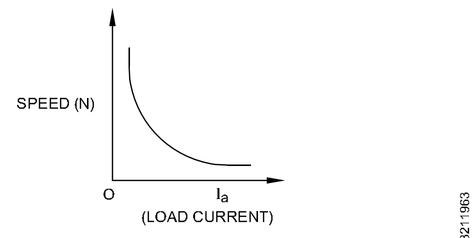
dangerous value. Therefore, the DC series motors are seldom used without load. Care should be taken while using belt drives where the load can be `OFF' if the belt breaks or slips out. To avoid this, usually the load is connected directly or through gears to a DC series motor.

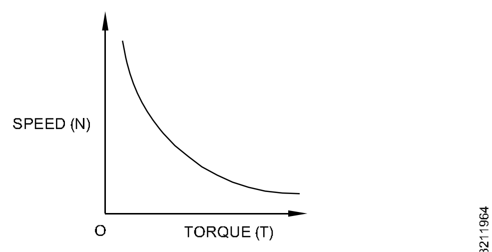
Fig 3



SPEED-LOAD CHARACTERISTIC

Speed-torque characteristics: Fig 4 shows the speed-torque characteristic of a DC motor. It shows that when the torque is low, the speed is high. This is due to the low field flux (N a 1/Ø). As the torque increases the motor draws more current and causes the speed to reduce. This is due to the increased field flux by increased load current in the DC series field.

Fig 4



SPEED-TORQUE CHARACTERISTIC

Uses of a DC series motor: The DC series motor is used in applications where torque and speed requirements vary substantially, and in jobs that require a heavy starting torque and a high rate of acceleration as in traction, hoists, cranes, and heavy construction trucks.

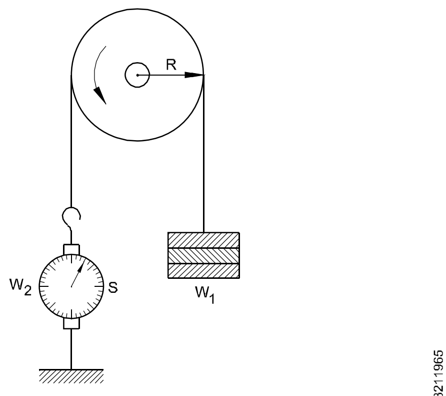
Method of changing the direction of rotation of a DC series motor: We know that by applying Fleming's left hand rule, the direction of rotation of the armature in a DC motor could be determined. According to Fleming's left hand rule, either by changing the polarity of the field or by changing the direction of current in the armature, the direction of rotation could be changed. However, if the polarity of the supply is changed, as both the polarity of field and the direction of current in the armature change, the direction of rotation will remain unchanged. Therefore, the direction of rotation of a DC series motor can be changed by changing either the field or the armature connection.

Method of loading a DC series motor: A DC series motor should never be operated without load. To keep the speed of the DC series motor within safe limits, we have to maintain a certain load on the shaft. This could be done by connecting the DC series motor to a direct-coupled load or by mounting a gear-coupled load.

The method of loading a DC series motor of small capacity for testing in a laboratory is by the brake test which is explained below.

Brake test (Method I): It is a direct method and consists of applying a brake through a special (camel hair) belt to a water-cooled drum mounted on the motor shaft as shown in Fig 5. One end of the belt is fixed to the ground via a spring balance S, and the other end is connected to a suspended weight W_1. The motor is run and the load on the motor is adjusted till it carries its full load current.

Fig 5



BRAKE TEST

Let W_1 – suspended weight in kg.

W_2 – reading on spring balance in kg.wt.

The net pull on the belt due to friction at the pulley is

$(W_1 – W_2)$ kg. wt. or 9.81 $(W_1 – W_2)$ newton. If R-radius of the pulley is in metre then, the shaft torque T_{sh} developed by the motor

$$= (W_1 – W_2)R \text{ kg.m}$$

$$= 9.81(W_1 – W_2)R \text{ N–m}$$

If n – motor or drum speed in r.p.s.

