Experiment 11

The Direct Current Motor – Part I

OBJECTIVE

- To examine the construction of a DC motor / generator.
- To measure the resistance of its windings.
- To study the nominal current capabilities of the various windings.

DISCUSSION

Direct current motors are unsurpassed for adjustable-speed applications, and for applications with severe torque requirements. Uncounted millions of small power [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 winding 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.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

The Direct Current Motor – Part I

☐ 1. Examine the construction of the DC Motor/Generator 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.

☐ 2. 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?

4
___

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 pose, is composed of fewer turns of larger diameter wire. Identify the series field winding.

☐ 3. Viewing the motor from the front of the module:

a. Identify the commutator.

b. Approximately how many commutator bars (segments) are there?

12
___

c. How many brushes are there?

2
___

d. The neutral position of the brushes is indicated by a red line 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 the left of the red indicator line. Move the lever both ways and then return it to the neutral position.

☐ 4. Viewing the front face of the module:

a. The shunt field winding (many turns of fine wire) is connected to terminals __5__ and __6__.

b. The series field winding (fewer turns of heavier wire) is connected to terminals __3__ and __4__.

c. The current rating for each winding is marked on the face of the module. Can you answer (a) and (b) having only this information? Explain.

☑ Yes ☐ No

Series windings use much more current

d. The brushes (commutator segments and armature winding) are connected to terminals 1 and 2.

☑ 5. The rheostat, mounted on the module face, is designed to control (and safely carry) the shunt field current.

a. It is connected to terminals 7 and 8.

b. What is its rated resistance value?

$R_{(field\ rheostat)}$ 500 Ω

☑ 6. You will now measure the resistance of each of the motor windings using the voltmeter-ammeter method. With this information you will calculate the power losses for each of the windings. Using your Power Supply, DC Voltmeter/Ammeter and DC Motor/Generator, connect the circuit shown in Figure 11-1.

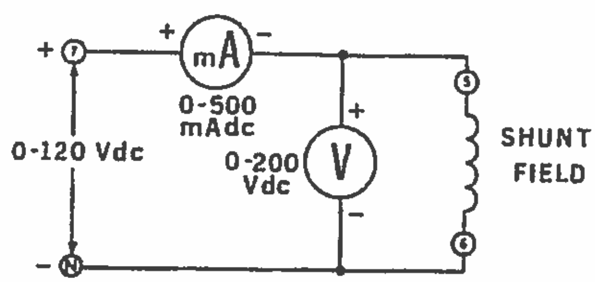


Figure 11-1.

☑ 7. Turn on the power supply.

a. Slowly increase the DC voltage until the shunt field winding is carrying 0.3 A of current as indicated by the 0-500 A dc meter (this is the nominal current value for the shunt field winding).

b. Measure and record the voltage across the shunt field winding.

$E_{(shunt\ field)}$ = 78 V dc (55 sd, 78 icad

c. Return the voltage to zero and turn off the power supply.

d. Calculate the resistance of the shunt field winding.

$R_{(shunt\ field)}$ = E/I = 78 / 0.3 = 260 Ω

e. Calculate the I^2R (power) losses of the shunt field winding.

$P_{(shunt\ field)}$ = I^2R = $(0.3)^2$ x 260 = 23.4 W

8. Connect the circuit shown in Figure 11-2.

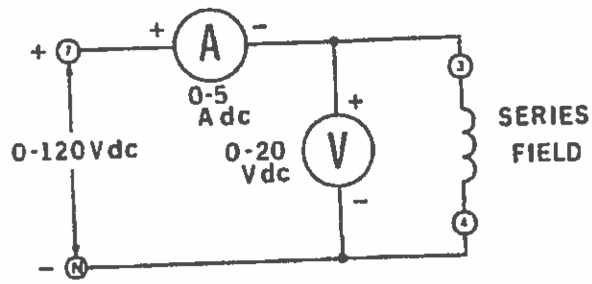


Figure 11-2.

a. This is the same circuit as shown in Figure 11-1 except that the series field winding has replaced the shunt field winding and that the 5 A dc meter has replaced the 500 mA dc meter.

b. Turn on the power supply. Slowly increase de DC voltage until the series field winding is carrying 3 A of current as indicated by the 5 A dc meter. (this is the nominal current value for the series field winding). **Warning! This only requires a few volts so advance the voltage control slowly.**

c. Measure and record the voltage across the series field winding.

$E_{(series\ field)}$ = 5.3 V dc

d. Return the voltage to zero and turn off the power supply.

e. Calculate the resistance of the series field winding.

$R_{(series\ field)}$ = E/I = 5.3 / 3 = 1.77 Ω

f. Calculate the I^2R losses of the series field winding.

$P_{(series\ field)}$ = I^2R = 3^2 x 1.77 = 15.9 W

☐ 9. Connect the circuit shown in Figure 11-3.

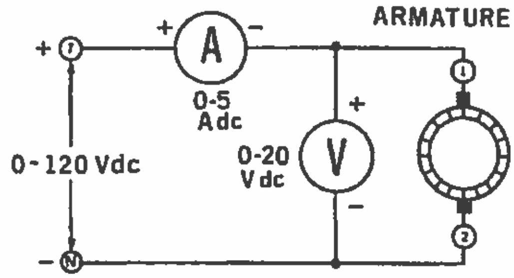


Figure 11-3.

Steps 9-11 don't make sense because the motor rotates at high speed.

a. This is the same circuit shown in Figure 11-2 except that the armature winding (plus the brushes) has replaced the series field winding.

b. Turn on the power supply. Slowly increase the DC voltage until the armature winding is carrying 3 A of current as indicated by the 5 A dc meter (this is the nominal current value for the armature winding).

c. Measure and record the voltage across the armature winding (plus brushes).

$E_{(armature)}$ = _____ V dc

d. Return the voltage to zero and turn off the power supply.

e. Calculate the resistance of the armature winding (plus brushes).

$R_{(armature)}$ = E/I = _____ / _____ = 7.6 Ω

f. Calculate the I^2R losses of the armature (plus brushes).

$P_{(armature)} = I^2R$ = _____ x _____ = _____ W

☐ 10. Rotate the armature winding approximately 90° to the left.

a. The brushes are now making contact with different commutator segments.

b. Repeat procedure 9.

c. E = _____ V dc, R = _____ Ω, P = _____ W

☐ 11. Rotate the armature 15° further to the left.

a. Repeat procedure 9.

b. E = ______ V dc, R = ______ Ω, P = ______ W

REVIEW QUESTIONS

1. What would be the shunt field current of your motor if the shunt field winding is excited by 120 V dc?

   $120V = I \cdot 260\Omega$ $I = 0.462 A$

2. If a current of 3 A dc flows in the series field winding of your motor, what would the resultant voltage drop be?

   $V = 3A \cdot 1.77\Omega = 5.31 V$

3. If the rheostat were connected in series with the shunt field winding and the combination placed across a 120 V dc line, what shunt field current variations could be obtained from your motor?

   $120V = I_{max} \cdot 260\Omega$ $I_{max} = 0.46A$ $120V = I_{min} \cdot (260\Omega + 500\Omega)$ $0.16A$

   $I_{minimum}$ = 0.16 A dc $I_{maximum}$ = 0.46 A dc

4. All of the windings and even the commutator of your motor are made of copper. Why?

   Copper is a good conductor

5. Why are the brushes or your motor made of carbon rather than copper?

   Carbon provides better physical contact characteristics.

