2.18 Necessity of Starter

All the d.c. motors are basically self starting motors. Whenever the armature and the field winding of a d.c. motor receives supply, motoring action takes place. So d.c. motors do not require any additional device to start it. The device to be used as a starter conveys a wrong meaning.

Key Point : *So starter is not required to start a d.c. motor but it enables us to start the motor in a desired, safe way.*

Now at the starting instant the speed of the motor is zero, (N = 0). As speed is zero, there cannot be any back e.m.f. as $E_b \propto N$ and N is zero at start.

$$\therefore \quad E_b \text{ at start} = 0$$

The voltage equation of a d.c. motor is,

$$V = E_b + I_a R_a$$

So at start, $$V = I_a R_a \qquad \text{as } E_b = 0$$

$$\therefore \quad \boxed{I_a = \frac{V}{R_a}} \qquad \text{... At start}$$

Key Point : *Generally motor is switched on with normal voltage and as armature resistance is very small, the armature current at start is very high.*

Consider a motor having full load input power as 8000 watts. The motor rated voltage be 250 V and armature resistance is 0.5 Ω.

Then at start, $E_b = 0$ and motor is operated at 250 V supply, so

$$I_a = \frac{V}{R_a} = \frac{250}{0.5} = 500 \text{ A}$$

While its full load current can be calculated as,

$$I_{\text{Full load}} = \frac{\text{Power input on full load}}{\text{Supply voltage}} = \frac{8000}{250} = 32 \text{ A}$$

So at start, motor is showing a tendency to draw an armature current which is 15 to 20 times more than the full load current.

Such high current drawn by the armature at start is highly objectionable for the following reasons :

1. In a constant voltage system, such high inrush of current may cause tremendous line voltage fluctuations. This may affect the performance of the other equipments connected to the same line.
2. Such excessively high armature current, blows out the fuses.
3. If motor fails to start due to some problems with the field winding, then a large armature current flowing for a longer time may burn the insulation of the armature winding.
4. As the starting armature current is 10 to 15 times more than the full load current, the torque developed which is proportional to the I_a will also be 10 to 15 times, assuming shunt motor operation. So due to such high torque, the shaft and other accessories are thus be subjected to large mechanical stresses. These stresses may cause permanent mechanical damage to the motor.

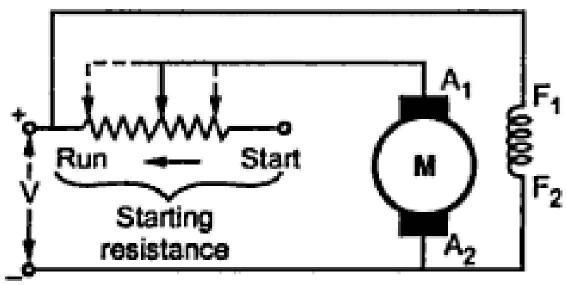

Fig. 2.24 Basic arrangement of a starter

To restrict this high starting armature current, a variable resistance is connected in series with the armature at start. This resistance is called **starter** or **a starting resistance.** So starter is basically a current limiting device. In the beginning the entire resistance is in the series with the armature and then gradually cut-off as motor gathers speed, producing the back e.m.f. The basic arrangement is shown in the Fig. 2.24.

In addition to the starting resistance, there are some protective devices provided in a starter. There are two types of starters used for d.c. shunt motors.

a) Three point starter

b) Four point starter

Let us see the details of three point starter.

2.26 Factors Affecting the Speed of a D.C. Motor

According to the speed equation of a d.c. motor we can write,

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$$

The factors Z, P, A are constants for a d.c. motor.

