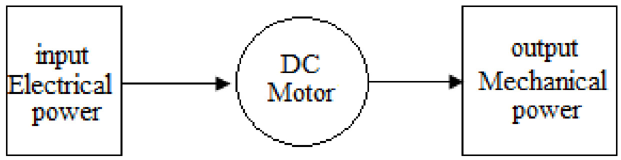
DC MOTORS

DC Motors

DC Motor is a Machine which converts Electrical energy into Mechanical energy. Dc motors are used in steel plants, paper mills, textile mills, cranes, printing presses, Electrical locomotives etc.



Working principle

It works on principle that '*When a current carrying conductor is placed in magnetic field, it experiences a force and the direction of the force is given by Fleming's left hand rule*'. Fleming's left hand rule states that "Stretch out the first finger, second finger and thumb of your left hand so that they are at right angles to one another. The first finger points the direction of magnetic field from N-pole to S-pole, second finger points the direction of current and thumb will indicates the direction rotation of conductor"

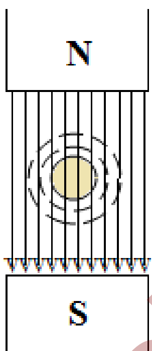


Figure (1)

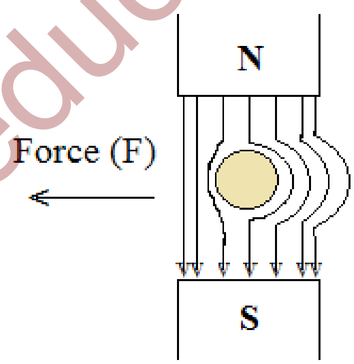


Figure (2)

Consider a conductor is placed in magnetic field. When a DC supply is connected to conductor, current flows through it which sets up its own flux around the conductor as shown in fig.(1). Let, the flux from N-pole to S-pole is main flux and the flux around the conductor is flux due to current carrying conductor. Now the interaction of both main flux and flux due to current carrying conductor, a force may act on conductor and conductor moves in anti-clock wise direction as shown in fig. (2).

Back EMF & its Significance

When a current carrying conductor (Armature winding) is placed in a magnetic field, torque develops and conductor (Armature) rotates the armature conductors cutting the magnetic field and an *emf* will be induced across the armature conductors. The direction of induced *emf* is opposite to the applied voltage. That is why this

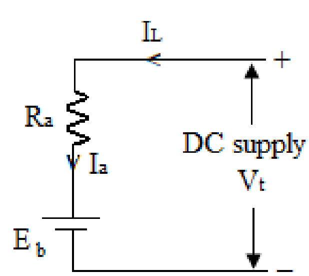


Figure (3)

induced *emf* is called back emf (E_b) and the magnitude of the back emf is (E_b) = $\frac{\Phi ZN}{60} * \frac{P}{A}$

The equivalent circuit of dc motor is as shown in fig. (3). From the diagram the armature current (I_a) = $\frac{Vt - Eb}{Ra}$. The main significance of the back emf is when the back emf is zero, the armature current may be 4to 5 times the normal current. When the back emf is increases, the armature current is limited to its normal current i.e the back emf acts as *safety valve*.

Types of D.C. Motors

DC Motors are generally classified into three groups according to their field excitation. Those are

(i) d.c. Shunt Motor

(ii) d.c. Series Motor

(iii) d.c Compound Motor

DC Shunt Motor

In a DC Shunt Motor, the field winding is connected in parallel with the armature winding as shown in fig (5). The shunt field winding has *many turns* of *thin* wire having high resistance. Therefore, a part of armature current flows through shunt field winding and the remaining current flows through the load.

From the diagram,

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_L = I_a + I_{sh}$ (or) $I_a = I_L - I_{sh}$

Terminal voltage $V_t = E_b + I_a R_a + B.D$

Generated EMF $E_b = V_t - I_a R_a - B.D$

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a – I_{sh})$

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current and B.D = Brush contact drop

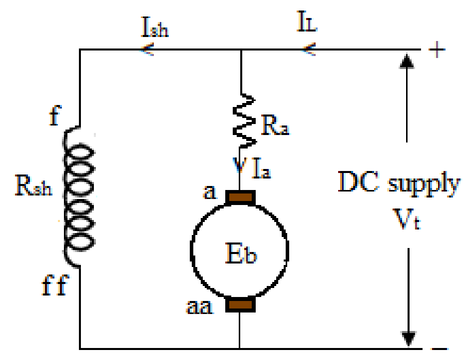


Figure (5)

DC Series Motor

If the field winding is connected in series with armature winding as shown in fig.(6) is called DC Series Motor. The series field winding has a *few turns* of *thick* having low resistance.

