LABORATORY SESSION 7
DC MOTOR LOAD CHARACTERISTI

CAUTION: High voltages are present in this Laboratory Experiment! Do not make any connections with the power on! The power must be turned off before the circuit is modified.

PURPOSE

The purpose of this experiment is to obtain the load characteristics of dc motors, and show how these depend upon the nature of the field excitation, and to demonstrate the speed control and reversing direction of rotation of a dc motor.

DISCUSSION

The dc motor is a highly versatile machine. It has superior torque and speed range capabilities as compared to induction motors driven from constant frequency supply. It is capable of quick reversal, and speed control over a wide range is achieved relatively easily. For this reason they are selected for use in applications requiring these characteristics, such as rolling mills, power shovels and railroad locomotives. Today, induction motors with solid-state drives are competitive with dc motors in speed control applications.

The torque developed by the dc motor is directly proportional to the armature current and the field flux.
$$T = KI_a\phi \tag{7.1}$$
On the other hand, the motor back emf is proportional to the motor speed and the field flux.
$$E = K\omega\phi \tag{7.2}$$
or
$$\omega = \frac{E}{K\phi} = \frac{V - R_a I_a}{K\phi} \tag{7.3}$$
Where ω is the motor speed in radian per second. Neglecting saturation effect, flux is proportional to the field current, i.e., $\phi = K_f I_f$. Letting $K_m = KK_f$, the above equation may be written as
$$\omega = \frac{V - R_a I_a}{K_m I_f} \tag{7.4}$$

Equation (7.4) suggests that speed control in dc machines can be achieved by three methods: Voltage control (V), field control (I_f), and armature resistance control.

Voltage control requires a controllable voltage source; but most available dc sources - main batteries - are essentially fixed voltages. Techniques of power electronics enable a variable voltage to be derived from an ac source, and the combination of an electronic controller with a dc motor makes a most effective variable speed drive system. This system dominated the market for over a decade, but it faces growing competition from the ac variable-frequency induction motor drive systems.

For a constant dc supply voltage, speed above normal can be obtained by reducing the field current (field weakening). For example, in a shunt motor, placing a resistance in series with the shunt field reduces the field current, yielding a higher operating speed. General-purpose shunt motors are designed to provide a 200% increase in rated speed by this method of speed control. However, because of the weakened flux, the permissible torque that can be delivered at the higher speed is correspondingly reduced in order to prevent excessive armature current. Speed below normal can be obtained by placing a resistance in series with the armature circuit. Since this resistance must carry the full armature current, its size and cost is considerably greater than those of the field rheostat. The main disadvantage of armature resistance control is the poor efficiency of operation.

Substituting for armature current from (7.1) into (7.4), the speed torque characteristic is given by

$$\omega = -\frac{R_a}{\left(K_m I_f\right)^2}T + \frac{V}{K_m I_f} \tag{7.5}$$

The great virtue of the dc motor is that three useful operating characteristics may be obtained by using the field winding in different ways. For shunt motor I_f, is constant and the speed torque characteristic can be written as

$$\omega = -K_1 T + K_2 \tag{7.6}$$

where $K_1 = \dfrac{R_a}{\left(K_m I_f\right)^2}$, and $K_2 = \dfrac{V}{K_m I_f}$.

This equation is just a straight line with a negative slope.

In series motor $I_a = I_f$, neglecting saturation (7.1) may be written as $T = K_m I_a^2$, and from (7.4) the speed torque characteristic of a series motor can be expressed as

$$\omega = K_3 \frac{1}{\sqrt{T}} - K_4 \tag{7.7}$$

where $K_3 = \dfrac{V}{\sqrt{K_m}}$, and $K_4 = \dfrac{R_a}{K_m}$.

From the above equation it can be seen that for an unsaturated series motor the speed is inversely proportional to the square root of the torque. A high torque is obtained at low speed and a low torque is obtained at high speed. With a small machine the windage and friction torque is sufficient to limit the no-load speed to a safe value, but a large series motor must never be started without a load or the speed will rise to a very high value and armature may burst under the rotational stresses. Series motors are used where large torque are required, as in subway cars, automobile starters, hoists, cranes, and blenders.