But as the value of armature resistance R_a and series field resistance R_{se} is very small, the drop $I_a R_a$ and $I_a (R_a + R_{se})$ is very small compared to applied voltage V. Hence neglecting these voltage drops the speed equation can be modified as,

$$N \propto \frac{V}{\phi} \qquad \text{as } E_b \approx V$$

Thus the factors affecting the speed of a d.c. motor are,

1. The flux ϕ
2. The voltage across the armature
3. The applied voltage V

Depending upon these factors the various methods of speed control are,

1. Changing the flux ϕ by controlling the current through the field winding called **flux control** methods.
2. Changing the armature path resistance which in turn changes the voltage applied across the armature called **rheostatic control**.
3. Changing the applied voltage called **voltage control** method.

Before studying how these methods are used for various types of d.c. motors, let us study the ratings of a d.c. motor. These ratings decide the range in which the speed of a particular d.c. motor can be varied.

2.27 Ratings of a D.C. Motor

To change the speed as per the requirements, it is not possible to increase the voltage or currents beyond certain limit. These limits are called ratings of the motor.

The maximum voltage that can be applied to the motor, safely is called **rated voltage** or **normal voltage** of the motor. While changing the applied voltage, one should not apply the voltage more than the rated voltage of the motor.

Similarly maximum current that field winding can carry, safely is called **rated field current** of the motor. Hence while changing the flux, one should not increase field current beyond its rated value. This is important rating as far as shunt motor is concerned. In a series motor, the entire armature current flows through the series field winding. The armature current is decided by the load and it cannot be changed by changing the resistance of the armature circuit. So the maximum current that armature winding can carry safely is decided by the load called **full load current** or **full load rating** of the motor. Motor should not be loaded more than its full load capacity indicated by its full load armature current.

Exceeding the rating is dangerous from the motor point of view as due to high currents, the heat produced, which is proportional to the square of the current is very large. This may damage the windings electrically.

$$\text{Now} \quad N \propto \frac{V}{\phi}$$

So for $V = V_{rated}$ and $\phi \propto I_f$ rated i.e. when there is no external resistance in the armature and field circuit and motor is excited by normal rated voltage, the speed obtained is called **rated speed** or **normal speed.**

$$\therefore \qquad N_{rated} \propto \frac{V_{rated}}{I_{f\ rated}}$$

> **Key Point** : *Note that the rated or normal speed is not the maximum speed with which motor can run safely but it is the speed when the electrical parameters controlling the speed are at their rated values.*

Practically a motor speed can be increased to approximately twice its normal speed safely.

Thus while controlling the speed, the voltage applied should not be more than rated voltage of a motor, the field current should not be more than its rated value and the current carried by armature should not be more than its full load value. All the ratings are provided by the manufacturer in the form of name plate of a d.c. motor. Let us study now the various methods as applied to different types of d.c. motors.

2.28 Speed Control of D.C. Shunt Motor

Out of the three methods, let us study flux control method.

2.28.1 Flux Control

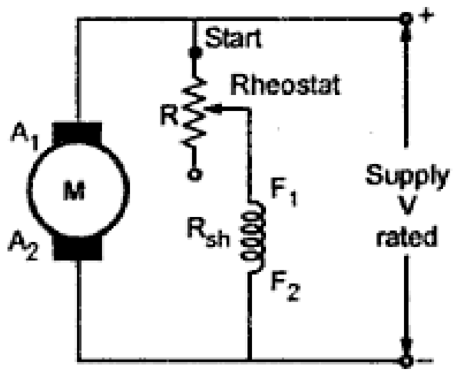

Fig. 2.34 Flux control of shunt motor

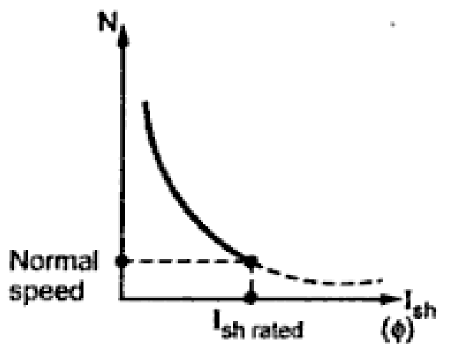

Fig. 2.35 N Vs I_{sh} (ϕ) for shunt motor

As indicated by the speed equation, the speed is inversely proportional to the flux. The flux is dependent on the current through the shunt field winding. Thus flux can be controlled by adding a rheostat (variable resistance) in series with the shunt field winding, as shown in the Fig. 2.34

