SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
(Approved by AICTE, New Delhi & Affiliated to Pondicherry University)
(Accredited by NBA-AICTE, New Delhi, ISO 9001:2000 Certified Institution &
Accredited by NAAC with "A" Grade)
Madagadipet, Puducherry - 605 107

Department of Electrical and Electronics Engineering

Subject Name: Electrical Machines - I **Subject Code: EE T33**

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UNIT III

DC MOTOR

DC Motor-torque equation – types-back emf and voltage equations-characteristics- Starting-Speed control- testing-direct, indirect and regenerative tests-Power flow and efficiency- separation of losses-retardation test- Braking - DC machines dynamics – Applications

Two Marks

1. **What is the principle of motor?**

   When a current carrying conductor is placed in a magnetic field it experiences a force tending to move it.

2. **How will you find the direction of force produced using Flemings left hand rule?**

   The thumb, forefinger & middle finger of left hand are held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of magnetic field, middle finger gives the direction of the current and thumb gives the direction of the force experienced by the conductor.

3. **How will you change the direction of rotation of d.c.motor?**

   Either the field direction or direction of current through armature conductor is reversed.

4. **What is back emf in d.c. motor?**

   As the motor armature rotates, the system of conductor come across alternate north and south pole magnetic fields causing an emf induced in the conductors. The direction of the emf induced in the conductor is in opposite to current. As this emf always opposes the flow of current in motor operation it is called as back emf.

5. **State Lenz's law.**

Any induced e.m.f will circulate a current in such a direction as to oppose the cause producing it.

$$e= -N\, dF/dt$$

6. **What is the function of no-voltage release coil in d.c. motor starter?**

As long as the supply voltage is on healthy condition the current through the NVR coil produce enough magnetic force of attraction and retain the starter handle in ON position against spring force. When the supply voltage fails or becomes lower than a prescribed value then electromagnet may not have enough force to retain so handle will come back to OFF position due to spring force automatically.

7. **What is the function of over load release coil in d.c. motor starter?**

It consists of an electromagnet connected in the supply line. If the motor becomes overloaded beyond a certain predetermined value, then triangular leveris lifted and short circuits the electromagnet. Hence, the arm is released and returns to OFF position

8. **Enumerate the factors on which speed of a d.c.motor depends?**

$N= (V-I_aR_a)/\Phi$ so speed depends on voltage applied to armature, flux per pole, resistance of armature.

9. **When is a four point DC starter required in DC motors?**

A four point DC starter is required for dc motor under field control.

10. **If speed is decreased in a dc motor, what happens to the back emf and armature current?**

If speed is decreased in a dc motor, the back emf decreases and armature current increases.

11. **What is the necessity of starter in dc motors?**

When a dc motor is directly switched on, at the time of starting, the motor back emf is zero. Due to this, the armature current is very high. Due to the very high current, the motor gets damaged. To reduce the starting current of the motor a starter is used.

12. **What are the types of starters used in DC motors?**

(i). Two point starter
(ii). Three point starter
(iii). Four point starter

13. **How does a series motor develop high starting torque?**

A dc series motor is always started with some load. So torque of dc series motor is now dependent on square of armature current. Due to this, series motor develops high starting torque.

14. **Why a DC series motor should not be started without load?**

A series motor should never be started without some mechanical load otherwise it may develop excessive speed and it may damage the motor.

15. Give some application of DC motors? Nov‘2013

The application of DC motors is Hoist, Lift, Lathes and Compressor

Applications of DC shunt motor

Lathes

Centrifugal pumps

Blowers and machine tools

Reciprocating pumps

Applications of DC series motor

- Traction work
- Electric locomotives
- Trolley, cars
- Cranes and hoists

Applications of DC compound motor

Rolling mills and other loads requiring large momentary toques.

16. Mention the types of braking of dc motor?

1. Regenerative braking
2. Dynamic braking
3. Plugging

17. What are the losses in dc motor?

1. Copper losses
2. Iron losses
3. Mechanical losses

18. Difference between series and shunt motors.

S.No	Series motor	Shunt motor
1.	Windings are connected in series	Windings are connected in parallel
2.	No load test is not applicable	No load test is applicable
3.	Speed, flux and current are varying	Speed, flux and current are constant

19. Why starting current high in DC motor and how the starter limits the starting current.

The current drawn by a motor armature is given by the relation,

$$I_a = (V - E_b)/R_a$$

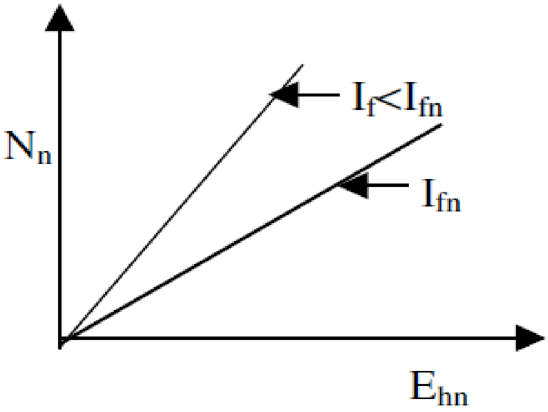
Where, V is the supply voltage, E_b the back e.m.f. and R_a the armature resistance.

When the motor is at rest, there is, as yet, obviously no back e.m.f. developed in the armature. If, now, full supply voltage is applied across the stationary armature, it will draw a very large current because armature resistance is relatively small. This excessive current will blow out the fuses and, prior to that, it will damage the commutator and brushes etc. To avoid this happening, a resistance is introduced in series with the armature (for the duration of starting period only, say 5 to 10 seconds) which limits the starting current to a safe value.

20. Name any 2 non-loading method of testing dc machines?

1. Swinburnes test
2. Hopkinson test

21. Draw the N Vs Eb characteristics of a dc motor for two different field currents.



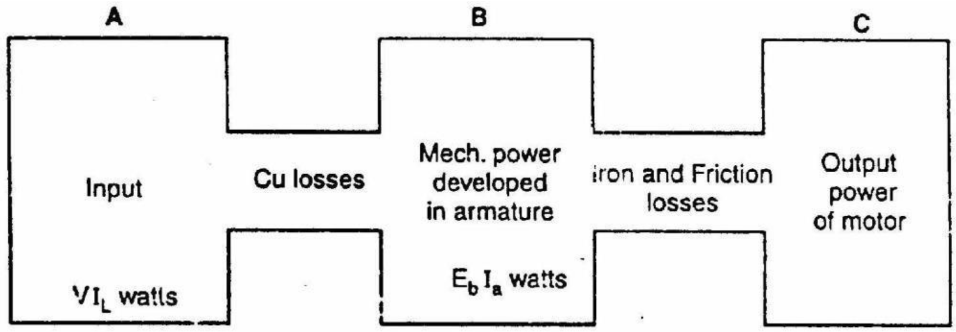
22. What is the basic difference between dc generator and dc motor

Generator converts mechanical energy into electrical energy. Motor converts electrical energy into mechanical energy. But there is no constructional difference between the two.

23. How does d.c. motor differ from d.c. generator in construction?

Generators are normally placed in closed room and accessed by skilled operators only. Therefore on ventilation point of view they may be constructed with large opening in the frame. Motors have to be installed right in the place of use which may have dust, dampness, inflammable gases, chemical etc. to protect the motors against these elements the motor frames are used partially closed or totally closed or flame proof.

24. Write the various power stages of DC motor Nov‘2013



25. List the different methods of speed control employed for DC motor. Nov 2013

(i) flux control method

(ii) armature control method

(iii) voltage control method.

26. Write down the equation for torque developed in DC motor. Nov‘2014

$$\boxed{= 0.159\ \text{Ø}}$$

27. Define efficiency of dc motor Nov‘2013

Efficiency = (output / input)*100

28. How will you change the direction of rotation of a DC motor? April 2015

Reverse the direction by simply reversing the armature leads

29. What are the drawbacks of brake test on dc machine? April 2012

- ✓ In brake test due the belt friction lot of heat will be generated and hence there is large dissipation of energy.
- ✓ . Cooling arrangement is necessary to minimize the heat. Mostly in our laboratories we use water as cooling liquid.
- ✓ . Convenient only for small rated machines due to limitations regarding heat dissipation arrangements.
- ✓ Power developed gets wasted hence brake test method is little expensive.
- ✓ The efficiency observed is on lower side.

30. When you will say the motor is running at base speed? April 2012

On a DC motor, the "rated speed" may be two types, "base speed," which is the speed at which the motor will first produce its maximum designed power output, and "maximum speed," the fastest the motor can spin while producing that same amount of power.

31. List various methods of starting DC motor Nov‘2014

(i). Two point starter

(ii). Three point starter

(iii). Four point starter

32. If speed is decreased in a DC motor, what happens to the back emf and armature current?

April 2014

From the speed equation N α Eb

The speed of the motor is directly proportional to back emf and inversely proportional to flux φ.

Therefore back emf and Ia decreases

33. What do you meant by stalling current in DC motor? April 2014

Stalling is a condition when the motor stops rotating. This condition occurs when the load torque is greater than the motor shaft torque i.e. break down torque condition. In this condition the motor draws maximum current but the motor does not rotate.Thiscurrent is called as Stalling current.

34. Why hopkinson‘s test called as regenerative test. April 2015

Hopkinson's Test is also known as Regenerative Test, Back to Back test and Heat Run Test. In Hopkinson Test, two identical shunt machines are required which are coupled both mechanically and electrically in parallel. One is acting as a motor and another one as a generator.

35. What is the use of retardation teat in DC motor? April 2015

This is the best and simplest method to find the efficiency of a constant-speed d.c. machine (e.g., shunt generator and motor). In this method, we find the mechanical (friction and windage) and iron losses of the machine. Then knowing the armature and shunt Cu losses at any load, the efficiency of the machine can be calculated at that load.

36. What is the significance of back emf in DC motor? April 2015

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

11 Marks

1. Explain the working principle of DC motor with neat diagram

INTRODUCTION

The input to a DC motor is electrical and the output is mechanical rotation or torque. lt is shown in figure 3.1. The fundamental principles and construction of the DC motors are identical with DC generators which have the same type of excitation. A DC machine that runs as a motor will also operate as a generator.

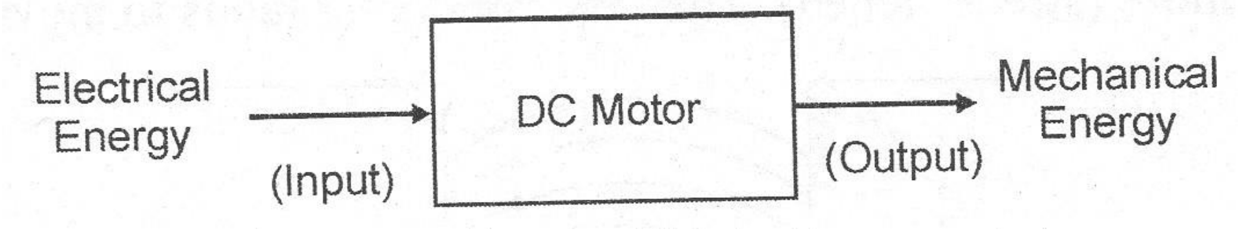


Fig. 3.1.

PRINCIPLE OF OPERATION

The basic principle of operation of d.c. motor is that –whenever a current carrying conductor is placed in a magnetic field, it experiences a force lending to move it.‖ The magnetic field between two poles, N and S, is shown in figure 3.2.

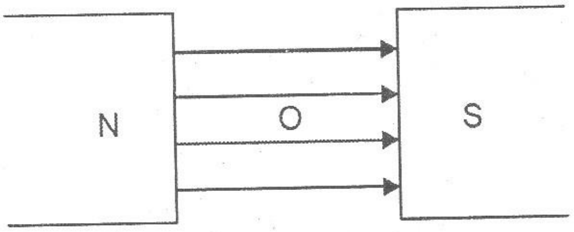


Fig. 3.2.

A current carrying conductor along with the direction of the flux loops around it is shown in figure 3.3.

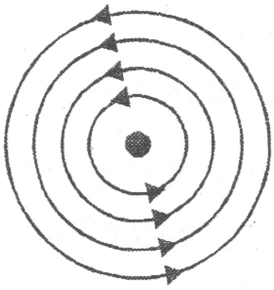


Fig. 3.3.

If a current carrying conductor is placed between two magnetic poles, as show in figure 3.4, both the fields will be distorted.

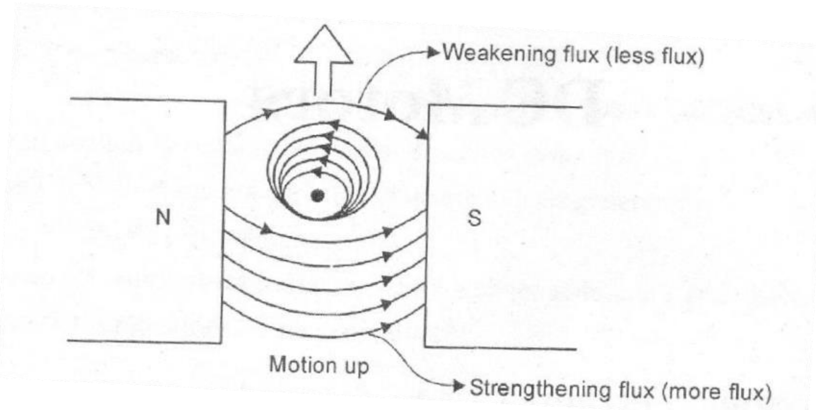


Fig. 3.4.

Above the conductor, the field is weakened (less flux) and below the conductor the field is strengthened. Therefore the conductor tends to move upwards. The force exerted upwards depends upon the intensity of the main field flux and magnitude of the current. Then the direction of the current through the conductor is reversed as shown in figure 3.5. Here, the field below the conductor is less (weakened) and field above the conductor is more (strengthened). Then the conductor tends to move downwards.

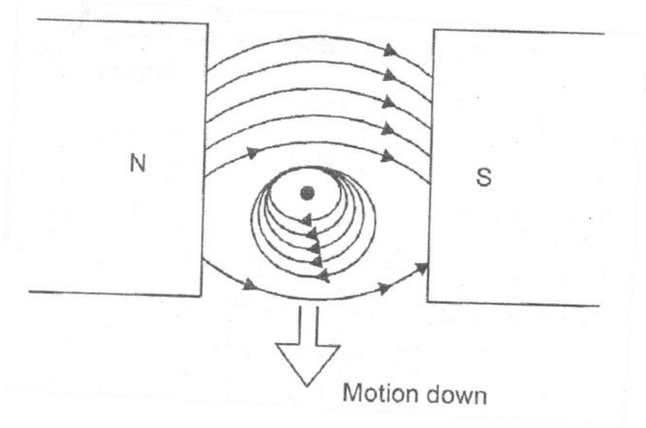


Fig. 3.5.

The magnitude of the force experienced by the conductor in a motor is given by

F = B I l Newtons

where

B = Magnetic field intensity in wb/m^2.

l = current in ampers

I = length ofthe conductor in metres.

The direction of motion is given by Fleming‘s Left Hand rule, which states that the thumb, fore finger and middle finger of the left hand are held such that the fingers show three mutually perpendicular directions and if the fore finger indicates direction of the field, and the middle finger indicates the direction of current, then the thumb points the direction of motion of conductor. ln a d.c. motor, a strong electromagnetic field and a large number of current carrying conductors housed in an armature, make the armature rotate.

2. Write short notes on back emf and what is the significance of Back emf.

BACK EMF

An interesting aspect of motoring action is while a machine functions as a motor, the conductors are cutting flux and that is exactly what is required for generator action to take place. This means that even when the machine is working as a motor, voltages are induced in the conductors. This emf is called the back emf or counter emf, since the cause for this is the rotation, which, in turn, is due to the supply voltage. According to Lenz‘s law, the direction of the back emf opposes the supply voltage.

The back emf is given by the same equation for induced emf of a generator as derived in chapter 2.

$$E_b = = \frac{\Phi Z P N}{60A} \text{ volt} \ldots\ldots\ldots(1)$$

where the symbols Φ ,P,A, Z and N have the same meaning as in chapter 2.

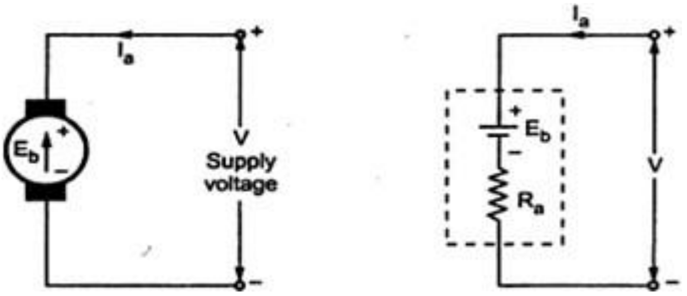


Fig.3.6 (a) Back emf in a dc motor (b) Equivalent circuit of a dc motor

Figure 3.6 shows the equivalent circuit of a motor. Here, the armature circuit is equivalent to a source of emf Eb, in series with a resistance of Ra and a DC supply is applied across these two. The voltage equation of this DC motor is

$$V = E_b + I_a R_a \text{ Volts} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From this equation, armature current

$$I_a = \frac{V - E_b}{R_a} \text{ Amps} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

V - applied voltage,

E_b - back emf,

I_a - armature current,

R_a - armature resistance

$V - E_b$-net voltage in the armature circuit.

From equations (1) and (2), the induced emf in the armature of a motor E_b depends upon armature speed and armature current I_a depends upon the back emf E_b for a constant input voltage V, and armature resistance R_a. If the motor speed is high, back emf E_b is large and therefore armature current is small. If the motor speed is low, then back emf E_b will be less and armature current is more.

IMPORTANCE OF BACK EMF

The DC motor is a self regulating machine because the development of back emf makes the DC motor to draw as much armature current which is just sufficient to develop the required load torque.

