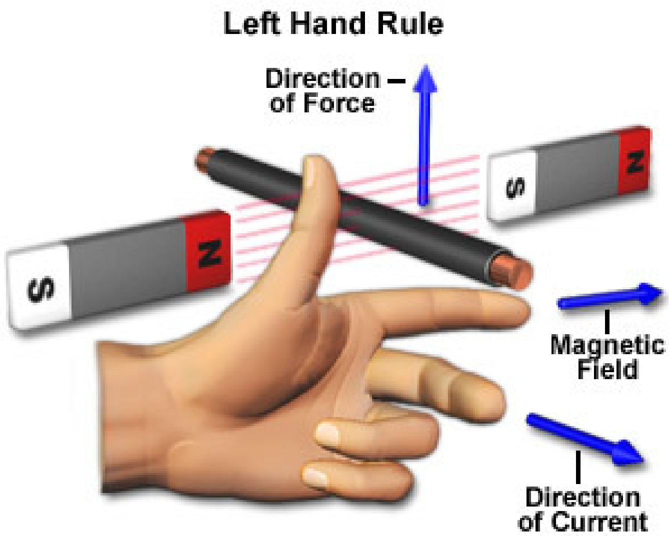
DC Motors

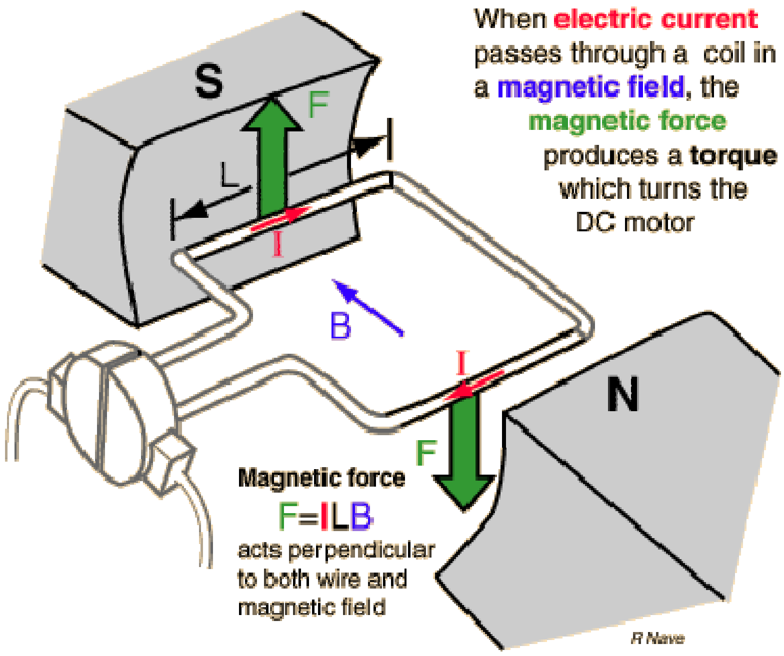
Although ac motors are used in most of the cases, DC motors have many applications and used for multi-purpose applications.

DC Motor Principle

A machine that converts dc power into mechanical energy is known as dc 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 the force is given by Fleming's left hand rule.

Fleming Left Hand Rule

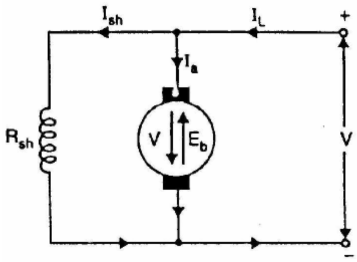




When **electric current** passes through a coil in a **magnetic field**, the **magnetic force** produces a **torque** which turns the DC motor

Back or Counter EMF

When the armature of a d.c. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence an e.m.f. is induced in them.



The induced e.m.f. acts in opposite direction to the applied voltage V(Lenz's law) and is known as back or counter e.m.f. E_b.

Significance of Back E.M.F

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.

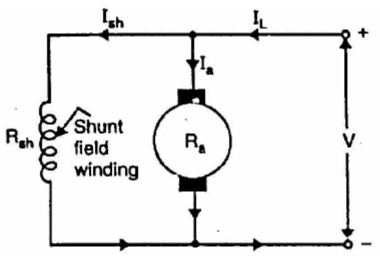
Back e.m.f. in a d.c. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement.