At the beginning the rheostat R is kept at minimum indicated as start in the Fig. 2.35. The supply voltage is at its rated value. So current through shunt field winding is also at its rated value. Hence the speed is also rated speed also called normal speed. Then the resistance R is increased due to which shunt field current I_{sh} decreases, decreasing the flux produced. As $N \propto (1/\phi)$, the speed of the motor increases beyond its rated value.

Thus by this method, the speed control above rated value is possible. This is shown in the Fig. 2.35, by speed against field current curve. The curve shows the inverse relation between N and ϕ as its nature is rectangular hyperbola.

It is mentioned that the rated values of electrical parameters should not be exceeded but the speed which is mechanical parameter can be increased upto twice its rated value.

2.28.1.1 Advantages of Flux Control Method

1. It provides relatively smooth and easy control.

2. Speed control above rated speed is possible.

3. As the field winding resistance is high, the field current is small. Hence power loss (I_{sh}^2 R) in the external resistance is very small, which makes the method more economical and efficient.

4. As the field current is small, the size of the rheostat required is small.

2.28.1.2 Disadvantages of Flux Control Method

1. The speed control below normal rated speed is not possible as flux can be increased only upto its rated value.

2. As flux reduces, speed increases. But high speed affects the commutation making motor operation unstable. So there is limit to the maximum speed above normal, possible by this method.

2.28.2 Armature Voltage Control Method or Rheostatic Control

The speed is directly proportional to the voltage applied across the armature. As the supply voltage is normally constant, the voltage across the armature can be controlled by adding a variable resistance in series with the armature as shown in the Fig. 2.36.

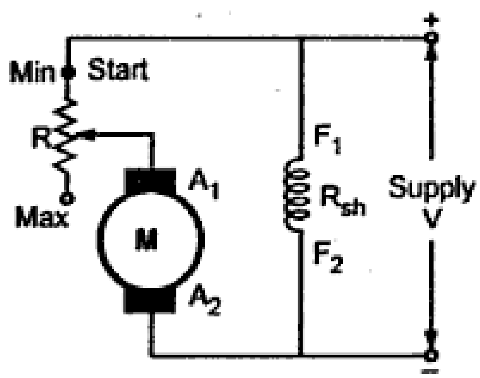

Fig. 2.36 Rheostatic control of shunt motor

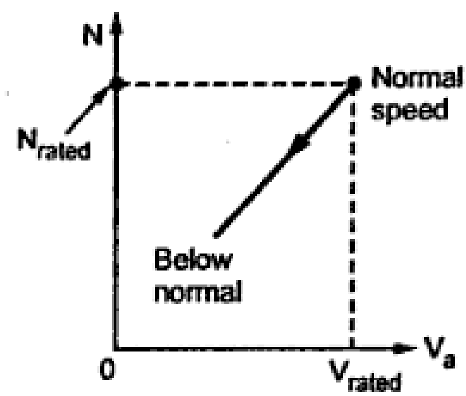

Fig. 2.37 N Vs voltage across armature

The field winding is excited by the normal voltage hence I_{sh} is rated and constant in this method. Initially the rheostat position is minimum and rated voltage gets applied across the armature. So speed is also rated. For a given load, armature current is fixed. So when extra resistance is added in the armature circuit, I_a remains same and there is voltage drop across the resistance added (I_a R). Hence voltage across the armature decreases, decreasing the speed below normal value. By varying this extra resistance, various speeds below rated value can be obtained.

So for a **constant load torque**, the speed is directly proportional to the voltage across the armature. The relationship between speed and voltage across the armature is shown in the Fig. 2.37.

