Experiment 7
Series DC Motor (I)

Objectives

- To determine the torque-speed characteristic curve.
- To find out how to reverse the direction of rotation of a series dc motor.

Introduction

A series dc motor is a motor whose filed windings consists of a relatively few turns connected in series with the armature circuit. The equivalent circuit for a series dc motor is shown in Figure 7.1.

![Figure 7.1: Equivalent circuit of a series connected dc motor](image)

In a series dc motor, the armature current, the field current, and the line current are all the same. The Kirchhoff's voltage law equation for this motor is

\[ V_T = E_A + I_A (R_A + R_s) \]  

**Induced Torque in a Series DC motor**

The terminal characteristics of a series dc motor is very different from that of the shunt dc motor. The basic behavior of a series dc motor is due to the fact that the flux is directly proportional to the armature current, at least until saturation is reached. As the load on the motor increases, its flux increases too. As seen earlier, an increase in the flux in the motor causes a decrease in its speed. The result is that a series dc motor has a sharply drooping torque-speed characteristic.

The induced torque in this machine is given by

\[ \tau_{ind} = K_m \phi I_A \]
The flux in this machine is directly proportional to its armature current (at least until the metal saturation). Therefore, the flux in the machine can be given by

\[ \phi = c I_A \] (7.3)

Where \( c \) is a constant of proportionality. The induced torque in this machine is thus given by

\[ \tau_{\text{ind}} = K_m \phi I_A \phi = K_m c I_A^2 \] (7.4)

In other words, the torque in the motor is proportional to the square of its armature current. As a result of this relationship, it is easy to see that a series motor gives more torque per ampere than any other dc motor. It is therefore used in applications requiring very high torques. Examples of such applications are the starter motors in cars, elevator motors, and tractor motors in locomotives.

**The Terminal Characteristic of a Series DC Motor**

To determine the terminal characteristic of a series dc motor, any analysis will be based on the assumption of linear magnetization curve, and then the effects of saturation will be considered in a graphical analysis. The assumption of a linear magnetization curve implies that the flux in the motor will be given equation 7.3 above. This equation will be used to derive the torque-speed characteristic curve for the series dc motor. The derivation of a series motor’s torque–speed characteristic starts with Kirchhoff’s voltage law:

\[ V_T = E_A + I_A (R_A + R_S) \] (7.5)

From equation 7.4, the armature current can be expressed as

\[ I_A = \sqrt{\frac{\tau_{\text{ind}}}{K_m c}} \] (7.6)

Also, \( E_A = K_b \phi \omega \). Substituting these expressions in equation 7.1 yields

\[ V_T = K_b \phi \omega + \sqrt{\frac{\tau_{\text{ind}}}{K_m c}} (R_A + R_S) \] (7.7)

If the flux can be eliminated from this expression, it will directly relate the torque of a motor to its speed. To eliminate the flux from the expression, notice that

\[ I_A = \frac{\phi}{c} \] (7.8)
And the induced torque equation can be written as

$$\tau_{\text{ind}} = \frac{K_m}{c} \phi^2$$

(7.9)

Therefore, the flux in the motor can be represented as

$$\phi = \sqrt{\frac{c}{K_m} \tau_{\text{ind}}}$$

(7.10)

Substituting Equation 7.10 into equation 7.7, assuming $K_m = K_b = K$ and solving for speed yields

$$\omega = \frac{V_T}{\sqrt{K_c} \sqrt{\tau_{\text{ind}}}} - \frac{R_s + R_d}{K_c}$$

(7.11)

Notice that for an unsaturated series dc motor, the speed of the motor varies as the reciprocal of the square root of the torque. That is quite an unusual relationship! This ideal torque-speed characteristic is plotted in Figure 7.2.

![Figure 7.2: Torque-speed characteristic for a series dc motor.](image)

One disadvantage of the series motors can be seen immediately from Equation 7.11. When the torque on the motor goes to zero, its speed goes to infinity. In practice, the torque can never go entirely to zero because of the mechanical, core, and stray losses that must be overcome. However, if no other load is connected to the motor, it can turn fast enough to seriously damage itself. Never completely unload a series dc motor, and never connect one to a load by a belt or other mechanism that could break. If that were to happen and the motor were to become unloaded while running, the results could be serious.
Speed Control of Series DC Motors
Unlike with the shunt dc motor, there is only one efficient way to change the speed a series dc motor. That method is to change the terminal voltage of the motor. If the terminal voltage is increased, the first term in equation 7.10 is increased, resulting in a higher speed for any given torque. The speed of series dc motors can also be controlled by the insertion of a series resistor into the motor circuit, but this technique is very wasteful of power and is used only for intermittent periods during the start up of some motors.

Procedure

CAUTION: AT NO TIME ALLOW THE LOAD TO GO TO ZERO ON A SERIES MOTOR!

Using the lab equipments shown in Figure 7.3 (where the nameplate of the series motor is shown in Figure 7.4), do the following:
1. Connect the circuit shown in Figure 7.5
2. Connect the dc power supply to the electromagnetic break and increase the voltage till the break current reaches 0.15 A.
3. Set the inserted armature resistor to its maximum.
4. Switch on the variable dc voltage power supply and then set the terminal voltage to 220 V.
5. Slowly turn off the inserted armature resistance and observe the speed increases.
6. Change the motor load using the electromagnetic break so that its current does not exceed 0.5 A or torque does not go below 2 N.m.
7. Complete Table 7.1.

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<th>(I_T,[A])</th>
<th>(P_{in},[W])</th>
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Table 7.1: Series motor data.
Figure 7.3: Real photo of lab equipments needed for the experiment.
Figure 7.4: Series motor tag.

Figure 7.5: Series motor wiring diagram.