6. If the series field winding of your motor was connected directly across the 120 V dc supply:

   a) What current would flow?

   $120V = I \cdot 1.77\Omega$ $I = 67.8A$

   b) What would the power loss be (in watts)?

   8136 W

   c) Is this power loss entirely given up as heat?

   ☐ Yes ☑ No

d) What do you think would happen to the winding if the current were sustained for a few minutes?

It would melt, likely causing an open circuit or short.

7. What is meant by a "nominal current" or "nominal voltage"?

It means the standard value in normal conditions.

8. If the armature winding and the series field winding of your motor were connected in series across a 120 V dc source, what would the starting current be?

$120V = I \cdot (1.77\Omega + 7.6\Omega)$ $I = 12.8 A$

9. In your motor, is the armature (plus brushes) resistance substantially the same for every rotational position of the armature? Explain.

☒ Yes ☐ No

The current always flows through approximately the same number of windings.

Experiment 12

The Direct Current Motor – Part II

OBJECTIVE

- To locate the neutral brush position.
- To learn the basic motor wiring connections.
- To observe the operating characteristics of series and shunt connected motors.

DISCUSSION

In order of a DC motor to run, current must flow in the armature winding. 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 is mainly determined by the armature voltage and the stator flux. 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 proportions if, accidentally, there is a complete loss of the stator field. DC motors have been known to fly apart under these overspeed conditions. However, your DC motor has been carefully designed to withstand possible overspeed condition.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

Finding the Neutral

☑ 1. You will now determine the neutral brush position for your DC motor by using alternating current. Using your Power Supply, AC Voltmeter and DC Motor/Generator, connect the circuit shown in Figure 12-1. Terminals 4 and N on the power supply will furnish variable 0-120 V ac as the voltage output control is advanced.

The Direct Current Motor – Part II

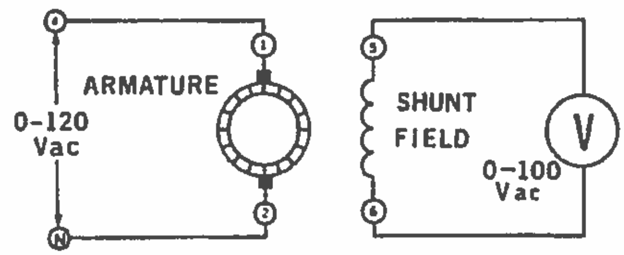


Figure 12-1.

DO NOT APPLY POWER AT THIS TIME!

☑ 2. Unlock the DC Motor/Generator and move it forward approximately 10 cm [4 in]. Reach behind the front face of the module and move the brush positioning lever to its maximum clockwise position. Do not slide the module back in place (you will later move the brushes again).

☑ 3. Turn on the power supply. Place the power supply voltmeter switch to its 4-N position. Slowly advance the voltage output control until the AC voltmeter connected across the shunt field winding indicates approximately 80 V ac. (The AC voltage across the shunt field is induced by the AC current through the armature. This will be covered in a later Experiment).

80V clockwise, 85V counter clockwise

☑ 4. a. Carefully reach behind the front face of the module (preferably keeping one hand in your pocket) and move the brushes from one extreme position to another. You will notice that the induced AC voltage across the field drops to zero and then increases again as you approach the other extreme counter-clockwise position.

b. Leave the brushes at the position where the induced voltage is zero. This is the neutral point of your DC Motor/Generator.

The leftmost AC Voltmeter on the 0-100V range gives exagerated values (reads 80V when it's about 55V).

Each time you use the DC Motor/Generator the brushes should be set at the neutral position.

c. Return the voltage to zero and turn off the power supply. Slide your DC Motor/Generator back in place and disconnect your circuit.

Series Motor Connections

☑ 5. Using your Power Supply, DC Voltmeter/Ammeter and DC Motor/Generator, connect the circuit shown in Figure 12-2. Notice that the armature is connected in series with the series field winding, across the input voltage.

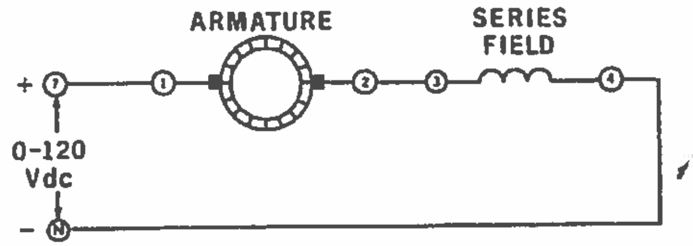


Figure 12-2.

☑ 6. Turn on the power supply. Place the power supply voltmeter switch to its 7-N position. Adjust the output voltage to 120 V dc.

☑ 7. a. Does the motor turn fast?

☑ Yes ☐ No

b. Using your hand tachometer, measure the motor speed in revolutions per minute.

Series speed = 5000 r/min (about; it wasn't at 120V most of the time)

Note: *The operating instructions are enclosed within the tachometer container.*

☑ 8. a. Reduce the power supply voltage and note the effect on motor speed. Comments:

Speed reduces a lot

b. Reduce the voltage until you can determine the direction of rotation (clockwise or counterclockwise).

Rotation = Clockwise

c. Reduce the voltage to zero and turn off the power supply.

☑ 9. Reconnect your circuit as shown in Figure 12-3. (The only change made to the circuit of Figure 12-2 is that the connections to the armature have been reversed).

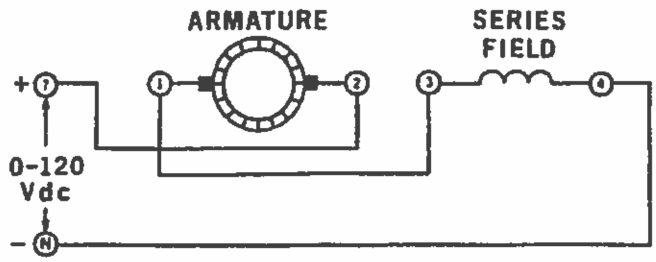


Figure 12-3.

☑ 10. Repeat procedures 6 through 8 (using the reversed armature connections shown in Figure 12-3).

Series speed$_{(reversed)}$ = ______ r/min   900 RPM @ 20V (higher voltage not measured)

Rotation = Counter clockwise

☑ 11. State a rule for changing the direction of rotation of a series connected DC motor.

Reverse the direction of the current through the armature.

Shunt Motor Connections

☑ 12. Connect the circuit shown in Figure 12-4. Notice that the rheostat is in series with the shunt field, and that this combination is in parallel with the armature, across the input voltage.

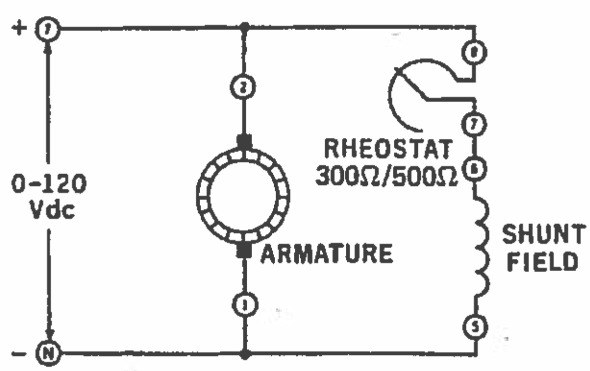


Figure 12-4.

