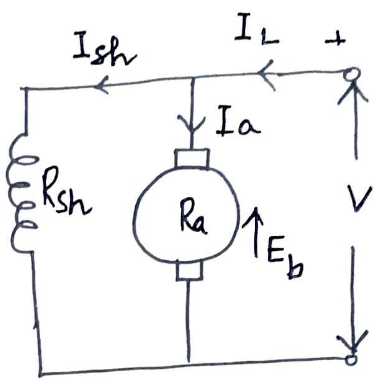
Speed of a DC motore.



Shunt motor

$$E_b = V - I_a R_a$$

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

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

$$\Rightarrow N = \frac{60A}{PZ}\left(\frac{V - I_a R_a}{\phi}\right)$$

$$= K.\frac{E_b}{\phi} \qquad \left[\because \frac{60A}{PZ} \text{ is const } \& \ E_b = V - I_a R_a\right]$$

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

In DC motor, speed is directly prop^n to back emf E_b and inversely proportional to flux per pole, ϕ.

Let a DC motor attains a speed N_2 from its initial speed N_1 and their corresponding flux and back emfs are (ϕ_1, E_{b_1}) and (ϕ_2, E_{b_2}).

$$\therefore N_1 \propto \frac{E_{b_1}}{\phi_1} \text{ and } N_2 \propto \frac{E_{b_2}}{\phi_2}$$

$$\Rightarrow \frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

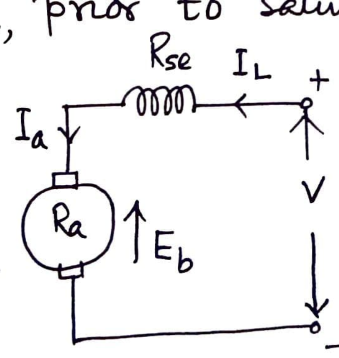
For a shunt motor, ϕ is const, i.e. $\phi_1 = \phi_2$

$$\therefore \frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}$$

For a series motor, $\phi \propto I_a$, prior to saturation

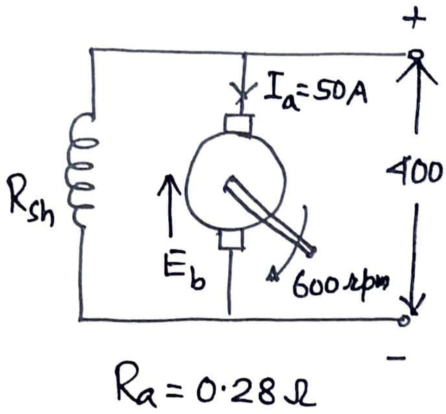
$$\therefore \frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{I_{a_1}}{I_{a_2}}$$

where I_{a_1} = initial armature current
I_{a_2} = final armature current



Series motor

Torque and Speed of a DC motor



Ex A 400 V, DC shunt motor is running at 600 rpm, taking armature current of 50A.

$$E_b = V - I_a R_a$$
$$= 400 - 50 \times 0.28$$
$$= 386\,V$$

Let the flux is reduced by 5% suddenly

$$E_b = \frac{P\phi Z N}{60A} = \left(\frac{PZ}{60A}\right)\phi N \Rightarrow E_b \propto \phi N$$

As the flux reduced suddenly, $E_b \propto \phi$ because inertia of heavy armature prevents any rapid change in speed

∴ Changed back emf, $E_b' = 0.95 \times 386 = 366.7\ V$

∴ Instantaneous armature current is

$$I_a' = \frac{V - E_b'}{R_a} = \frac{400 - 366.7}{0.28} = 118.9\,A$$

A sudden reduction of 5% in the flux has caused the armature current to increase about 2.4 times the initial value of 50 A. This will result in the production of high value of torque.

However, soon the steady conditions will prevail. This will depend on the system inertia; the more rapidly the motor can alter the speed, the sooner the emf rises and the armature current falls.

6. A d.c. shunt motor running on no-load takes 5 A at 200 V. The field resistance is 100 Ω and the armature resistance is 0·1 Ω. Find the approximate maximum efficiency and the load current at which it occurs. **[90% ; 100 A]**

7. A 220 V series motor takes a current of 35 A and runs at 500 r.p.m. The armature resistance is 0·25 Ω and the series field resistance is 0·3 Ω. If iron and friction losses amount to 600 W, find (*i*) armature torque (*ii*) shaft torque (*iii*) overall efficiency. **[(*i*) 134 N-m (*ii*) 122·5 N-m (*iii*) 83·4%]**

8. A shunt machine generates 220 V at 800 r.p.m. on open-circuit. Armature resistance is 0·4 Ω and field resistance is 160 Ω. The machine takes 5 A running as a motor on no-load at 220 V. Find the efficiency and speed of the machine as a motor taking 45 A at 220 V. Armature weakens the field by 3%. **[81·2% ; 759 r.p.m.]**

9. One of the two similar 500 V shunt machines *A* and *B* running light takes 3 A. When *A* is mechanically coupled to *B*, the input to *A* is 3·5 A with *B* unexcited and 4·5 A when *B* is separately excited to generate 500 V. Calculate the friction and windage loss and core loss of each machine. **[250 W ; 500 W]**

10. A 100 V shunt motor is developing 6 b.h.p. and the overall efficiency at this load is 86%. Armature resistance is 0·06 Ω and shunt field resistance is 50 Ω. Find (*i*) current taken (*ii*) copper losses (*iii*) iron and friction losses. **[(*i*) 52·05 A (*ii*) 350 W (*iii*) 379 W]**

5.21 D.C. MOTOR CHARACTERISTICS

There are three principal types of d.c. motors *viz.*, shunt motors, series motors and compound motors. Both shunt and series types have only one field winding wound on the core of each pole of the motor. The compound type has two separate field windings wound on the core of each pole. The performance of a d.c. motor can be judged from its characteristic curves known as motor characteristics. Following are the three important characteristics of a d.c. motor :

(*i*) **Torque and Armature current characteristic (T_a/I_a)**

It is the curve between armature torque T_a and armature current I_a of a d.c. motor. It is also known as *electrical characteristic* of the motor.

(*ii*) **Speed and armature current characteristic (N/I_a)**

It is the curve between speed N and armature current I_a of a d.c. motor. It is very important characteristic as it is often the deciding factor in the selection of the motor for a particular application.

(*iii*) **Speed and torque characteristic (N/T_a)**

It is the curve between speed N and armature torque T_a of a d.c. motor. It is also known as *mechanical characteristic*.

5.22 CHARACTERISTICS OF SHUNT MOTORS

Fig. 5·30 shows the connections of a d.c. shunt motor. The field current I_{sh} is constant since the field winding is directly connected to the supply voltage V which is assumed to be constant. Hence, the flux in a shunt motor is *approximately constant.

(*i*) **T_a/I_a Characteristic.** We know that in a d.c. motor,

$$T_a \propto \phi I_a$$

Since the motor is operating from a constant supply voltage, flux ϕ is constant (neglecting armature reaction).

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

Hence T_a/I_a characteristic is a straight line passing through the origin as shown in Fig. 5·31. The shaft torque (T_{sh}) is less than T_a and is shown by a dotted line. It is clear from the curve that a very large current is required to start a heavy load. Therefore, a shunt motor should not be started on heavy load.

* Due to armature reaction, flux decreases a little but the decrease in flux is usually negligible under normal conditions.

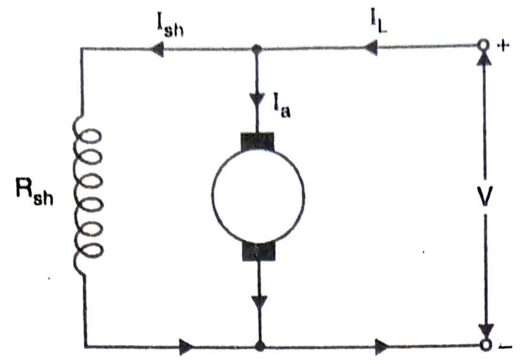


Fig. 5.30

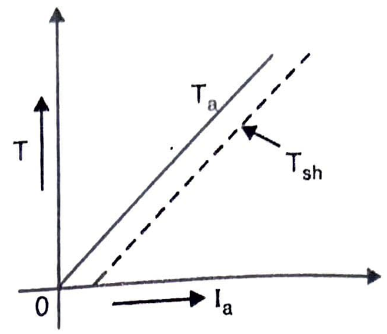


Fig. 5.31

(*ii*) **N/I_a Characteristic.** The speed N of a d.c. motor is given by ;

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

The flux ϕ and back e.m.f. E_b in a shunt motor are almost constant under normal conditions. Therefore, speed of a shunt motor will remain constant as the armature current varies (dotted line AB in Fig. 5·32). Strictly speaking, when load is increased, E_b ($= V - I_a R_a$) and ϕ decrease due to the armature resistance drop and armature reaction respectively. However, E_b decreases slightly more than ϕ so that the *speed of the motor decreases slightly with load (line AC in Fig. 5.32).

(*iii*) **N/T_a Characteristic.** The curve is obtained by plotting the values of N and T_a for various armature currents (See Fig. 5·33). It may be seen that speed falls somewhat as the load torque increases.

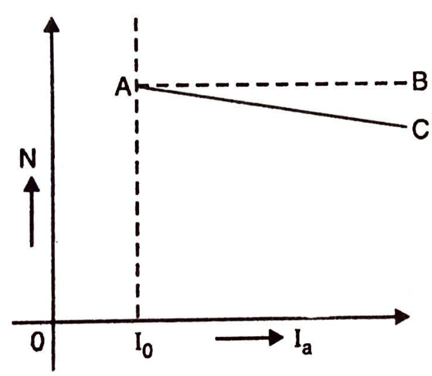


Fig. 5.32

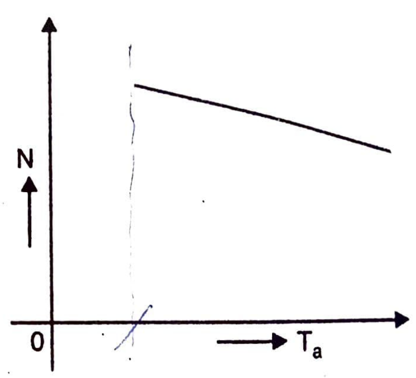


Fig. 5.33

Conclusions : Following two important conclusions are drawn from the above characteristics :

(*i*) There is slight change in the speed of a shunt motor from no-load to full-load. Hence, it is *essentially* a constant-speed motor.

(*ii*) The starting torque is not high because $T_a \propto I_a$.

5.23 CHARACTERISTICS OF SERIES MOTORS

Fig. 5·34 shows the connections of a series motor. Note that current passing through the field winding is the same as that in the armature. If the mechanical load on the motor increases, the armature current also increases. Hence, the flux in a series motor increases with the increase in armature current and *vice-versa*.

* It may be noted that characteristic does not have a point of zero armature current because a small current (no-load current I_0) is necessary to maintain rotation of the motor at no-load.

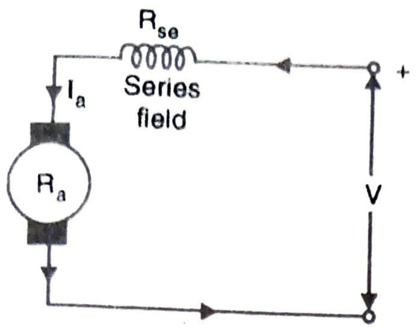


Fig. 5.34

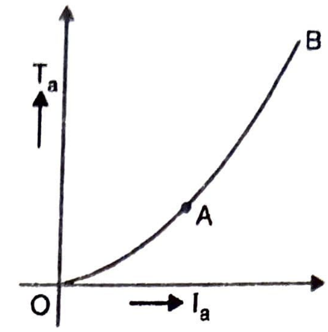


Fig. 5.35

(i) **T_a/I_a Characteristic.** We know that :

$$T_a \propto \phi I_a$$

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

After magnetic saturation, ϕ is constant so that $T_a \propto I_a$

Thus upto magnetic saturation, the armature torque is directly proportional to the square of armature current. If I_a is doubled, T_a is almost quadrupled. Therefore, T_a/I_a curve upto magnetic saturation is a parabola (portion OA of the curve in Fig. 5·35). However, after magnetic saturation, torque is directly proportional to the armature current. Therefore, T_a/I_a curve after magnetic saturation is a straight line (portion AB of the curve in Fig. 5.35).

It may be seen that in the initial portion of the curve (*i.e.* upto magnetic saturation), $T_a \propto I_a^2$. This means that starting torque of a d.c. series motor will be very high as compared to a shunt motor (where $T_a \propto I_a$).

(ii) **N/I_a Characteristic.** The speed N of a series motor is given by ;

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

When the armature current increases, the back e.m.f. E_b decreases due to $I_a(R_a + R_{se})$ drop while the flux ϕ increases. However, $I_a(R_a + R_{se})$ drop is quite small under normal conditions and may be neglected.

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

$$\propto \frac{1}{I_a} \text{ upto magnetic saturation}$$

Thus, upto magnetic saturation, the N/I_a curve follows the hyperbolic path as shown in Fig. 5·36. After saturation, the flux becomes constant and so does the speed.

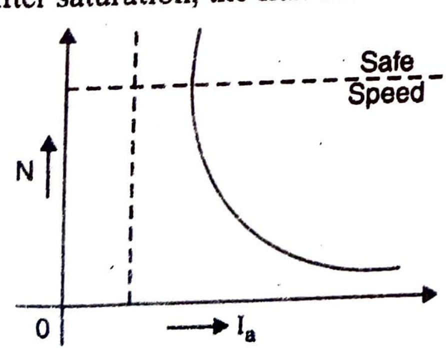


Fig. 5.36

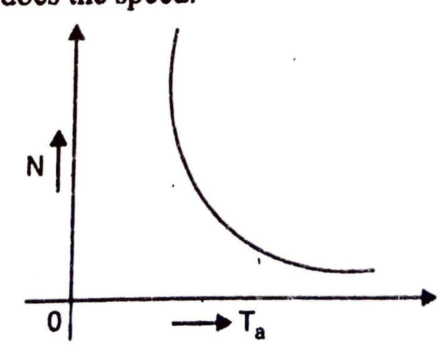


Fig. 5.37

(iii) **N/T_a Characteristic.** The N/T_a characteristic of a series motor is shown in Fig. 5.37. It is clear that series motor develops high torque at low speed and *vice-versa*. It is because an increase in torque requires an increase in armature current, which is also the field current.

The result is that flux is strengthened and hence the speed drops ($\because N \propto 1/\phi$). Reverse happens should the torque be low.

Conclusions : Following three important conclusions are drawn from the above characteristics of series motors :

(*i*) It has a high starting torque because initially $T_a \propto I_a^2$.

(*ii*) It is a variable speed motor (See N/I_a curve in Fig. 5.36) *i.e.*, it automatically adjusts the speed as the load changes. Thus if the load decreases, its speed is automatically raised and *vice-versa*.

(*iii*) At no-load, the armature current is very small and so is the flux. Hence, the speed rises to an excessive high value ($\because N \propto 1/\phi$). This is dangerous for the machine which may be destroyed due to centrifugal forces set up in the rotating parts. *Therefore, a series motor should never be started on no-load.* However, to start a series motor, mechanical load is first put and then the motor is started.

Note. The minimum load on a d.c. series motor should be great enough to keep the speed within limits. If the speed becomes dangerously high, then motor must be disconnected from the supply.

5.24 COMPOUND MOTORS

A compound motor has both series field and shunt field. The shunt field is always stronger than the series field. Compound motors are of two types :

(*i*) *Cumulative-compound motors* in which series field aids the shunt field.

(*ii*) *Differential-compound motors* in which series field opposes the shunt field.

Differential compound motors are rarely used due to their poor torque characteristics at heavy loads.

5.25 CHARACTERISTICS OF CUMULATIVE COMPOUND MOTORS

Fig. 5.38 shows the connections of a cumulative-compound motor. Each pole carries a series as well as shunt field winding ; the series field aiding the shunt field.

(*i*) **T_a/I_a Characteristic.** As the load increases, the series field increases but shunt field strength remains constant. Consequently, total flux is increased and hence the armature torque ($\because T_a \propto \phi I_a$). It may be noted that torque of a cumulative-compound motor is greater than that of shunt motor for a given armature current due to series field [See Fig. 5.39].

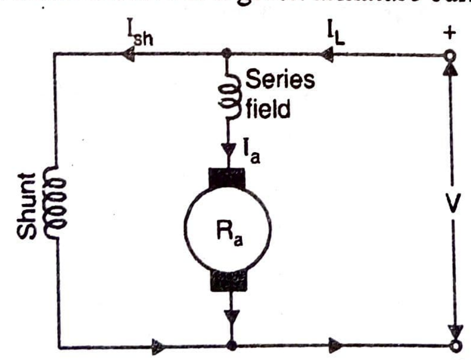


Fig. 5.38

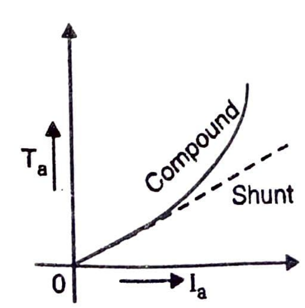


Fig. 5.39

(*ii*) **N/I_a Characteristic.** As explained above, as the load increases, the flux per pole also increases. Consequently, the speed ($N \propto 1/\phi$) of the motor falls as the load increases (See Fig. 5.40). It may be noted that as the load is added, the increased amount of flux causes the speed to decrease more than does the speed of a shunt motor. Thus the speed regulation of a cumulative compound motor is poorer than that of a shunt motor.

Note : Due to shunt field, the motor has a definite no load speed and can be operated safely at no-load.

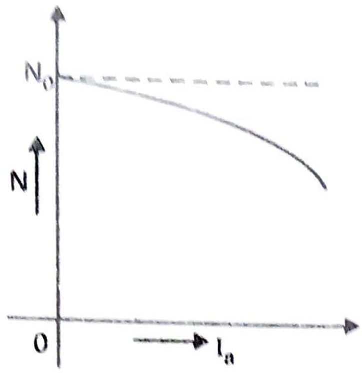


Fig. 5.40

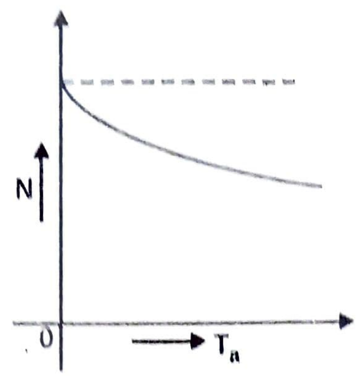


Fig. 5.41

(*iii*) ***N/T$_a$* Characteristic.** Fig. 5.41 shows N/T_a characteristic of a cumulative compound motor. For a given armature current, the torque of a cumulative compound motor is more than that of a shunt motor but less than that of a series motor.

Conclusions : A cumulative compound motor has characteristics intermediate between series and shunt motors.

(*i*) Due to the presence of shunt field, the motor is prevented from running away at no-load.

(*ii*) Due to the presence of series field, the starting torque is increased.

5.26 COMPARISON OF THREE TYPES OF MOTORS

(*i*) The speed regulation of a shunt motor is better than that of a series motor.

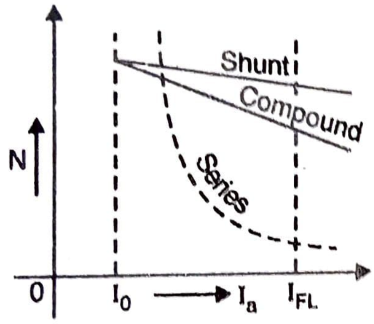


Fig. 5.42

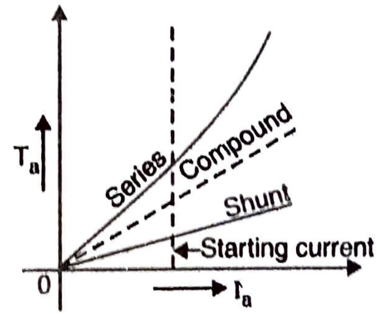


Fig. 5.43

However, speed regulation of a cumulative compound motor lies between shunt and series motors (See Fig. 5.42).

(*ii*) For a given armature current, the starting torque of a series motor is more than that of a shunt motor. However, the starting torque of a cumulative compound motor lies between series and shunt motors (See Fig. 5.43).

(*iii*) Both shunt and cumulative compound motors have definite no-load speed. However, a series motor has dangerously high speed at no-load.

5.27 APPLICATIONS OF D.C. MOTORS

1. **Shunt motors.** The characteristics of a shunt motor reveal that it is an approximately constant speed motor. It is, therefore, used

(*i*) where the speed is required to remain almost constant from no-load to full-load

(*ii*) where the load has to be driven at a number of speeds and any one of which is required to remain nearly constant

Industrial use : Lathes, drills, boring mills, shapers, spinning and weaving machines etc.

2. **Series motors.** It is a variable speed motor *i.e.*, speed is low at high torque and *vice-versa*. However, at light or no-load, the motor tends to attain dangerously high speed. The motor has a high starting torque. It is, therefore, used

(*i*) where large starting torque is required *e.g.*, in elevators and electric traction

(*ii*) where the load is subjected to heavy fluctuations and the speed is automatically required to reduce at high torques and *vice-versa*

Industrial use : Electric traction, cranes, elevators, air compressors, vacuum cleaners, hair drier, sewing machines etc.

3. **Compound motors.** Differential-compound motors are rarely used because of their poor torque characteristics. However, cumulative-compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

Industrial use : Presses, shears, reciprocating machines etc.

5.28 TROUBLES IN D.C. MOTORS

Several troubles may arise in a d.c. motor and a few of them are discussed below :

1. **Failure to start.** This may be due to (*i*) ground fault (*ii*) open or short-circuit fault (*i*... wrong connections (*iv*) too low supply voltage (*v*) frozen bearing or (*vi*) excessive load.

2. **Sparking at brushes.** This may be due to (*i*) troubles in brushes (*ii*) troubles in commutator (*iii*) troubles in armature or (*iv*) excessive load.

(*i*) Brush troubles may arise due to insufficient contact surface, too short a brush, too little spring tension or wrong brush setting.

(*ii*) Commutator troubles may be due to dirt on the commutator, high mica, rough surface or eccentricity.

(*iii*) Armature troubles may be due to an open armature coil. An open armature coil will cause sparking each time the open coil passes the brush. The location of this open coil is noticeable by a burnt line between segments connecting the coil.

3. **Vibrations and pounding noises.** These may be due to (*i*) worn bearings (*ii*) loose parts (*iii*) rotating parts hitting stationary parts (*iv*) armature unbalanced (*v*) misalignment of machine (*vi*) loose coupling etc.

4. **Overheating.** The overheating of motor may be due to (*i*) overloads (*ii*) sparking at the brushes (*iii*) short-circuited armature or field coils (*iv*) too frequent starts or reversals (*v*) poor ventilation (*vi*) incorrect voltage.