A series dc motor will operate quite well from a single-phase ac supply. Universal motors of this kind are widely used in portable power tools and domestic appliances such as food mixers.

A compound dc motor is a motor with both a shunt and a series field, which combines the best features of both the shunt and a series motor.

In order to reverse the direction of rotation of a dc motor, it is necessary to reverse the direction of current through the armature with respect to the current of the field circuit. This is done simply by reversing either the armature circuit connections with respect to the field circuit or vice versa. Reversal of both circuit connections will produce the same direction of rotation. In designing automatic starters and control equipment, the armature circuit is usually selected for reversal for several reasons. First the field is highly inductive circuit, and frequent reversal induces undesirable high emfs. Second, if the shunt field is reversed, the series field must also be reversed; otherwise the motor will be differentially compounded. Third, if the reversing switch is defective and field circuit fails to close, the motor may ``run away."

Just as dc generators are compared by their voltage regulations, dc motors are compared by their speed regulations. The speed regulation (SR) is defined by

$$SR = \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100 \tag{7.8}$$

The motor efficiency is given by

$$\eta = \frac{P_O}{P_i} \times 100 \tag{7.9}$$

In the case of motor, input power is electrical and is given by

$$P_i = VI_L \tag{7.10}$$

I_L is the line current. For shunt and compound motors $I_L = I_a + I_f$. The output power is computed from the measurement of the dynamometer pull as follows:

$$T = Pull \text{ (Kg)} \times 9.81 \times \text{Arm radius (0.305 m)} \quad \text{N-m} \tag{7.11}$$

$$P_o = \omega T \quad \text{Watts} \tag{7.12}$$

where ω is speed in rad/sec given by $\omega = \frac{2\pi n}{60}$, n is speed in RPM.

PROCEDURE

1. Shunt motor

Connect the dc motor for shunt operation as shown in Figure 7.1. For this part you don't need to complete the dynamometer wiring. Use two DC ammeters to measure the armature and the field currents, and a dc voltmeter to measure the motor terminal voltage. At start, the motor back emf, E_a, is zero and the starting current is very high. In order to limit the starting current, a $5\,\Omega$ resistor is inserted in the armature circuit.
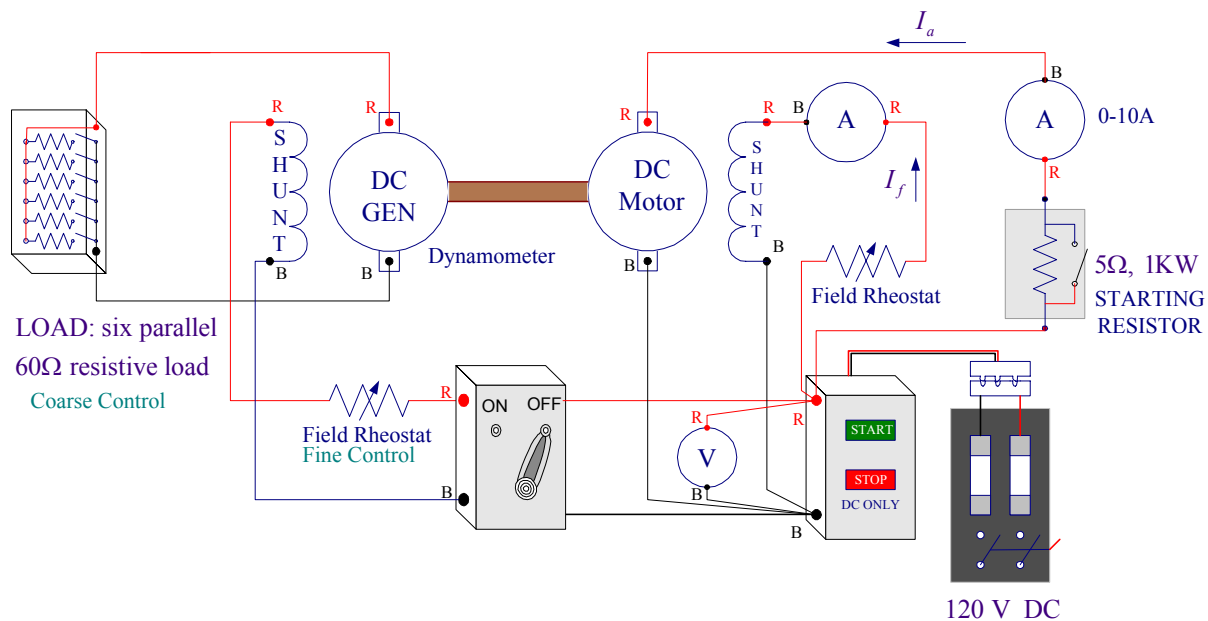
Figure 7.1 DC shunt motor connections