DC Motor Types

- Shunt Wound
- Series Wound
- Compound wound

Shunt Wound Motor

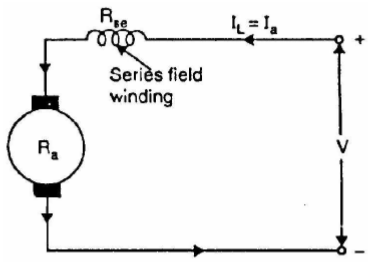
In shunt wound motor the field winding is connected in parallel with armature.
The current through the shunt field winding is not the same as the armature current.



Shunt field windings are designed to produce the necessary m.m.f. by means of a relatively large number of turns of wire having high resistance. Therefore, shunt field current is relatively small compared with the armature current

Series Wound Motor

- **In series wound motor the field winding is connected in series with the armature.** Therefore, series field winding carries the armature current. Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with much fewer turns than shunt field windings for the same mmf.



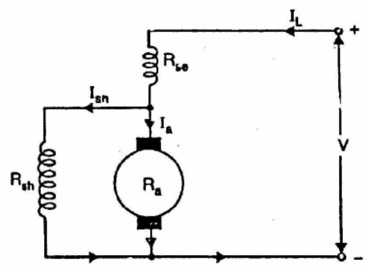
Therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

Compound Wound Motor

Compound wound motor has two field windings; one connected in parallel with the armature and the other in series with it. There are two types of compound motor connections

1) Short-shunt connection

2) Long shunt connection

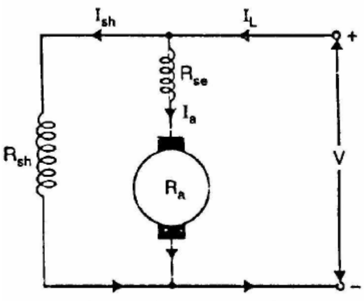


Short-shunt connection

When the shunt field winding is directly connected across the armature terminals it is called short-shunt connection.

Compound Wound Motor

When the shunt winding is so connected that it shunts the series combination of armature and series field it is called long-shunt connection.



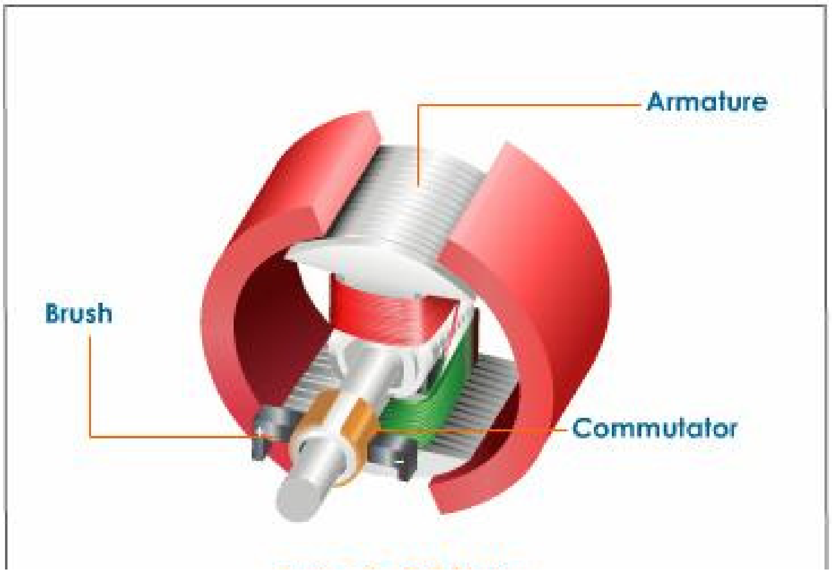
Long-shunt connection

Parts of a DC Motor

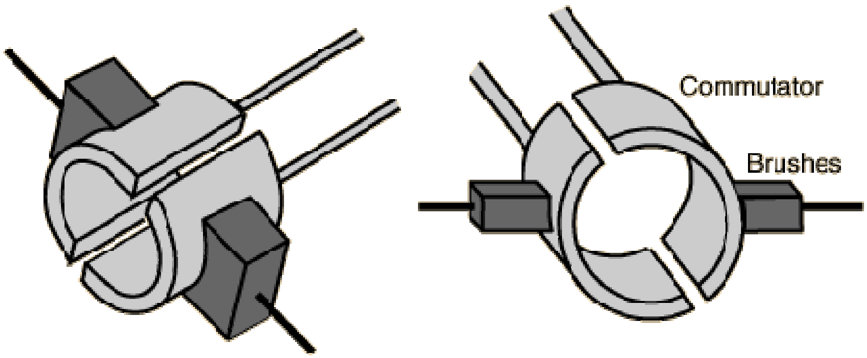
A simple motor has six parts

- Armature/ Rotor
- Commutator
- Brushes
- Axle
- Permanent Magnet
- DC Power supply