Motor output power $= T_{sh} \times 2\pi n$ watt

$$= 2\pi \times 9.81\, n\, (W_1 – W_2)R \text{ watt}$$

$$= 61.68\, n\, (W_1 – W_2)R \text{ watt.}$$

Let, V = supply voltage;

I= load current taken by the motor.

Then, input power = VI watt.

$$\text{Therefore, efficiency} = \frac{\text{output}}{\text{input}} = \frac{61.68n(W_1 - W_2)R}{VI}$$

Further the metric horsepower developed by the motor can be calculated by the formula

$$\text{HP metric} = \frac{2\pi n T_{sh}}{735.6}$$

where 'n' is the speed in r.p.s.

T_{sh} is the shaft torque in newton metres.

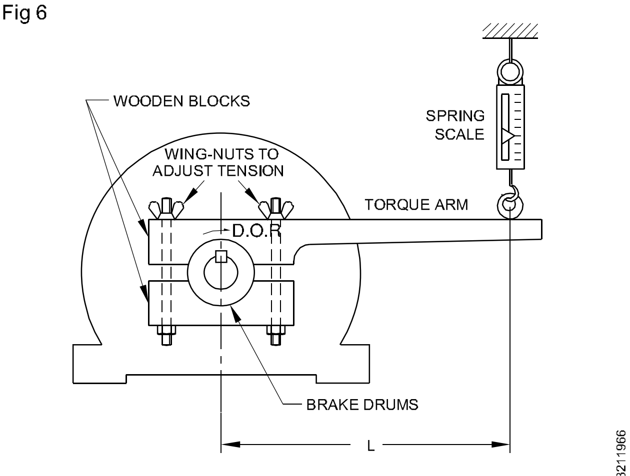
The power rating given in the name-plate of the motor indicates the horsepower which is developed at the shaft.

The simple brake test described above can be used for small motors only, because in the case of larger motors, it is difficult to dissipate the large amount of heat generated at the brake.

> **It is most important to remember that a series motor should never be operated without a load.**
>
> **The field is very weak at no load. Operating the motor without a load will allow the motor to reach such high speeds that the centrifugal force will cause the windings to tear free.**

Brake test (Method II): The torque developed by a motor may be measured alternatively by a device called a prony brake as shown in Fig 6.

Fig 6



PRONY BRAKE USED FOR MEASURING TORQUE DEVELOPED BY A MOTOR

There are various prony brake designs available. In Fig 6, the brake drum is encased in split wooden blocks. By tightening the wing-nuts, the pressure of the wooden blocks on the brake drum can be varied, and thereby, the load can be adjusted to the desired value. The brake drum has an extension torque arm that is fastened to a spring scale which measures the force developed on the brake drum in newtons. The torque developed is the product of the net force on the scale (in newtons) X the effective length (L) of the torque arm in metres.

Torque = force x distance

= spring balance reading in Kg.wt x 'L' in metres.

The efficiency and the output of the motor in metric horsepower could be calculated as explained in the above paragraphs.

Example 1: A prony brake arm is 0.4 m in length. The wing-nuts on the brake are tightened on the motor pulley, creating a force of 50 Kg.wt. What is the torque that is being developed by the motor?

1 Kg.wt = 9.8 newtons

Torque = force x length(distance)

= 50 x 9.81 x 0.4

= 196.2 newton metres.