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

1. When the DC motor is operating on no load condition, small torque is required to overcome the friction and windage losses. Therefore the back emf is nearly equal to input voltage and armature current is small i.e., I_a is very low.

   $$\therefore E_b = V$$

2. When load is suddenly put on to the motor. Motor tries to slow down. So speed of the motor reduces due to which back emf also decreases. So the net voltage across the armature $V - E_b$ increases and motor draws more armature current. As F = BIL newtons, due to increase current, force experienced by the conductors and hence the torque on the armature increases. The increase in torque is just sufficient to satisfy increased load demand. The motor speed stops decreasing, when the armature current is just enough to produce torque demanded by the new load.
3. When the load on DC motor is decreased, the speed of the motor tries to increase and hence back emf increases. This causes ($V - E_b$) to eventually reduce the current drawn by the armature. The decrease in armature current causes decrease in driving torque and steady state condition are reached, where the driving torque is equal to the load torque. The motor speed stops increasing when the armature current is just enough to produce the less torque required by the new load.

   From the above three important points, the back emf E_b of a DC motor regulate the armature current and it makes the motor self regulating. .

Key point: So back emf regulates the flow of armature current and it automatically alters the armature current to meet the load requirement. This is the practical significance of back emf

3. How do we induce rotation in a DC motor?

Principle of magnetic attraction and repulsion is used to attain rotation in an electrical machine.

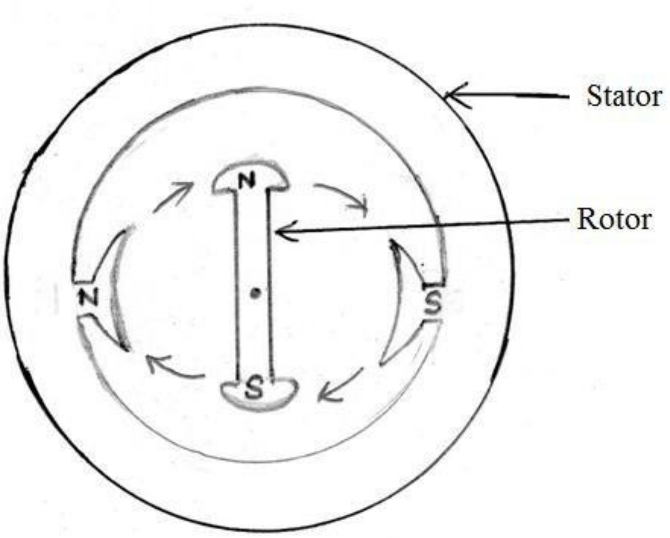


Fig. 3.7

When the rotor is in such a position as shown above then the north pole on the rotor is repelled by the stator north pole. Similarly south pole on the rotor is repelled by stator south pole.

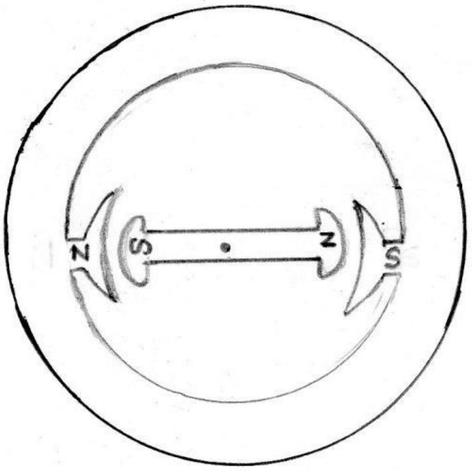


Fig. 3.8

When it is aligned in such a position as shown above, then the position of the field on either stator or rotor must be changed to obtain complete rotation. In DC motor the rotor poles are changed to get continues rotation and this is possible by changing the direction of current flow in rotor.

For simplicity let us consider a two pole DC machine and a rotor with single conductor.

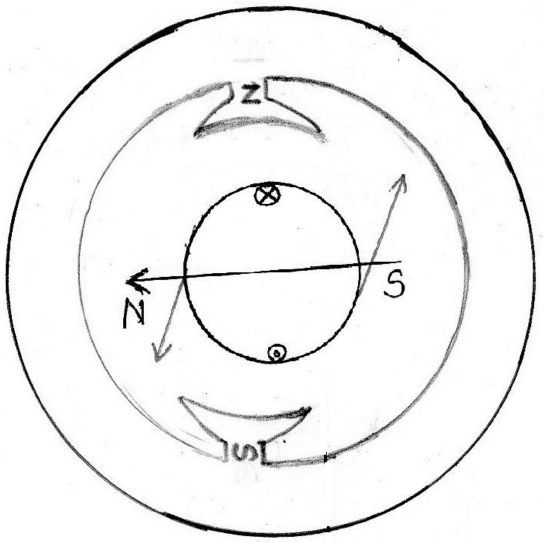


Fig. 3.9

Due to the flow of current through the armature conductor, magnetic field will be produced around the conductor , which in turn induces north and south poles on the rotor as shown above . Now due to magnetic attraction and repulsion the rotor will tends to rotate in such a direction as indicated in the above figure.

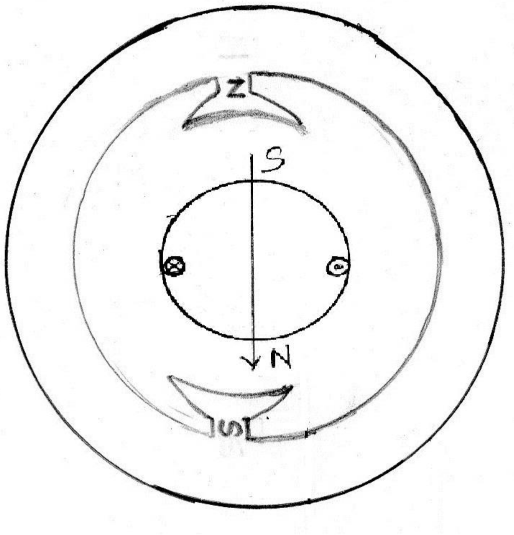


Fig. 3.10

At one stage it will align in a position as shown above and of course it will not stop here due to mechanical inertia in the rotor and the north pole on the rotor will overshoot the stator south pole, similarly the rotor south pole will overshoot the stator north pole.

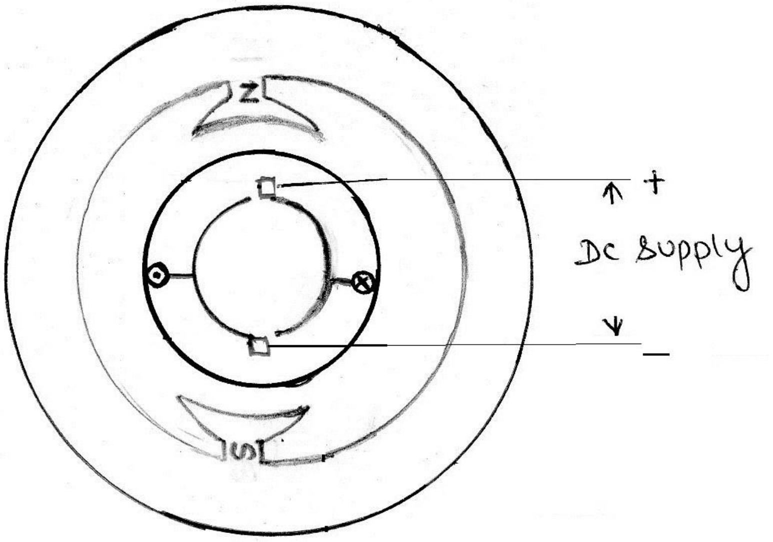


Fig. 3.11

At this position the polarity of armature current is changed. So that repulsion and attraction continues in the same direction.

The change in polarity of current is achieved through commutator. Commutator is placed in rotor, so that it makes permanent contact with the conductors. Commutator is basically a conducting ring split into two parts in this case and is connected to two sides of the coil.

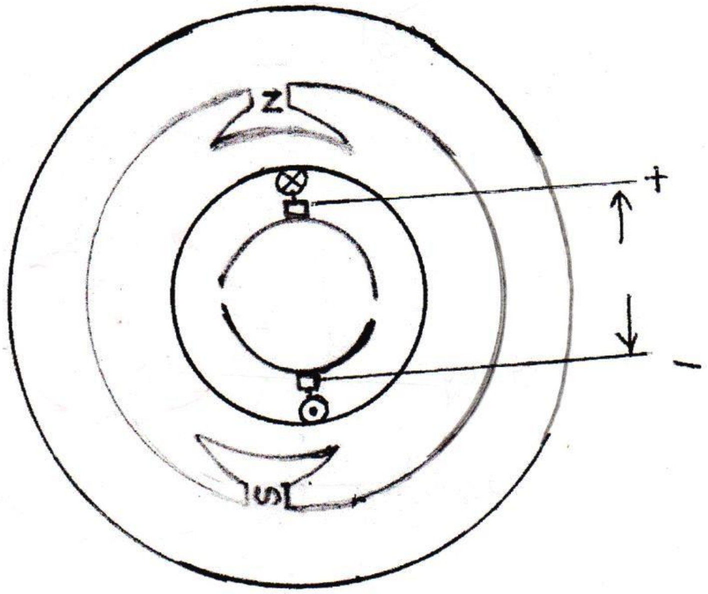


Fig. 3.12

The external connection is done through brushes, which slides on the commutator ring.

4. **Obtain the expression for the enmf and torque developed in a DC motor.** April 2013
5. **Derive the expression for torque and power developed in a DC machine.** Nov' 2014

TORQUE

The turning (or) twisting force about an axis is called torque.

Consider a wheel of radius R meters acted upon a force _F‘ newtons as shown in figure,

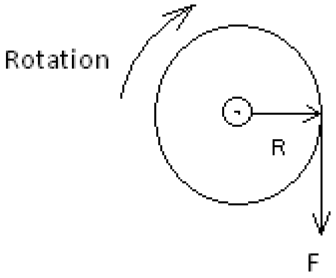


Fig. 3.13

Let the wheel is rotating at a speed of _N‘ rpm . Then angular speed of the wheel is

$$\omega = \frac{2\Pi N}{60} \text{ Rad/sec}$$

So, workdone in one revolution is,

W = F × distance travelled in one revolution.

W = F × 2ΠR Joules.

And

$$P = \text{Power developed} = \frac{\text{Workdone}}{\text{Time}}$$

$$= \frac{F \times 2\Pi R}{\text{Time for one revolution}} = \frac{2\Pi R.F}{\frac{60}{N}}$$

$$= F \times R \times \left(\frac{2\Pi N}{60}\right)$$

Therefore, power $P = T \times \omega$ watts.

(T_a) – Gross torque developed by armature of the motor.

The gross mechanical power developed in armature = $E_b I_a$

Power in armature, $E_b I_a$ = Armature torque, $T_a \times \frac{2\Pi N}{60}$

But back emf, E_b in a motor $= \frac{\emptyset PNZ}{60A}$

$$\frac{\emptyset PNZ}{60A} \times I_a = T_a \times \frac{2\Pi N}{60}$$

$$\text{Therefore } T_a = \frac{1}{2\Pi} \emptyset\, I_a \, \frac{PZ}{A}$$

$$\boxed{T_a = 0.159\, \emptyset\, I_a \frac{PZ}{A}}$$

This is the torque equation of a DC motor.

Hence the torque of a given DC motor is proportional to the product of the armature current and the flux.

Shaft torque (T_{sh})

The torque developed by the armature is called armature torque. It is denoted as T_a. The full armature torque is not available for doing useful work. Some amount of torque is used for supplying iron and friction losses in the motor.

This torque is called lost torque. It is denoted as T_f. The remaining torque is available in the shaft. It is used for doing useful work. This torque is known as shaft torque or useful torque. It is denoted as T_{sh} . The armature torque is the sum of the lost torque and shaft torque.

$$\therefore T_a = T_f + T_{sh}$$

The output power of the motor is

$$P_{out} = T_{sh} \times 2\pi N/60 \text{ Watt}$$

$$T_{sh} = \frac{P_{out}}{2\pi N/60} \text{ N-m}$$

$$= \frac{P_{out} \cdot 60}{2\pi N} \text{ N-m}$$

$$T_{sh} = 9.55 \frac{P_{out}}{N} \text{ N-m}$$

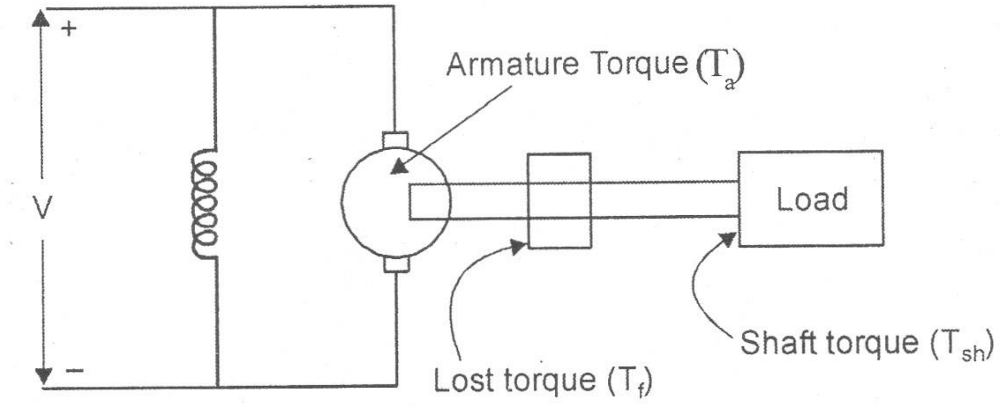


Fig. 3. 14

6. Derive the torque equation of a DC motor. Also draw the torque – armature current characteristics for a DC shunt and series motor. April 2015

TORQUE

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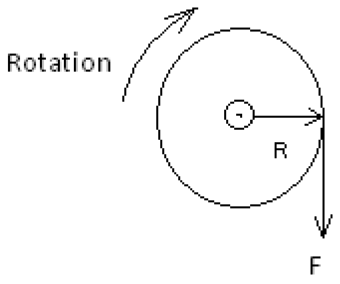
Consider a wheel of radius R meters acted upon a force _F‘ newtons as shown in figure,



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So, workdone in one revolution is,

W = F × distance travelled in one revolution.

$$W = F \times 2\Pi R \text{ Joules.}$$

And

$$P = \text{Power developed} = \frac{\text{Workdone}}{\text{Time}}$$

$$= \frac{F \times 2\Pi R}{\text{Time for one revolution}} = \frac{2\Pi R.F}{\frac{60}{N}}$$

$$= F \times R \times \left(\frac{2\Pi N}{60}\right)$$

Therefore, power $P = T \times \omega$ watts.

(T_a) – Gross torque developed by armature of the motor.

The gross mechanical power developed in armature = $E_b I_a$

Power in armature, $E_b I_a$ = Armature torque, $T_a \times \frac{2\Pi N}{60}$

But back emf, E_b in a motor $= \frac{ØPNZ}{60A}$

$$\frac{ØPNZ}{60A} \times I_a = T_a \times \frac{2\Pi N}{60}$$

$$\text{Therefore } T_a = \frac{1}{2\Pi} Ø\, I_a \frac{PZ}{A}$$

$$\boxed{T_a = 0.159\, Ø\, I_a \frac{PZ}{A}}$$

This is the torque equation of a DC motor.

Hence the torque of a given DC motor is proportional to the product of the armature current and the flux.

i) Torque-Armature current characteristics of shunt motor

For a d.c. motor T α Φ I_a

For a constant values of R_{sh} and supply voltage V, I_{sh} is also constant and hence flux is also constant.

∴ $T_a \alpha I_a$

The equation represents a straight line, passing through the origin, as shown in the Fig. 3.21. Torque increases linearly with armature current. It is seen earlier that armature current is decided by the load. So as load increases, armature current increases, increasing the torque developed linearly.

Now if shaft torque is plotted against armature current, it is known that shaft torque is less than the armature torque and the difference between the two is loss torque T_f as shown. On no load T_{sh}= 0 but armature torque is present which is just enough to overcome stray losses shown as T_{ao}. The current required is I_{ao} on no load to produce T_{ao} and hence T_{sh} graph has an intercept of I_{ao} on the current axis.

To generate high starting torque, this type of motor requires a large value of armature current at start This may damage the motor hence d.c. shunt motors can develop moderate starting torque and hence suitable for such applications where starting torque requirement is moderate.

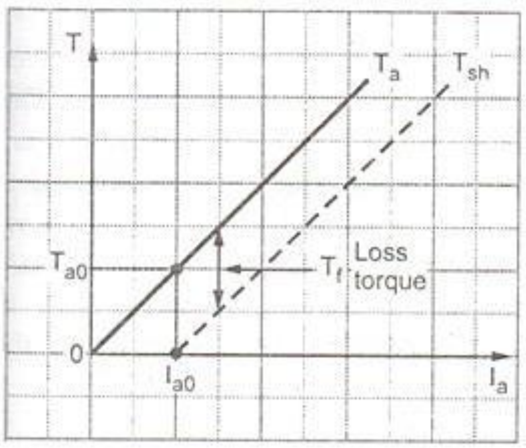


Fig. 3.21 T Vs I_a for shunt motor

ii) Torque-Armature current characteristics of series motor

In case of series motor the series field winding is carrying the entire armature current. So flux produced is proportional to the armature current.

∴ Φ α I_a

Hence $T_a \alpha \Phi I_a \alpha I_a^2$

Thus torque in case of series motor is proportional to the square of the armature current. This relation is parabolic in nature as shown in the Fig. 3.24.

As load increases, armature current increases and torque produced , increases proportional to the square of the armature current up to a certain limit.

As the entire I_a passes through the series field, there is a property of an electromagnet called saturation, may occur. Saturation means though the current through the winding increases, the flux produced remains constant.

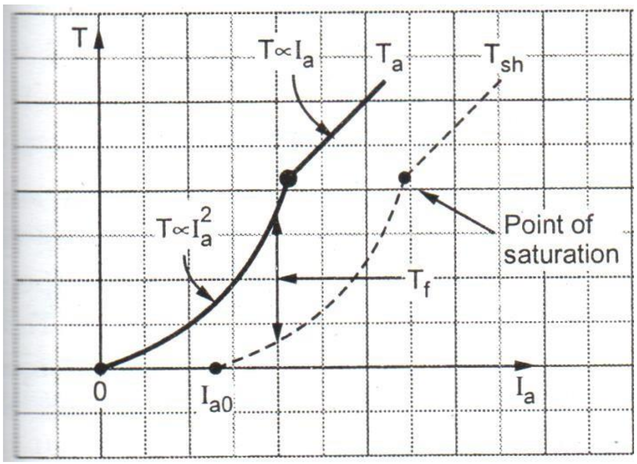


Fig. 3.24

Hence after saturation the characteristics take the shape of straight line as flux becomes constant, as shown. The difference between T_a and T_{sh} is loss torque T_f which is also shown in the Fig. 3.24.