Parts of a DC Motor



Commutator and Brushes



Commutation in DC Motor

In order to produce unidirectional force (or torque) on the armature conductors of a motor, the conductors under any pole must carry the current in the same direction at all times.

The function of commutator and brush gear in a dc motor is to cause the reversal of current in a conductor as it moves from one side of a brush to the other.

Voltage Equation of Motors

Let in a d.c. motor

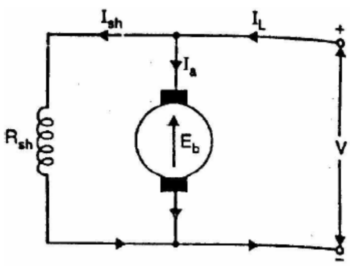
V = applied voltage

E_b = back e.m.f.

R_a = armature resistance

I_a = armature current

Since back e.m.f. E_b acts in opposition to the applied voltage V, the net voltage across the armature circuit is V-E_b. The armature current I_a is given by



$$I_a = \frac{V - E_b}{R_a}$$

$$V = E_b + I_a R_a$$

This is known as voltage equation of the d.c. motor

Condition For Maximum Power

The mechanical power developed by the motor is $P_m = E_b I_a$

Since, V and Ra are fixed, power developed by the motor depends upon armature current. For maximum power, dP_m/dI_a should be zero.

$$\therefore \quad \frac{dP_m}{dI_a} = V - 2I_a R_a = 0$$

$$\text{or} \quad I_a R_a = \frac{V}{2}$$

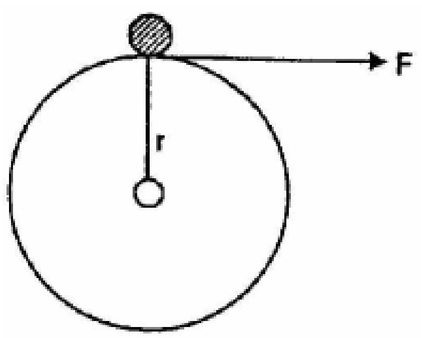
$$\text{Now,} \quad V = E_b + I_a R_a = E_b + \frac{V}{2} \qquad \therefore \quad E_b = \frac{V}{2}$$

Hence mechanical power developed by the motor is maximum when back e.m.f. is equal to half the applied voltage.

Armature Torque of a DC Motor

Torque is the turning moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts

$$T = F \times r$$



In dc motor, each conductor is acted upon by circumferential force, F at a distance r.

Let in a d.c. motor

- r = average radius of armature in m
- ℓ = effective length of each conductor in m
- Z = total number of armature conductors
- A = number of parallel paths
- i = current in each conductor = I_a/A
- B = average flux density in Wb/m2
- ϕ = flux per pole in Wb
- P = number of poles

Force on each conductor, $F = B\, i\, \ell$ newtons

Torque due to one conductor = $F \times r$ newton- metre

Total armature torque, $T_a = Z\, F\, r$ newton-metre

$= Z\, B\, i\, \ell\, r$

$i = I_a/A$, $B = \phi/a$ $\quad a = 2\pi r \ell / P$.

where a is the x-sectional area of flux path per pole

$$T_a = Z \times \frac{\phi}{2\pi\, r \ell / P} \times \frac{I_a}{A} \times \ell \times r = \frac{Z\phi I_a P}{2\pi\, A}\ \text{N - m}$$

$$T_a = 0.159\, Z\phi I_a \left(\frac{P}{A}\right) \text{N - m}$$

Since Z, P and A are fixed for a given machine,

$$\therefore \quad T_a \propto \phi I_a$$

Speed of a DC Motor

$$E_b = V - I_a R_a$$

But $$E_b = \frac{P\phi Z N}{60\ A}$$

$$\therefore \quad \frac{P\phi Z N}{60\ A} = V - I_a R_a$$

or $$N = \frac{(V - I_a R_a)}{\phi} \frac{60\ A}{P Z}$$

or $$N = K \frac{(V - I_a R_a)}{\phi}$$ where $$K = \frac{60 A}{PZ}$$

Speed of a DC Motor

But $$V - I_a R_a = E_a$$

$$\therefore \quad N = K \frac{E_b}{\phi}$$

or $$\boxed{N \propto \frac{E_b}{\phi}}$$

Therefore, in a dc motor speed is directly proportional to back emf, E_b and inversely proportional to flux, ϕ.