2.28.2.1 Potential Divider Control

The main disadvantage of the above method is, the speed up to zero is not possible as it requires a large rheostat in series with the armature which is practically impossible. If speed control from zero to the rated speed is required, by rheostatic method then voltage across the armature can be varied by connecting rheostat in a potential divider arrangement as shown in the Fig. 2.38.

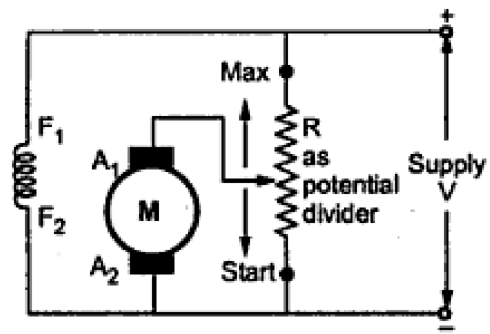

Fig. 2.38 Potential divider arrangement

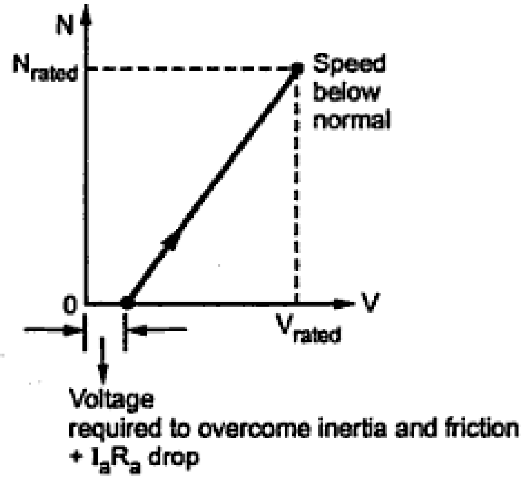

Fig. 2.39 N Vs V

When the variable rheostat position is at 'start' point shown, voltage across the armature is zero and hence speed is zero. As rheostat is moved towards 'maximum' point shown, the voltage across the armature increases, increasing the speed. At maximum point the voltage is maximum i.e. rated hence maximum speed possible is rated speed. The relationship is shown in the Fig. 2.39.

When the voltage across the armature starts increasing, as long as motor does not overcome inertial and frictional torque, the speed of the motor remains zero. The motor requires some voltage to start hence the graph of voltage and the speed does not pass through the origin as shown in the Fig. 2.39.

2.28.2.2 Advantages of Rheostatic Control

1. Easy and smooth speed control below normal is possible.
2. In potential divider arrangement, rheostat can be used as a starter.

2.28.2.3 Disadvantages of Rheostatic Control

1. As the entire armature current passes through the external resistance, there are tremendous power losses.
2. As armature current is more than field current, rheostat required is of large size and capacity.
3. Speed above rated is not possible by this method.
4. Due to large power losses, the method is expensive, wasteful and less efficient.
5. The method needs expensive heat dissipation arrangements.

2.28.3 Applied Voltage Control

Multiple voltage control : In this technique the shunt field of the motor is permanently connected to a fixed voltage supply, while the armature is supplied with various voltages by means of suitable switch gear arrangements.

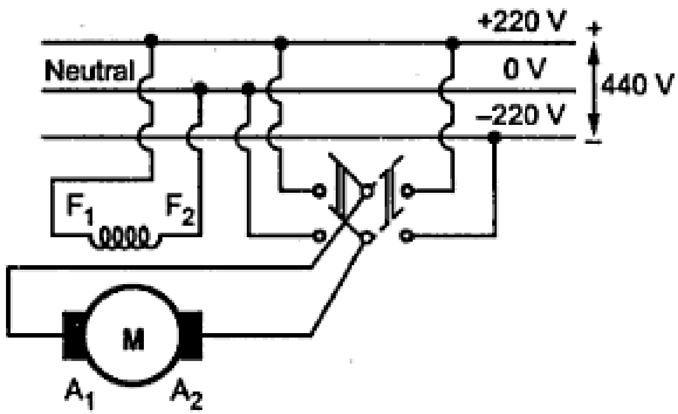

Fig. 2.40 Multiple voltage control

The Fig. 2.40 shows a control of motor by two different working voltages which can be applied to it with the help of switchgear.