At start as $T_a \alpha I_a^2$, these types of motors can produce high torque for small amount of armature current hence the series motors are suitable for the applications which demand high starting torque.

7. Derive the relationship between speed and torque

SPEED AND TORQUE EQUATION

For a DC motor, the speed equation is obtained as follows

We know

$$E_b = V - I_a R_a = \frac{\Phi Z N}{60} . \frac{P}{A}$$

$$\text{Or } V - I_a R_a = \frac{\Phi Z N}{60} . \frac{P}{A}$$

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

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

$$N = \frac{K(V - I_a R_a)}{\Phi}$$

Where K is a constant.

Speed equation becomes $N \alpha \frac{(V - I_a R_a)}{\Phi}$

Or $N \alpha \frac{E_b}{\Phi}$

Hence the speed of the motor is directly proportional to back emf E_b and inversely proportional to flux Φ, By varying the flux and voltage, the motor speed can be changed.

The torque equation of a DC motor is given by

$T \alpha \Phi I_a$

Here, the flux Φ directly proportional to the current flowing through the field winding i.e.,

$\Phi \alpha I_f$

For DC shunt motor, the shunt field current I_{sh} is constant as long as input voltage is constant. Therefore flux is also constant.

Hence $T \alpha \Phi I_a$ becomes

$T \alpha I_a$

So, for DC shunt motor torque is directly proportional to the armature current. For DC series motor, the series field current is equal to the armature current Ia. Here, the flux Φ is proportional to the armature current I_a

$\Phi \alpha I_a$

Hence $T \alpha \Phi I_a$ becomes

$T \alpha I_a^2$

So, for DC series motor, the torque is directly proportional to the square of the armature current. The speed and torque equations are mainly used for analyzing the various characteristics of DC motors.

8. Explain the different types of DC motors with neat circuit diagram.

CLASSIFICATIONS OF DC MOTORS

The classification of DC motors is similar to that of the DC generators. The classification is based on the connections of field winding in relation to the armature.

The types of DC motors are

i) Separately excited DC motor

ii) Self excited DC motor

- Series motor
- Shunt motor
- Compound motor
  a) Long shunt compound motor b) Short shunt compound motor

SEPARATELY EXCITED DC MOTOR

Figure 3. shows connections diagram of a separately excited DC motor. Here, the field winding and armature are separated. The field winding is excited by a separate DC source. That is why it is called separately excited DC motor.

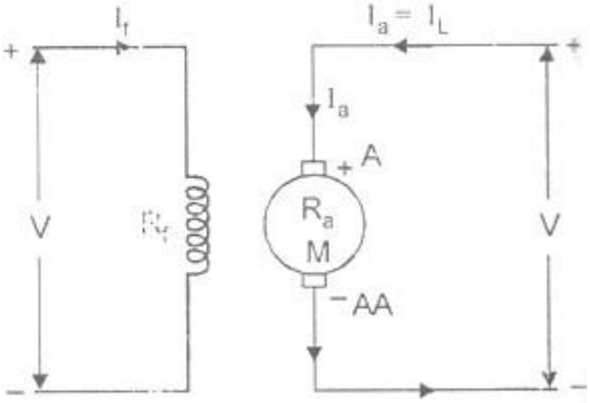


Fig.3.15

From this diagram,

Armature current I_a = line current I_L

Back emf E_b = V - $I_a R_a$ - V_{brush}

V_{brush} is very small and therefore it is neglected.

DC SERIES MOTOR

DC series motor means, the field winding is connected in series with armature. Figure 3. shows connection diagram of a DC series motor. The field winding should have less number of turns of thick wire. R_{se} is the resistance of the series field winding. Normally R_{se} value is very small.

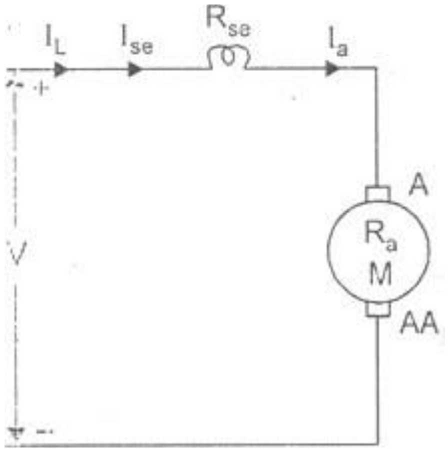


Fig. 3.16

In a DC series motor

I_L = line current drawn from the supply

Armature current I_a = series field current $I_{se} = I_L$

$$I_a = I_{se} = I_L$$

The voltage equation is given by

$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$

where, $I_a = I_{se}$

$\therefore V = E_b + I_a(R_a + R_{se}) + V_{brush}$

V_{brush} - voltage drop in the brush.

Normally it is neglected.

and hence $V = E_b + I_a(R_a + R_{se})$

In a DC series motor, full armature current flows through the series field winding. Therefore, flux produced is directly proportional to the armature current i.e.,

$$\Phi \propto I_{se} \propto I_a$$

DC SHUNT MOTOR

In a DC shunt motor, the field winding is connected across the armature. Figure 3. shows the connection diagram of a DC shunt motor. Here, the shunt field winding has more number of turns with less cross-sectional area. R_{sh} is the shunt field winding resistance. R_a is the armature resistance. The value of R_a is very small and R_{sh} is quite large. The input voltage V is equal to the voltage across the armature and field winding.

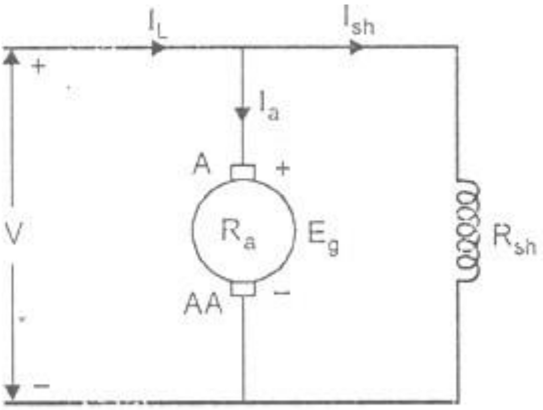


Fig. 3.17

I_L is the line current drawn from the supply. The line current is divided into two paths, one through the field winding and second through the armature i.e

$$I_L = I_a + I_{sh}$$

where, I_a = armature current ; I_{sh} = shunt field current

$$I_{sh} = \frac{V}{R_{sh}}$$

Voltage equation ofa DC shunt motor is given by

$$V = E_b + I_a R_a + V_{brush}$$

In shunt motor, flux produced by field winding is proportional to the field current I_{sh}. i.e, Here, the input voltage is constant and so the flux is also constant. Therefore, DC shunt motor is also called a constant flux motor or constant speed motor.

DC COMPOUND MOTOR

A DC compound motor consists of both series and shunt field windings.

a) Long shunt compound motor

In this motor, the shunt field winding is connected across both armature and series field winding. Figure 3. shows connection diagram of a long shunt compound motor.

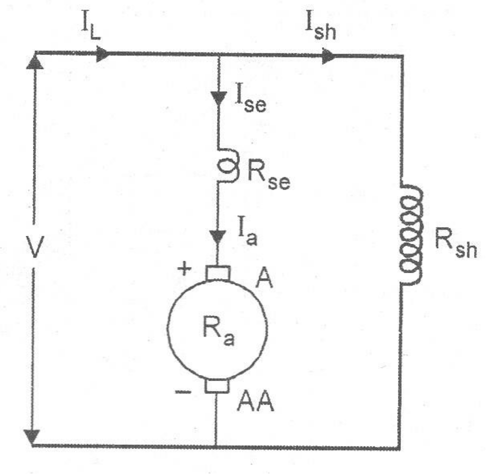


Fig. 3.18

From this diagram

$$I_L = I_{se} + I_{sh}$$

$$I_{se} = I_a$$

$$\therefore I_L = I_a +$$

$$I_{sh} \; I_{sh} = \frac{V}{R_{sh}}$$

The voltage equation of this motor is given by

$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

Where $I_a = I_{se}$ $\therefore V = E_b + I_a (R_a + R_{se}) + V_{brush}$

b) Short shunt compound motor

In this type of motor, the shunt field winding is across the armature and series field winding is connected in series with this combination. Figure 3. shows connection diagram of a short shunt compound motor.

$I_L = I_{se}$, $I_L = I_a + I_{sh}$

$\therefore I_L = I_{se} = I_a + I_{sh}$

The voltage across the shunt field Winding can be found out from the voltage equation.

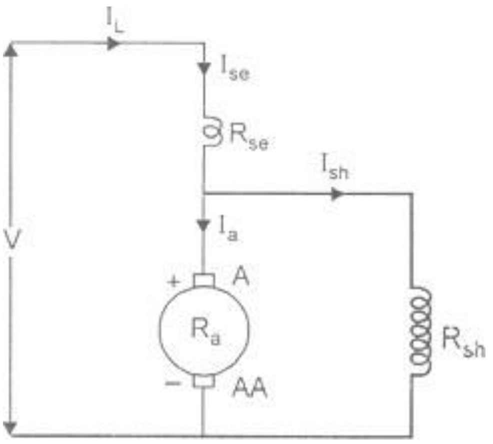


Fig. 3.19

$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$

$I_{se} = I_L$

$V = E_b + I_a R_a + I_L R_{se} + V_{brush}$

Voltage drop across the shunt field winding is = $V - I_L R_{se}$

$V_{sh} = E_b + I_a R_a + V_{brush}$

$\therefore I_{sh} = \frac{V - I_L R_{se}}{R_{sh}}$

The compound motors again can be classified into two types

i) Cumulative compound motor ii) Differential compound motor

Cumulative compound motor

In this type of motor, the two field winding fluxes aid each other i.e., flux due to the series field winding strengthens the flux due to the shunt field winding. The winding connection diagram is shown in figure 3..

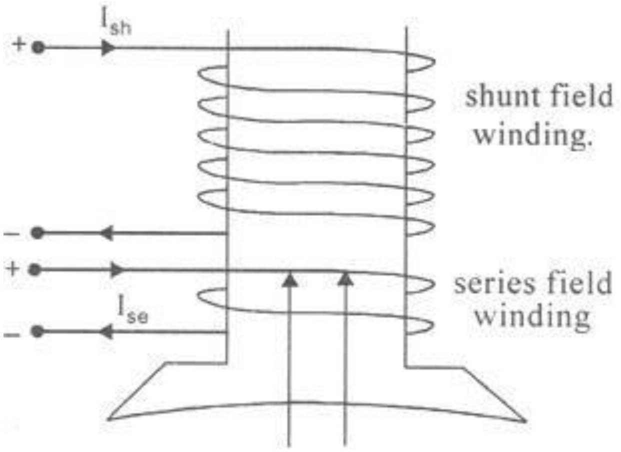


Fig. 3.20

Differential compound motor

In this type of motor, the two field winding fluxes oppose each other i.e., flux due to series field winding weakens the field due to shunt field winding. Figure 3. shows winding connection diagram of this motor.

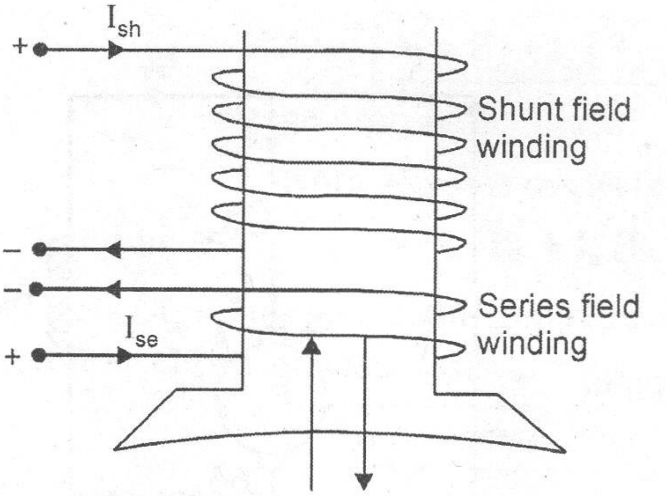


Fig. 3.21

9. Explain the electrical and mechanical characteristics of DC motors

D.C. MOTOR CHARACTERISTICS

The performance of a d.c. motor under various conditions can be judged by the following characteristics.

i) Torque-Armature current characteristics (T Vs I_a) :

The graph showing the relationship between the torque and the armature current is called a torque-armature current characteristic. These are also called electrical characteristics.

ii) Speed-Armature current characteristics (N Vs I_a) :

The graph showing the relationship between the speed and armature current characteristics

iii) Speed-Torque characteristics (N Vs T) :

The graph showing the relationship between the speed and the torque of the motor is speed-torque characteristics of the motor. These are also called mechanical characteristics.

The nature of these characteristics can easily be obtained by using speed and torque derived in section 3.6. These characteristics play a very important role in selecting a type of motor for a particular application.

Characteristics of D.C. Shunt Motor

i) Torque-Armature current characteristics

For a d.c. motor $T \alpha \Phi I_a$

For a constant values of R_{sh} and supply voltage V, I_{sh} is also constant and hence flux is also constant.

$\therefore \qquad T_a \alpha I_a$

The equation represents a straight line, passing through the origin, as shown in the Fig. 3.21. Torque increases linearly with armature current. It is seen earlier that armature current is decided by the load. So as load increases, armature current increases, increasing the torque developed linearly.

Now if shaft torque is plotted against armature current, it is known that shaft torque is less than the armature torque and the difference between the two is loss torque T_f as shown. On no load $T_{sh}= 0$ but armature torque is present which is just enough to overcome stray losses shown as T_{ao}. The current required is I_{ao} on no load to produce T_{ao} and hence T_{sh} graph has an intercept of I_{ao} on the current axis.

To generate high starting torque, this type of motor requires a large value of armature current at start This may damage the motor hence d.c. shunt motors can develop moderate starting torque and hence suitable for such applications where starting torque requirement is moderate.

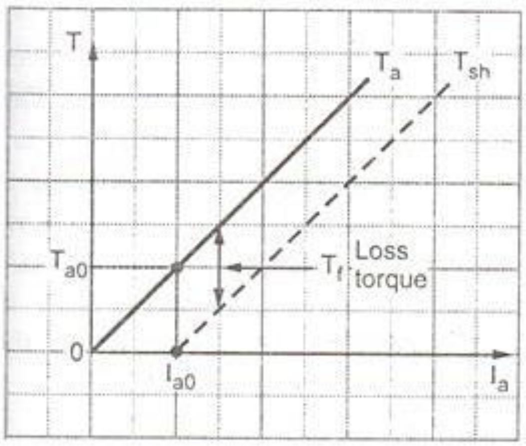


Fig. 3.21 T Vs I_a for shunt motor

ii) Speed-Armature current characteristics

From the speed equation we get,

$$N \alpha \frac{V - I_a R_a}{\Phi} = V - I_a R_a \qquad \text{as } \Phi \text{ is constant.}$$

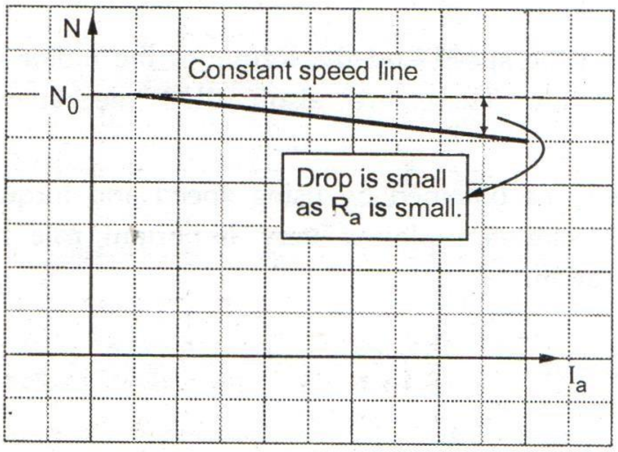


Fig. 3.22 N vs I_a for shunt motor

So as load increases, the armature current increases and hence drop $I_a R_a$ also increases. Hence for constant supply V - $I_a R_a$ decreases and hence speed reduces. But as R_a is very small, for change in I_a from no load to full load, drop $I_a R_a$ is very small and hence drop in speed is also not significant from no load to full load. So the characteristics is slightly droping as shown in the Fig. 3.21.

Key Point: But for all practical purposes these type of motors are considered to be a constant speed motors.

iii) Speed-Torque characteristics

These characteristics can be derived from the above two characteristics. This graph is similar to speed-armature current characteristics as torque is proportional to the armature current. This curve shows that the speed almost remains constant though torque changes from no load to full load conditions. This is shown in the Fig. 3.23.

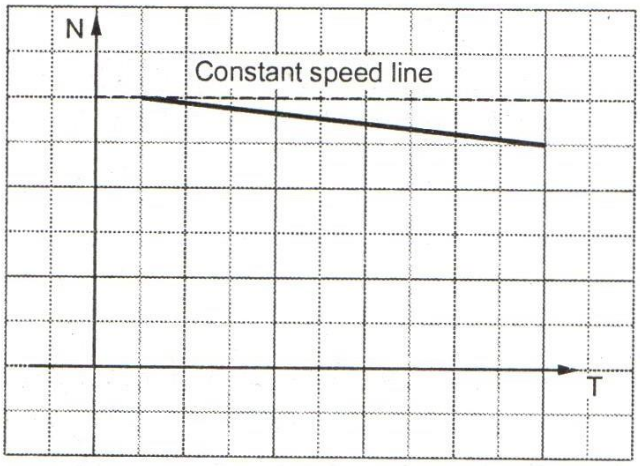


Fig. 3.23 N Vs T for shunt motor

CHARACTERISTICS OF D.C. SERIES MOTOR

i) Torque-Armature current characteristics

In case of series motor the series field winding is carrying the entire armature current. So flux produced is proportional to the armature current.

$$\therefore \quad \Phi \propto I_a$$

Hence $T_a \propto \Phi I_a \propto I_a^2$

Thus torque in case of series motor is proportional to the square of the armature current. This relation is parabolic in nature as shown in the Fig. 3.24.