Speed Relations

$$N_1 \propto \frac{E_{b1}}{\phi_1} \quad \text{and} \quad N_2 \propto \frac{E_{b2}}{\phi_2}$$

$$\therefore \quad \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

(i) For a shunt motor, flux practically remains constant so that $\phi_1 = \phi_2$.

$$\therefore \quad \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

(ii) For a series motor, $\phi \propto I_a$ prior to saturation.

$$\therefore \quad \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

where I_{a1} = initial armature current
I_{a2} = final armature current

Problem

A 220 V dc shunt motor runs at 500 rpm when the armature current is 50 A. Calculate the speed if the torque is doubled. Given that Ra=0.2 Ω

$T_{a2}/T_{a1}=I_{a1}/I_{a2}$; $N_2/N_1=E_{b2}/E_{b1}$

$E_b=V_a-I_aR_a$

Losses and Efficiency of a DC Motor

Losses in DC Motor:

1) Copper Loss
2) Iron Loss
3) Mechanical Loss

The efficiency of a d.c. motor is the ratio of output power to the input power

$$\text{Efficiency, } \eta = \frac{\text{output}}{\text{input}} \times 100 = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

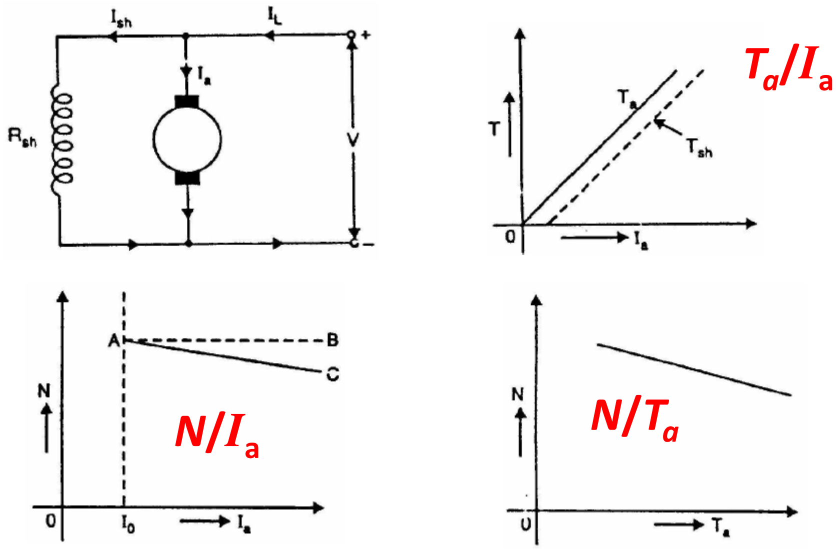
DC Motor Characteristic

(i) **Torque and armature current characteristics** (T_a/I_a): It is the curve between armature torque and armature current of a dc motor

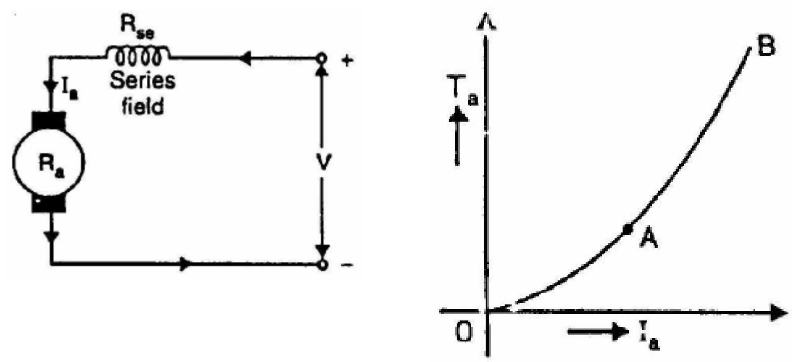
(ii) **Speed and armature current characteristics** (N/I_a): It is the curve between speed and armature current.