In large factories, various values of armature voltages and corresponding arrangement can be used to obtain the speed control.

2.28.3.1 Advantages of Applied Voltage Control

1. Gives wide range of speed control.
2. Speed control in both directions can be achieved very easily.
3. Uniform acceleration can be obtained.

2.28.3.2 Disadvantages of Applied Voltage Control

1. Arrangement is expensive as provision of various auxiliary equipments is necessary.
2. Overall efficiency is low.

*** General steps to solve problems on speed control :**

1. Identify the method of speed control i.e. in which winding of the motor, the external resistance is to be inserted.
2. Use the torque equation, $T \propto \phi I_a$ to determine the new armature current according to the condition of the torque given. Load condition indicates the condition of the torque.
3. Use the speed equation $N \propto \frac{E_b}{\phi}$ to find the unknown back e.m.f. or field current.
4. From the term calculated above and using voltage current relationship of the motor, the value of extra resistance to be added, can be determined. The above steps may vary little bit according to the nature of the problem but are always the base of any speed control problem.

Example 2.12 : *A 250 V d.c. shunt motor has a shunt field resistance of 200 Ω and an armature resistance of 0.3 Ω. For a given load, motor runs at 1500 r.p.m. drawing a current of 22 A from the supply. If a resistance of 150 Ω is added in series with the field winding, find the new armature current and the speed. Assume load torque constant and magnetisation curve to be linear.*

Solution : The Fig. 2.41 shows the two conditions.

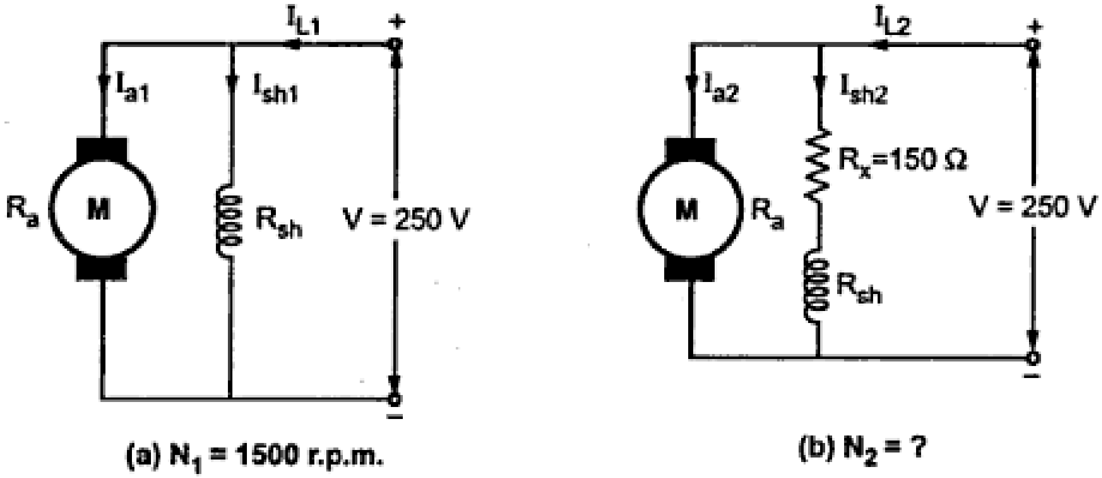

Fig. 2.41

The method is flux control method.

$$V = 250\ \text{V},\quad R_a = 0.3\ \Omega,\quad R_{sh} = 200\ \Omega$$

In first case, $I_{L1} = 22$ A

$$I_{sh1} = \frac{V}{R_{sh}} = \frac{250}{200} = 1.25\ \text{A}$$

$\therefore$ $I_{a1} = I_{L1} - I_{sh1} = 22 - 1.25 = 20.75$ A

Now $T \propto \phi I_a \propto I_{sh} I_a$ (as $\phi \propto I_{sh}$)