As load increases, armature current increases and torque produced , increases proportional to the square of the armature current up to a certain limit.

As the entire I_a passes through the series field, there is a property of an electromagnet called saturation, may occur. Saturation means though the current through the winding increases, the flux produced remains constant.

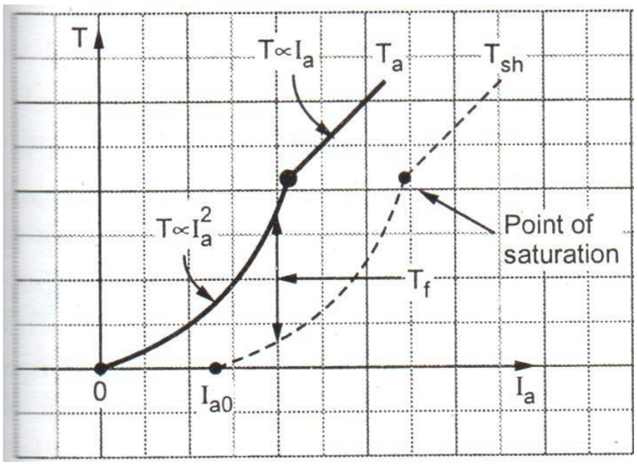


Fig. 3.24

Hence after saturation the characteristics take the shape of straight line as flux becomes constant, as shown. The difference between T_a and T_{sh} is loss torque T_f which is also shown in the Fig. 3.24.

At start as $T_a \propto I_a^2$, these types of motors can produce high torque for small amount of armature current hence the series motors are suitable for the applications which demand high starting torque.

ii) Speed-Armature current characteristics

From the speed equation we get,

$$N \propto \frac{E_b}{\Phi} \propto \frac{V - I_a R_a - I_a R_{se}}{I_a} \qquad \text{as } \Phi \propto I_a \text{ in case of series motor}$$

Now the values of R_a and R_{se} are so small that the effect of change in I_a on speed overrides the effect of change in V - $I_a R_a - I_a R_{se}$ on the speed.

Hence in the speed equation, E_b approximately equal to V and can be assumed constant.

$$N \alpha \frac{1}{I_a}$$

So speed-armature current characteristics is rectangular hyperbola type as shown in the Fig.3.25

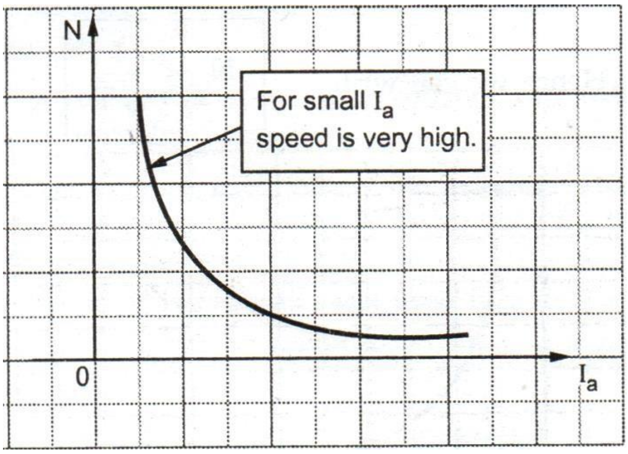


Fig.3.25

iii) Speed-Torque characteristics

In case of series motors, $T \alpha \; I_a^2$ and $N \alpha \frac{1}{I_a}$

Hence we can write, $N \alpha \frac{1}{\sqrt{T}}$

Thus as torque increases when load increases, the speed decreases. .On no load, torque is very less and hence speed increases to dangerously high value. Thus the nature of the speed – toque characteristics is similar to the nature the speed-armature current characteristics. The speed-torque characteristics of a series motor is shown in the Fig.3.26.

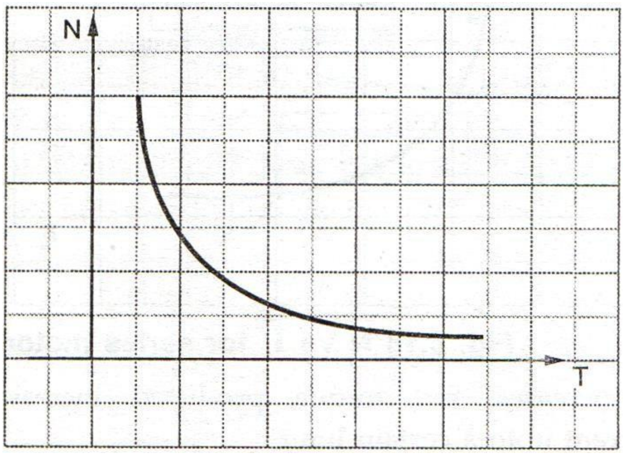


Fig.3.26

3.8.3 Why Series Motor is Never Started on No Load ?

It is seen earlier that motor armature current is decided by the load. On light load or no load, the armature current drawn by the motor is very small.

In case of a d.c. series motor, $\Phi \alpha I_a$ and

on no load as I_a is small hence flux produced is also very small.

According to speed equation,

$N \alpha \frac{1}{\Phi}$ as E_b is almost constant.

So on very light load or no load as flux is very small, the motor tries to run at dangerously high speed which may damage the motor mechanically. This can be seen from the speed-armature current and the speed-torque characteristics that on low armature current and low torque condition motor shows a tendency to rotate with dangerously high speed.

This is the reason why series motor should never be started on light loads or no load Conditions. For this reason it is not selected for belt drives as breaking or slipping of belt causes to throw the entire load off on the motor and made to run motor with no load which is dangerous.

CHARACTERISTICS OF DC COMPOUND MOTOR

Compound motor characteristics basically depends on the fact whether the motor is cumulatively compound or differential compound. All the characteristics of the compound motor are the combination of the shunt and series characteristic.

Cumulative compound motor is capable of developing large amount of torque at low Speeds just like series motor. However it is not having a disadvantage of series motor even at light or no load. _The shunt field winding produces the definite flux and series flux helps the shunt field flux to increase the total flux level.

So cumulative compound motor can run at a reasonable speed and will not run with dangerously high speed like series motor on light or no load condition.

In differential compound motor as two fluxes oppose each other, the resultant flux decreases as load increases thus the machine runs at a higher speed with increase in the load.

This property is dangerous as on full load the motor may try to run with dangerously high speed. So differential compound motor is generally not used in practice.

The various characteristics of both the types of compound motors cumulative and the differential are shown in the Fig.3.26 (a), (b) and (c).

The exact shape of these characteristics depends on the relative contribution of series and shunt field windings. If the shunt field winding is more dominant then the characteristics take the shape of the shunt motor characteristics. While if the series field winding is more dominant then the characteristics take the shape of the series characteristics

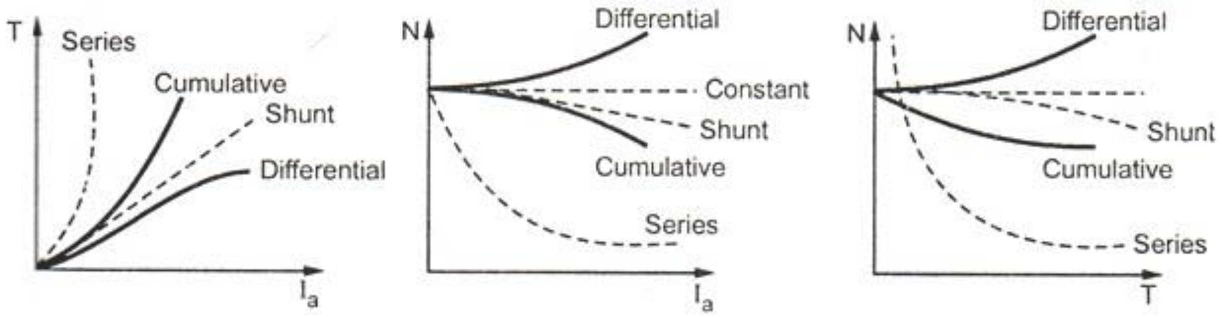


Fig.3.27 Characteristics of d.c. compound motor

10. **Draw the mechanical characteristics of DC shunt and series motor and explain with circuit diagrams**. April 2012

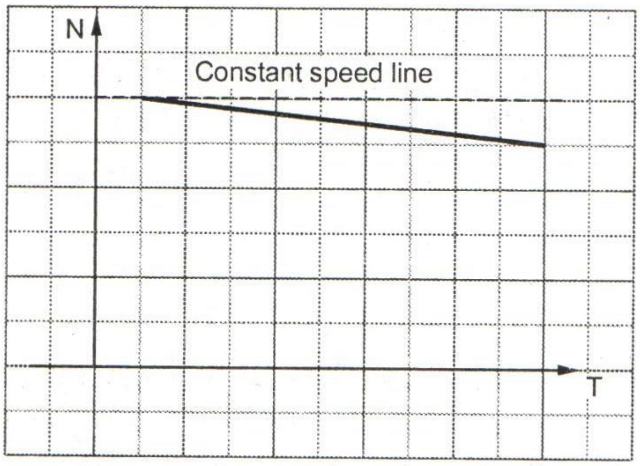
Speed-Torque characteristics (N Vs T) :

The graph showing the relationship between the speed and the torque of the motor is speed-torque characteristics of the motor. These are also called mechanical characteristics.

The nature of these characteristics can easily be obtained by using speed and torque derived in section 3.6. These characteristics play a very important role in selecting a type of motor for a particular application.

i) Speed-Torque characteristics of shunt motor

These characteristics can be derived from the above two characteristics. This graph is similar to speed-armature current characteristics as torque is proportional to the armature current. This curve shows that the speed almost remains constant though torque changes from no load to full load conditions. This is shown in the Fig. 3.23.

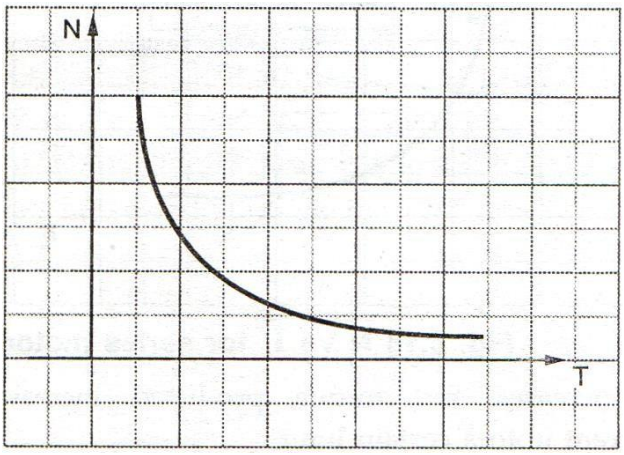


iii) Speed-Torque characteristics series motor

In case of series motors, $T \alpha \; I_a^2$ and $N \alpha \frac{1}{I_a}$

Hence we can write, $N \alpha \frac{1}{\sqrt{T}}$

Thus as torque increases when load increases, the speed decreases. .On no load, torque is very less and hence speed increases to dangerously high value. Thus the nature of the speed – toque characteristics is similar to the nature the speed-armature current characteristics. The speed-torque characteristics of a series motor is shown in the Fig.3.26.



11. List the applications of various types of DC motors.

APPLICATIONS OF DC MOTORS

DC shunt motors are used where the speed has to remain nearly constant with load and where a high starting torque is not required.

Series motors are used where the load is directly attached to the shaft or through a gear arrangement and where there is no danger of the load being –thrown off‖.

Compound motors are used for driving heavy machine tools .

The applications of the various motor is stated in the Table 3.1

Types of motor	**Characteristics**	**Applications**
Shunt	Speed is fairly constant and medium starting torque.	1) Blowers and fans 2)Centrifugal and reciprocating pump 3) Lathe machines 4) Machine tools 5) Milling machines 6) Drilling machines
Series	High starting torque. No load	1) Cranes

	condition is dangerous. Variable speed.	2) Hoists, Elevators 3) Trolleys 4) Conveyors 5) Electric locomotives
Cumulative compound	High starting torque, No load condition is allowed.	1) Rolling mills 2) Punches 3) Shears 4) Heavy planers 5) Elevators
Differential compound	Speed increases as load increases.	Not suitable for any practical application.

Table 3.1

12. **Explain the need of starters in a DC motor. Also explain 3 point starter operation with sketch.**

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 $E_b \alpha$ N and N is zero at start.

$\therefore$ E_b at start = 0

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

$$V = E_b + I_a R_a$$

So at start, $V = I_a R_a$ ….As $E_b = 0$

$$\therefore I_a = \frac{V}{R_a}$$

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,

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

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.

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 shown in the Fig. 3.28.

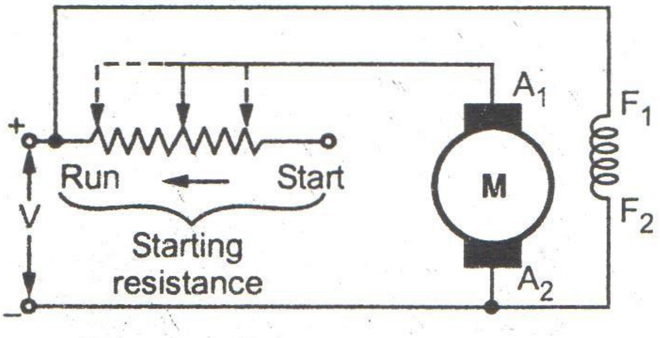


Fig. 3.28. Basic arrangement of a starter

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

a) Three point starter

b) Four point starter

c) Two point starter

Let us see the details of three point starter.

13. Draw the diagram of 3 point starter and explain various protective devices available in 3point starter. April 2015

THREE POINT STARTER

The Fig. 3.28 shows this type of starter

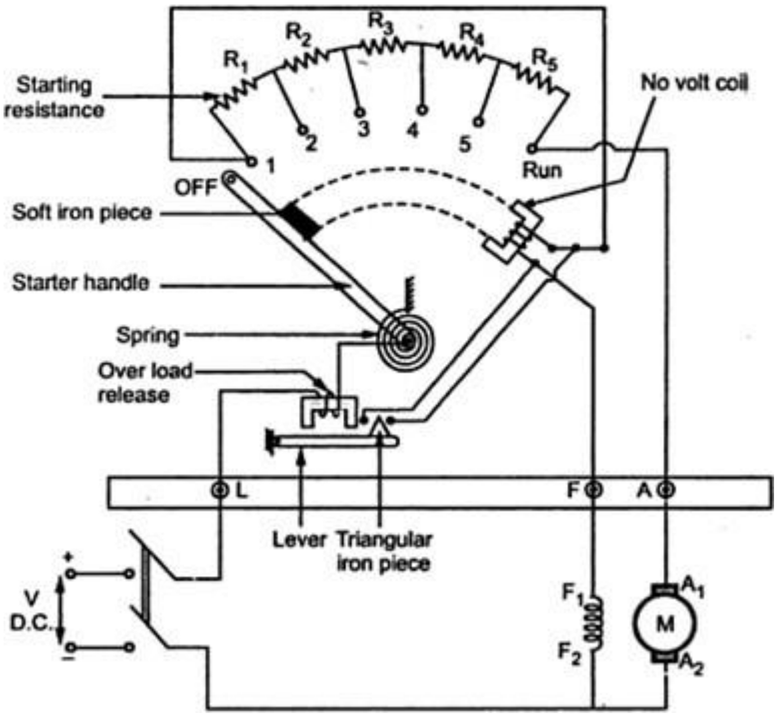


Fig. 3.28 Three point starter

The starter is basically a variable resistance, divided into number of sections. The contact points of these sections are called studs and brought out separately shown as OFF,
1, 2, …upto RUN. There are three main points of this starter :

1. 'L' -> Line terminal to be connected to positive of supply.
2. 'A' --> h To be connected to the armature winding.
3. 'F' -> To be connected to the field winding.

Point 'L' is further connected to an electromagnet called **overload release** (OLR). The second end of 'OLR' is connected to a point where handle of the starter is pivoted. This handle is free to move from its other side against the force of the spring. This spring brings back the handle to the OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to the another electromagnet called **No Volt Coil** (NVC). The NVC is further connected to terminal 'F'. The starting resistance is entirely in series with the armature. The OLR and NVC are the two protecting devices of the starter.

Operation : Initially the handle is in the OFF position. The d.c. supply to the motor is switched on. Then handle is slowly moved ,against the spring force to make a contact with stud no. 1. At this point, field winding gets supply through the parallel path provided to starting resistance, through NVC. While entire starting resistance comes in series with the armature and armature current which is high at start, gets limited. As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., cutting out the starting resistance gradually from the armature circuit. Finally when the starter handle is in 'RUN' position, the entire starting resistance gets removed from the armature circuit and motor starts operating with normal speed. The handle is moved manually, and the obvious question is how handle will remain in the 'RUN' position, as long as motor is running ? Let us see the action of NVC which will give the answer to this question along with some functions of NVC.

Functions of No Volt Coil

1. The supply to the field winding is derived through NVC. So when field current flows, it magnetizes the NVC. When the handle is in the 'RUN' position, soft iron piece connected to the handle gets attracted by the magnetic force produced by NVC. Design of NVC is such that it holds the handle in 'RUN' position against the force of the spring as long as supply to the motor is proper. Thus NVC holds the handle in the 'RUN' position and hence also called **hold on coil**.

2. Whenever there is supply failure or if field circuit is broken, the current through NVC gets affected. It looses its magnetism and hence not in a position to keep the soft iron piece on the handle, attracted. Under the spring force, handle comes back to OFF position, switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problem. The entire starting resistance comes back in series with the armature when attempt is made to start the motor everytime. This prevents the damage of the motor caused due to accidental starting.
3. NVC performs the similar action under low voltage conditions and protects the motor from such dangerous supply conditions as well.

