EE 448

Lab Experiment No. 4

Introduction to DC Motors
I. INTRODUCTION

The purpose of this experiment is to examine the construction of a DC motor/generator, to learn the basic motor wiring connections, and to study the performance characteristics of a shunt and series dc motor. **INSTRUMENTS AND COMPONENTS:**

- Power Supply Module (120Vac, 0-120Vdc)   EMS 8821
- DC Metering Module (200V, 5A)    EMS 8412
- DC Motor/Generator Module     EMS 8211
- Connections Leads       EMS 8941
- Timing Belt        EMS 8942
- Electrodynamometer Module     EMS 8911
- Strobotac

II. BACKGROUND

Direct current motors are unsurpassed for adjustable-speed applications, and for applications with severe torque requirements. Millions of fractional horsepower DC motors are used by the transportation industries in automobiles, trains and aircraft where they drive fans and blowers for air conditioners, heaters and defrosters; they operate windshield wipers and raise and lower seats and windows. One of their most useful functions is for the starting of gasoline and Diesel engines in autos, trucks, buses, tractors and boats.

The DC motor contains a **stator** and a **rotor**, the latter being more commonly called an **armature**. The **stator** contains one or more windings per pole, all of which are designed to carry direct current, thereby setting up a magnetic field.

The **armature** and its windings are located in the path of this magnetic field, and when the winding also carries a current, a torque is developed causing the motor to turn.

A **commutator** associated with the armature winding is actually a mechanical device, to assure that the armature current under any given stator pole will always circulate in the same direction irrespective of position. If a commutator were not used, the motor could not make more than a fraction of a turn, before coming to a halt.

In order for a DC motor to run, current must flow in the armature winding and the stator must develop a magnetic field (flux), either by means of a shunt winding or a series winding (or both).

The torque developed by a DC motor is directly proportional to the armature current and the stator flux. On the other hand, motor speed **increases** when the voltage applied to the armature increases. Motor speed will also **increase** when the stator flux is **reduced**. As a matter of fact, the speed can attain dangerous levels if,
accidentally, there is a complete loss of the stator field. DC motors have been known to fly apart under these over speed conditions. However, your DC motor has been carefully designed to withstand possible over speed conditions.

In a shunt motor, the field winding, as well as the armature winding, is connected in parallel (shunt) directly to the dc supply lines. If the dc line voltage is constant, then the armature voltage and the field strength will be constant. It is, therefore, apparent that the shunt motor should run at a reasonably constant speed. The speed does tend to drop with an increasing load on the motor. This drop in speed is mainly due to the resistance of the armature winding. Shunt motors with low armature winding resistance run at nearly constant speeds through a broad range of loads.

Just like most energy conversion devices, the dc shunt motor is not 100% efficient. In other words, all of the electric power which is supplied to the motor is not converted into mechanical power. The power difference between the input and output is dissipated in the form of heat, and constitutes what are known as the "losses" of the machine. These losses increase with load, with the result that the motor gets hot as it delivers more mechanical power.

The series motor behaves quite differently. In this motor, the magnetic field is produced by the current which flows through the armature winding; with the result that the magnetic field is weak when the motor load is light (the armature winding draws minimum current). The magnetic field is strong when the load is heavy (the armature winding draws maximum current). The armature voltage is nearly equal to the supply 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.

III. PRELAB EXERCISES

In the lab you will be measuring the quantities: source voltage, field current, armature current, speed, and load torque. Suppose these measurements are 120V, 0.25A, 2.6A, 1675rpm, and 9 lbf.in.

- Compute the speed and load torque in SI units (rad/sec and Nm respectively)
• Assuming shunt connected DC motor, compute back emf, field resistance, armature resistance, field loss, armature loss, power efficiency, starting torque, and no-load speed. Assuming stator flux to be linear function of field current, determine the constant $K_F$.

• Suppose the connection is switched to series mode while maintaining the same voltage and load torque $= 0.25$ lbf.in. Assuming stator flux to be linear function of field current, determine the new speed, armature/field current, back emf, field loss, armature loss, power efficiency, and starting torque.

IV. LABORATORY EXPERIMENTS

CAUTION! HIGH VOLTAGES ARE PRESENT IN THIS LABORATORY EXPERIMENT! DO NOT MAKE ANY CONNECTIONS WITH THE POWER ON! THE POWER SHOULD BE TURNED OFF AFTER COMPLETING EACH INDIVIDUAL MEASUREMENT!