1.1 Speed Control

With starting resistance at the IN position and the field rheostat set for minimum resistance, start only the motor (Dynamometer is off). When the motor comes to speed, short the starting resistor. Note the direction of rotation (looking in from the motor end of the bench).

Direction of rotation=_____

Observe the effect of changing the shunt field resistance on the motor speed. An increase in field resistance results in

_____

Turn the starting resistance to the IN position and observe the effect of increasing the armature circuit resistance on the motor speed. An increase in armature circuit resistance results in

_____

Turn the power off.

1.2 Reversal of direction of rotation of a dc motor

Investigate the effect on the direction of rotation for the following changes:

CAUTION: TURN THE POWER OFF WHEN MAKING ANY CHANGES. ALWAYS WHEN STARTING THE MOTOR MAKE SURE THE STARTING RESISTOR SWITCH IS TURNED TO THE **IN** POSITION AND THE FIELD RHEOSTAT IS SET FOR **MINIMUM** RESISTANCE.

      a.   Reverse the shunt field. Start the motor and observe the direction of rotation.

            Direction of rotation = _____

      b.   Reconnect the shunt field as per original circuit, but reverse the armature connections. Start the motor and observe the direction of rotation.

            Direction of rotation = _____

      c.   Reverse both the shunt field and armature connections. Start the motor and observe the direction of rotation.

            Direction of rotation = _____

2. Shunt motor load characteristics

The shunt motor is loaded by means of the dynamometer. Connect the dynamometer as a separately-excited dc generator as shown in Figure 7.1.

If necessary, zero the dynamometer scale. With starting resistance at the IN position and the field rheostat set for minimum resistance, start the motor. When the motor comes to speed, short the starting resistor. With the dynamometer on no-load and its field winding open (dc supply off) adjust the dc motor field rheostat for no-load speed (with field rheostat set to its minimum value). Record the following data for the motor in Table 1: the dc supply voltage, armature current, field current, motor speed and the dynamometer pull. Keep the motor field rheostat constant through this test. Energize the dynamometer field and adjust its field rheostat for a generated emf in the range of 50-110 V (to observe the dynamometer voltage connect a voltmeter across the load bank). Using the load resistor for coarse adjustments and the dynamometer field rheostat for fine adjustment, load the motor in step until it draws an armature current of approximately 8 A. Record the indicated load data in Table 1.

