation of the field poles, flux  $\phi$  is independent of armature current  $I_a$ . Therefore, the torque varies proportionally to  $I_a$  only,  $T \propto I_a$ . Therefore, after magnetic saturation,  $T_a$ - $I_a$  curve becomes a straight line. The shaft torque ( $T_{sh}$ ) is less than armature torque ( $T_a$ ) due to stray losses. Hence, the curve  $T_{sh}$  vs  $I_a$  lies slightly lower.

In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.

### Speed Vs. Armature Current ( $N$ - $I_a$ )

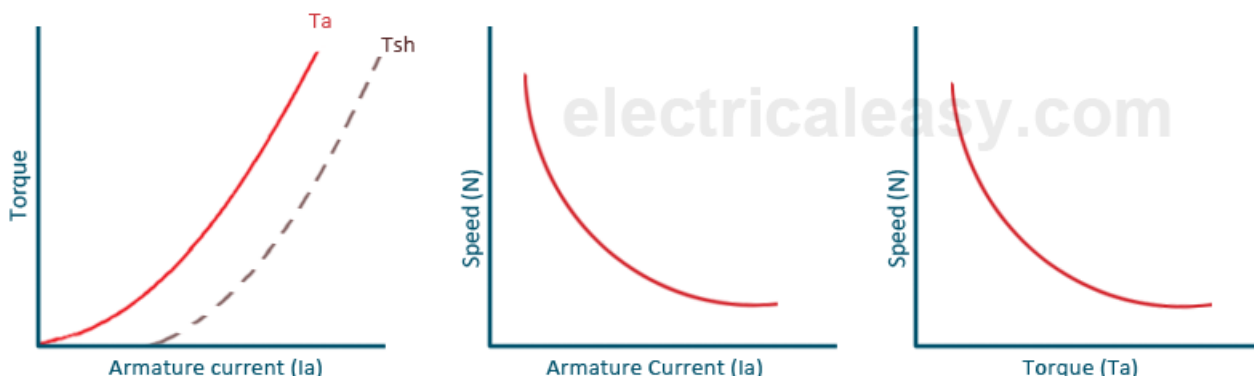
We know the relation,  $N \propto E_b / \phi$

For small load current (and hence for small armature current) change in back emf  $E_b$  is small and it may be neglected. Hence, for small currents speed is inversely proportional to  $\phi$ . As we know, flux is directly proportional to  $I_a$ , speed is inversely proportional to  $I_a$ . Therefore, when armature current is very small the speed becomes dangerously high. That is **why a series motor should never be started without some mechanical load**.

But, at heavy loads, armature current  $I_a$  is large. And hence, speed is low which results in decreased back emf  $E_b$ . Due to decreased  $E_b$ , more armature current is allowed.

### Speed Vs. Torque ( $N$ - $T_a$ )

This characteristic is also called as **mechanical characteristic**. From the above two **characteristics of DC series motor**, it can be found that when speed is high, torque is low and vice versa.



## Characteristics of DC series motor

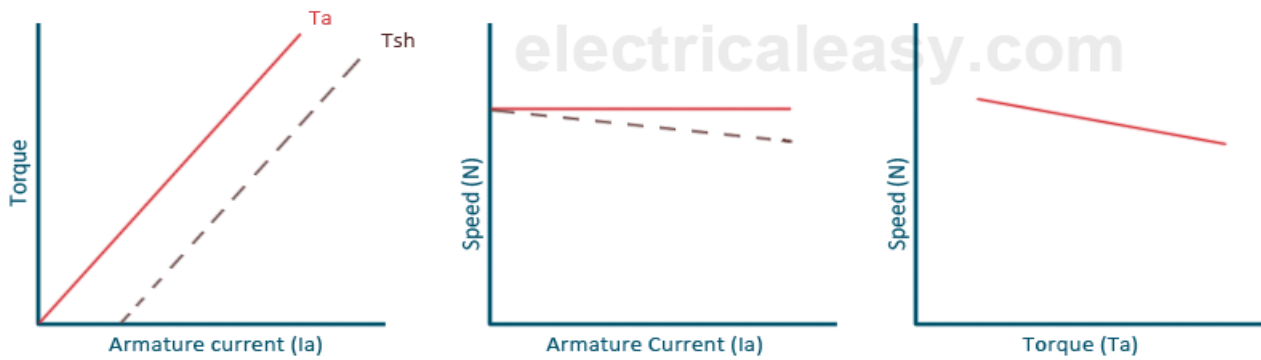
### Characteristics Of DC Shunt Motors

#### Torque Vs. Armature Current (Ta-Ia)

In case of DC shunt motors, we can assume the field flux  $\phi$  to be constant. Though at heavy loads,  $\phi$  decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux  $\phi$ , we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin. Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load.**

#### Speed Vs. Armature Current (N-Ia)

As flux  $\phi$  is assumed to be constant, we can say  $N \propto E_b$ . But, as back emf is also almost constant, the speed should remain constant. But practically,  $\phi$  as well as  $E_b$  decreases with increase in load. Back emf  $E_b$  decreases slightly more than  $\phi$ , therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor.** In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.



## Characteristics of DC shunt motor

### Characteristics Of DC Compound Motor

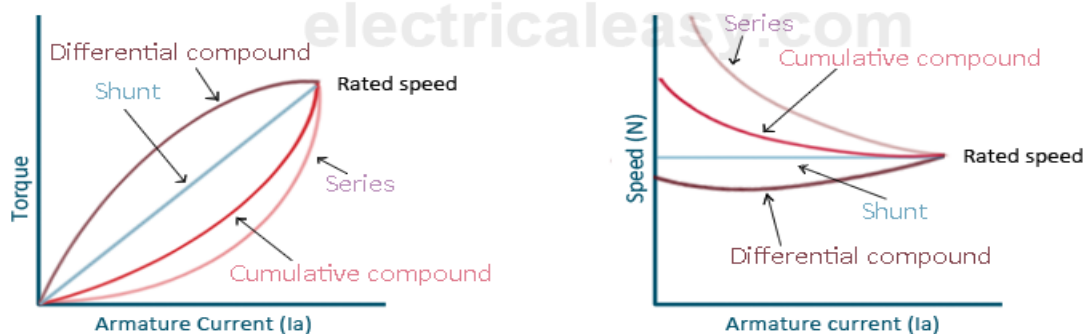
DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.

#### (a) Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

#### (b) Differential compound motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ( $N \propto E_b/\phi$ ). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.



## Characteristics of DC compound motor