Example 2: In the above case calculate the metric horsepower developed by the motor when the shaft speed is 1500 r.p.m.

$$\text{HP metric} = \frac{2\pi n T_{sh}}{735.6}$$

$$n = \frac{1500}{60} = 25 \text{ r.p.s. } (n = \text{r.p.s})$$

$$T_{sh} = 196.2 \text{ N.m}$$

$$\text{HP (metric)} = \frac{2\pi \times 25 \times 196.2}{735.5} = 41.9 \text{ HP (metric)}$$

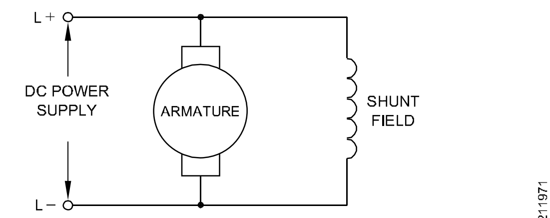
Characteristic and applications of a DC shunt motor

Objectives: At the end of this lesson you shall be able to

- **describe the characteristics of a DC shunt motor**
  - **– speed vs load characteristics**
  - **– torque vs load characteristics**
  - **– torque vs speed characteristics**
- **state the applications of a DC shunt motor.**

Shunt motor: As shown in Fig 1, in a shunt motor, the field is connected directly across the armature and the supply. The field current, and hence, the field flux are constant. When operating without a load, the torque requirement is small, since it is only needed to overcome windage and friction losses. Because of the constant field flux, the armature will develop a back emf that will limit the current to the value needed to develop only the required torque.

Fig 1



DC SHUNT MOTOR

Speed load characteristic of the DC shunt motor: Shunt motors are classified as constant speed motors. In other words, there is very little variation in the speed of the shunt motor from no load to full load. Equation 1 may be used to determine the speed of the DC motor at various loads.

$$N = \frac{V - I_a R_a}{K_1 \varnothing} = \frac{E_b}{K_1 \varnothing} \text{ (Eqn.1)}$$

where

N - speed of the armature in r.p.m.

V - applied voltage

I_a - armature current at a specific load

R_a - armature resistance

Ø - flux per pole

K_1 - a constant value for the specific motor

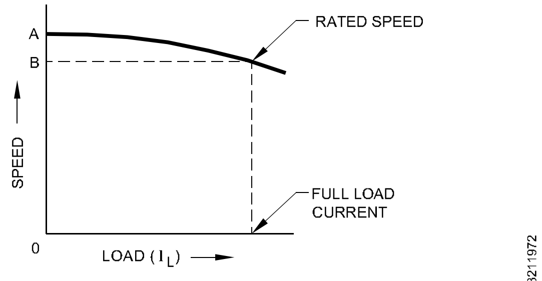
E_b - the back emf

In a shunt motor, V,R_a,K_1 and Ø are practically constant values, and the armature current is the only variable. At no load the value of 'I_a' is small, leading to the maximum speed. At full load, $I_a R_a$ is generally about 5 percent of V. The actual value depends upon the size and design of the motor. Consequently, at full load, the speed is about 95 percent of the no-load value.

However the speed will drop slightly to reduce the back emf such that the armature can draw more current to develop an increased torque from no load to full load.

Fig 2 shows the speed-load characteristic of a DC shunt motor. From the curve it is observed that the speed slightly drops from its no-load speed OA to OB when the motor delivers full load. This is due to the increased $I_a R_a$ drop in armature. As the drop is small, the DC shunt motor is regarded as a practically constant speed motor.

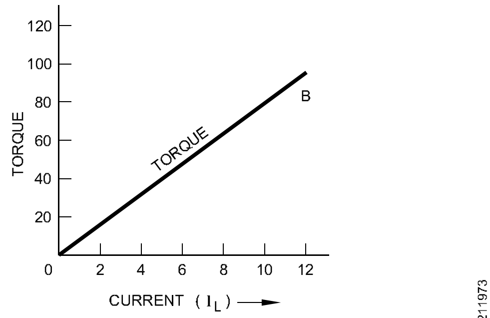
Fig 2



LOAD VERSUS SPEED CHARACTERISTIC OF DC SHUNT MOTOR

Torque vs load characteristics of the DC shunt motor: Motor torque is proportional to the product of the field flux and the armature current. As the field flux is constant, the torque varies as the load current varies. Fig 3 shows the torque vs load curve of a DC shunt motor. From this it is clear that the torque is directly proportional to load or armature current I_a.