$\therefore$ $$\frac{T_1}{T_2} = \frac{I_{sh1}}{I_{sh2}} \times \frac{I_{a1}}{I_{a2}}$$

As load torque is constant, $T_1 = T_2$

$\therefore$ $I_{sh1}\, I_{a1} = I_{a2}\, I_{sh2}$ ... (1)

Now $$I_{sh2} = \frac{V}{R_{sh} + R_x} = \frac{250}{(200+150)} = 0.7142\ \text{A}$$

Substituting in equation (1),

$$1.25 \times 20.75 = I_{a2} \times 0.7142$$

$\therefore$ $I_{a2} = 36.3125$ A

Hence $E_{b1} = V - I_{a1} R_a = 250 - 20.75 \times 0.3 = 243.775$ V

and $E_{b2} = V - I_{a2} R_a = 250 - 36.3125 \times 0.3 = 239.1062$ V

Using speed equation $N \propto \frac{E_b}{\phi} \propto \frac{E_b}{I_{sh}}$

$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{I_{sh2}}{I_{sh1}}$$

$$\therefore \quad \frac{1500}{N_2} = \frac{243.775}{239.1062} \times \frac{0.7142}{0.125}$$

$$\therefore \quad N_2 = \mathbf{2575.03\ r.p.m.}$$

This shows that as flux ϕ decreases, the speed increases.

Example 2.13 : *A 250 V, d. c. series motor takes 30 A when running at 800 r.p.m., calculate the speed at which motor will run if field winding is shunted by a resistance equal to the field winding resistance and the load torque is increased by 50 %. Armature resistance is 0.15 Ω and series field resistance is 0.1 Ω. Assume the flux produced is proportional to the field current.*

Solution : The method is field diverter. The two conditions are shown in the Fig. 2.48 (a) and (b).

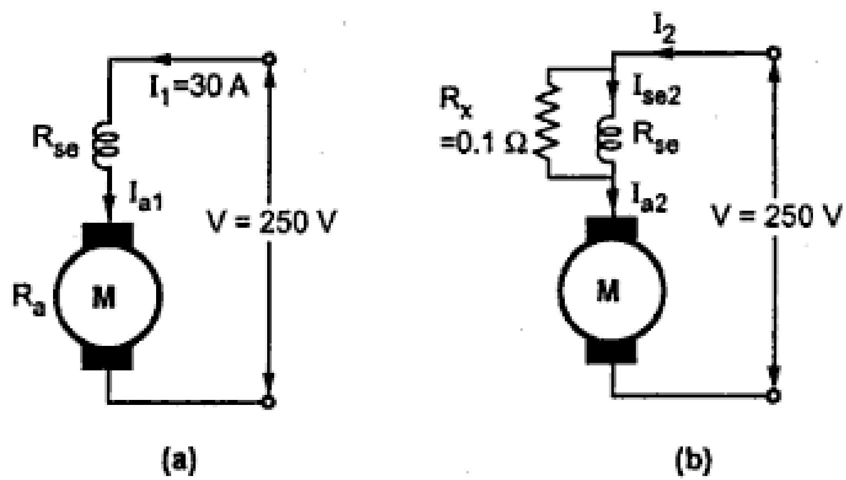

Fig. 2.48

$$V = 250\ V,\ R_a = 0.15\ \Omega,\ R_{se} = 0.1\ \Omega$$

In first case, $N_1 = 800$ r.p.m.

$$I_1 = I_{a1} = I_{se1} = 30\ A$$

$$\phi \propto I_{se}$$

According to torque equation, $T \propto \phi I_a \propto I_{se} I_a$

$$\therefore \quad \frac{T_1}{T_2} = \frac{I_{se1}}{I_{se2}} \times \frac{I_{a1}}{I_{a2}}$$