From the circuit,

Armature current = Series field current = Load current

i.e $I_a = I_{se} = I_L$

Terminal voltage, $V_t = E_b + I_a R_a + I_{se} R_{se} + B.D$

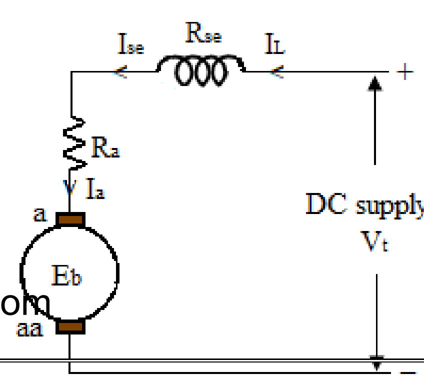


Figure (6)

$= E_b + I_a (R_a + R_{se}) + B.D$

Generated EMF $E_b = V_t - I_a (R_a + R_{se}) - B.D$

Power developed in armature = Eb Ia

In put Power = $V_t I_L = V_t I_a$ (since $I_a = I_L$)

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current and B.D = Brush contact drop

DC Compound Motor

In a DC compound motor, there are two sets of field windings on each pole, one is in series with the armature and the other in parallel with the armature. Based on these field winding connections, the DC compound moors are classified into

(i) Long shunt compound motor
(ii) Short shunt compound motor

Long shunt compound motor

In a Long Shunt Compound motor, the shunt field winding is in parallel with both series field and armature winding as shown in fig. (7).

From the diagram

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_L = I_a + I_{sh}$ (or) I_a or $I_{se} = I_L - I_{sh}$

Terminal voltage $V_t = E_b + I_a R_a + I_{se} R_{se}) + B.D$

Generated EMF $E_g = V_t - I_a R_a - I_{se} R_{se} - B.D$

$= V_t - I_a (R_a + R_{se}) - B.D$

Power developed in armature = Eb Ia

Input Power = $V_t I_L = V_t (I_a + I_{sh})$

Where

I_a = Armature current,

R_a = Armature Resistance,

V_t = Terminal voltage,

I_L = Load current and

B.D = Brush contact drop

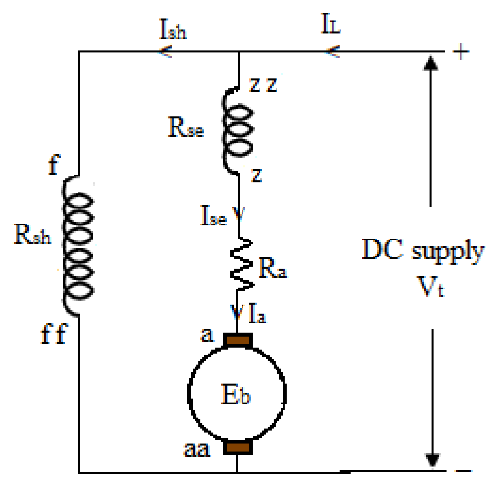


Figure (7)

Short shunt compound motor

In a Short Shunt Compound motor, the shunt field winding is connected in parallel with armature winding only as shown in fig. (8).

From the diagram

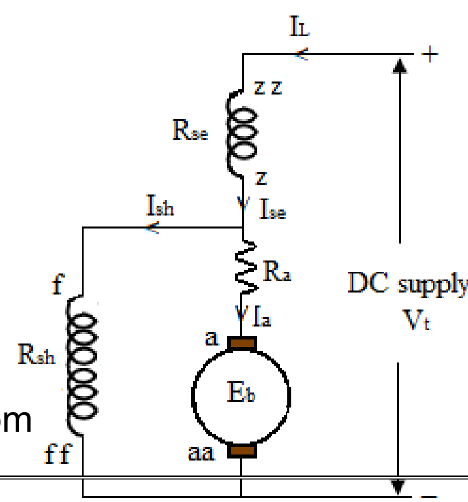


Figure (8)