(iii) **Speed and torque characteristics** (N/T_a): It is the curve between speed and armature torque.

Characteristics of a shunt motor

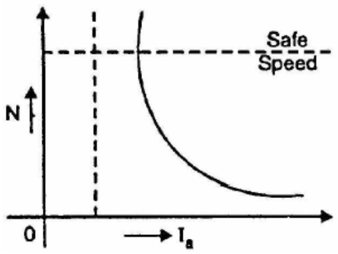


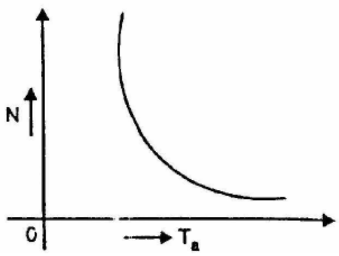
Characteristics of a Series Motor



$$T_a \propto \phi I_a$$

Upto magnetic saturation, $\phi \propto I_a$ so that $T_a \propto I_a^2$



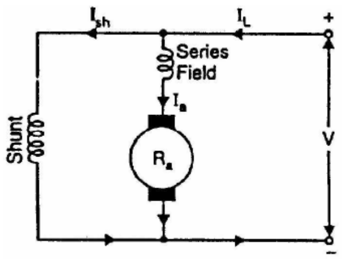


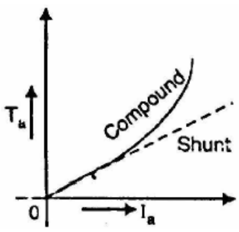
N/I_a Characteristic. The speed N of a series motor is given by;

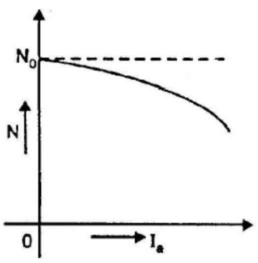
$$N \propto \frac{E_b}{\phi} \qquad \text{where} \qquad E_b = V - I_a(R_a + R_{se})$$

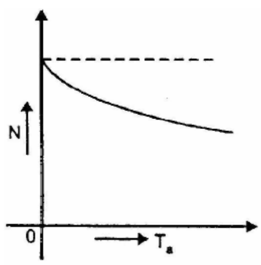
$$N \propto \frac{1}{\phi}$$

Characteristics of a compound motor









Applications of DC Motor

Shunt Motor:

The characteristics of a shunt motor reveal that it is an approximately constant speed motor.

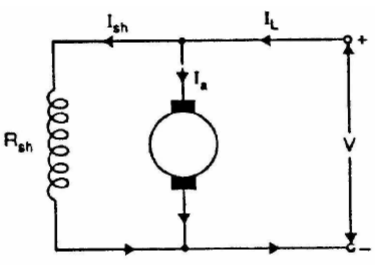
Industrial Use: Lathes, Drills, Boring Mills, Shapers , Spinning, and weaving machines

Series Motor: It is a variable speed motor i.e. speed is low at high torque and vice versa. This motor is used when large starting torque is required.

Industrial Use: Electric Traction Cranes, Elevators, hair drier, Sewing machine

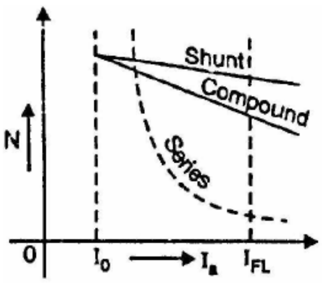
Problem

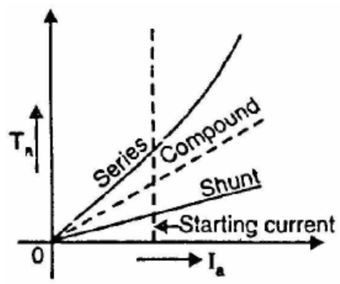
A 440 V shunt Motor has armature resistance of 0.8 Ω and field resistance of 200 Ω. Determine the back emf when giving an output of 7.46 KW at 85% efficiency.