☑ 13. a. Adjust the rheostat for minimum resistance (approximately 0 Ω, when turned fully clockwise).

b. Turn on your power supply and adjust for 120 V dc.

c. Using your tachometer measure the motor speed.

Shunt speed$_{(zero\ ohms)}$ = 790 r/min @20V

d. Adjust the rheostat for maximum resistance (approximately 500 Ω). 1030@20V

e. Determine the direction of rotation.

Rotation = clockwise

☑ 14. a. Return the voltage to zero and turn off the power supply.

b. Reverse the polarity of the input voltage by interchanging the power supply connection leads only.

☑ 15. Repeat procedure 13 and compare your results:

a. Did the rotation change direction?

☐ Yes ☑ No

b. Did the speed change?

☐ Yes ☑ No

c. Return the voltage to zero and turn off the power supply.

☑ 16. Interchange the connection leads to the power supply. Your circuit should be the same as the one shown in Figure 12-4. Now reverse the connections to the armature only.

☑ 17. Repeat procedure 13 and compare the direction of rotation to that found in procedure 13.

Rotation = Counter clockwise

☑ 18. a. While the motor is still running, momentarily open the shunt field circuit by removing the connection lead from one of the terminals of the shunt field winding (5 or 6). Be extremely careful not to touch any of the other terminal connections or any metal during this procedure. Be prepared to immediately cut power to the motor by turning off the power supply.

b. Explain what happens when a DC motor loses power to its shunt field.

It stopped very quickly

c. Could the same thing occur in a series field connected DC motor? Explain.

☐ Yes ☑ No

If current does not flow through the series field it won't flow through the armature either.

☐ 19. Connect the circuit shown in Figure 12-5. Note that the armature is connected to the variable 0-120 V dc output (terminals 7 and N) while the shunt field is now connected to the fixed 120 V dc output (terminals 8 and N).

132 V (measured

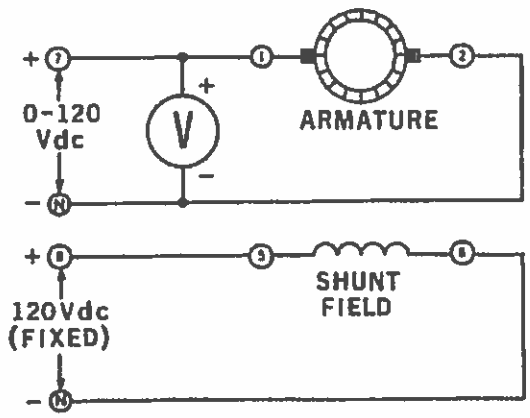


Figure 12-5.

☑ 20. a. Turn on the power supply. Adjust the armature voltage to 30 V dc as indicated by the meter.

b. Use your hand tachometer and measure the motor speed. Record your speed measurement in Table 12-1. (Wait until the motor speed stabilizes before you take your measurement).

c. Repeat (b) for each of the voltage values listed in the Table. Return voltage to zero and turn off the power supply.

E (volts)	0	30	60	90	120
SPEED (r/min)	0	330	590	950	1185

Table 12-1.

d. Plot each of the points from Table 12-1 on the graph shown in Figure 12-6. Draw a smooth curve through your plotted points.

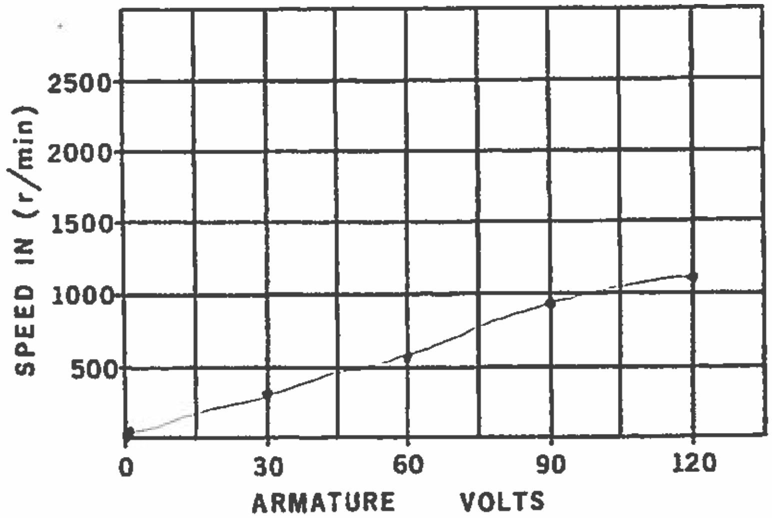


Figure 12-6.

e. Does varying the armature voltage (with the shunt field voltage held constant) offer a good method of speed control?

☑ Yes ☐ No

REVIEW QUESTIONS

1. Explain how to locate the neutral brush position in a DC motor.

   Apply power to the armature and measure voltage acros the shunt field winding. Move the brushes until the voltage induced in the shunt winding is 0.

2. Would the motor turn if only the armature were excited (had voltage applied across it)?

   ☑ Yes ☐ No (Very surprised)

3. Why is it dangerous to supply power to an unloaded series connected DC motor?

   It can spin too fast and fly appart

4. In what two ways may the rotation of a shunt connected DC motor be reversed?

   Reverse direction of current through the armature.
   Reverse direction of current through the shunt windings.

5. Why are field loss detectors necessary in large DC motors?

If the field is lost it needs to cut power or it can run too fast and fly apart.

6. In procedure 20:

a) Does the motor speed double when the armature voltage is doubled? Explain.

☐ Yes ☑ No

Almost. It is very close to doing so, but not quite.

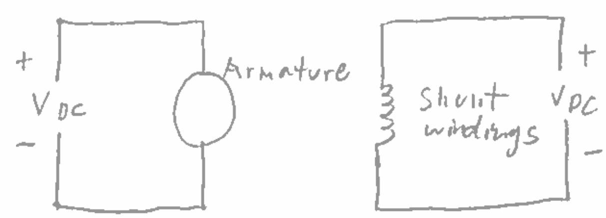
b) Would it be correct to say "with a fixed field voltage, the speed of a shunt motor is proportional to its armature voltage?" Explain.

☐ Yes ☑ No

It is very close to linear but not quite.

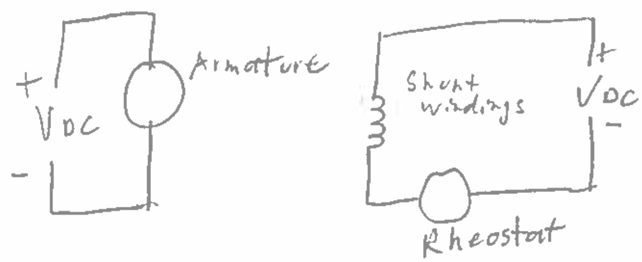
7. Draw a circuit showing how you would connect:

a) a shunt motor to a DC supply.

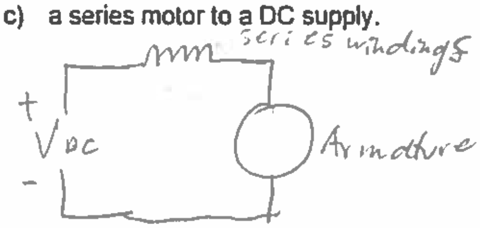


(Alternatively use the same power supply for both armature and shunt field windings).

b) a shunt motor to a DC supply, using a field rheostat.



c) a series motor to a DC supply.