Series field current $I_{se} = I_L = I_a + I_{sh}$

Armature current $I_a = I_{se} - I_{sh}$

Terminal voltage $V_t = E_b + I_a R_a + I_{se} R_{se} + B.D$

Generated EMF $E_b = V_t - I_a R_a - I_{se} R_{se} - B.D$

Power developed in armature = $E_b I_a$

Input Power = $V_t I_L$

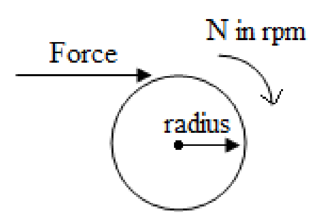
Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

and B.D = Brush contact drop

Armature Torque (T_a) Equation of D.C. Motor

Torque is defined as '*turning and twisting movement of force about an axis*'. Mathematically, Torque can be defined as product of force and the radius at which the force is act i. **T = F****r***.**

Let a pulley with a radius of ' *r* ' is rotating with a speed of N rpm, a force of F newtons is acting on the pulley. Then



Work done by the force = Force * Distance

$= F * 2\pi r$ joules

Power developed = Work done * time

[time = time required to complete a revolution = N/60]

$= F * 2\pi r * N/60$

$= (F * r)\, 2\pi N/60$

$= T\, 2\pi N/60$ watts

If the torque developed by the motor is T_a ,

The Power developed in armature (P_a) = $T_a\, 2\pi N/60$ watts --------------------- (1)

But Power developed in armature (P_a) = $E_b I_a$ ------------------------------ (2)

From equations (1) & (2), $T_a\, 2\pi N/60 = E_b I_a$

$$T_a = \frac{Eb\, Ia}{2\Pi N/60}$$

$$T_a = \frac{1}{2\Pi} * \phi Z Ia \frac{P}{A}$$

$$\text{Armature torque } T_a = 0.159\,\phi Z Ia \frac{P}{A}$$

Shaft Torque *(T_{sh})*

A part of armature torque is lost as Iron & Mechanical losses, the remaining torque is available at shaft of the motor, this torque is called shaft torque (T_{sh}). Practically, shaft torque (T_{sh}) is less than armature torque (T_a).

$$\text{Shaft torque } (T_{sh}) = 9.55 \frac{\text{Output Power}}{N}$$

Losses & Effiency of a D.C. Machine

Losses of a D.C. Machine

The losses in a d.c. machine (generator or motor) may be divided into three classes. Those are

(i) copper losses
(ii) iron or core losses and
(iii) mechanical losses.

Copper losses

The copper losses are directly proportional to square of the current passing through the winding. Copper losses due to currents in the various windings of the machine are:

(i) Armature copper loss = $I_a^2\ R_a$; Where I_a is the armature current and R_a armature resistance.

(ii) Shunt field copper loss = $I_{sh}^2\ R_{sh}$; Where I_{sh} is the shunt field current and R_{sh} shunt field resistance.

(iii) Series field copper loss = $I_{se}^2\ R_{se}$; Where I_{se} is the series field current & R_{se} series field resistance.

Iron or Core losses

These losses occur in the armature of a d.c. machine and are due to the rotation of armature in the magnetic field of the poles. They are of two types

(i) Hysteresis loss
(ii) Eddy current loss.

Hysteresis loss

The Hysteresis loss, $P_h \alpha\ \eta\ B_m^{\ 1.6}\ f\ V$ watts

Where B_m = Maximum flux density in armature, f = Frequency, V = Volume of armature in m^3

η = Steinmetz hysteresis co-efficient

In order to reduce this loss in a d.c. machine, armature core is made of silicon steel material, because the silicon steel material has a low value of Steinmetz hysteresis co-efficient.

Eddy current loss:

The Eddy current loss, $P_e\ \alpha\ K_e\ B_m^2\ f^2\ t^2\ V$ watts

Where Ke = Constant , Bm = Maximum flux density in Wb/m^2, f = Frequency t = Thickness of lamination in mts and V = Volume of core in m^3

Eddy current losses can be reduced by laminating the armature core and pole core.

Mechanical losses

These losses are due to friction and windage effects. Mechanical losses are classified into two classes, those are

(i) Friction loss (These losses are due to friction at bearings and brushes)

(ii) Windage loss (These losses are due air friction of rotating armature).

These losses depend upon the speed of the machine. But for a given speed, they are practically constant.