Action of Overload Release

The current through the motor is taken through the OLR, an electromagnet. Under overload condition, high current is drawn by the motor from the supply which passes through OLR. Below this magnet, there is an arm which is fixed at its fulcrum and normally resting in horizontal position. Under overloading, high current though OLR produces enough force of attraction to attract the arm upwards. Normally magnet is so designed that up to a full load value of current, the force of attraction produced is just enough to balance the gravitational force of the arm and hence not lifting it up. At the end of this arm, there is a triangular iron piece fitted. When the arm is pulled upwards the triangular piece touches to the two points which are connected to the two ends of NVC. This shorts the NVC and voltage across NVC becomes zero due to which NVC looses its magnetism. So under the spring force, handle comes back to the OFF position, disconnecting the motor from the supply. Thus motor gets saved from the overload conditions.

In this starter, it can be observed that as handle is moved from different studs one by one, the part of the starting resistance which gets removed from the armature circuit, gets added to the field circuit. As the value of starting resistance is very small as compared to the field winding resistance, this hardly affects the field winding performance. But this addition of the resistance in the field circuit can be avoided by providing a brass arc or copper arc connected just below the stud, the end of which is connected to NVC, as shown in the Fig. 8.29.

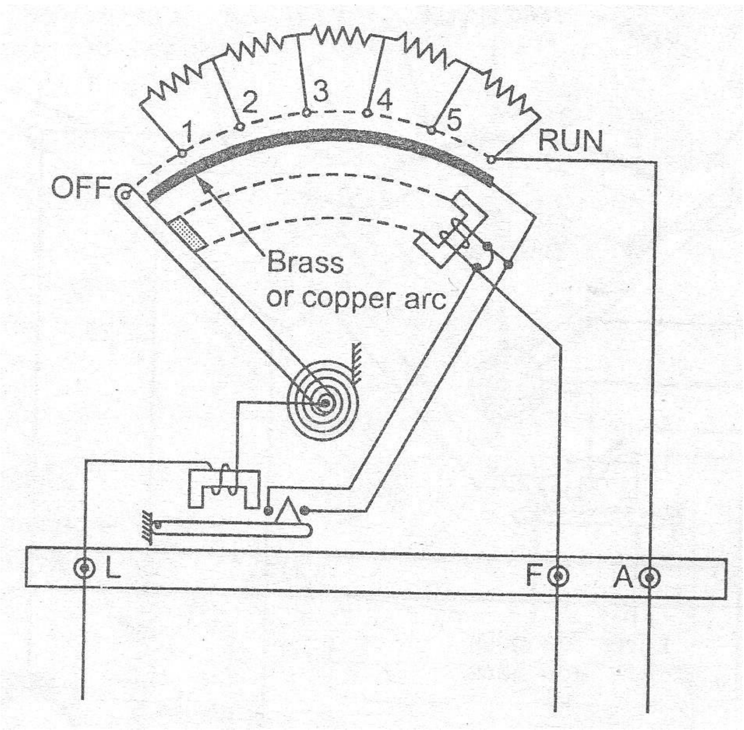


Fig. 3.29. Three point starter with brass arc

The handle moves over this arc, supplying the field current directly bypassing the starting resistance. When such an arc is provided, the connection used earlier to supply field winding, is removed.

Disadvantage

In this starter, the NVC and the field winding are in series. So while controlling the speed of the motor above rated, field current is reduced by adding an extra resistance in series with the field winding. Due to this, the current through NVC also reduces. Due to this, magnetism produced by NVC also reduces. This may release the handle from its RUN position switching off the motor. To avoid the dependency of NVC and the field winding, four point starter is used, in which NVC and the field winding are connected in parallel.

14. Describe a 4 point starter mentioning about the modifications made in a 3 point starter.

FOUR POINT STARTER

The basic difference between three point and four point starter is the connection of NVC. In three point, NVC is in series with the field winding while in four point starter NVC is connected independently across the supply through the fourth terminal called ‗N‘ in addition to the 'L', 'F' and 'A'.

Hence any change in the field current does not affect the performance of the NVC. Thus it is ensured that NVC always produce a force which is enough to hold the handle in _RUN‘ position, against force of the spring, under all the operating conditions. Such a current is adjusted through NVC with the help of fixed resistance R connected in series with the NVC using fourth point 'N' as shown in Fig. 3.30.

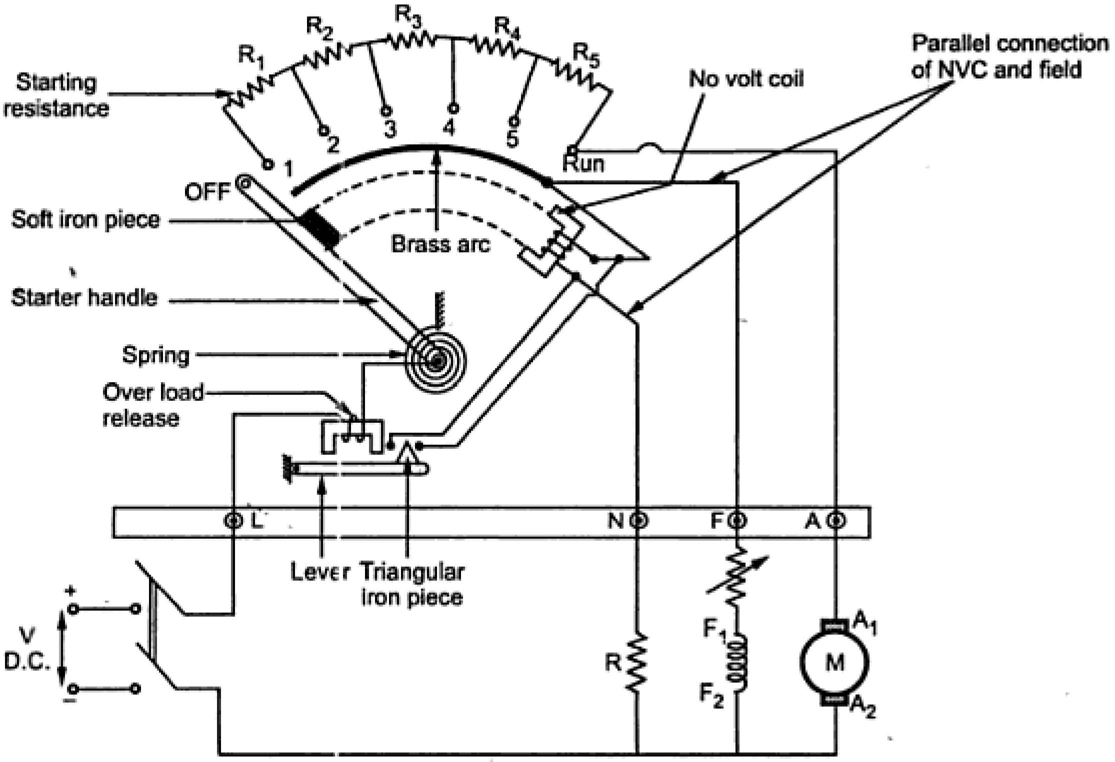


Fig. 3.30 Four Point Starter

Disadvantage

The only limitation of the four point starter is, it does not provide high speed protection to the motor. If under running condition, field gets opened, the field reduces to zero. But there is some residual flux present and $N \alpha \frac{1}{\Phi}$ the motor tries to run with dangerously high speed. This is called high speeding action of the motor. In three point starter as NVC is in series with the field, under such field failure, NVC releases handle to the OFF position. But in four point starter NVC is connected directly across the supply and its current is maintained irrespective of the current through the field winding.

Hence it always maintains handle in the RUN position, as long as supply is there. And thus it does not protect the motor from field failure conditions which result into the high speeding of the motor.

15. Explain with a neat sketch, the 2 point starter in a DC motor.

D.C. SERIES MOTOR STARTER

Three point and four point starters are used for d.c. shunt motors. In case of series motors, field and armature are in series and hence starting resistance is inserted in series with the field and armature. Such a starter used to limit the starting current in case of d.c. series motors is called two point starter. The basic construction of two point starter is similar to that of three point starter except the fact that it has only two terminals namely Line (L) and Field (F). The F terminal is one end of the series combination of field and the armature Winding. The starter is shown in the Fig. 3.31.

The action of the starter is similar to that of three point starter. The handle of the starter is in OFF position. When it is moved to ON, motor gets the supply and the entire starting resistance is in series with the armature and field. It limits the starting current. The current through no volt coil energises it and when handle reaches to RUN position the no volt coil holds the handle by attracting the soft iron piece on the handle. Hence the no volt coil is also called hold on coil.

The main problem in case of d.c. series motor is its overspeeding action when the load is less. This can be prevented using two point starter. The no volt coil is designed in such a way that it hold the handle in"RUN position only when it carries sufficient current, for which motor can run safely. If there is loss of load then current drawn by the motor decreases, due to which no volt coil looses its required magnetism and releases the handle. Under spring force, handle comes back to OFF position, protecting the motor from overspeeding. Similarly if there is any supply problem such that voltage decreases suddenly then also no volt coil releases the handle and protects the motor from adverse supply conditions.

The overload condition can be prevented using overload release. When motor draws excessively high current due to overload, then current through overload magnet increases. This energises the magnet upto such an extent that it attracts the lever below it. When lever is lifted upwards, the triangular piece attached to it touches the two points, which are the two ends of no volt coil. Thus no volt coil gets shorted, loosing its magnetism and releasing the handle back to OFF position. This protects the motor from overloading conditions.

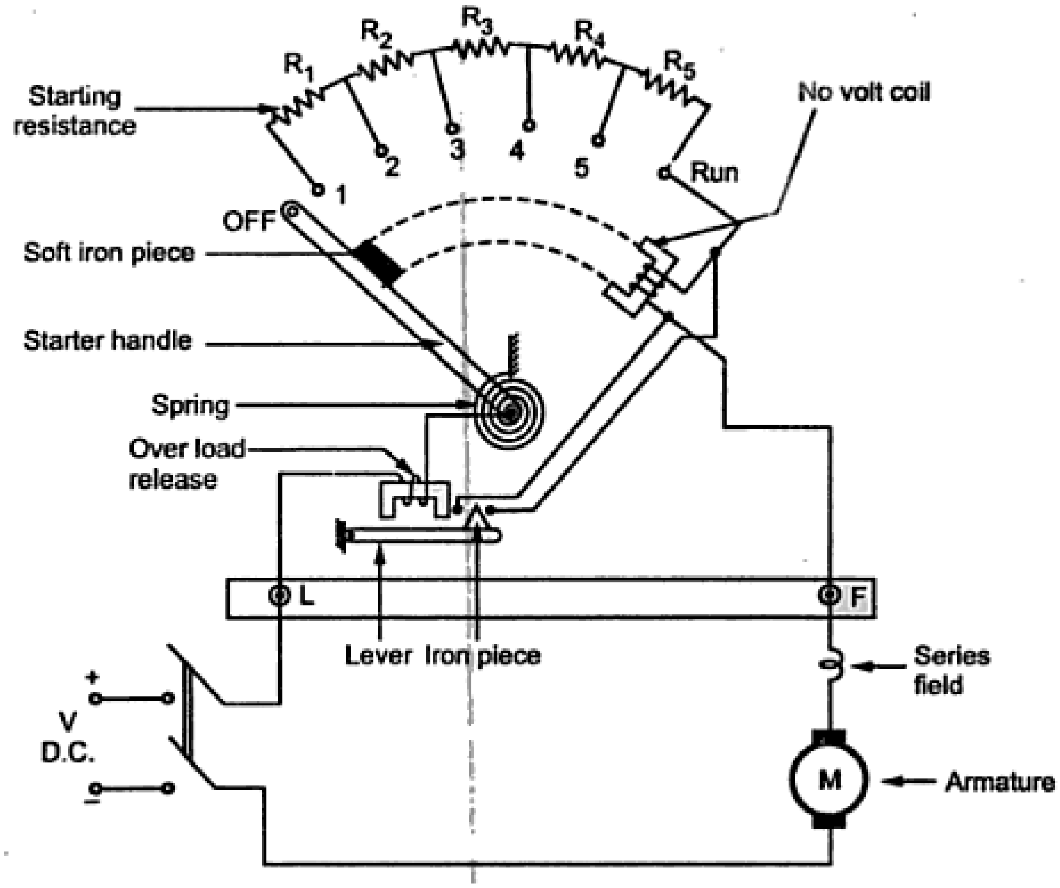


Fig. 3.31. Series motor starter

Key Point : The starter has two points L connected to line i.e. supply and F connected to series field of the motor. Hence it is called two point starter.

Problem: A 15 kW, 250 V, 1200 rpm, shunt motor has 4 poles, 4 parallel armature paths and 900 armature conductors. Assume Ra = 0.2 Ω. At rated speed and rated output the armature current is 75 A and I_f = 1.5 A. Calculate

(1) The flux/pole (2) The torque developed (3) Rotational losses (4) Efficiency (5) The shaft load (useful torque) (6) If the shaft load remains fixed, but the field flux is reduced to 70% of its value by field control, determine the new operating speed.

Given data:

Output power P_{out} = 15 kW, Supply voltage V= 250 V

Speed N_1 = 1200 rpm, Number of conductors Z = 900

Number of poles P = 4, Number of parallel paths A = 4

Armature resistance Ra = 0.2 Ω, Armature current la = 75 A

Field current I_f = 1.5 A, Flux Φ_2= 0.7 Wb

To Find:

1) Flux/Pole (Φ2) Torque developed (T) 3) Rotational loss

4) Efficiency 5) Shaft load (useful torque) 6) Speed N_2

Solution:

1) Flux/Pole (Φ

Back emf E_b= V-Ia Ra

$= 250- 75\times0.2 = \underline{235V}$

$$E_b = \frac{P\Phi ZN}{60A}$$

$$\Phi = \frac{E_b 60A}{PzN} = \frac{235\times60\times4}{4\times900\times1200} = 13.05\text{mWb}$$

$\underline{\Phi = 13.05\text{mWb}}$

2) Torque developed

$$T = 9.55\times\frac{E_b Ia}{N} = 9.55\times\frac{235\times75}{1200} = 140.26 \text{ N-m}$$

$\underline{T_a = 140.26 \text{ N-m}}$

3) Rotational loss

Power developed in armature = E_b Ia

= 235 × 75= 17625 W

Rotational losses = E_b Ia - P_{out}

= 17625 - 15000= 2625 W

Rotational losses = $\underline{2625 \text{ W}}$

4) Efficiency

Input power $P_{in} = V\, I_L = V\,(Ia + I_f)$

= 250 (75 + 1.5)= 19125 W

$$\eta = \frac{P_{out}}{P_{in}}\times 100 = \frac{15000}{19125}\times 100 = 78.43\%$$

$\underline{\%\ \eta = 78.43\%}$

5) Shaft load (Tsh) or Useful torque

$$T_{sh} = 9.55\,\frac{P_{out}}{N} = 9.55 \times \frac{15000}{1200} = 119.37 \text{ N-m}$$

$\underline{T_{sh} = 119.37 \text{ N-m}}$

6) Speed (N_2)

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\Phi_1}{\Phi_2}$$

Now T_a α Ia. Hence T_{a1}α $\Phi_1 I_{a1}$, T_{a2}α $\Phi_2 I_{a2}$

Since $T_{a1} = T_{a2}$

$$\Phi_1 I_{a1} = \Phi_2 I_{a2}$$

$$\Phi_1\, 75 = 0.7\Phi_1 I_{a2}$$

$$I_{a2} = 107.14 \text{ A}$$

$$E_{b2} = V - I_{a2}\, Ra = 250 - 107.4 \times 0.2 = 228.57 \text{ V}$$

$$\frac{N_2}{1200} = \frac{228.57}{235} \times \frac{\Phi_1}{0.7\Phi_1}$$

$\underline{N_2 = 1667.3 \text{ rpm}}$

Problem

A 200V D.C shunt motor running at 1000 rpm takes an armature current of 18A. It is required to reduce the speed to 600 rpm. What must be the value of resistance to be inserted in the armature circuit if the original armature resistance is 0.3Ω. Take I_a as constant.

A 400V DC shunt motor takes 5A at no load, its armature resistance is 0.5Ω and shunt field resistance is 200Ω. Estimate the efficiency when the motor takes 50A on full load.

16. Explain the various losses of DC motor and also explain the efficiency calculation.

LOSSES IN A D.C. MOTOR

The losses occurring in a d.c. motor are the same as in a d.c.

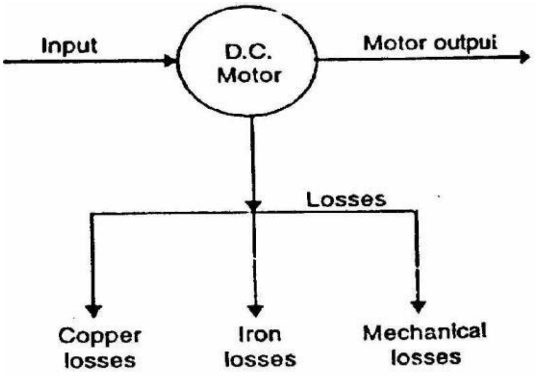


Fig. 3.32

These are

(i) copper losses

(ii) Iron losses or magnetic losses

(ii) mechanical losses

As in a generator, these losses cause (a) an increase of machine temperature and

(b) reduction in the efficiency of the d.c. motor.

The following points may be noted:

(i) Apart from armature Cu loss, field Cu loss and brush contact loss, Cu losses also occur in interpoles (commutating poles) and compensating windings. Since these windings carry armature current (Ia),

Loss in interpole winding = I_a^2 ´ Resistance of interpole winding

Loss in compensating winding = I_a^2´ Resistance of compensating winding

(ii) Since d.c. machines (generators or motors) are generally operated at constant flux density and constant speed, the iron losses are nearly constant.

(iii) The mechanical losses (i.e. friction and windage) vary as the cube of the

speed of rotation of the d.c. machine (generator or motor). Since d.c. machines are generally operated at constant speed, mechanical losses are considered to be constant.