8. In what two ways can the speed of DC motor be varied?

a) Change the voltage to the armature.

b) change the current through the field windings

(and of course, change the load).

9. Of the two methods given in (8):

   a) which method gives the greatest speed range? a______

   b) which method is the most economical (uses fewer parts)? a______

Experiment 24

The DC Shunt Motor

OBJECTIVE

- To study the torque vs speed characteristics of a shunt wound DC motor.
- To calculate the efficiency of the shunt wound DC motor.

DISCUSSION

The speed of any DC motor depends mainly upon its armature voltage and the strength of the magnetic field. 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.

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 mechanical power.

In this Experiment you will investigate the efficiency of a DC shunt motor.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

The DC Shunt Motor

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Using your Power Supply, DC Motor/Generator, DC Voltmeter/Ammeter and Electrodynamometer, connect the circuit shown in Figure 24-1.

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 120 V ac output of the power supply (terminals 1 and N).

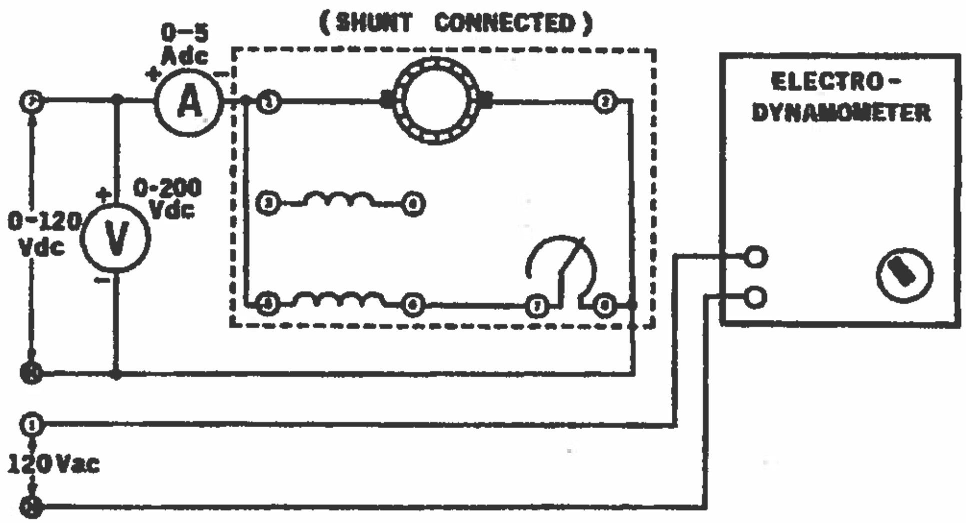


Figure 24-1.

Couple the dynamometer to the DC motor/generator with the timing belt as shown in the photo.

☑ 2. Set the shunt field rheostat control knob at its full cw position (for maximum shunt field excitation). Make sure the brushes are in their neutral position.

☑ 3. Set the dynamometer control knob at its full ccw position (to provide a minimum starting load for the DC motor).

The DC Shunt Motor

☑ 4. Turn on the power supply. Adjust the variable output voltage to 120 V dc as indicated by the meter. Note the direction of rotation; if it is not clockwise, turn off the power supply and interchange the shunt field connections.

☑ 5. a. Adjust the shunt field rheostat for a no-load motor speed of 1800 r/min as indicated on your hand tachometer. (Make sure that the voltmeter, connected across the input of your circuit, indicates exactly 120 V dc).

> **Note:** *Do not change the field rheostat adjustment for the remainder of the experiment.*

b. Measure the line current, as indicated by the ammeter, for a motor speed of 1800 r/min. Record this value in Table 24-1.

> **Note:** *For an exact torque of 0 N·m [0 lbf·in], uncouple the motor from the dynamometer.*

E (volts)	I (amps)	SPEED (r/min)	TORQUE (N·m)
120	0.4	1800	0
120	1.3	1710	0.3
120	1.8	1630	0.6
120	2.4	1550	0.9
120	3.2	1470	1.2

Table 24-1.

Actually used the lbf·in values

E (volts)	I (amps)	SPEED (r/min)	TORQUE (lbf·in)
120			0
120			3
120			6
120			9
120			12

Table 24-1.

☑ 6. a. Apply a load to your DC motor by varying the dynamometer control knob until the scale marked on the stator housing indicates 0.3 N·m [3 lbf·in]. (Readjust the power supply, if necessary, to maintain exactly 120 V dc).

b. Measure the line current and motor speed. Record these values in Table 24-1.

c. Repeat for each of the torque values listed in the Table, while maintaining a constant 120 V dc input.

d. Return the voltage to zero and turn off the power supply.

☑ 7. a. Plot the recorded motor speed values from Table 24-1 on the graph of Figure 24-2.

b. Draw a smooth curve through your plotted points.

c. The completed graph represents the speed vs torque characteristics of a typical DC shunt-wound motor. Similar graphs for series wound and compound wound DC motors will be constructed in the following two Experiments. The speed vs torque characteristics for each type of motor will then be compared and evaluated.

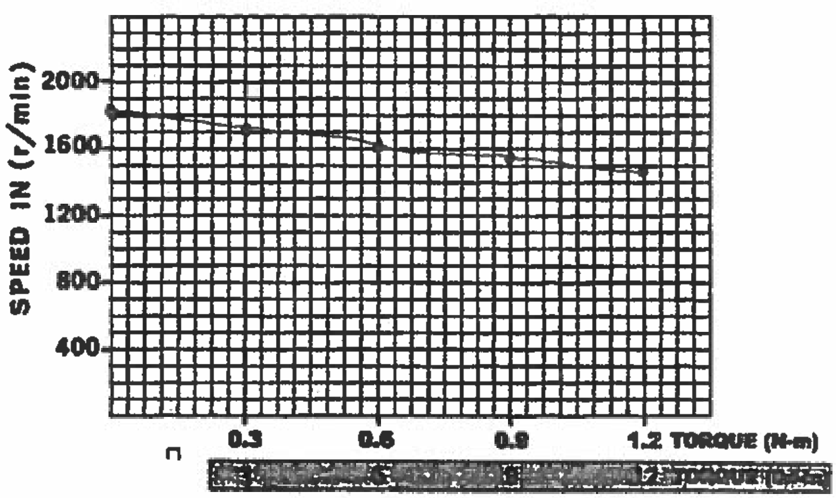


Figure 24-2.

☑ 8. Calculate the speed vs torque regulation (full load = 1.2 N·m [9 lbf·in]) using the equation:

$$\text{Regulation} = \frac{(\text{no load speed}) - (\text{full load speed})}{(\text{full load speed})} \times 100\%$$

Speed regulation = 22 %

The DC Shunt Motor

☑ 9. Set the dynamometer control knob at its full cw position (to provide the maximum starting load for the shunt-wound motor).

☑ 10. a. Turn on the power supply and gradually increase the DC voltage until the motor is drawing 3 A of line current. The motor should turn very slowly or not at all.

b. Measure and record the DC voltage and the torque developed.

E = 24 V Torque = 1.3 N·m [lbf·in] (lbf·in) 0.147 Nm

c. Return the voltage to zero and turn off the power supply.

☑ 11. a. The line current in procedure 10 is limited only by the equivalent DC resistance of the shunt-wound motor.

b. Calculate the value of the starting current if the full line voltage (120 V dc) were applied to the shunt-wound DC motor.

