Lab 7: **DC motors: shunt, series, and compounded.**

**Objective:** to study the torque vs. speed characteristics of DC motors; to calculate the efficiency of these motor types.

**Equipment:** Power Supply, DAI, Direct current machine (DC motor) (8211), Electrodynamometer (8960), timing belt.

**Theory:**

**Electrodynamometer** measures torque. Electrodynamometer is an electrical break, in which the breaking force can be varied electrically. It consists of a stator and a squirrel-cage rotor. The stator is free to turn; however, its motion is restricted by a spring. A DC current is applied to the stator winding generating a magnetic field that passes through the stator and the rotor. The strength of the stator magnetic field can be increased or decreased by the front panel control. This strength determines the degree at which the revolving rotor can cause the stator to change position on its axis. As the rotor turns (being belt-coupled to the driving motor), a voltage is induced in the rotor bars, and the resulting eddy currents react with the magnetic field causing the stator to turn. The electrodynamometer is calibrated in Newton-meters (Nm). The power output (in horsepower) of the motor is defined by the following relation:

\[
P_{\text{out, hp}} = \frac{1.4 \cdot \omega_{\text{rpm}} \cdot T_{\text{Nm}}}{10000}
\]

where \(\omega_{\text{rpm}}\) is the motor speed in revolutions per minute, \(T_{\text{Nm}}\) is its torque in Newton-meters.

**Shunt motor.** The field coil and the armature windings are connected in shunt or parallel across the power source. The armature winding consists of relatively few turns of heavy gauge wire. The voltage across two windings is the same but the armature draws considerably more current than the field coil. Torque is caused by the interaction of the current caring armature winding with the magnetic field produced by the field coil. If the DC line voltage is constant, the armature voltage and the field strength will be constant. The speed regulation is quite good; the speed is a function of armature current and is not precisely constant. As the armature rotates within the magnetic field, an EMF is induced in its wining. This EMF is in the direction opposite to the source EMF and is called the counter EMF (CEMF), which varies with rotational speed. Finally, the current flow through the armature winding is a result of the difference between source EMF and CEMF. When the load increases, the motor tends to slow down and less CEMF is induced, which in turn increases the armature current providing more torque for the increased load.

Motor speed is increased by inserting resistance into the field coil circuit, which weakens the magnetic field. Therefore, the speed can be increased from “basic” or full-load, full-field value to some maximum speed set by the electrical and mechanical limitations of the motor.
The power difference between the motor input and the output is dissipated in form of heat and constitutes to the losses of the machine. These losses increase with load, since the motor heats up as it delivers mechanical power.

Series motor. The field coil and armature windings are connected in series to the power source. The field coil is wound with a few turns of heavy gauge wire. In this motor, the magnetic field is produced by the current flowing through the armature winding; with the result that the magnetic field is weak when the motor load is light (the armature winding draws a minimum current). The magnetic field is strong when the load is heavy (the armature winding draws a maximum current). The armature voltage is nearly equal to the PS line voltage (just as in the shunt wound motor if we neglect the small drop in the series field). Consequently, the speed of the series wound motor is entirely determined by the load current. The speed is low at heavy loads, and very high at no load. In fact, many series motors will, if operated at no load, run so fast that they destroy themselves. The high forces, associated with high speeds, cause the rotor to fly apart, often with disastrous results to people and property nearby. The torque of any DC motor depends upon the product of the armature current and the magnetic field. For the series wound motor this relationship implies that the torque will be very large for high armature currents, such as occur during start-up. The series wound motor is, therefore, well adapted to start large heavy-inertia loads, and is particularly useful as a drive motor in electric buses, trains and heavy duty traction applications. Compared to the shunt motor, the series DC motor has high starting torque and poor speed regulation.

Cumulative compound motor combines the operating characteristics of the series and shunt motors. The high torque capability of the series wound DC motor is somewhat compromised by its tendency to overspeed at light loads. This disadvantage can be overcome by adding a shunt field, connected in such a way as to aid the series field. The motor then becomes a cumulative compound machine. Again, in special applications where DC motors are used in conjunction with flywheels, the constant speed characteristic of the shunt wound motor is not entirely satisfactory since it does not permit the flywheel to give up its kinetic energy by an appropriate drop in motor speed. This kind of application (which is found in punch-press work), requires a motor with a "drooping" speed characteristic, that is, the motor speed should drop significantly with an increase in load. The cumulative compound wound DC motor is well adapted for this type of work.