Since the iron and mechanical losses are independent of load, these losses are called as *constant losses*. But the copper loss depends on load or load current, so the copper losses are called as *variable losses*. The constant losses and Shunt field copper losses are combinely called as *stray losses*. Therefore the total losses are the sum of constant losses and variable losses.

Effiency of a D.C. Machine

The power stage diagram of a DC Machine is as shown in figure(9).

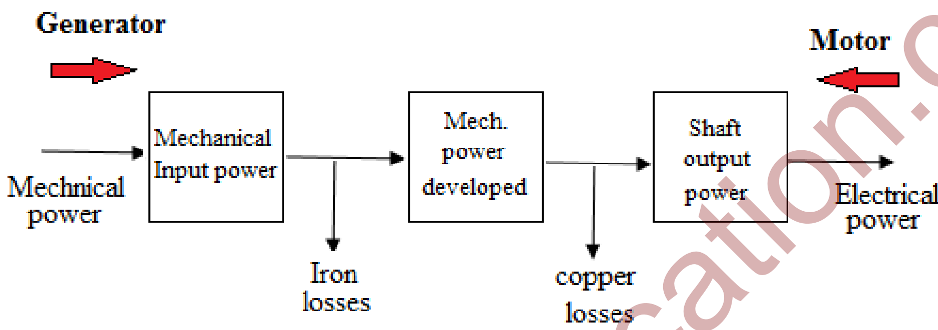


Figure (9)

for DC Generator

The efficiency of a d.c. generator is not constant but varies with load. Consider a shunt generator delivering a load current I_L at a terminal voltage V_t .

Generator output = $V_t I_L$

Generator input = Output + Losses

$= V_t I_L$ + Variable losses + Constant losses

$= V_t I_L + I_a^2 R_a + P_i$

$= V_t I_L + (I_L + I_{sh})^2 R_a + P_i \quad (I_a = I_L + I_{sh})$

$$\text{Generator Effiency } (\eta_{gen}) = \frac{\text{Output power}}{\text{Input power}} * 100 = \frac{V_t I_L}{V_t I_L + (I_L + I_{sh})^2 R_a + P_i} * 100$$

For DC Motor

The efficiency of a d.c. motor is not constant but varies with load. Consider a shunt motor delivering a load current I_L at a terminal voltage V_t .

Motor Input = $V_t I_L$

Motor Output = Input - Losses

$= V_t I_L$ - Variable losses - Constant losses

$= V_t I_L - I_a^2 R_a - P_i$

$= V_t I_L - (I_L - I_{sh})^2 R_a - P_i \quad (I_a = I_L - I_{sh})$

$$\text{Motor Effiency } (\eta_{motor}) = \frac{\text{Output power}}{\text{Input power}} * 100 = \frac{V_t I_L}{V_t I_L - (I_L - I_{sh})^2 R_a - P_i} * 100$$

D.C. Motor Characteristics

The performance of a d.c. motor can be measured from its characteristic curves known as motor
Characteristics, below mentioned are the three important characteristics of a d.c. motor:

(i) *Torque and Armature current characteristic (Ta/Ia)*
It is the curve between armature torque Ta and armature current Ia of a d.c. motor. It is also known as electrical characteristic of the motor.

(ii) *Speed and armature current characteristic (N/Ia)*
It is the curve between speed N and armature current Ia of a d.c. motor. It is very important characteristic in the selection of the motor for a particular application.

(iii) *Speed and torque characteristic (N/Ta)*
It is the curve between speed N and armature torque Ta of a d.c. motor. It is also known as mechanical characteristic.

Characteristics of Shunt Motor

The connections of a d.c. shunt motor is shown in fig.(9). The field current I_{sh} is constant since the field winding is directly connected to the constant supply voltage V_t. Hence, the flux in a shunt motor is constant $(\Phi \propto_{sh})$.

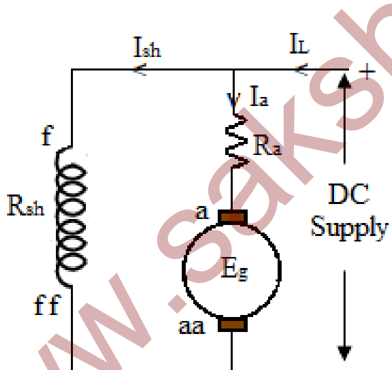


Figure (9)