A. Examine the construction of the DC Motor/Generator module, EMS 8211 paying particular attention to the motor, rheostat, connection terminals and wiring. Note that the motor housing has been designed to allow you to view the internal construction. Most commercial motors do not have this open construction.

• Viewing the motor from the rear of the module:
  a. Identify the armature winding.
  b. Identify the stator poles.
  c. How many stator poles are there?
  d. The shunt field winding on each stator pole is composed of many turns of small diameter wire. Identify the shunt field winding.
  e. The series field winding, wound inside the shunt field winding on each stator pole, is composed of fewer turns of larger diameter wire. Identify the series field winding.

• Viewing the motor from the front of the module:
  a. Identify the commutator.
  b. Approximately how many commutator bars (segments) are there?
  c. How many brushes are there?
  d. The neutral position of the brushes is indicated by a red dot marked on the motor housing. Identify it.
  e. The brushes can be positioned on the commutator by moving the brush adjustment lever to the right or to the left of the red indicator dot. Move the lever both ways and then return it to the neutral position.

• Viewing the front face of the module:
  a. Identify the shunt field winding (many turns of fine wire) is connected to terminals __________ and __________.
  b. The series field winding (fewer turns of heavier wire) is connected to terminals __________ and __________.
  c. The brushes (commutator segments and armature winding) are connected to terminals __________ and __________.
• The rheostat, mounted on the module face, is designed to control (and safely
carry) the shunt field current. It is connected to terminals __________ and __________. What is its maximum resistance
value_____________________________?

B. Connect the circuit shown in Figure 1. Note that the armature is connected to
the variable 0-120Vdc output (terminals 7 and N) while the shunt field is
connected to the fixed 120Vdc output (terminals 8 and N).

![Figure 1: Separately Excited Connection Diagram](image)

• Turn on the power supply. Adjust the armature voltage to values shown in
Table 1. Use your strobotac and measure the motor speed. Record your
speed measurement in Table 1. (Wait until the motor speed stabilizes before
you take your measurement). Plot each of the points from Table 1 (i.e. Plot
speed versus armature voltage). Draw a smooth curve through your plotted
points.

<table>
<thead>
<tr>
<th>V (volts)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEED (rpm)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Speed versus Armature Voltage Measurements
C. Using your EMS Power Supply, DC Motor/Generator, DC Metering and Electrodynamometer Modules, connect the circuit shown in Figure 2. **DO NOT APPLY POWER AT THIS TIME!** Notice that the motor is wired for shunt field operation and is connected to the variable dc output of the power supply (terminals 7 and N). The electrodynamometer is connected to the fixed 120V ac output of the power supply (terminals 1 and N). Do not couple the dynamometer to the dc motor/generator with the timing belt at this time.

- Set the shunt field rheostat control knob at its full CW position (for maximum shunt field excitation). Turn on the power supply. Adjust the variable output voltage to 120Vdc as indicated by the meter. Adjust the shunt field rheostat for a no-load motor speed of 1800 r.p.m. as indicated on your strobotac. (Make sure that the volt-meter, connected
across the input of your circuit, indicates exactly 120Vdc). Measure the armature and field currents as indicated by the ammeters, for a motor speed of 1800 r.p.m. Record these values in Table 2.

- Return the voltage to zero and turn off the power supply. Couple the dynamometer to the dc motor/generator with the timing belt. Set the dynamometer control knob at its full CCW position. Turn on the power supply and adjust the variable output voltage to 120Vdc. Readjust the field current using the field rheostat to the value obtained in previous step if necessary. Apply a load to your dc motor by varying the dynamometer control knob until the scale marked on the dynamometer housing indicates 3 lbf.in. (Readjust the power supply, if necessary, to maintain exactly 120Vdc). Measure the armature and field currents and motor speed. Record these values in Table 2. Repeat for each of the torque values listed in Table 2, while maintaining a constant 120Vdc input. Return the voltage to zero and turn off the power supply.