Starting current = 15 A

$V = IR$ $\quad 120 = I \cdot 8$

$24 = 3 \cdot R$ $\quad I = 15$

$R = 8$

REVIEW QUESTIONS

1. Calculate the mechanical output power by the shunt-wound DC motor when the torque is 1.2 N·m [9 lbf·in]. Use the equation: (12 lb·in = 1.36 N·m)

$$P_{out}\ (W) = \frac{2\pi \times N \times T}{60} = \frac{2\pi \times 1470 \times 1.36}{60} = 209\ W$$

where: P_{out} = Mechanical Output Power in watts (W)
N = Speed in revolutions per minute (r/min)
T = Torque in Newton·meter (N·m)

$$P_{out}\ (hp) = \frac{1.59 \times N \times T}{100\ 000}$$

where: P_{out} = Mechanical Output Power in horse power (hp)
N = Speed in revolutions per minute (r/min)
T = Torque in pound-force-inches (lbf·in)

P_{out} = 0.28 W [hp]

The DC Shunt Motor

[redacted]

209 W

[redacted] W

2. What is the input power (in watts) of the motor in Question 1?

Input power = 384 W

3. Knowing the input and output power in watts, calculate the efficiency of the motor in Question 1.

Efficiency = (power out/power in) x 100%

Efficiency = 54 %

4. What are the losses (in watts of the motor in Question 1)?

Losses = 175 W

5. List where some of these losses occur.

Heat, produced in all wiring and even the belt.

The DC Shunt Motor

6. Would the losses decrease if a cooling fan is mounted on the motor shaft? Explain.

   ☐ Yes ☑ No

   It would disipate heat but not reduce losses.

7. Give two reasons why losses are undesirable.

   They consume power and heat the motor

8. How much larger is the starting current than the normal full load current?

   15A - 3.2A = 11.8A

Experiment 25

The DC Series Motor

OBJECTIVE

- To study the torque vs speed characteristics of a series wound DC motor.
- To calculate the efficiency of the series wound DC motor.

DISCUSSION

The shunt wound DC motor was seen to have almost constant speed because its armature voltage and magnetic field remained substantially unchanged from no-load to full-load. 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.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

The DC Series Motor

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Using your Power Supply, DC Motor/Generator, DC Voltmeter/Ammeter and Electrodynamometer, connect the circuit shown in Figure 25-1.

DO NOT APPLY POWER AT THIS TIME!

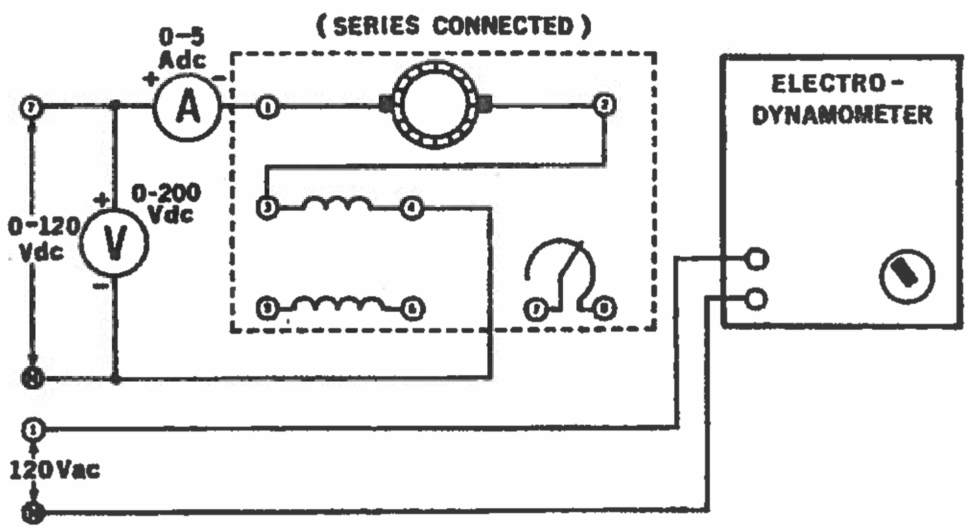


Figure 25-1.

Couple the dynamometer to the DC motor/generator with the timing belt.

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 120 V ac output of the power supply (terminals 1 and N).

☑ 2. Set the dynamometer control knob at its mid-range position (to provide a starting load for the DC motor).

The DC Series Motor

☑ 3. a. Turn on the power supply. Gradually increase the DC voltage until the motor starts to turn. Note the direction of rotation. If it is not cw, turn off the power and interchange the series field connections.

b. Adjust the variable voltage for exactly 120 V dc as indicated by the meter.

☑ 4. a. Adjust the loading of your DC series wound motor by varying the dynamometer control knob until the scale marked on the stator housing indicates 1.2 N·m [12 lbf·in]. (Readjust the power supply, if necessary, to maintain exactly 120 V dc).

b. Measure the line current and motor speed (use your hand tachometer). Record these values in Table 25-1.

c. Repeat for each of the torque values listed in the Table, while maintaining a constant 120 V dc input.

d. Return the voltage to zero and turn off the power supply.

E (volts)	I (amps)	SPEED (r/min)	TORQUE (N·m)	Inch lb
120	0.23	4800	0	0
120	1.4	2130	0.3	2.66
120	1.8	1720	0.6	5.3
120	2.2	1520	0.9	8.0
120	2.6	1380	1.2	10.6

Table 25-1.

E (volts)	I (amps)	SPEED (r/min)	TORQUE (lbf·in)
120			0
120			3
120			6
120			9
120			12

Table 25-1.

Note: *For an exact torque of 0 N·m [lbf·in], uncouple the motor from the dynamometer.*

The DC Series Motor

☑ 5. a. Plot the recorded motor speed values from Table 25-1 on the graph of Figure 25-2.

b. Draw a smooth curve through your plotted points.

c. The completed graph represents the speed vs torque characteristics of a typical DC series wound motor. A similar graph for the compound wound DC motor will be constructed in the next Experiment. the speed vs torque characteristics for each type of motor will then be compared and evaluated.

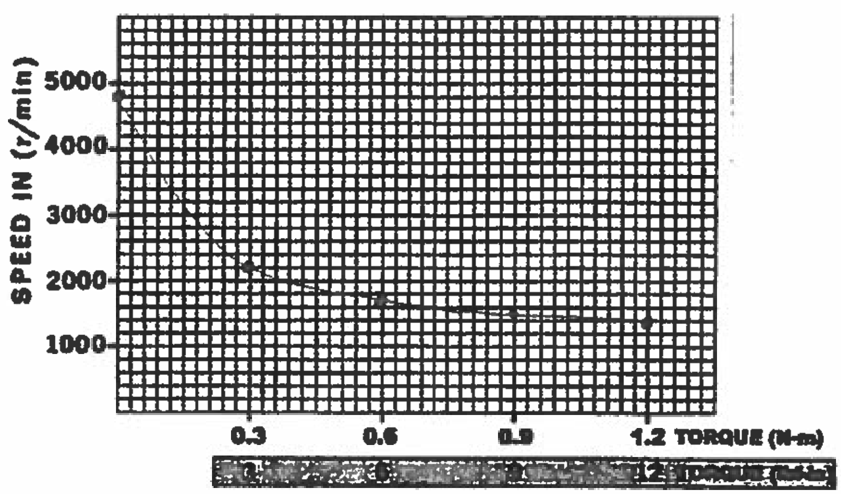


Figure 25-2.