POWER STAGES

The power stages in a d.c. motor are represented diagrammatically in Fig. 3.32

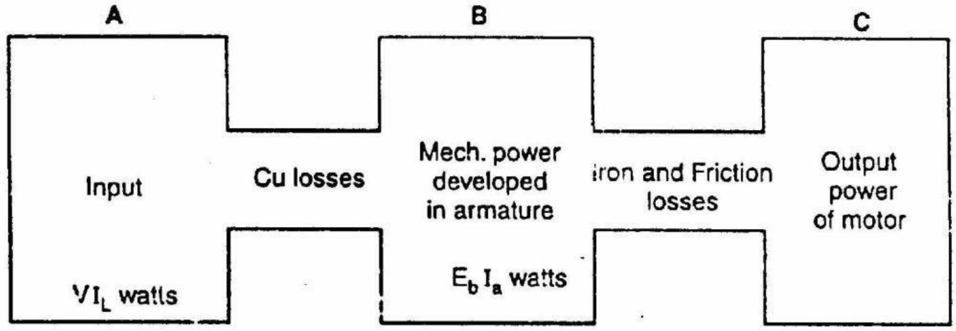


Fig. 3.32

A - B = Copper losses

B - C = Iron and friction losses

EFFICIENCY OF A D.C. MOTOR

Overall efficiency, hc = C/A= $\frac{\text{Mechanical power output}}{\text{Electrical power input}}$

$$= \frac{\text{Input power} - \text{Total Losses}}{\text{Input power}}$$

Electrical efficiency, he = B/A= $\frac{\text{Mech.power developed in armature}}{\text{Electrical power input}}$

Mechanical efficiency, hm = C/B= $\frac{\text{Mechanical power output}}{\text{Mech.power developed in armature}}$

17. Describe various methods of speed control of DC motor.

SPEED CONTROL OF D.C. MOTORS

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.

The speed of a d.c. motor is given by:

N □□ $\frac{E_b}{\Phi}$ □□□□□□□i□

Or N= K $\frac{(V - I_a R)}{\Phi}$ r.p.m.

Where, R = Ra for shunt motor

= Ra + Rse. for series motor

From exp. (i), it is clear that there are three main methods of controlling the speed of a d.c. motor, namely:

(i) By varying the flux per pole (Φ). This is known as flux control method.

(ii) By varying the resistance in the armature circuit. This is known as armature control method.

(iii)By varying the applied voltage V. This is known as voltage control method.

SPEED CONTROL OF D.C. SHUNT MOTORS

The speed of a shunt motor can be changed by

(i) flux control method

(ii) armature control method

(iii) voltage control method.

The first method (i.e.flux control method) is frequently used because it is simple and inexpensive.

1 Flux control method

It is based on the fact that by varying the flux f, the motor speed (N□□ 1/Φ) can be changed and hence the name flux control method. In this method, a variable resistance (known as shunt field rheostat) is placed in series with shunt field winding as shown in Fig. (3.33).

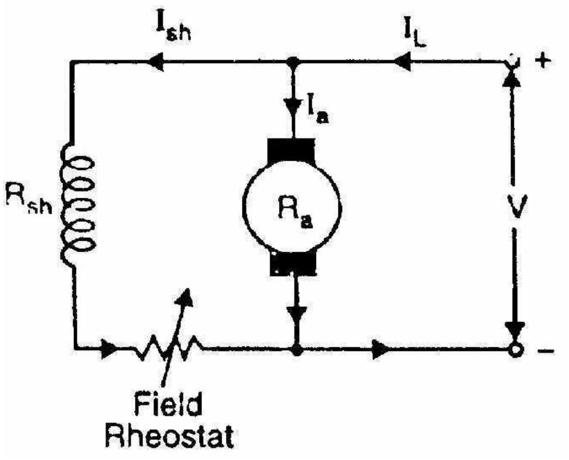


Fig. 3.33

The shunt field rheostat reduces the shunt field current I_{sh} and hence the flux Φ.

Therefore, we can only raise the speed of the motor above the normal speed (See Fig.3.34).

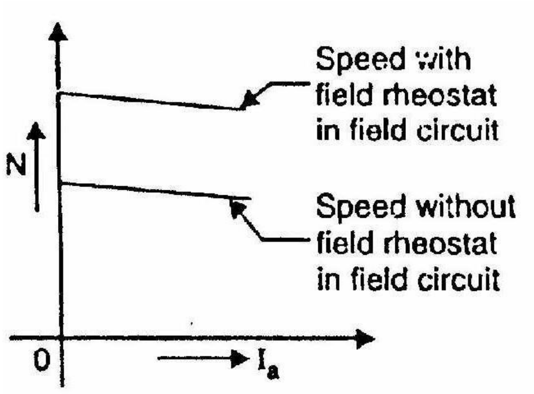


Fig. 3.34

Advantages

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of Ish.

(iii) The speed control exercised by this method is independent of load on the machine.

Disadvantages

(i) Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below Rsh—the shunt field winding resistance.

(ii) There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

Note. The field of a shunt motor in operation should never be opened because its speed will increase to an extremely high value.

2 Armature control method

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 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 RC (known as controller resistance) in series with the armature as shown in Fig. (3.35).

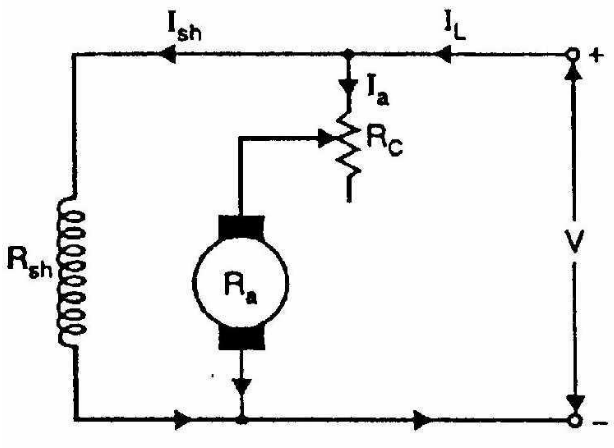


Fig. 3.35

N □ V - Ia (Ra + RC)

where RC = controller resistance

Due to voltage drop in the controller resistance, the back e.m.f. (Eb) is decreased. Since N µ Eb, the speed of the motor is reduced. The highest speed obtainable is that corresponding to RC

= 0 i.e., normal speed. Hence, this method can only provide speeds below the normal speed (See Fig.3.36).

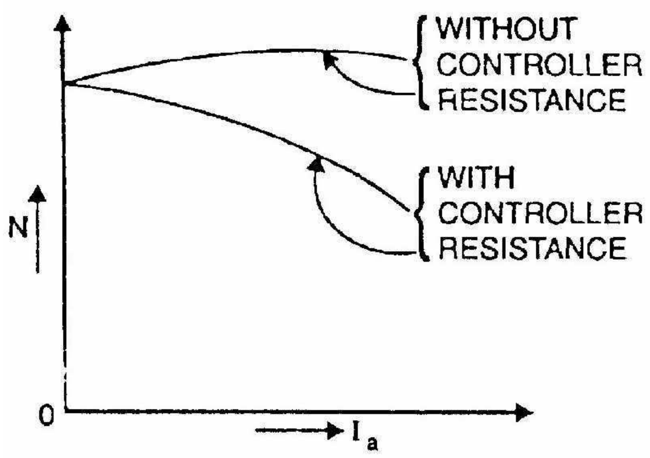


Fig. 3.35

Disadvantages

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

(ii) The speed varies widely with load since the speed depends upon the voltage drop in the controller resistance and hence on the armature current demanded by the load.

(iii) The output and efficiency of the motor are reduced.

(iv) This method results in poor speed regulation.

Due to above disadvantages, this method is seldom used to control the speed of shunt motors.

Note. The armature control method is a very common method for the speed control of d.c. series motors. The disadvantage of poor speed regulation is not important in a series motor which is used only where varying speed service is required.

3 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.

i) Multiple voltage control.

In this method, the shunt field of the motor is connected permanently across a-fixed voltage source. The armature can be connected across several different voltages through a suitable switchgear. In this way, voltage applied across the armature can be changed. The speed will be approximately proportional to the voltage applied across the armature. Intermediate speeds can be obtained by means of a shunt field regulator.

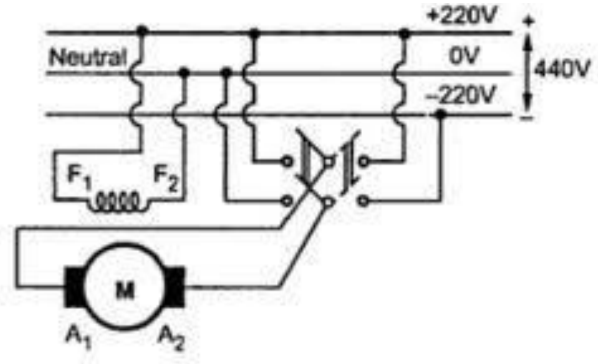
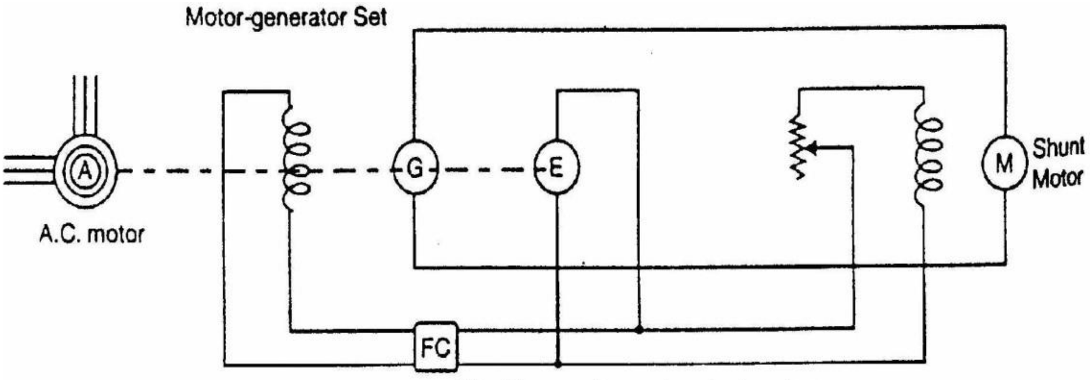


Fig. 3.36

ii) Ward-Leonard system.

In this method, the adjustable voltage for the armature is obtained from an adjustable-voltage generator while the field circuit is supplied from a separate source. This is illustrated in Fig. (3.37). The armature of the shunt motor M (whose speed is to be controlled) is connected directly to a d.c. generator G driven by a constant-speed a.c. motor A. The field of the shunt motor is supplied from a constant-voltage exciter E. The field of the generator G is also supplied from the exciter E. The voltage of the generator G can be varied by means of its field regulator. By reversing the field current of generator G by controller FC, the voltage applied to the motor may be reversed and hence the direction of rotation of the motor can be changed. Sometimes, a field regulator is included in the field circuit of shunt motor M for additional speed adjustment. With this method, the motor may be operated at any speed upto its maximum speed.



Ward-Leonard speed-control system.

Fig. 3.37

Advantages

(a) The speed of the motor can be adjusted through a wide range without resistance losses which results in high efficiency.

(b) The motor can be brought to a standstill quickly, simply by rapidly reducing the voltage of generator G. When the generator voltage is reduced below the back e.m.f. of the motor, this back e.m.f. sends current through the generator armature, establishing dynamic braking. While this takes place, the generator G operates as a motor driving motor A which returns power to the line.

(c) This method is used for the speed control of large motors when a d.c. supply is not available.

Disadvantage

A special motor-generator set is required for each motor and the losses in this set are high if the motor is operating under light loads for long periods.

SPEED CONTROL OF D.C. SERIES MOTORS

The speed control of d.c. series motors can be obtained by (i) flux control method (ii) armature-resistance control method (iii) Applied voltage control. The second method is mostly used.

1 Flux control method

In this method, the flux produced by the series motor is varied and hence the speed. The variation of flux can be achieved in the following ways:

(i) **Field divertcrs**. In this method, a variable resistance (called field diverter) is connected in parallel with series field winding as shown in Fig.(3.38). Its effect is to shunt some portion of the line current from the series field winding, thus weakening the field and increasing the speed (□□N □□1/□). The lowest speed obtainable is that corresponding to zero current in the diverter (i.e., diverter is open). Obviously, the lowest speed obtainable is the normal speed of the motor. Consequently, this method can only provide speeds above the normal speed. The series field diverter method is often employed in traction work.

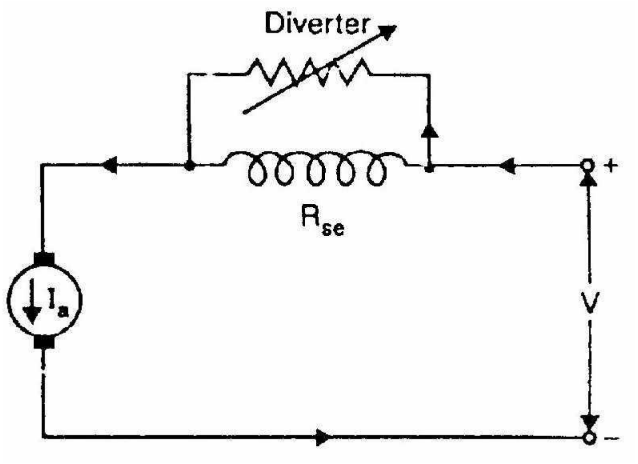


Fig. 3.38

(ii) **Armature diverter**.

In order to obtain speeds below the normal speed, a variable resistance (called armature diverter) is connected in parallel with the armature as shown in Fig. (3.39). The diverter shunts some of the line current, thus reducing the armature current. Now for a given load, if I_a is decreased, the flux □□must increase (□□T □□□Ia). Since N □□1/□, the motor speed is decreased. By adjusting the armature diverter, any speed lower than the normal speed can be obtained.

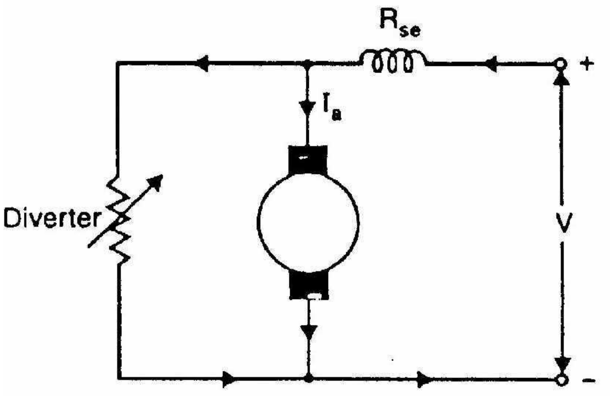


Fig. 3.38

(iii) **Tapped field control**.

In this method, the flux is reduced (and hence speed is increased) by decreasing the number of turns of the series field winding as shown in Fig. (3.39). The switch S can short circuit any part of the field winding, thus decreasing the flux and raising the speed. With full turns of the field winding, the motor runs at normal speed and as the field turns are cut out, speeds higher than normal speed are achieved.

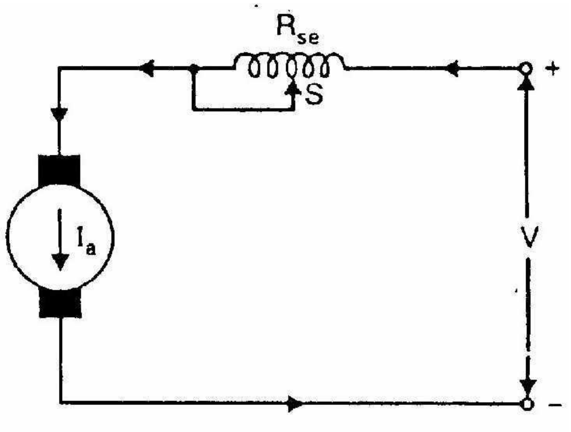


Fig. 3.39

(iv) **Paralleling field coils**.

This method is usually employed in the case of fan motors. By regrouping the field coils as shown in Fig. (3.40), several fixed speeds can be obtained.

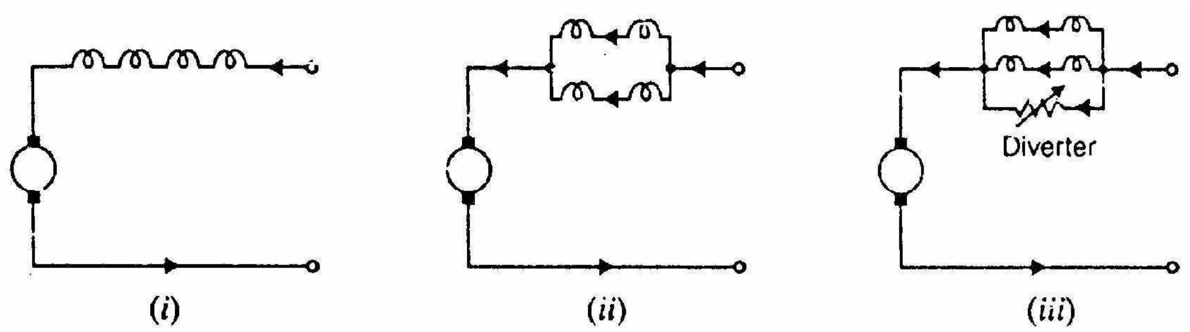


Fig. 3.40

2. Armature-resistance control

In this method, a variable resistance is directly connected in series with the supply to the complete motor as shown in Fig. (5.10). This reduces the voltage available across the armature and hence the speed falls. By changing the value of variable resistance, any speed below the normal speed can be obtained. This is the most common method employed to control the speed of d.c. series motors. Although this method has poor speed regulation, this has no significance for series motors because they are used in varying speed applications.