Fig 3

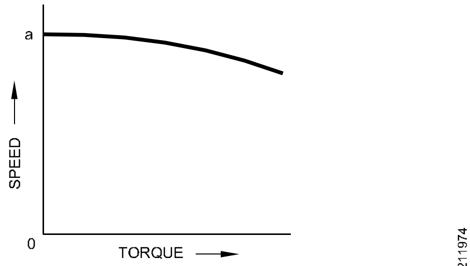


TORQUE VERSUS LOAD CHARACTERISTIC CURVE

The starting torque of a shunt motor is about 1.5 times the full load torque indicating that the shunt motor does not have as high a starting torque as the series motor, but it has much better speed regulation.

Torque Vs speed characteristics: Fig 4 shows the torque speed characteristic of a DC shunt motor. From the curve it is observed that the increase in torque has negligible effect on the speed. The speed slightly drops as the torque increases.

Fig 4



SPEED VERSUS TORQUE CHARACTERISTIC OF DC SHUNT MOTOR

Application of DC shunt motor: A DC shunt motor is best suited for constant speed drives. It meets the requirements of many industrial applications. Some specific applications are machine tools, wood planers, circular saws, grinders, polishers, printing processes, blowers and motor generator sets.

When working with a shunt motor, never open the field circuit when it is in operation. If this happens, as the flux is only due to the residual field, the motor speed increases to a dangerous magnitude. At light loads this speed could become dangerously high, and the armature may fly off.

DC compound motor - load characteristics

Objectives: At the end of this lesson you shall be able to
- **state the types, applications of DC motors**
- **state the characteristic of a DC compound motor**
- **state the precautions to be observed while starting a differential compound motor.**

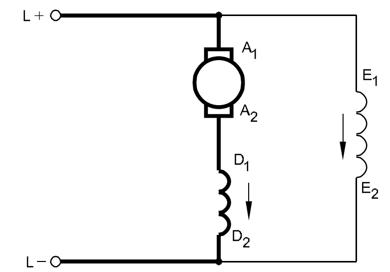
DC compound motor: A DC compound motor has both shunt and series fields for producing the required main flux in the poles. A DC compound machine can be used as a motor or generator. It can be classified as indicated below.

Compound motor
- Cumulative compound
  - Long shunt
  - Short shunt
- Differential compound
  - Long shunt
  - Short shunt

Cumulative compound motor: When the series field of the DC compound motor is connected in such a way that its flux aids the flux produced by the shunt field, as shown in Fig 1, then it is called a cumulative compound motor.

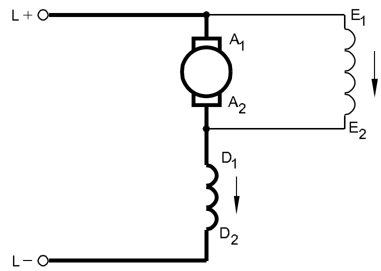
Depending on the shunt field connection, it is further sub-divided as the long shunt, (Fig 1) the short shunt (Fig 2) cumulative compound motor.

Fig 1



CUMULATIVE COMPOUND MOTOR (LONG SHUNT)

Fig 2

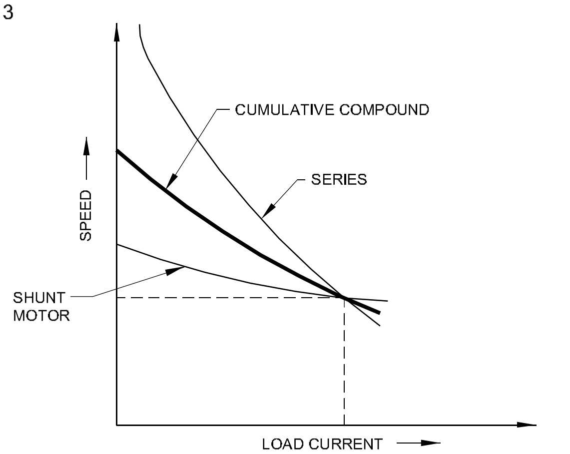


CUMULATIVE COMPOUND MOTOR (SHORT SHUNT)

As this motor has both shunt and series fields, it has the combined behaviour of the shunt and series motor, depending on the magnitude of the fluxes due to these two fields. If the series ampere-turns are more predominant than the shunt ampere-turns at full load, then it has a higher starting torque than the shunt motor, and its speed falls more than that of the shunt motor. If the shunt ampere-turns are more predominant than the series ampere-turns at full load, the motor acts almost like a shunt motor but its speed drops a little more than that of a shunt motor.