☑ 6. Calculate the speed vs torque regulation (full load = 1.2 N·m [redacted] using the equation:

$$\text{Regulation} = \frac{(\text{no load speed}) - (\text{full load speed})}{(\text{full load speed})} \times 100\%$$

Speed regulation = 248 %

☑ 7. Set the dynamometer control knob at its full cw position (to provide the maximum starting load for the series wound motor).

☑ 8. a. Turn on the power supply and gradually increase the DC voltage until the motor is drawing 3 A of line current. The motor should turn slowly.

b. Measure and record the DC voltage and the torque developed.

E = 35 V   Torque = 14 in·lb N·m [lbf·in] = 1.58 N·m

c. Return the voltage to zero and turn off the power supply.

☐ 9. a. The line current in procedure 8 is limited by the equivalent DC resistance of the series wound motor.

b. Calculate the value of the starting current if the full line voltage (120 V dc) were applied to the series wound DC motor.

Starting current = 10.3 A

REVIEW QUESTIONS

1. Calculate the mechanical output power developed by the series wound DC motor when the torque is 1.2 N·m [9 lbf·in]. Use the equation:

$$P_{out}\ (W) = \frac{2\pi \times N \times T}{60}$$ 173.4

where: P_{out} = Mechanical Output Power in watts (W)
N = Speed in revolutions per minute (r/min)
T = Torque in Newton·meter (N·m)

$$P_{out}\ (hp) = \frac{1.59 \times N \times T}{100\ 000}$$

where: P_{out} = Mechanical Output Power in horse power (hp)
N = Speed in revolutions per minute (r/min)
T = Torque in pound-force-inches (lbf·in)

$\frac{1.59 \cdot 1380 \cdot 10.62}{100000} = 0.233$

P_{out} = 0.233 W [hp]

1. Knowing that 1 hp is equivalent to 746 W, what is the equivalent "output power" of the motor?

174 W

Output power = ____ W

The DC Series Motor

2. What is the input power (in watts) of the motor in Question 1?

   170v·2.6A = 312 W

   Input power = 312 W

3. Knowing the input and output power in watts, calculate the efficiency of the motor in Question 1.

   $\frac{174}{312} \times 100 = 55.77$

   Efficiency = 56 %

4. What are the losses (in watts) of the motor in Question 1?

   312 - 174 = 138

   Losses = 138 W

?

5. How much larger is the starting current than the normal full load current?

   10.3A - 2.6A = 7.4A

6. Compare the shunt wound DC motor and the series wound DC motor on the basis of:

   a) Starting torque Shunt: 0.147 N·m, Series 1.58 N·m
   Series provides greater torque

   b) Starting current Shunt: 15A, Series: 10.3

   c) Efficiency Shunt: 54%, Series: 56%, not a significant difference

   d) Speed regulation Shunt has much more steady speed across torque (Shunt: 22.4%, Series: 248%)

Experiment 26

The DC Compound Motor

OBJECTIVE

- To study the torque vs speed characteristics of a compound wound DC motor.
- To calculate the efficiency of the compound wound DC motor.

DISCUSSION

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 use in conjunction with flywheels, the constant speed characteristic of the shunt wound motor is not entirely satisfactory, because 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 "dropping" 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.

Thus, as the load increases, the armature current increases, which increases 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 still more and could cause the motor runaway.

Differential compound motors are sometimes made with weak series fields which compensate somewhat for the normal slowing of a shunt motor under load and, hence, have more constant speed. Differential compound motors are not used very often.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

The DC Compound Motor

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Using your Power Supply, DC Motor/Generator, DC Voltmeter/Ammeter and Electrodynamometer, connect the circuit shown in Figure 26-1.

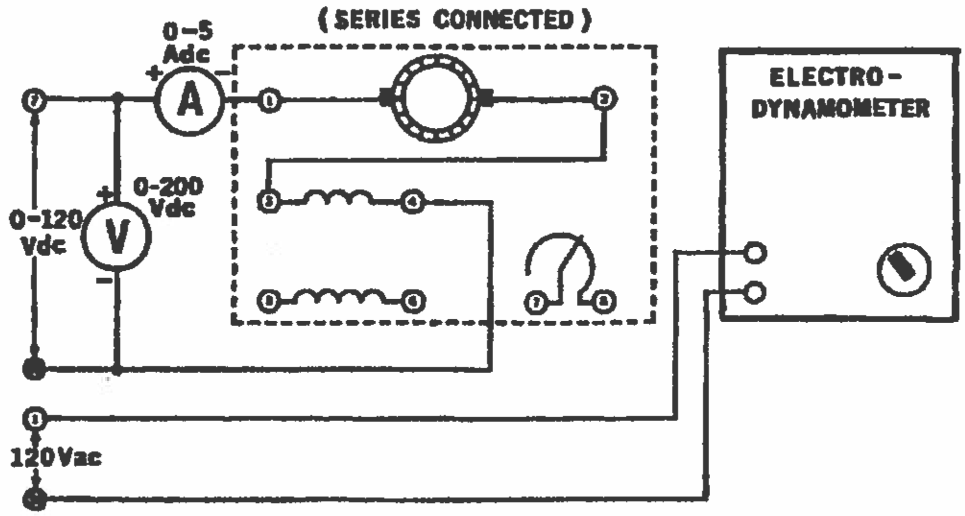


Figure 26-1.

DO NOT APPLY POWER AT THIS TIME!

Couple the dynamometer to the DC motor/generator with the timing belt.

Notice that the motor is wired for series operation (the shunt field winding and the rheostat not in the circuit as yet), and is connected to the variable DC output of the power supply (terminals 7 and N). The electrodynamometer is connected to the fixed 120 V ac output of the power supply (terminals 1 and N).

☑ 2. Set the dynamometer control knob at its full ccw position (to provide a minimum starting load for the motor).

☑ 3. a. Turn on the power supply. Gradually increase the DC voltage until the motor starts to turn. Note the direction of rotation. If it is no cw, turn off the power and interchange the series field connections.

b. Return the voltage to zero and turn off the power supply.

☐ 4. Connect the shunt field, in series with the rheostat, to terminals 1 and 4 as shown in Figure 26-2.

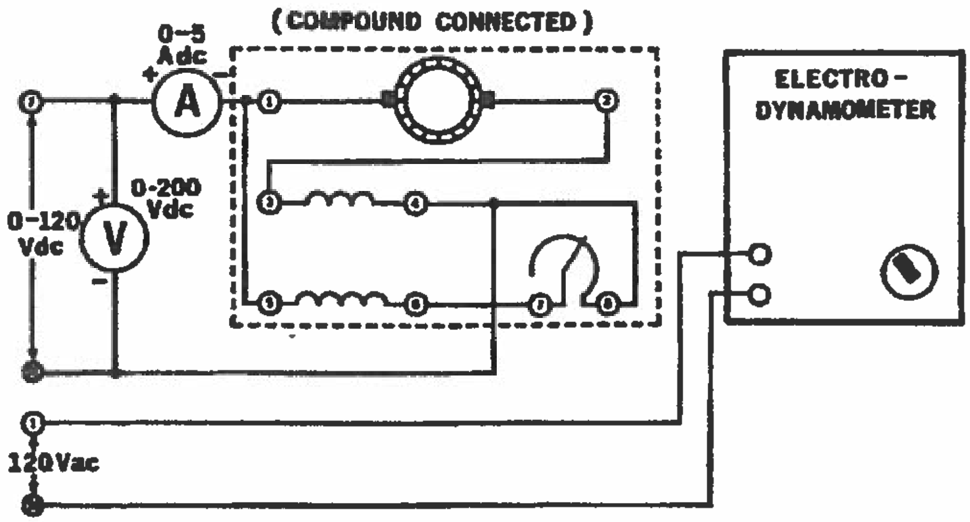


Figure 26-2.