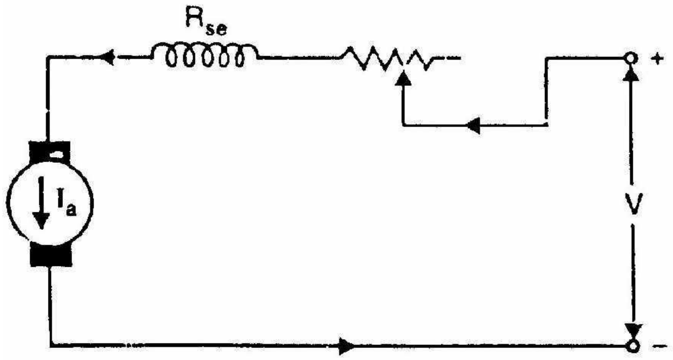


Fig. 3.40

3 Applied voltage control

In this method, a series motor is excited by the voltage obtained by a series generator as shown in the Fig.3.41.

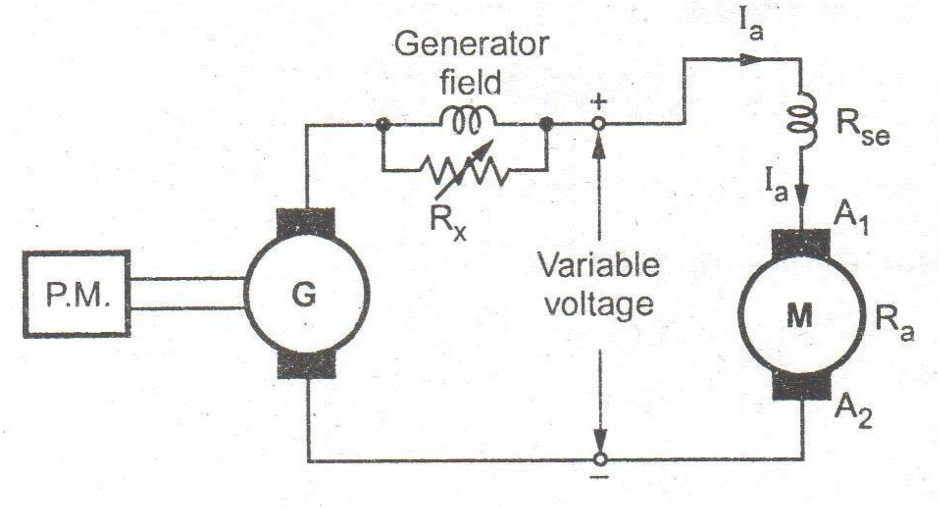


Fig. 3.41

The generator is driven by a suitable prime mover. The voltage obtained from the , generator is controlled by a field divertor resistance connected across series field winding of the generator.

As Eg α Φ, the flux change is achieved, gives the variable voltage at the output terminals. Due to the change in the supply voltage, the various speeds of the d.c. series motor can be obtained.

Note : All he advantages and disadvantages of various methods, discussed as applied to shunt-motor are equally applicable to speed control of series motor.

18. Write short notes on Testing methods of DC motor

TESTING OF D.C. MACHINES

There are several tests that are conducted upon a d.c. machine (generator or motor) to judge its performance. One important test is performed to measure the efficiency of a d.c. machine. The efficiency of a d.c. machine depends upon its losses. The smaller the losses, the greater is the efficiency of the machine and vice-versa. The consideration of losses in a d.c. machine is important for two principal reasons. First, losses determine the efficiency of the machine and appreciably influence its operating cost. Secondly, losses determine the heating of the machine and hence the power output that may be obtained without undue deterioration of the insulation.

There are different methods of testing d.c motors. These are broadly classified as :

i) Direct method of testing
ii) Indirect method of testing

1 DIRECT METHOD OF TESTING (BRAKE TEST)

In this method the d.c. motor which is to be tested is actually loaded and input and output are measured. The efficiency is given by

$$\text{Efficiency, } \eta = \frac{\text{Output}}{\text{Input}}$$

Generally this method is employed to small motors. The motor is loaded by means of a brake applied to the water cooled pulleys.

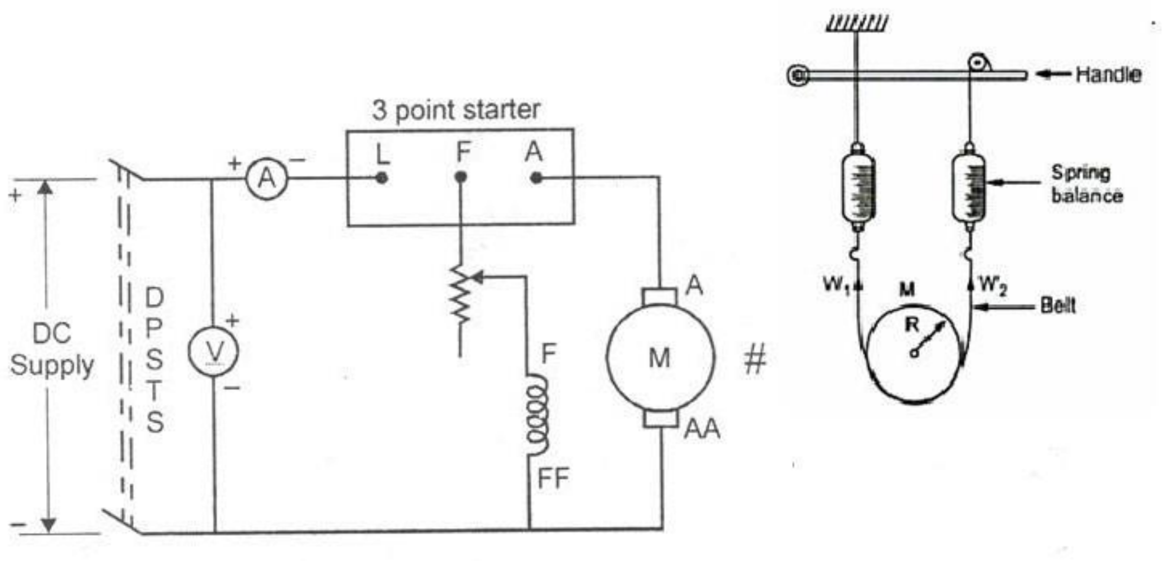


Fig. 3.42

The water cooled pulley is coupled to the motor shaft.One end of the belt is fixed through spring balance and the other is connected to a handle to adjust the tension on the belt.

By adjusting the tension of belt, the load is adjusted to give the various values of currents. The load is finally adjusted to get full load current. The power developed gets wasted against the friction between belt and shaft. Due to the braking action of belt the test is called brake test.

The tension in the belt can be adjusted using the handle. The tension in kg can be obtained from the spring balance readings.

Let R = Radius of pulley in metre
N = Speed in r.p.m.
W_1 = Spring balance reading on tight side in kg
W_2 = Spring balance reading on slack side in kg

So net pull on the belt due to friction at the pulley is the difference between the two spring balance readings.

$$\boxed{\text{Net pull} = W_1 - W_2 \text{ kg} = 9.81\,(W_1 - W_2)\text{ N}}$$

As radius R and speed N are known, the shaft torque developed can be obtained as,

$$\boxed{T_{sh} = \text{net pull} \times R = 9.81\,(W_1 - W_2)\,R \quad \text{N-m}}$$

Hence the output power can be obtained as,

$$\boxed{P_{out} = T_{sh} \times \omega = 9.81\,(W_1 - W_2)\,R \times \frac{2\pi N}{60}\text{ W}}$$

Now let, V = Voltage applied in volts
I = Total line current drawn in amps.

then $$\boxed{P_{in} = VI \quad \text{W}}$$

Thus if the readings are taken on full load condition then the efficiency can be obtained as,

$$\boxed{\%\,\eta = \frac{P_{out}}{P_{in}} \times 100}$$

Adjusting the load step by step till full load, number of readings can be obtained. The speed can be measured by tachometer. Thus all the motor characteristics can be plotted.

Advantages

The advantages of brake test,

1. Actual efficiency of the motor under working conditions can be found out.
2. The method is simple and easy to perform.
3. Can be performed on any type of d.c. motor.

Disadvantages

The disadvantages of brake test,

1. Due to friction, heat is generated and hence there is large dissipation of energy.
2. Some type of cooling arrangement is necessary.
3. Convenient only for small machines due to limitations regarding heat dissipation arrangements.
4. The power developed gets wasted hence method is expensive.

2 SWINBURNE’S TEST (OR) NO LOAD TEST

In this method, the d.c. machine (generator or motor) is run as a motor at noload and losses of the machine are determined. Once the losses of the machine are known, its efficiency at any desired load can be determined in advance. It may be noted that this method is applicable to those machines in which flux is practically constant at all loads e.g., shunt and compound machines. Since this test is performed on no-load condition, d.c series motor‘s efficiency cannot be determined. As its speed is dangerously high at no load. Let us see how the efficiency of a d.c. shunt machine (generator or motor) is determined by this method. The test insists of two steps:

(i) Determination of hot resistances of windings

The armature resistance Ra and shunt field resistance Rsh are measured using a battery, voltmeter and ammeter. Since these resistances are measured when the machine is cold, they must be converted to values corresponding to the temperature at which the machine would work on full-load.

(ii) Determination of constant losses

The machine is run as a motor on no-load with supply voltage adjusted to the rated voltage i.e. voltage stamped on the nameplate. The speed of the motor is adjusted to the rated speed with the help of field regulator R.

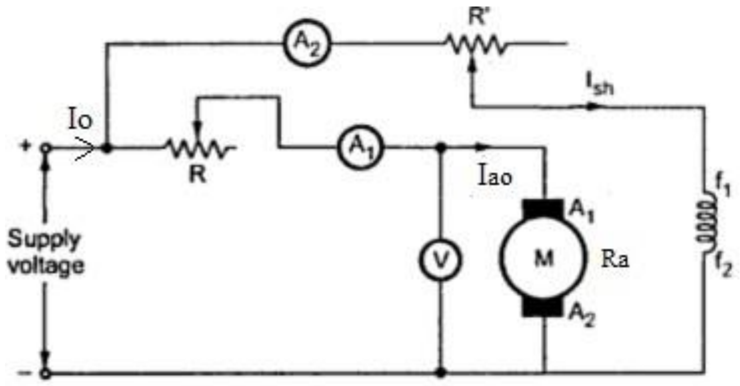


Fig. 3.43

Let; V = Supply voltage

I_0 = No-load current read by ammeter A1

Ish = Shunt-field current read by ammeter A2

No-load armature current, $Ia_0 = I_0 - Ish$

No-load input power to motor = $V I_0$

No-load power input to armature = $V Ia_0 = V(I_0 - Ish)$

Since the output of the motor is zero, the no-load input power to the armature supplies (a) iron losses in the core (b) friction loss (c) windage loss (d) armature Cu loss □□□I_{ao}^2□R_a□□□or

$(I_o - I_{sh})^2$□□

Constant losses, WC = Input to motor - Armature Cu loss

or

$W_c = V I_o - (I_o - Ish)^2 R$

Since constant losses are known, the efficiency of the machine at any other load can be determined. Suppose it is desired to determine the efficiency of the machine at load current I. Then,

Armature current, $Ia = I - Ish$ ... if the machine is motoring

$= I + Ish$ ... if the machine is generating

Efficiency when running as a motor

Input power to motor = VI

Armature Cu loss = $(Ia^2 R_a) = (I - I_{sh})^2 R_a$

Constant losses = W_c found above

Total losses $=(\mathrm{I} - \mathrm{I}_{sh})^2 R_a) + W_c$

Motor efficiency, $\eta_m = \frac{\mathrm{Input} - \mathrm{Losses}}{\mathrm{Input}} = \frac{\mathrm{VI} - (\mathrm{I} - \mathrm{I}_{sh})^2 \mathrm{R}_a - \mathrm{W}_c}{\mathrm{VI}}$

Efficiency when running as a generator

Output of generator = VI

Armature Cu loss =(

$(I + I_{sh})^2 R_a$

Constant losses = WC found above

Total losses $=(\mathrm{I} + \mathrm{I}_{sh})^2 R_a) + W_c$

□□Generator efficiency, $\eta_g = \frac{\mathrm{Output}}{\mathrm{Output} + \mathrm{Losses}} = \frac{\mathrm{VI}}{\mathrm{VI} + (\mathrm{I} + \mathrm{I}_{sh})^2 \mathrm{R}_a + \mathrm{W}_c}$

Advantages of Swinburne’s test

(i) The power required to carry out the test is small because it is a no-load test. Therefore, this method is quite economical.

(ii) The efficiency can be determined at any load because constant losses are known.

(iii) This test is very convenient.

Disadvantages of Swinburne's test

(i) It does not take into account the stray load losses that occur when the machine is loaded.

(ii) This test does not enable us to check the performance of the machine on full-load. For example, it does not indicate whether commutation on fullload is satisfactory and whether the temperature rise is within the specified limits.

(iii) This test does not give quite accurate efficiency of the machine. It is because iron losses under actual load are greater than those measured. This is mainly due to armature reaction distorting the field.

19. What is meant by braking of DC motors? Describe briefly the dynamic braking of DC shunt motor.

Electric Braking

Sometimes it is desirable to stop a d.c. motor quickly. This may be necessary in case of emergency or to save time if the motor is being used for frequently repeated operations. The motor and its load may be brought to rest by using either (i) mechanical (friction) braking or (ii) electric braking. In mechanical braking, the motor is stopped due to the friction between the moving parts of the motor and the brake shoe i.e. kinetic energy of the motor is dissipated as heat. Mechanical braking has several disadvantages including non-smooth stop and greater stopping time.

In electric braking, the kinetic energy of the moving parts (i.e., motor) is converted into electrical energy which is dissipated in a resistance as heat or alternativley, it is returned to the supply source (Regenerative braking). For d.c. shunt as well as series motors, the following three methods of electric braking are used:

(i) Rheostatic or Dynamic braking

(ii) Plugging

(iii) Regenerative braking

It may be noted that electric braking cannot hold the motor stationary and mechanical braking is necessary. However, the main advantage of using electric braking is that it reduces the wear and tear of mechanical brakes and cuts down the stopping time considerably due to high braking retardation.

(i) Plugging

In this method, connections to the armature are reversed so that motor tends to rotate in the opposite direction. Thus providing the necessary braking effect, when the motor comes to rest, the supply must be cut off otherwise the motor will start rotating in the opposite direction. The supply must be cut off close to zero speed using a current or speed directional relay and applying back-up mechanical or hydraulic brakes to bring the motor to a halt.

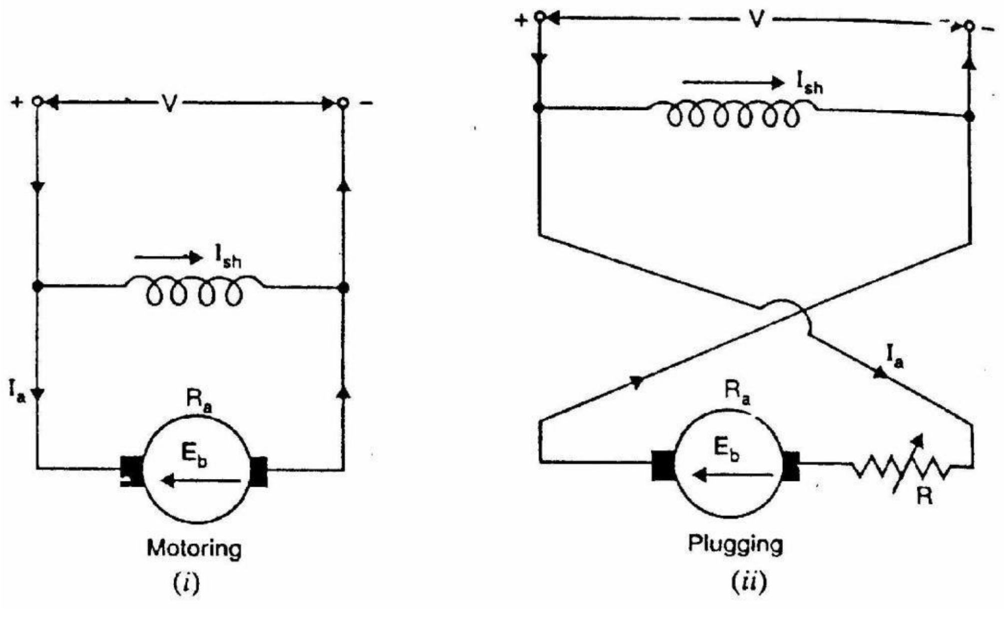


Fig. 3.44

Fig. (3.44) (ii) shows plugging of a d.c. shunt motor. Note that armature connections are reversed while the connections of the field winding are kept the same. As a result the current in the armature reverses. During the normal running of the motor [See Fig. 3.44 (i)], the back e.m.f. E_b opposes the applied voltage V. However, when armature connections are reversed, back e.m.f. E_b and V act in the same direction around the circuit. Therefore, a voltage equal to V + E_b is impressed across the armature circuit. Since $E_b \sim V$, the impressed voltage is approximately 2V. In order to limit the current to safe value, a variable resistance R is inserted in the circuit at the time of changing armature connections.

We now investigate how braking torque depends upon the speed of the motor.Referring to Fig. (3.44) (ii),

Armature current, $I_a = \frac{V+E_b}{R+R_a} = \frac{V}{R+R_a} + \frac{K_1 N \Phi}{R+R_a}$ $(\because E_b \alpha N\Phi)$

Braking torque, $T_B = K_2 I_a \Phi = K_2\Phi\left(\frac{V}{R+R_a} + \frac{K_1 N \Phi}{R+R_a}\right) = K_3\Phi + K_4 N\Phi^2$

For a shunt motor, □□is constant.