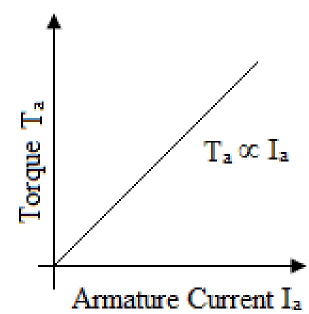
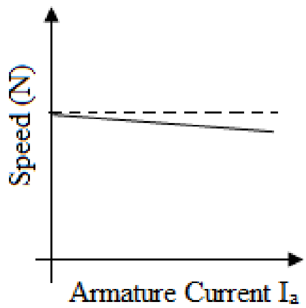


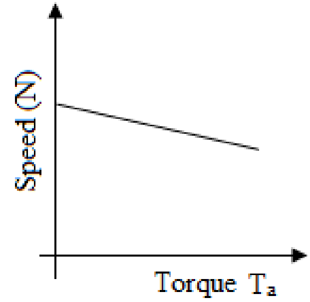
Figure (10)

(i) **Ta/Ia Characteristic:** We know that in a d.c. motor, Ta /Ia. Since the motor is operating from a Φ constant supply voltage, flux is constant.

$$\therefore Ta \propto Ia$$

Hence Ta/Ia characteristic is a straight line passing through the origin as shown in Fig. (10). It is clear from the curve that a very large current is required to start a heavy load. Therefore, a shunt motor should not be started on heavy load.





(iii) N/Ia Characteristic

The speed N of a. d.c. motor is given by $N \alpha \frac{E_b}{\phi}$. The flux (Φ) in a shunt motor is almost constant under normal conditions. Therefore, the speed of a shunt motor will remain constant as the armature current varies. But practically, when load is increased, load current I_L and armature current I_a also increased (since $I_a = I_L + I_{sh}$). Therefore the back emf E_b =(Vt- Ia Ra) decrease due to the armature resistance drop and results in slightly decrease in the speed of the motor.

(iv) N/Ta Characteristic

The curve is obtained by plotting the values of N and T_a for various armature currents. It may be seen that speed falls as the load torque increases as shown in N/Ta characteristics.

Characteristics of Series Motor

The connections of a d.c. series motor is shown in fig.(11).
From the circuit $I_L = I_{se} = I_a$.
If the load on the motor increases, then the armature current also increases. Hence, the flux in a series motor increases with the increase in armature current ($\Phi \propto I_f$) and vice-versa.

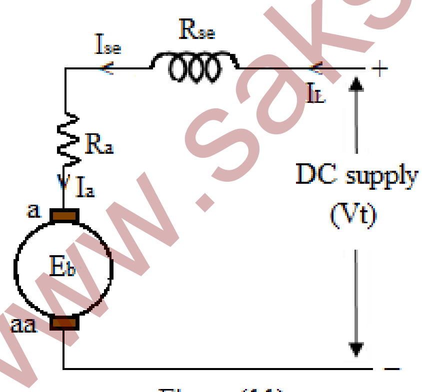


Figure (11)

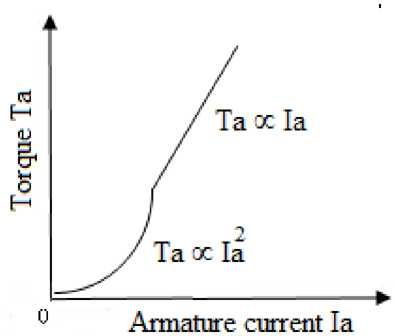


Figure (12)

(i) **Ta/Ia Characteristic**:

We know that: $T_a \propto I_a$

Before saturation, $\Phi \propto I_a$ so that $T_a \propto I^2{}_a$ and after magnetic saturation, Φ is constant so that T_a Φ I_a. Therefore up to saturation, Torque Vs Armature current curve is a parabola and after saturation, torque is directly proportional to the armature current. Therefore, Ta/Ia curve after saturation is a straight line as shown in fig.(12).