☑ 5. Turn on the power supply. Adjust the voltage for 120 V dc 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 the voltage to zero and turn off the power supply. Interchange the shunt field connections to terminals 1 and 4 to obtain the cumulative-compound mode of operation.

☑ 6. With the input at exactly 120 V dc adjust the shunt field rheostat for a no-load motor speed of 1800 r/min as indicated by your hand tachometer.

Note: *Do not change the field rheostat adjustment for the remainder of the experiment.*

☐ 7. a. Apply a load to your DC motor by varying the dynamometer control knob until the scale marked on the stator housing indicates 0.3 N·m (3 lbf·in). (Readjust the power supply, if necessary, to maintain exactly 120 V dc).

The DC Compound Motor

b. Measure the line current and motor speed. Record these values in Table 26-1.

c. Repeat for each of the torque values listed in the Table, while maintaining a constant 120 V dc input.

d. Return the voltage to zero and turn off the power supply.

E (volts)	I (amps)	SPEED (r/min)	TORQUE (N·m)	lbf·in	N·m
120	0.4	1800	0	0	0
120	1.15	1400	0.3	3	0.34
120	1.5	1310	0.6	6	0.68
120	1.95	1200	0.9	9	1.02
120	2.3	1130	1.2	12	1.36

Table 26-1.

E (volts)	[illegible]	[illegible]	TORQUE (N·m)
120	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]

Table 26-1.

Note: For an exact torque of 0 N·m [redacted], uncouple the motor from the dynamometer.

☑ 8. a. Plot the recorded motor speed values from Table 26-1 on the graph of Figure 26-3.

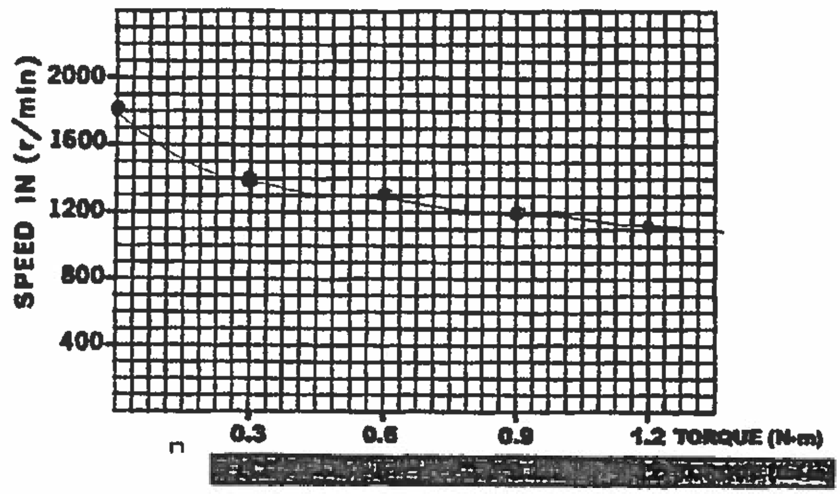


Figure 26-3.

b. Draw a smooth curve through your plotted points.

c. The completed graph represents the speed vs torque characteristics of a typical DC compound wound motor.

☑ 9. Calculate the speed vs torque regulation (full load = 1.2 N·m [redacted]) using the equation:

$$\text{Regulation} = \frac{(\text{no load speed}) - (\text{full load speed})}{(\text{full load speed})} \times 100\%$$

Speed regulation = 59.2 %

☑ 10. Set the dynamometer control knob at its full cw position (to provide the maximum starting load for the compound wound motor).

☑ 11. a. Turn on the power supply and gradually increase the DC voltage until the motor is drawing 3 A of line current. The motor should turn very slowly or not at all.

b. Measure and record the DC voltage and the torque developed.

E = 36 V Torque = 15.5 lbf·in N·m [redacted] (1.75 N·m)

c. Return the voltage to zero and turn off the power supply.

The DC Compound Motor

☐ 12. a. The line current in procedure 11 is limited only by the equivalent DC resistance of the compound wound motor.

b. Calculate the value of the starting current in the full line voltage 120 V dc) were applied to the compound wound DC motor.

Starting current = 10 A

$V = IR$
$36 = 3 \cdot R \quad R = 12\,\Omega$
$120 = I \cdot 12$
$I = 10\,A$

REVIEW QUESTIONS

1. Calculate the mechanical output power developed by the compound wound DC motor when the torque is 1.2 N·m [redacted]. Use the equation:

$$P_{out}\,(W) = \frac{2\pi \times N \times T}{60}$$

where: P_{out} = Mechanical Output Power in watts (W)
N = Speed in revolutions per minute (r/min)
T = Torque in Newton-meter (N·m)

[redacted]

____

____

____

P_{out} = ______ W [redacted] 0.216 Hp

[redacted]

____

____

[redacted]

The DC Compound Motor

2. What is the input power (in watts) of the motor in Question 1?

Input power = 161 W

3. Knowing the input and output power in watts, calculate the efficiency of the motor in Question 1.

161

1202.3

Efficiency = 45 %

4. What are the losses (in watts) of the motor in Question 1?

Losses = 199 W

5. How much larger is the starting current than the normal full load current?

10A − 2.3A = 7.7A

6. A compound wound DC motor is more stable than a series wound DC motor and its starting characteristics are almost as good. Explain this statement.

A compound wound DC motor does not spin out of control as easily as a series wound motor at low torque.

7. Compare the compound, series and shunt motors on the basis of:

a) Starting torque Compound: 1.75 N·m

Series: 1.58 N·m Shunt: 0.147 N·m

The DC Compound Motor

b) **Starting current** Compound: 10A
Series: 10.3 Shunt: 15A

c) **Efficiency** Compound: 45%
Series: 56% Shunt: 54%

d) **Speed regulation** Compound: 59.3%
Series: 248% Shunt: 22.4%

Experiment 27

The DC Separately Excited Shunt Generator

OBJECTIVE

- To study the properties of the separately excited DC shunt generator under no-load and full-load conditions.
- To obtain the saturation curve of the generator.
- To obtain the armature voltage vs armature current load curve of the generator.

DISCUSSION

A DC machine can run either as a motor or as a generator. A motor converts electrical power into mechanical power while a generator converts mechanical power into electrical power. A generator must, therefore, be mechanically driven in order that it may produce electricity.

Since the field winding is an electromagnet, current must flow through it to produce a magnetic field. This current is called the excitation current, and can be supplied to the field winding in one of two ways; it can come from a separate, external DC source, in which case the generator is called a separately excited generator; or it can come from the generator's own output, in which case the generator is called a self-excited generator.