Speed-load characteristic: Fig 3 shows the speed-load characteristic of the cumulative compound motor, and also of the series and shunt motors for comparison. The speed of this motor falls more than the shunt motor but falls less than the series motor. As the speed load curve starts from Y-axis, unlike in a DC series motor, the cumulative compound motor can also run on no-load at a specified speed.

Fig 3

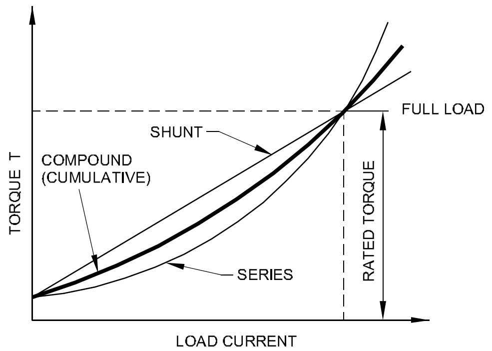


SPEED-LOAD CHARACTERISTIC OF CUMULATIVE COMPOUND MOTOR

The increased drop in speed at load is due to the combined drop of the voltage due to armature and series field resistances.

Torque-load characteristic: Fig 4 shows the torque-load characteristic of the cumulative compound motor, and also that of the series and shunt motors for comparison. Up to full load, the torque developed in a cumulative compound motor is less than that in the shunt motor but more than in the series motor.

Fig 4

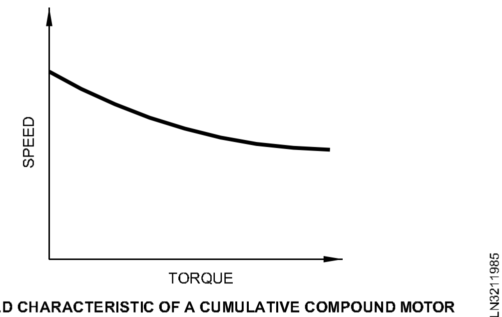


TORQUE-LOAD CHARACTERISTIC OF COMPOUND MOTOR (CUMULATIVE)

However, at the time of starting, the starting current is about 1.5 times the full load current, and hence, the cumulative compound motor produces a high torque, which is better than that of the shunt motor during starting.

Torque-speed characteristic: Fig 5 shows the torque-speed characteristic of the cumulatively compound motor. As the total flux of the motor increases with load, the speed decreases but the torque increases. As the output power is proportional to the product of speed and torque, the cumulative compound motor will not be overloaded in case of sudden appearance of load as in rolling mills.

Fig 5



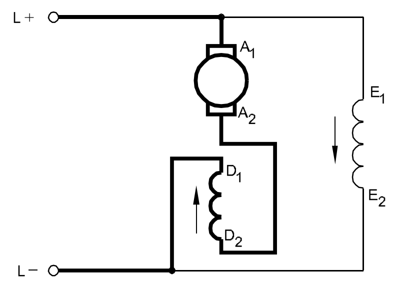
TORQUE SPEED CHARACTERISTIC OF A CUMULATIVE COMPOUND MOTOR

Application of cumulative compound motors: Compound motors are used to drive machines that require a relatively constant speed under varying loads. They are frequently used on machines that require sudden application of heavy loads, such as presses, shears, compressors, reciprocating tools, steel rolling machinery and elevators. Compound motors are also used when it is desired to protect the motor by causing it to decrease the speed under heavy loads. However, using a flywheel along the motor facilitates almost constant speed by converting the stored energy in the flywheel to be utilised during heavy loads. During light loads the kinetic energy is stored in the flywheel.