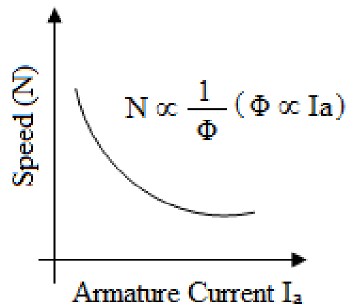


Figure (13)

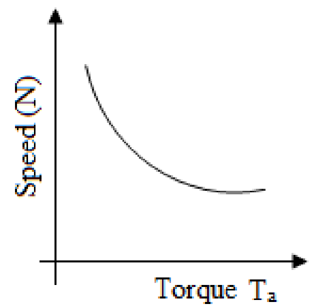


Figure (14)

(ii) **N/Ia Characteristic:**

The speed N of a. d.c. motor is given by $N \alpha \frac{E_b}{\phi}$. For constant back emf, speed $N \alpha \frac{1}{\phi}$

but the flux (Φ) ∝ field current ($I_{se} = I_a$). Therefore the speed $N \alpha \frac{1}{I_a}$. Thus, the Speed (N) Vs armature current (Ia) curve is hyperbolic as shown in Fig. (13).

(iii) **N/Ta Characteristic**: The speed (N) Vs Torque (Ta) characteristic of a series motor is shown in Fig. (14).

Speed Control of D.C. Shunt Motor

There are two methods to control the speed of a d.c. motor, namely:

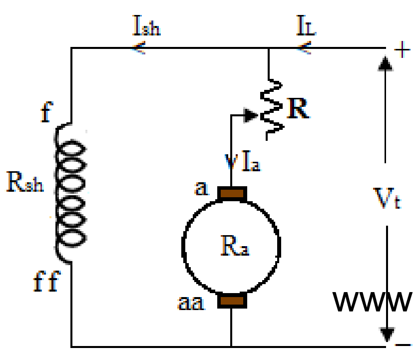
(i) Armature Control Method (ii) Flux Control Method

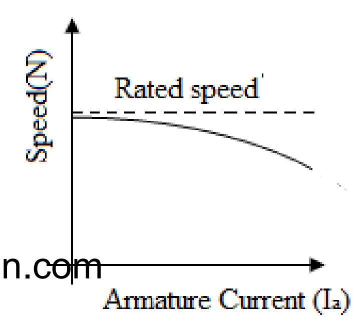
Armature Control Method

We know that the speed of a d.c. motor is $N \alpha \frac{E_b}{\phi}$

or $N = K \frac{Vt - I_a R_a}{\phi}$

From the above equation it is clear that, by varying the back emf (E_b) the speed of the motor can be varied. The following figure shows the arrangement for armature control method. In this method an additional resistance of R ohms is connected in series with the armature.





Now the speed of the motor $N \propto E_b$ i.e $N \propto V_t - I_a (R_a + R)$. Due to the voltage drop in resistance (R), the back e.m.f. (E_b) is decreased. Since $N \propto E_b$, the speed of the motor is reduced from the normal speed. This method gives the speeds always less than the normal speeds.

The main drawbacks of this method are

(i) A large amount of power is wasted in the resistance (R) since it carries full armature current Ia.

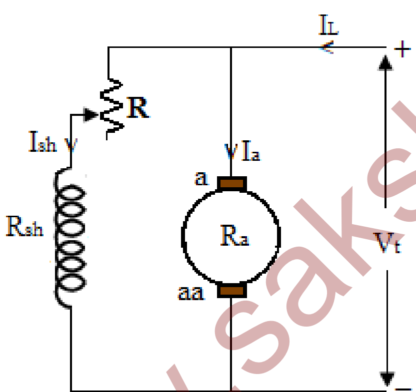
(ii) The output and efficiency of the motor are reduced due to large amount of power is wasted in the resistance (R).

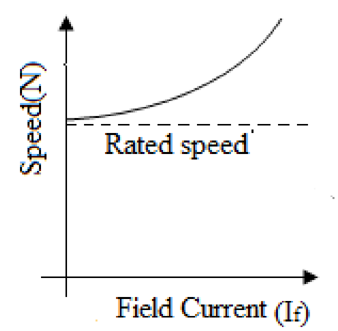
(iii) This method results in poor speed regulation.

Flux or Field Control Method

We know that the speed of a d.c. motor is $N \,\alpha\, \frac{E_b}{\phi}$

From the above equation it is clear that, by varying the flux (Φ), the speed of the motor can be varied hence it is called flux or field control method. The following figure shows the arrangement for flux control method. In this method an additional resistance of R ohms is connected in series with the shunt field winding.





By increasing the additional resistance, the flux (Φ) decreases, this results in increase in speed from the normal speed. This method always gives the speeds above the normal speed.

Advantages

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in additional resistance (R) due to shunt field current I_{sh}.

The main drawback of this method is only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below the shunt field resistance (R_{sh}).