Table I Shunt motor

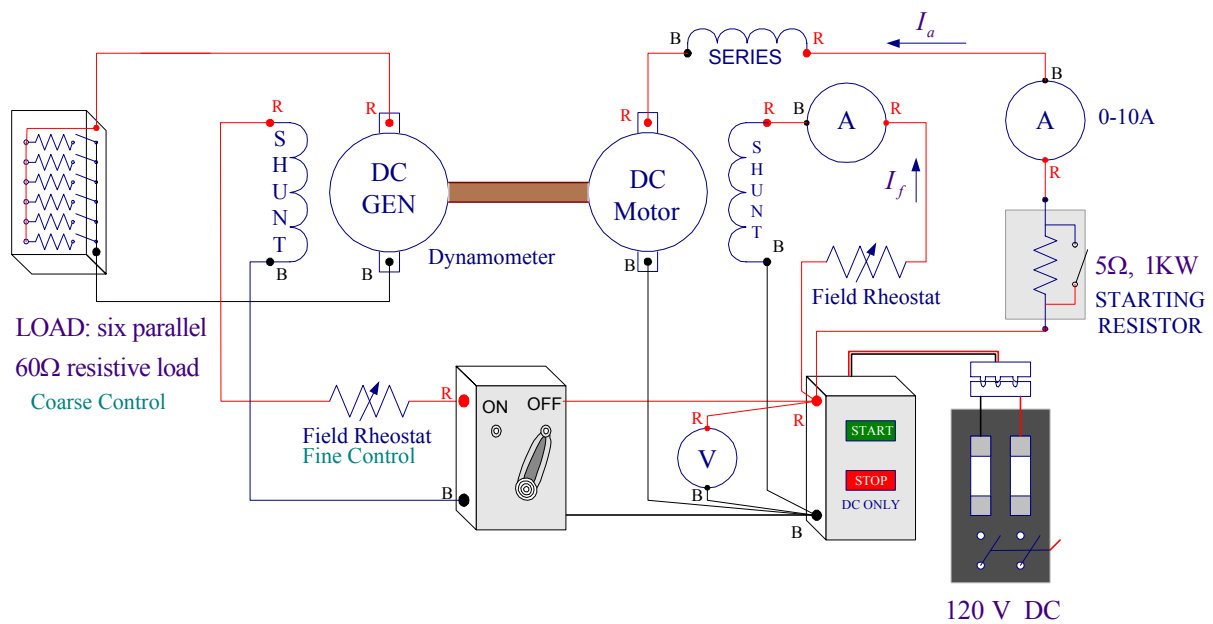| Measured Data					Calculated Data				
V Volts	I_a Amps	I_f Amps	n RPM	Pull Kg	$I_L = I_a + I_f$ Amps	$P_i = VI_L$ Watts	Torque N-m	$P_o = \omega T$ Watts	η Percent

Evaluate the calculated data and enter in Table I.

CAUTION: TURN OFF POWER BEFORE MAKING ANY CHANGES

3. Cumulatively-compound motor

Connect the dc motor for long-shunt cumulatively-compound operation by inserting the series field between armature and the ammeter shown in Figure 7.2. The black terminal of the series field should be connected to the red terminal of the armature. Leave all other connections unchanged.

Zero the dynamometer scale. With starting resistance at the IN position and the field rheostat set for minimum resistance, start the motor. When the motor comes to speed, short the starting resistor. With the dynamometer on no-load and its field winding open (dc supply off) adjust the dc motor field rheostat for the same no-load speed as before. Record the no-load data in Table II. Keep the motor field rheostat constant through this test. Energize the dynamometer field and adjust its field rheostat for a generated emf in the range of 50-110 V. Using the load resistor for coarse adjustments and the dynamometer field rheostat for fine adjustment, load the motor in step until it draws an armature current of approximately 8 A. Record the indicated load data in Table II.

Figure 7.2   Circuit for long-shunt compound motor
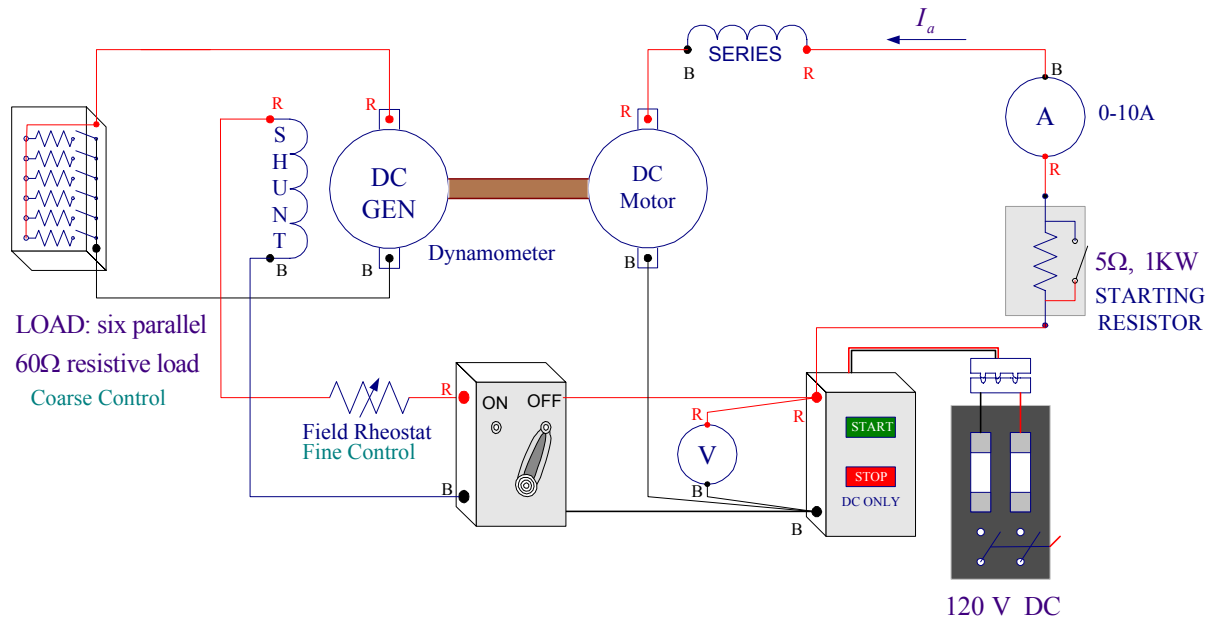
Table II Cumulatively Compound Motor

Measured Data					Calculated Data				
V Volts	I_a Amps	I_f Amps	n RPM	Pull Kg	$I_L = I_a + I_f$ Amps	$P_i = VI_L$ Watts	Torque N-m	$P_o = \omega T$ Watts	η Percent

Evaluate the calculated data and enter in Table II.

Turn the power off.

4. Series motor

Remove the shunt field connection and connect the motor for series operation as shown in Figure 7.3.

Figure 7.3 Circuit for series motor

A series motor at no-load will attain a dangerously high speed. To prevent overspeed, before starting the motor turn the dynamometer field supply on and leave one load resistor in. Start the motor. If the motor speed is too high add more load resistor on the dynamometer. Short the starting resistor. Adjust the load for an armature current of approximately 8 A. Record all the load data in Table III. Reduce the load in step until speed reaches almost 3000 rpm and at each step measure the readings. (Do not exceed 3000 rpm).

Table III Series Motor

Measured Data					Calculated Data				
V Volts	I_a Amps	$I_f = I_a$ Amps	n RPM	Pull Kg	$I_L = I_a$ Amps	$P_i = VI_L$ Watts	Torque N-m	$P_o = \omega T$ Watts	η Percent

Evaluate the calculated data and enter in Table III.

5. Use **ee340lab7** function as explained in the Appendix to check your computed data and obtain the required plots.

REPORT REQUIREMENTS

1.   Discuss the observation made in part 1.1 and explain how speed above normal and below normal are obtained for a shunt motor driven from a constant dc voltage source. Is the result consistent with equation (7.4)?

2.   In what two ways may the rotation of a shunt connected dc motor be reversed and which way is the preferred method?

3.   Using (7.8) determine the percentage speed regulation at full-load for each type of connection and compare. For the purpose of this experiment, assume that the full-load armature current is 8 A.

4.   Perform the indicated calculations in Tables I-III, and show sample calculations.

5.   Plot speed versus torque for each motor on the same sheet. Compare speed torque characteristic for different connections, and explain the theoretical basis for the shape of all the curves. Refer to (7.6) and (7.7).

6.   Plot torque versus armature current for each motor on the same sheet and discuss the curves.

7.   Plot efficiency versus output for each connection and discuss the motor efficiency.

Appendix

In MATLAB, from **F**ile/**N**ew/**M**-File, open the MATLAB Editor. Enter the data for the shunt excited dc motor in the $n \times 5$ matrix named Shunt. Each column represents a variable that must be entered in the order shown below. Enter the data for the remaining cases. Use the function named **ee340lab7** as indicated below to obtain the calculated data and the required plots. The function **ee340lab7** has been added to the MATLAB available on the MSOE network. If you have your own MATLAB student version you may download this function to your Laptop.

```
%          V         Ia         If         n         Pull
Shunt = [


                                                    ];

    %      V         Ia         If         n         Pull
Comp =   [



                                                    ];

 %         V         Ia         If         n         Pull
Series =[


                                                    ];
ee340lab7(Shunt, Comp, Series)
```