Never open the shunt field of a compound motor when the motor is operating at high load.

Differential compound motor: When the series field of the DC compound motor is connected in such a way that its flux opposes (bucks) the flux produced by the shunt field as shown in Fig 6, it is called a differential compound motor.

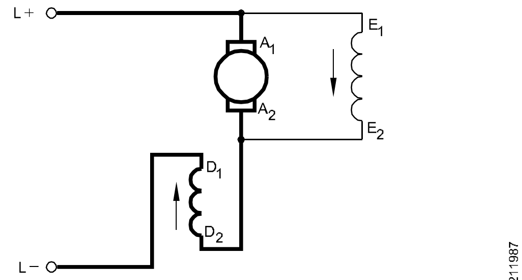
Fig 6



DIFFERENTIAL COMPOUND MOTOR (LONG SHUNT)

Depending upon the shunt field connection, the compound motor is further subdivided as long shunt (Fig 6) and short shunt (Fig 7) differential compound motor.

Fig 7

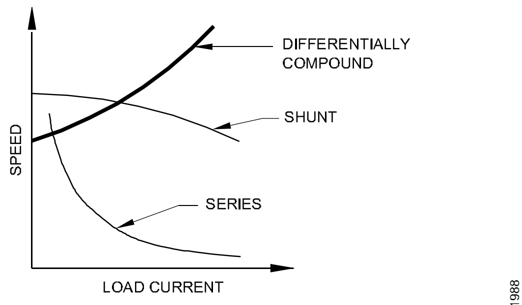


DIFFERENTIAL COMPOUND MOTOR (SHORT SHUNT)

As the series field flux is in the opposite direction to the shunt field flux, there is some inherent problem at the time of starting. At the time of starting, the shunt field takes some time to build up, whereas a heavy rush of current will be through the series field and armature. The motor will, therefore, tend to start up the wrong way. When the shunt field is fully established, the total flux, which is the difference of series and shunt field fluxes, may be so small that the motor may not produce sufficient torque to run the motor. Hence it is advisable to short-circuit the series field of the differential compound motor at the time of starting, and then put the series field in the circuit when the motor is running.

Characteristics of a differential compound motor: The speed-load characteristic of the differential compound motor, shown in Fig 8, indicates that the motor speed increases with the increase in load due to the fact that the total flux decreases at the increased load.

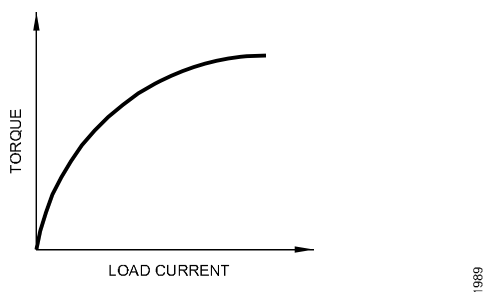
Fig 8



SPEED - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

The torque-load characteristic of the DC differential compound motor shown in Fig 9, indicates that the torque increases with the increased load.

Fig 9

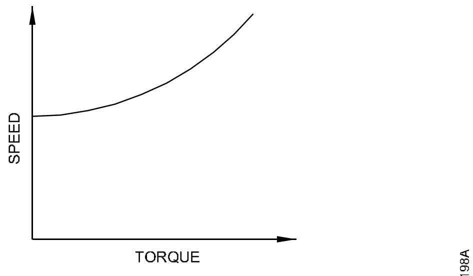


TORQUE - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Fig 10 shows the torque-speed characteristic indicating that both speed and torque increase in the machine, resulting in the overloading of the machine initially, and thereby, reaching an unstable state.

Application of DC differential compound motor: This motor is not in common use due to its unstable behaviour at overloads. This motor is dangerous to use unless there is no possibility of the load exceeding the normal full load value as it is designed to work within full load limits.

Fig 10



TORQUE-SPEED CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR