

DC Motor Calculations, part 2

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1. Field speed control

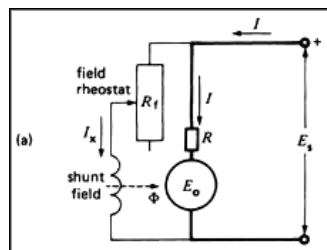
According to Eq. 5.7 we can also vary the speed of a dc motor by varying the field flux F . Let us now keep the armature voltage E_s constant so that the numerator in Eq. 5.7 is constant. Consequently, the motor speed now changes in inverse proportion to the flux F if we increase the flux the speed will drop, and vice versa.

This method of speed control is frequently used when the motor has to run above its rated speed, called base speed To control the flux (and hence, the speed), we connect a rheostat R_f in series with the field (Fig 5 8a).

To understand this method of speed control, suppose that the motor in Fig 5 8a is initially running at constant speed The counter-emf E_o is slightly less than the armature supply voltage E_s due to the IR drop in the armature If we suddenly increase the resistance of the rheostat, both the exciting current I_x and the flux F will diminish. This immediately reduces the cemf E_o , causing the armature current I to jump to a much higher value. The current changes dramatically because its value depends upon the very small difference between E_s and E_o Despite the weaker field, the motor develops a greater torque than before It will accelerate until E_o is again almost equal to E_s .

Clearly, to develop the same E_o with a weaker flux, the motor must turn faster We can therefore raise the motor speed above its nominal value by introducing a resistance in series with the field For shunt-wound motors, this method of speed control enables high-speed/base-speed ratios as high as 3 to 1. Broader speed ranges tend to produce instability and poor commutation.

Under certain abnormal conditions, the flux may drop to dangerously low values For example, if the exciting current of a shunt motor is interrupted accidentally, the only flux remaining is that due to the remanent magnetism in the poles * This flux is so small that the motor has to rotate at a dangerously high speed to induce the required cemf Safety devices are introduced to prevent such runaway conditions.



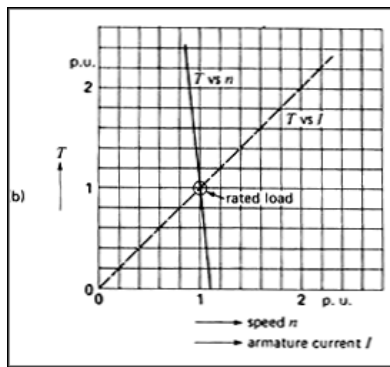


Figure 5.8a. Schematic diagram of a shunt motor including the field rheostat
b. Torque-speed and torque-current characteristic of a shunt motor.

2. Shunt motor under load

Consider a dc motor running at no-load. If a mechanical load is suddenly applied to the shaft, the small no-load current does not produce enough torque to carry the load and the motor begins to slow down. This causes the cemf to diminish, resulting in a higher current and a corresponding higher torque. When the torque developed by the motor is exactly equal to the torque imposed by the mechanical load, then, and only then, will the speed remain constant (see Section 311). To sum up, as the mechanical load increases, the armature current rises and the speed drops.

The speed of a shunt motor stays relatively constant from no-load to full-load. In small motors, it only drops by 10 to 15 percent when full-load is applied. In big machines, the drop is even less, due in part, to the very low armature resistance. By adjusting the field rheostat, the speed can, of course, be kept absolutely constant as the load changes.

* The term residual magnetism is also used. However the IEEE Standard Dictionary of Electrical and Electronics Terms states 'If there are no air gaps in the magnetic circuit the remanent induction will equal the residual induction; if there are air gaps the remanent induction will be less than the residual induction.'

Typical torque-speed and torque-current characteristics of a shunt motor are shown in Fig. 5.8b. The speed, torque and current are given in per-unit values. The torque is directly proportional to the armature current. Furthermore, the speed changes only from 1.1 pu to 0.9 pu as the torque increases from 0 pu to 2 pu.

Example 5-4

A shunt motor rotating at 1500 r/min is fed by a 120 V source (Fig. 5.9a). The line current is 51 A and the shunt-field resistance is 120 Ω . If the armature resistance is 0.1 Ω , calculate the following;

- The current in the armature
- The counter-emf
- The mechanical power developed by the motor

Solution:

- The field current (Fig. 5.9b) is

$$I_x = 120\text{V}/120\ \Omega = 1\text{A}$$

The armature current is

$$I = 51 - 1 = 50\text{ A}$$

- The voltage across the armature is

$$E = 120\text{ V}$$

Voltage drop due to armature resistance is

$$IR = 50 \times 0.1 = 5\text{ V}$$

The cemf generated by the armature is

$$E_o = 120 - 5 = 115\text{ V}$$

- The total power supplied to the motor is

$$P_i = EI = 120 \times 51 = 6120 \text{ W}$$

Power absorbed by the armature is

$$P_a = EI = 120 \times 50 = 6000 \text{ W}$$

Power dissipated in the armature is

$$P = I^2 R = 50^2 \times 0.1 = 250 \text{ W}$$

Mechanical power developed by the armature is

$$P = 6000 - 250 = 5750 \text{ W}$$

(equivalent to $5750/746 = 7.7 \text{ hp}$)

The actual mechanical output is slightly less than 5750 W because some of the mechanical power is dissipated in bearing friction losses, in windage losses, and in armature iron losses.