Motor input power=
Motor input current=19.95 A
Shunt current= V/R_{sh}=2.2 A
Armature Current, Ia = 17.75 A
Back emf=V-IaRa=425.8 V

Comparison of three types of Motor





1) The speed regulation in shunt motor is better than series motor
2) The starting torque of a series motor is more than other motor
3) Both shunt and compound motors have definite no load speed, however series motors have dangerously high speed at no load.

DC machine

Motors and generators are dc machines. There are several tests to judge the performance of a DC machine. The efficiency of a dc machine depends upon the losses. The smaller the losses, the greater is the efficiency of the machine.

Armature Reaction

What is meant by armature reaction?

In dc machine, the main field is produced by the field coils. In both the generating and motoring modes, the armature carries current and magnetic field is established, which is called armature flux. The effect of armature flux on main field is called the armature reaction.

What armature reaction does?

It demagnetizes or weakens the magnetic flux/field.

It cross-magnetises or distorts it.

Overcome:

The demagnetizing effect can be overcome by adding extra ampere-turns on the main field. The cross magnetizing effect can be reduced by having common poles.

Advantage of DC Motor

Although a far greater percentage of electric motors in service are a.c. motors,the d.c. motor is of considerable industrial importance. The principal advantage of a d.c. motor is that its speed can be changed over a wide range by a variety of simple methods. Such a fine speed control is generally not possible with a.c. motors. In fact, fine speed control is one of the reasons for the strong competitive position of d.c. motors in the modem industrial applications.

Speed Control of DC Motor

The speed of a dc motor is given by

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

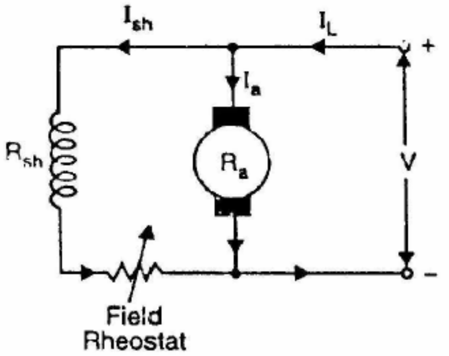
or $$N = K\frac{(V - I_a R)}{\phi} \text{ r.p.m.}$$

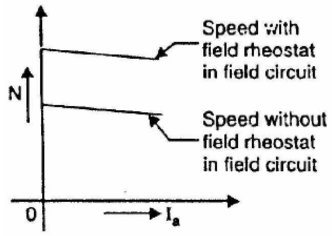
where $R = R_a$ for shunt motor

$= R_a + R_{se}$. for series motor

i) **Flux Control**: By varying the flux per pole.
ii) **Armature Control**: By varying the resistance in the armature circuit.
iii) **Voltage Control**: By varying the applied voltage.

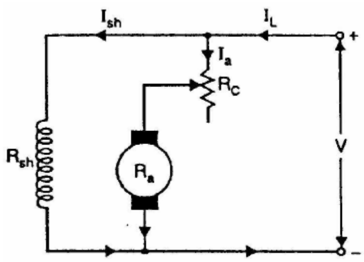
Flux Control Method

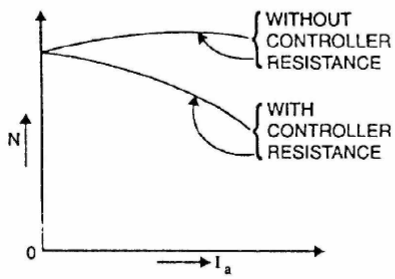




It is based on the fact that by varying the flux f, the motor speed (N) can be changed and hence the name flux control method. In this method, a variable resistance is placed in series with shunt field winding.

Armature Control Method





$$N \propto V - I_a(R_a + R_C)$$

This method is based on the fact that by varying the voltage available across the armature, the back e.m.f and hence the speed of the motor can be changed. This is done by inserting a variable resistance in series with the armature.

Voltage Control Method

In this method, the voltage source supplying the field current is different from that which supplies the armature. This method avoids the disadvantages of poor speed regulation and low efficiency as in armature control method. However, it is quite expensive. Therefore, this method of speed control is employed for large size motors where efficiency is of great importance.

Quotation

Learn to enjoy every minute of your life. Be happy now. Don't wait for something outside of yourself to make you happy in the future. Think how really precious is the time you have to spend, whether it's at work or with your family. Every minute should be enjoyed and savored. **- *Earl Nightingale***