$\therefore$ Braking torque, $T_B = K_5 + K_6 N$

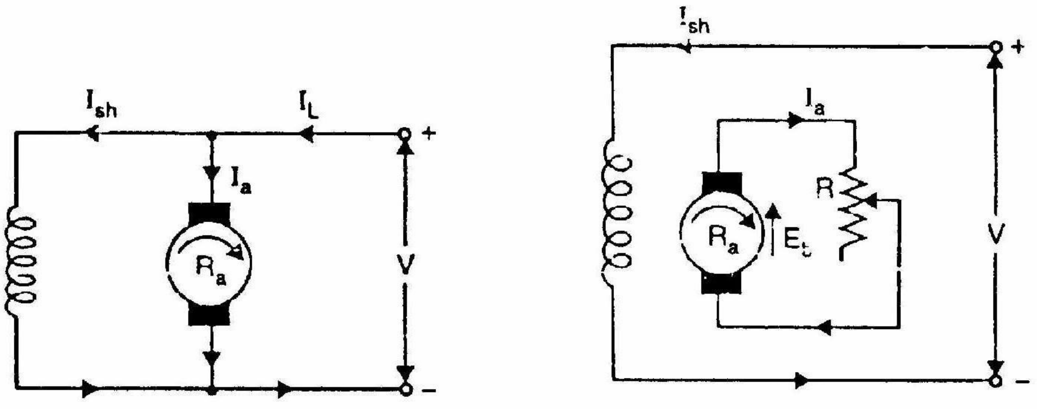
Thus braking torque decreases as the motor slows down. Note that there is some braking torque (T_B = k5) even when the motor speed is zero.

The large initial current and the resultant high mechanical stress restrict the application of plugging to small motors only.

(ii) Rheostatic or Dynamic braking

In this method, the armature of the running motor is disconnected from the supply and is connected across a variable resistance R. However, the field winding is left connected to the supply. The armature, while slowing down, rotates in a strong magnetic field and, therefore, operates as a generator, sending a large current through resistance R. This causes the energy possessed by the rotating armature to be dissipated quickly as heat in the resistance. As a result, the motor is brought to standstill quickly.

Fig. (5.13) (i) shows dynamic braking of a shunt motor. The braking torque can be controlled by varying the resistance R. If the value of R is decreased as the motor speed decreases, the braking torque may be maintained at a high value. At a low value of speed, the braking torque becomes small and the final stopping of the motor is due to friction. This type of braking is used extensively in connection with the control of elevators and hoists and in other applications in which motors must be started, stopped and reversed frequently.



Motoring
(*i*)

Dynamic Braking
(*ii*)

Fig. 3.45

The braking time is a function of the system inertia, load torque and motor rating.

We now investigate how braking torque depends upon the speed of the motor. Referring to Fig. (3.45) (ii),

Armature current, $I_a = \frac{E_b}{R+R_a} = \frac{K_1 N\Phi}{R+R_a}$ $(\because E_b \,\alpha\, N\Phi)$

Braking torque, $T_B = K_2 I_a \Phi = K_2 \Phi (\frac{K_1 N\Phi}{R+R_a}) = K_3 N\Phi^2$

where K_2 and K_3 are constants

For a shunt motor, Φ is constant.

$\therefore$ Braking torque, $T_B \,\alpha\, N$

Therefore, braking torque decreases as the motor speed decreases.

(iii) Regenerative braking

In the regenerative braking, the motor is run as a generator. As a result, the kinetic energy of the motor is converted into electrical energy and returned to the supply. Fig. (3.46) shows two methods of regenerative braking for a shunt motor.

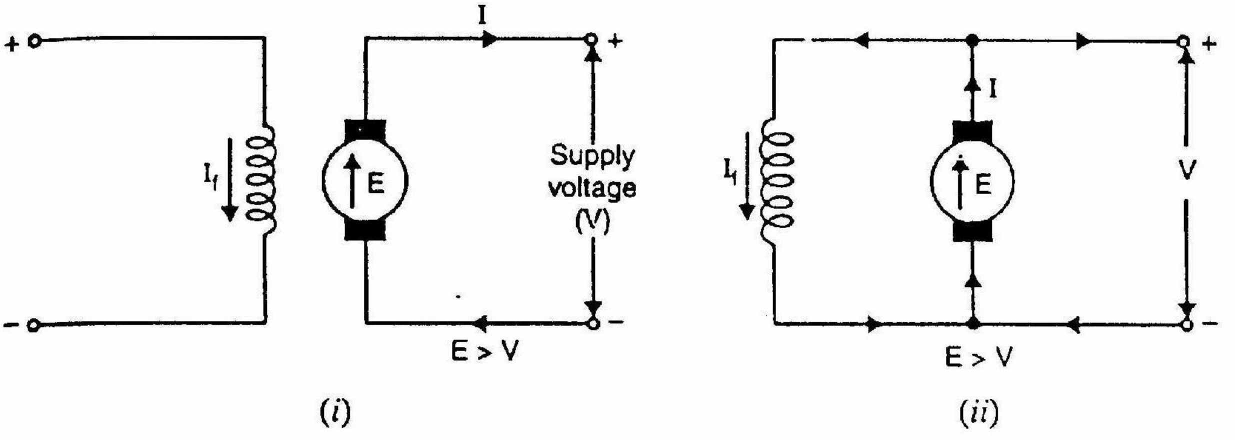


Fig. 3.46

a) In one method, field winding is disconnected from the supply and field current is increased by exciting it from another source [See Fig. 3.46 (i)]. As a result, induced e.m.f. E exceeds the supply voltage V and the machine feeds energy into the supply. Thus braking torque is provided upto the speed at which induced e.m.f. and supply voltage are equal. As the machine slows down, it is not possible to maintain induced e.m.f. at a higher value than the supply voltage. Therefore, this method is possible only for a limited range of speed.

b) In a second method, the field excitation does not change but the load causes the motor to run above the normal speed (e.g., descending load on a crane). As a result, the induced e.m.f. E becomes greater than the supply voltage V [See Fig. 3.46 (ii)]. The direction of armature current I, therefore, reverses but the direction of shunt field current If remains unaltered. Hence the torque is reversed and the speed falls until E becomes less than V.

20. Explain the dynamics of DC machines

DC MACHINE DYNAMICS

The DC machines are quite versatile and are capable of giving a variety of V-A and speed-torque characteristics by suitable combinations of various field windings. With solid-state controls their speeds and outputs can be controlled easily over a wide range for both dynamic and steady-state operation. By addition of the feedback circuit, the machine characteristics can be further modified, The aim of this section is to study dc machines with reference to their dynamic characteristics.

For illustration, let us consider the separately excited dc machine shown schematically in Fig. 3.47

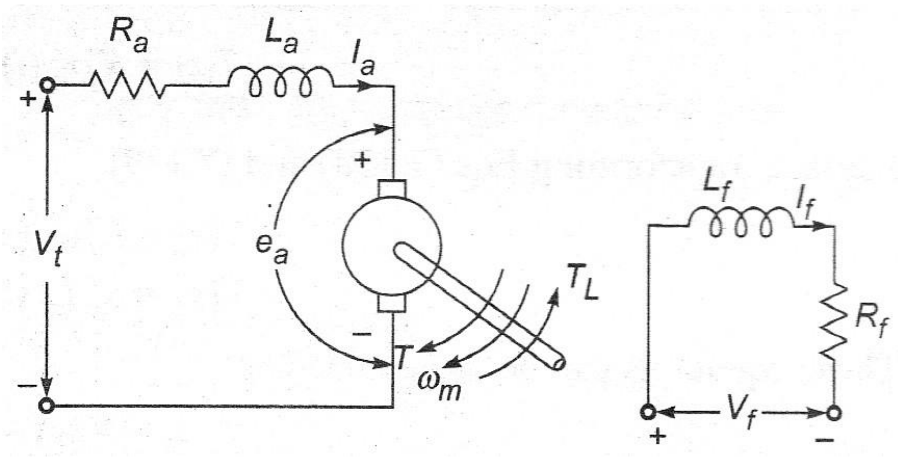


Fig. 3.47

The two inductance parameters appearing in Fig. 3.47 are

L_a= armature self-inductance ;

L_f = self inductance of field winding;

For dynamic analysis it is convenient to use speed in rad/s than rpm.

Applying kirchhoff‟s law to armature circuit,

V (t)= $e_a(t)$ + $R_a i_a(t)$ + $L_a \frac{d}{dt}$ $i_a(t)$ …..(1)

Where $e_a(t)$= $K_e i_f(t)\omega_m(t)$; K_e = constant (Φ(t)α $i_f(t)$) …..(2)

Similarly for the field circuit,

$V_f(t)$=$R_f i_f(t)$+ $L_f \frac{d}{dt}$ $i_f(t)$ …..(3)

For motoring operation, the dynamic equation for the mechanical system is

T(t)=$K_t i_f(t)\, i_a(t)$ = $J \frac{d}{dt}$ $\omega_m(t)$+D$\omega_m(t)$+$T_L(t)$ …..(4)

Where J = moment of inertia of motor and load in Nms^2

D = viscous damping coefficient representing rotational torque loss, Nm rad/s

Energy storage is associated with the magnetic fields produced by I_f and I_a and with the kinetic energy of the rotating parts.

Transfer functions and block diagrams

In the simple linear case of motor response to changes in armature voltage, it is assumed that the field voltage is constant and steady-state is existing on the field, i.e. $I_f =$ constant. Equations (1),(2) and (3) now becomes linear as given below

$$V(t) = K'_e\,\omega_m(t) + R_a i_a(t) + L_a \frac{d}{dt} i_a(t) \qquad \text{.....(5)}$$

$$T(t) = K'_t\, i_a(t) = J\frac{d}{dt}\,\omega_m(t) + D\omega_m(t) + T_L(t) \qquad \text{.....(6)}$$

Laplace transforming equation‘s (5) and (6)

$$V(s) = K'_e\,\omega_m(s) + (R_a + sL_a)\, I_a(s) \qquad \text{.....(7)}$$

$$T(s) = K'_t\, I_a(s) = (sJ + D)\,\omega_m(s) + T_L(s) \qquad \text{.....(8)}$$

These equations can be reorganized as

$$I_a(s) = \frac{V(s) - K'_e\,\omega_m(s)}{(R_a + sL_a)}$$

$$= [V(s) - K'_e\,\omega_m(s)] \times \frac{1/R_a}{1+s\tau_a} \qquad \text{.....(9)}$$

Where $\tau_a = L_a/R_a$ = armature time-constant

Also $$\omega_m(s) = \frac{[T(s) - T_L(s)]}{(sJ + D)}$$

$$= [T(s) - T_L(s)] \times \frac{1/D}{1+s\tau_m} \qquad \text{.....(10)}$$

Where $\tau_m = J/D$ = mechanical time-constant

$$T(s) = K'_t\, I_a(s) \qquad \text{.....(11)}$$

From equ‘s (9) to (11), the block diagram of the motor can be drawn as in Fig.3.48

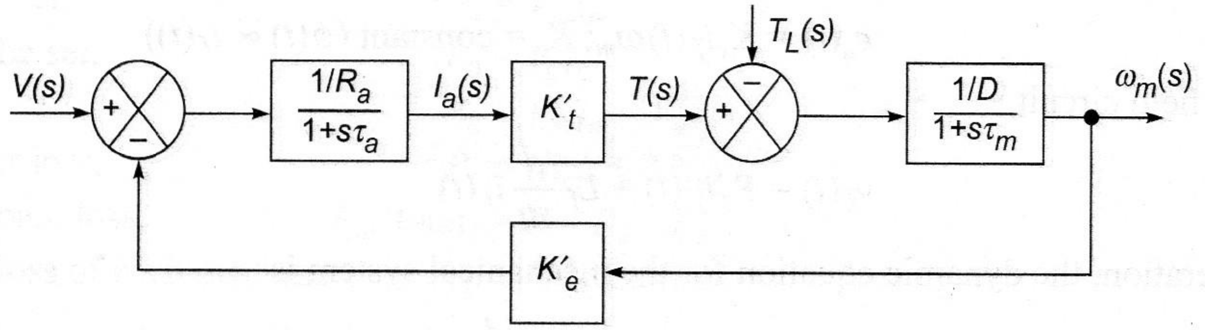


Fig.3.48 Block diagram of separately excited dc motor

21. Explain the Hopkinson‘s test on DC motor and describe how to calculate efficiency of DC motor. April 2013.

22. Explain the procedure for Hopkinson‘s test on DC machine in determining the efficiency when it is working as (a) generator (b) motor. Nov‘ 2012

23. With circuit explain the efficiency calculation of DC motor by regenerative test. Nov‘ 2014

HOPKINSON’S TEST

This is a **regenerative test** in which two identical dc shunt machines are coupled mechanically and tested simultaneously. One of the machines is made to act as a motor driving the other as a generator which supplies electric power to motor.

The set therefore draws only loss-power from the mains while the individual machines can be fully loaded.

Fig. 3.47. shows the connection diagram for Hopkinson‘s test. One of the machines of the set is started as a motor (starter connections are not shown in the figure) and brought to speed. The two machines are made parallel by means of switch S after checking that similar polarities of the machine are connected across the switch. If this is the case, the voltage across the switch can be almost reduced to zero by adjustment of the field currents of the machines. Otherwise the polarities of either one of the armatures or one of the fields must be reversed and the set restarted. The switch S is closed after checking that the voltage across it is negligible so that heavy circulating current will not flow in the local loop of armatures on closing the switch.

The speed of the set and electric loading of the machines can be adjusted by means of rheostats placed in the two field circuits. The cause-effect relationship to load variation is given below:

$$I_{fg}\uparrow \;\rightarrow\; E_{ag} \;\uparrow\; E_{ag} \rightarrow> E_{am} \qquad I_{ag}\rightarrow, I_{am}\uparrow \qquad \uparrow$$

$$\uparrow \qquad \uparrow$$

$$I_{fm} \;\downarrow\; n \rightarrow \qquad E_{ag} \rightarrow> E_{am} \qquad I_{ag}\rightarrow, I_{am}\uparrow$$

Computation of losses and efficiencies:

Current drawn from the supply , $I_a = I_{am} - I_{ag}$; motor draws more current as it runs the generator

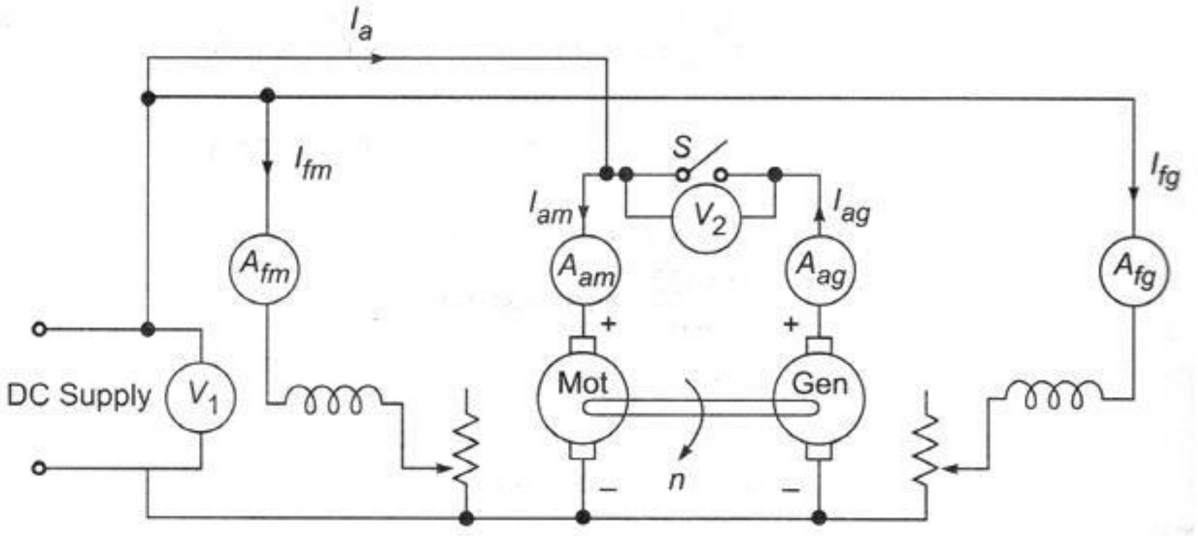


Fig. 3.47

Armature copper loss in generator = $I_{ag}{}^2 R_{ag}$

Armature copper loss in motor = $I_{am}{}^2 R_{am}$

Copper loss in field winding of generator = $V_t I_{fg}$

Copper loss in field winding of motor = $V_t I_{fm}$

But total losses in generator and motor are equal to the power supplied by the mains.

Power drawn from the supply = $V_t I_a$

The stray losses of both machines can be calculated as,

Total stray loss for both the machines = $V_t I_a - I_{am}{}^2 R_{am} - I_{ag}{}^2 R_{ag}$

$= W_s$

Assuming that the stray losses are equally divided between the two machines.

Stray loss for each machine = $W_s/2$

The machine which is acting as a motor,

Total losses = $I_{am}{}^2 R_{am} + V_t I_{fm} + \frac{W_s}{2}$

Input to motor = $V_t(I_a + I_{ag})$

Efficiency of motor, $\eta_m = \frac{Output}{Input} = \frac{Input - Losses}{Input}$

$$\eta_m = \frac{V_t(I_a + I_{ag}) - [I_{am}{}^2 R_{am} + V_t I_{fm} + \frac{W_s}{2}]}{V_t(I_a + I_{ag})}$$

The machine which is acting as a generator,

$$\text{Total losses} = I_{ag}{}^2 R_{ag} + V_t I_{fg} + \frac{W_S}{2}$$

$$\text{Output of generator} = V_t I_{ag}$$

$$\text{Efficiency of generator, } \eta_g = \frac{Output}{Input} = \frac{Output}{Output + Losses}$$

$$\eta_g = \frac{V_t I_{ag}}{V_t I_{ag} + I_{ag}{}^2 R_{ag} + V_t I_{fg} + \frac{W_S}{2}}$$

Advantages

The various advantages of Hopkinson's test are,

1. The power required for conducting the test is small compared. to full load powers of the two machines.
2. Since the machines are operated at full load conditions, change in iron loss due to distortion in flux at full load will be included in the calculations.
3. As the machines are tested under full load conditions, the temperature rise and quality of commutation of the two machines can be observed.
4. The test is economical as power required to conduct the test is very small which is just sufficient to meet the losses.
5. There is no need for arranging any actual load. Similarly by changing the field currents of two machines, the load can be easily changed and a load test over complete range of load can be taken.

Disadvantages

The various disadvantages of Hopkinson's test are,

1. There is difficulty in availability of two identical machines.
2. The iron losses in the two machines cannot be separated. The iron losses are different in both the machines because of different excitations.
3. The machines are not loaded equally in case of small machines which may lead to difficulty in analysis.

This test is better suited in case of large machines.