### Table 2: Shunt Connected

<table>
<thead>
<tr>
<th>V (volts)</th>
<th>I_a (amps)</th>
<th>I_f (amps)</th>
<th>SPEED (rpm)</th>
<th>TORQUE (lbf.in)</th>
<th>P_in (watts)</th>
<th>P_out (watts)</th>
<th>eff (%)</th>
</tr>
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<tr>
<td>120</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<tr>
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<td>3</td>
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<td>120</td>
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<td>6</td>
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<tr>
<td>120</td>
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<td>9</td>
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<tr>
<td>120</td>
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<td>12</td>
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</tbody>
</table>

- Plot the recorded motor speed values from Table 2 (i.e. Plot speed versus torque). Draw a smooth curve through your plotted points. The completed graph represents the speed vs torque characteristics of a typical dc shunt-wound motor.

- Calculate the speed regulation for the shunt connected motor (full load = 9 lbf.in) using the equation:

\[
\text{Speed regulation} = \frac{\text{speed(no load)} - \text{speed(full load)}}{\text{speed(full load)}} = \text{___________}%
\]

- Set the dynamometer control knob at its full CW position (to provide the maximum starting load for the shunt-wound motor). Turn on the power supply and gradually increase the dc voltage until the motor is drawing 3
amperes of armature current. The motor should turn slowly or not at all. Measure and record the dc voltage and the torque developed.

\[ V = \text{________} \text{ Volts} \quad \text{torque} = \text{________} \text{ lbf.in} \]

- Return the voltage to zero and turn off the power supply. The armature current in the previous step is limited only by the equivalent dc resistance of the shunt-wound motor. Calculate the value of the starting armature current if the full line voltage (120Vdc) were applied to the shunt-wound dc motor.

Starting current = ____________ A

D. Using your EMS Power Supply, DC Motor/Generator, DC Metering and Electro-dynamometer Modules, connect the circuit shown in Figure 3. **DO NOT APPLY POWER AT THIS TIME!** Do not couple the dynamometer to the dc motor/generator with the timing belt until later. Notice that the motor is wired for series operation (the shunt field winding and the rheostat are not used) and is connected to the variable dc output of the power supply (terminals 7 and N). The electrodynamometer is connected to the fixed 120Vac output of the power supply (terminals 1 and N).

![Series Connection Diagram](image)

**Figure 3: Series Connection Diagram**
• Turn on the power supply. Gradually increase the supply control until the voltage reaches exactly 120Vdc. Measure the line current and motor speed. Record the values in Table 3.
• Return the voltage to zero and turn off the power supply. Couple the dynamometer to the dc motor/generator with the timing belt. Set the dynamometer control knob at its full mid-range position (to provide a starting load for the motor). Turn on the power supply and adjust the variable voltage to 120Vdc. Adjust the loading of your dc series wound motor by varying the dynamometer control knob until the scale marked on the dynamometer housing indicates 3 lbf.in. (Readjust the power supply, if necessary, to maintain exactly 120Vdc). Measure the line current and motor speed. Record these values in Table 3. Repeat for each of the torque values listed in Table 3, while maintaining a constant 120Vdc input. Return the voltage to zero and turn off the power supply.

Table 3: Series Connected

<table>
<thead>
<tr>
<th>V (volts)</th>
<th>Ia (amps)</th>
<th>SPEED (rpm)</th>
<th>TORQUE (lbf.in)</th>
<th>P_in (watts)</th>
<th>P_out (watts)</th>
<th>eff (%)</th>
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</thead>
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</tbody>
</table>

• Plot the recorded motor speed values from Table 3 (i.e. Plot speed versus torque). Draw a smooth curve through your plotted points. The completed graph represents the speed vs torque characteristics of a typical dc series wound motor.
• Calculate the speed regulation for the series connected motor (full load = 9 lbf.in).

Speed regulation = _____________%
• Set the dynamometer control knob at its full cw position (to provide the maximum starting load for the series wound motor). Turn on the power supply and gradually increase the dc voltage until the motor is drawing 3 amperes of armature current. The motor should turn slowly. Measure and
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record the dc voltage and the torque developed.

\[ V = \text{___________} \text{Volts} \quad \text{TORQUE} = \text{___________} \text{lbf.in} \]

- Return the voltage to zero and turn off the power supply. The line current in previous step is limited by the equivalent dc resistance of the series wound motor. Calculate the value of the starting current if the full line voltage (120Vdc) were applied to the series wound dc motor.

Starting current = \text{______________} \text{A}

V. CONCLUSION

1. Calculate the starting torques from the torque-speed graphs.

2. How does the starting torque vary between motors operating at the same current?

3. Which motor has better speed regulation and why?