The series field can also be connected so that it produces a magnetic field opposing that of the shunt field. This produces a differential compound motor, which has very limited application, principally because it tends to be unstable.

As the load increases, the armature current increases increasing the strength of the series field. Since it acts in opposition to the shunt winding, the total flux is reduced, with the result that the speed increases. An increase in speed will generally further increase the load, which raises the speed and could cause the motor to run away.

The shunt field winding places a practical limit on maximum no-load speed and it may be operated at no load. The shunt coil also provides for better speed regulation than a series motor; while the series coil provides for greater starting torque than a shunt motor. After the motor is started, the series coil is shorted out for better speed regulation. Cumulative compound motors are used where fairly constant speed under irregular loading is needed.
The speed vs. torque regulation for motors can be computed as:

\[
\text{regulation} = \frac{\omega_{\text{no load}} - \omega_{\text{full load}}}{\omega_{\text{full load}}} \cdot 100 \%
\]  

(07-2)

where \(\omega_{\text{no load}}\) and \(\omega_{\text{full load}}\) are no load and full load motor speeds.

Figure 07-1
Experiment:

1) Using the DC motor module, the electrodynamometer, PS, wires, and timing belt, construct the circuit implementing the shunt motor as shown in Figure 07-3. Do not apply power at this time! Notice that the motor is wired for shunt field operation and is connected to the variable DC source (terminals 7 and N) while the electrodynamometer is connected to the fixed low voltage AC source by the grey cable (“1” in Fig. 07-2). Using thin red wires, connect the “torque” and “speed” outputs of the dynamometer (“2” and “3” in Fig. 07-2) to the “T” and “N” terminals of the DAI; connect “ground” terminals of dynamometer (“4” in...
Set the “MODE” switch of the dynamometer to the “DYN” position and the dynamometer load control switch to the “MAN” position as shown in Fig. 07-2.

**Figure 07-3**

2) Couple the dynamometer to the DC motor by the belt (refer to Figure 07-4 while disregarding the old dynamometer). Note that the dynamometer could be installed either on the right from the motor, or on the left of it! Set the shunt field rheostat control knob on the motor at its utmost clockwise position for maximum shunt field excitation. Set the dynamometer control knob at its utmost counter-clockwise position to provide a minimum starting load for the motor.

3) Turn ON the PS and set the input voltage to 120 V as indicated by the **E1** meter. Note the direction of rotation. If it is not clockwise, turn OFF the PS and interchange the shunt field connections.

4) Adjust the shunt field rheostat for a no-load motor speed of 1800 rpm as read by the tachometer. Note that, although the dynamometer is set to a “zero” torque, due to friction and other mechanical imperfections it still exerts a non-zero load to the motor. Take this into consideration while discussing accuracy of your results. Do not change the field rheostat adjustment for the remainder of the experiment. Make sure that the input voltage is exactly 120 V. Record the values of input voltage, line current, torque, and speed (1800 rpm) in a Data table. Turn OFF the PS.
5) Turn ON the PS and apply a load to your motor by varying the dynamometer’s control knob until the indicator shows 0.2 Nm. (Readjust the PS, if necessary, to maintain the input voltage of exactly 120 V). Record the values of input voltage, line current, torque (0.2 Nm), and speed as measured by the tachometer in a Data table.

6) Repeat the same measurements – while recording the values of input voltage, line current, torque, and speed in your Data table – for the following load torques: 0.4, 0.6, 0.8, 1.0, and 1.2 Nm. Note: keep the input voltage at exactly 120 V.

7) Set the input voltage to zero, set the dynamometer control knob to its utmost clockwise position to provide the maximum starting load for the motor. Gradually increase the input DC voltage until the motor is drawing the line current of 3 A. The motor should either rotate very slowly, or be still. Record the values of input voltage, line current, torque, and speed in your Data table. Turn OFF the PS.