SHORT ANSWER QUESTIONS

Q. 1. *Why is the speed of a shunt motor practically constant ?*

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

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

In a shunt motor, V, R_a and ϕ are practically constant. At no-load, the armature current is very small and $I_a R_a$ drop is negligible as compared to V. At full-load, $I_a R_a$ drop is ordinarily about 5% of V. Consequently, the full-load speed of the motor is about 95% of the no-load value. This fall in speed is reduced slightly due to armature reaction. In some cases, armature reaction is sufficient to cause the speed to remain nearly constant. For these reasons, a shunt motor is considered a constant speed motor, though the speed decreases slightly with the increase in load.

Q. 2. *What is the chief advantage of a d.c. series motor?*

Ans. The outstanding characteristic of a series motor is that it has high torque at low speeds and *vice-versa*. It is well-suited for traction purposes such as in electric trains. Acceleration is rapid because the torque is high at low speeds. Furthermore, the series motor automatically slows down as the train goes up an incline surface, yet turns at top speed on the flat ground. The power of a series motor tends to be constant because high torque is accompanied by low speed and *vice-versa*. Series motors are also used in electric cranes and hoists ; light loads are lifted quickly and heavy loads more slowly.

Q. 3. *Why is the actual operating efficiency of a series motor less than that of a shunt motor?*

Ans. Although the efficiency of a series motor varies about the same as that of a shunt motor, the actual operating efficiency is usually considerably lower. This is due to the fact that a series motor seldom runs at its rated load, but is continuously accelerating and decelerating.

Q. 4. *Can a d.c. series motor be operated on a.c. supply?*

Ans. If current direction through a series motor is reversed, the polarities of the field poles and the armature conductors are both reversed, resulting in a pushing effort between them in the same direction. Because of this, a series motor will operate on a.c. supply, its direction of rotation being the same for both half cycles. The lower the frequency of a.c., the greater the torque that can be produced. If the frequency is high, the inductive reactance of the coil limits the current that can flow and the torque of the motor.

Note. When d.c. is applied to a series motor, the current flowing has nothing to oppose it except the resistance in the circuit. This results in high starting current and torque.

Q. 5. *Will a d.c. shunt motor operate on an a.c. supply?*

Ans. The shunt winding has a large number of turns so that it has appreciable inductance. When a.c. is applied to a shunt motor, the large inductive reactance of shunt winding will reduce the field current too much. Consequently, shunt motor will not usually run on a.c. supply.

Q. 6. *Why is a d.c. series motor used to start heavy loads?*

Ans. In a d.c. motor, $T \propto \phi I_a$. For a d.c. series motor, at first, $\phi \propto I_a$ so that $T_a \propto I_a^2$. If current increases two-fold, the torque will increase four-fold. Consequently, the starting torque of a d.c. series motor is very high. For this reason, it is used to start heavy loads.

Q. 7. *Why is the torque of a cumulatively-compounded motor more than that of a shunt motor?*

Ans. The current-torque characteristic of a cumulatively-compounded motor is intermediate between those of a shunt motor and a series motor. When armature current is zero, the field strength is only due to shunt winding. As the load is applied, the series turns increase the flux, causing the torque $T_a \propto \phi I_a$ for any given current to be greater than it would be for a shunt motor.

Q. 8. *Why does not cumulatively-compounded motor run at dangerous speed at light loads?*

Ans. At no-load, the flux due to series field of a cumulatively-compounded motor is almost zero. However, the flux due to shunt winding prevents the motor from running at dangerously high speed.

Q. 9. *What will happen if a shunt motor running at no-load has its shunt winding opened accidentally?*

Ans. If a shunt motor, running at no-load, has its shunt field suddenly opened or burnt out, the back e.m.f. will fall to nearly zero. The armature current will continuously increase the speed of the motor until its parts fly apart.

Q. 10. *What will happen if the shunt field winding of a loaded shunt motor accidentally breaks?*

Ans. If the shunt winding of a loaded motor accidentally breaks, the loss of shunt field current would result in stopping of the motor or burn out the armature or fuse.