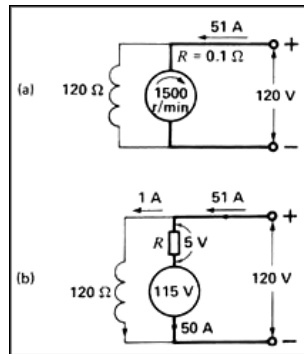


Figure 5.9 See Example 5.4.

3. Series motor

A series motor is identical in construction to a shunt motor except for the field. The field is connected in series with the armature and must, therefore, carry the full armature current (Fig. 5.10a). This series field is composed of a few turns of wire having a cross section sufficiently large to carry the current.

Although the construction is similar, the properties of a series motor are completely different from those of a shunt motor. In a shunt motor, the flux F per pole is constant at all loads because the shunt field is connected to the line. But in a series motor the flux per pole depends upon the armature current and, hence, upon the load. When the current is large, the flux is large and vice versa. Despite these differences, the same basic principles and equations apply to both machines.

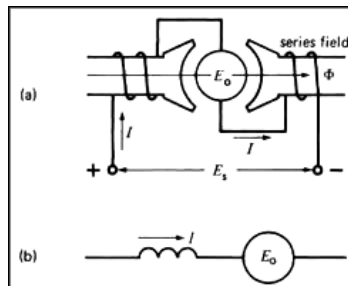


Figure 5.10a. Series motor connection diagram b. Schematic diagram of a series motor

When a series motor operates at full-load, the flux per pole is the same as that of a shunt motor of identical power and speed. However, when the series motor starts up, the armature current is higher than normal, with the result that the flux per pole is also greater than normal. It follows that the starting torque of a series motor is considerably greater than that of a shunt motor. This can be seen by comparing the T versus I curves of Figs 5.8 and 5.11.

On the other hand, if the motor operates at less than full-load, the armature current and the flux per pole are smaller than normal. The weaker field causes the speed to rise in the same way as it would for a shunt motor with a weak shunt field. For example, if the load current of a series motor drops to half its normal value, the flux diminishes by half and so the speed doubles. Obviously, if

the load is small, the speed may rise to dangerously high values. For this reason we never permit a series motor to operate at no-load. It tends to run away, and the resulting centrifugal forces could tear the windings out of the armature and destroy the machine.

4. Series motor speed control

When a series motor carries a load, its speed may have to be adjusted slightly. Thus, the speed can be increased by placing a low resistance in parallel with the series field. The field current is then smaller than before, which produces a drop in flux and an increase in speed.

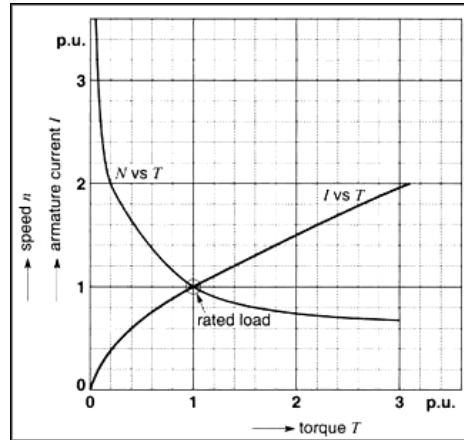


Figure 5.11 Typical speed-torque and current-torque characteristic of a series motor.

Conversely, the speed may be lowered by connecting an external resistor in series with the armature and the field. The total IR drop across the resistor and field reduces the armature supply voltage, and so the speed must fall.

Typical torque-speed and torque-current characteristics are shown in Fig. 5.11. They are quite different from the shunt motor characteristics given in Fig. 5.8b.

Example 5-5

A 15 hp, 240 V, 1780 r/min dc series motor has a full-load rated current of 54 A. Its operating characteristics are given by the per-unit curves of Fig. 5.11.

Calculate

- The current and speed when the load torque is 24 N·m
- The efficiency under these conditions

Solution

- We first establish the base power, base speed, and base current of the motor. They correspond to the full-load ratings as follows:

$$P_B = 15 \text{ hp} = 15 \times 746 = 11\,190 \text{ W}$$

$$n_B = 1780 \text{ r/min}$$

$$I_B = 54 \text{ A}$$

The base torque is, therefore,

$$\begin{aligned} T_B &= \frac{9.55 P_B}{n_B} = 9.55 \times 11\,190 / 1\,780 \\ &= 60 \text{ N·m} \end{aligned}$$

A load torque of 24 N·m corresponds to a per-unit torque of

$$T(\text{pu}) = 24/60 = 0.4$$

Referring to Fig. 5.11, a torque of 0.4 pu is attained at a speed of 1.4 pu. Thus, the speed is

$$\begin{aligned}n &= n(\text{pu}) \times n_B = 1.4 \times 1780 \\&= 2492 \text{ r/min}\end{aligned}$$

From the T vs I curve, a torque of 0.4 pu requires a current of 0.6 pu. Consequently, the load current is

$$I = I(\text{pu}) \times I_B = 0.6 \times 54 = 32.4 \text{ A}$$

b. To calculate the efficiency, we have to know P_o and P_i .

$$P_i = EI = 240 \times 32.4 = 7776 \text{ W}$$

$$P_o = nT/9.55 = 2492 \times 24/9.55$$

$$= 6263 \text{ W}$$

$$h = P_o/P_i = 6263/7776 = 0.805 \text{ or } 80.5\%$$

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5. Applications of the series motor

Series motors are used on equipment requiring a high starting torque. They are also used to drive devices which must run at high speed at light loads. The series motor is particularly well adapted 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 a grade yet turns at top speed on 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.

6. Buy the Book

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