8) While keeping the dynamometer’s connections unchanged, construct the series DC motor as shown in Figure 07-5. Do not apply power at this time! Notice that the motor is wired for series operation and is connected to the variable DC source (terminals 7 and N) while the electrodynamometer is connected to the fixed low power AC source. Couple the dynamometer to the DC motor by the belt.
9) Turn ON the PS and gradually increase the input voltage. Note the direction of rotation. If it is not clockwise, turn OFF the PS and interchange the series field connections (terminals 3 and 4). Set the input voltage to approximately 120 V as indicated by the \( E_1 \) meter (Note: strictly speaking, the input voltage should be exactly 120 V. However, the motor speed could be very high. Therefore, considering the age of the equipment, it might be necessary keep the motor at safer speed levels, say, not exceeding 2500 rpm). Record the values of input voltage, line current, torque, and speed in a Data table.

10) Repeat the same measurements – while recording the values of input voltage, line current, torque, and speed in your Data table – for the following load torques: 0.4, 0.6, 0.8, 1.0, and 1.2 Nm. Note: keep the input voltage at exactly the value as was determined in 9).

11) Set the input voltage to zero, set the dynamometer control knob to its utmost clockwise position to provide the maximum starting load for the motor. Gradually increase the input DC voltage until the motor is drawing the line current of 3 A. The motor should rotate very slowly. Record the values of input voltage, line current, torque, and speed in your Data table. Turn OFF the PS.

12) While keeping the dynamometer’s connections unchanged, modify your circuit as shown in Figure 07-6. First, uncouple the dynamometer from the motor. Couple the dynamometer to the DC motor by the belt.
13) Turn ON the PS and set the input voltage to 120 V as indicated by the meter. If the motor is running at an excessively high speed then it is in the *differential-compound mode*. If this is the case, return voltage to zero and turn OFF the PS. Interchange the shunt field connections to terminals 1 and 4 to obtain the *cumulative-compound mode* of operation.

14) With the input voltage at exactly 120 V, adjust the shunt field rheostat for a no-load motor speed of 1800 rpm as measured by the tachometer. Record the values of input voltage, line current, torque, and speed (1800 rpm) in a Data table.

15) Repeat the same measurements – while recording the values of input voltage, line current, torque, and speed in your Data table – for the following load torques: 0.4, 0.6, 0.8, 1.0, and 1.2 Nm. Note: keep the input voltage at exactly 120 V. *Note: do not readjust the shunt field!*

16) Set the input voltage to zero, set the dynamometer control knob to its utmost clockwise position to provide the maximum starting load for the motor. Gradually increase the input DC voltage until the motor is drawing the line current of 3 A. The motor should either rotate very slowly or be still. Record the values of input voltage, line current, torque, and speed in your Data table. Turn OFF the PS; disconnect your circuit.

**In your report:**

1) Using Matlab, for the data collected in Parts 4, 5, and 6, plot the shunt motor speed vs. its torque characteristic.

2) For the data collected for the shunt motor, calculate and report the speed vs. torque regulation for the shunt motor assuming that the full load = 1.0 Nm.

3) The line current measured in Part 7 is limited only by the equivalent DC resistance of the shunt motor. Baring this in mind, calculate the value of starting current for the maximum starting load and the full line voltage of 120 V applied to the shunt motor. *Hint: you may need to estimate the armature resistance first.*
4) On separate axes, using the data collected in Parts 9 and 10, plot the series motor speed vs. its torque characteristic.

5) For the data collected for the series motor, calculate and report its speed vs. torque regulation assuming that the full load = 1.0 Nm.

6) The line current measured in Part 11 is limited by the equivalent DC resistance of the series wound motor. Baring this in mind, calculate the value of starting current for the maximum starting load and the full line voltage of 120 V applied to the series motor.

7) On separate axes, using the data collected in Parts 14 and 15, plot the compounded motor speed vs. its torque characteristic.

8) For the data collected for the compound motor, calculate and report its speed vs. torque regulation assuming that the full load = 1.0 Nm.

9) The line current measured in Part 16 is limited only by the equivalent DC resistance of the compound wound motor. Baring this in mind, calculate the value of starting current for the maximum starting load and the full line voltage of 120 V applied to the series motor.

10) Compare speed vs. torque characteristics, speed regulations, and starting currents of the three types of DC motors you studied. What are your conclusions?