Assume that the shunt field is excited by a DC current, thereby setting up a magnetic flux in the generator. If the rotor (or more correctly, the armature) is rotated by applying mechanical effort to the shaft, the armature coils will cut the magnetic flux, and a voltage will be induced in them. This voltage is AC and in order to get DC out of the generator, a rectifier must be employed. This role is carried out by the commutator and the brushes.

The voltage induced in the coils (and, therefore, the DC voltage at the brushes) depends only upon two things - the speed of rotation and the strength of the magnetic field. If the speed is doubled, the voltage doubles. If the field strength is increased by 20%, the voltage also increases by 20%.

Although separate excitation requires a separate DC power source, it is useful in cases where a generator must respond quickly and precisely to an external control source, or when the output voltage must be varied over a wide range.

With no electrical load connected to the generator, no current flows and only a voltage appears at the output. However, if a resistance load is connected across the output, current will flow and the generator will begin to deliver electric power to the load.

The machine which drives the generator must then furnish additional mechanical power to the generator. This is often accompanied by increased noise and vibration of the motor and the generator, together with a drop in speed.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

No Load Characteristics

☑ 1. Because of its constant running speed, the synchronous motor will be used to mechanically drive the DC generator. Using your Power Supply, AC Ammeter and Three-Phase Synchronous Motor/Generator, connect the circuit shown in Figure 27-1.

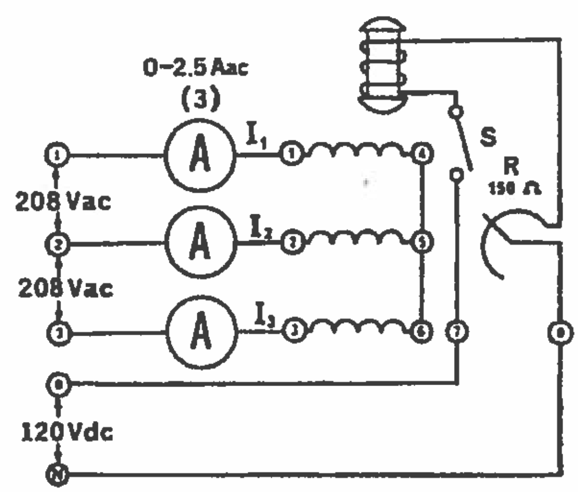


Figure 27-1.

DO NOT APPLY POWER AT THIS TIME!

☑ 2. Terminals 1, 2 and 3 on the power supply provide fixed three-phase power for the three stator windings. (Three-phase power will be covered in later Experiments). Terminals 8 and N on the power supply provide fixed DC power for the rotor winding. Set the rheostat control knob to its proper position for normal excitation (Experiment 23, procedure 6).

☑ 3. a. Using your DC Motor/Generator and DC Voltmeter/Ammeter, connect the circuit shown in Figure 27-2.

b. Connect the shunt field of the generator, terminals 5 and 6, to the variable DC output of the power supply, terminals 7 and N, while connecting the 500 mA meter in series with the positive lead.

c. Connect the 200 V dc meter across the generator output (armature (terminals 1 and 2).

d. Couple the synchronous motor and the DC generator with the timing belt.

e. Make sure the brushes are in their neutral position.

f. Have your instructor check your circuit.

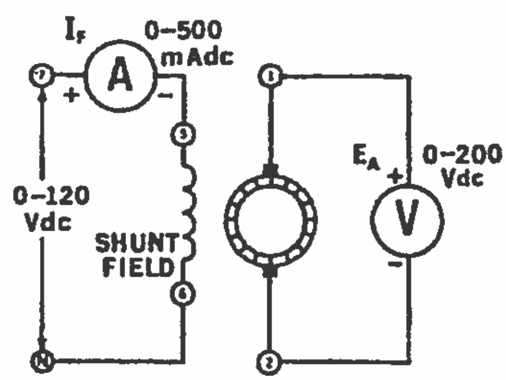


Figure 27-2.

CAUTION!

The switch in the excitation circuit of the synchronous motor should be closed (I) only when the motor is running.

☑ 4. a. Turn on the power supply. The synchronous motor should start running.

b. Close the switch S.

c. Vary the shunt field current I_F by rotating the voltage control knob on the power supply. Note the effect on the generator output (armature voltage) E_A as indicated by the 200 V dc meter.

d. Measure and record in Table 27-1 the armature voltage E_A for each of the listed field currents.

I_F (milliamperes)	E_A (volts)	
0	11.5	12.4
50	27	26.3
100	47.5	50
150	71	73
200	92	95
250	111	114.5
300	126	130
350	138	143
400	149	153

Table 27-1.

e. Return the voltage to zero and turn off the power supply.

f. Can you explain why there is an armature voltage even when the field current is zero?

There is residual magnetism in the field coils.

5. a. Reverse the polarity of the shunt field by interchanging the leads to terminals 5 and 6 on the DC generator.

b. Turn on the power supply and adjust for a field current I_F of 300 mA dc.

c. Did the armature voltage reverse its polarity?

☑ Yes ☐ No

d. Return the voltage to zero and turn of the power supply.

☐ 6. a. Interchange the leads to the 200 V dc meter.

b. Turn on the power supply and adjust for a field current I_F of 300 mA dc.

c. Measure and record the armature voltage.

E_A = 127.4 V dc

d. Is the armature voltage approximately the same as in procedure 4 (at an I_F of 300 mA), except for reversed polarity?

☑ Yes ☐ No

e. Return the voltage to zero and turn off the power supply.

☑ 7. a. Reverse the rotation of the driving motor by interchanging any two of the stator lead connections (terminals 1, 2 or 3) to the synchronous motor.

b. Turn on the power supply and adjust for a field current I_F of 300 mA dc.

c. Did the armature voltage reverse its polarity?

☑ Yes ☐ No

d. Return the voltage to zero and turn off the power supply.

☑ 8. a. Interchange the leads to the 200 V dc meter.

b. Turn on the power supply and adjust for a field current I_F of 300 mA dc.

c. Measure and record the armature voltage.

E_A = 124 V dc

d. Is the armature voltage approximately the same as in procedure 4 (at an I_F of 300 mA), except for reversed polarity?

☑ Yes ☐ No

e. Return the voltage to zero and turn off the power supply.

Load Characteristics

☑ 9. Using your Resistive Load, connect the circuit shown in Figure 27-3. Place the resistance switches so that the total load resistance is 120 Ω.

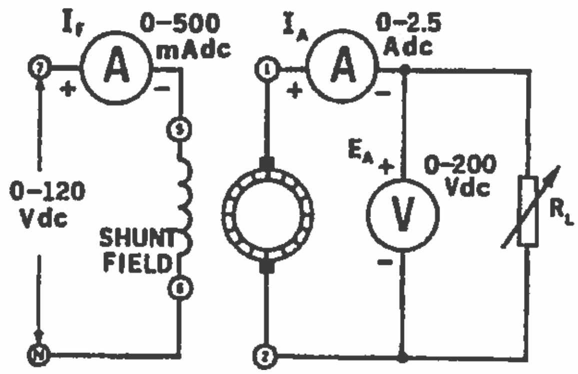


Figure 27-3.

☑ 10. a. Turn on the power supply. The synchronous motor should start running.

b. Adjust the shunt field current I_F until the generator is delivering an output voltage of 120 V dc. The ammeter I_A should indicate 1 A dc.

c. Record the shunt field current I_F.

I_F = 330 mA

This is the nominal I_F at the rated power output (120 V x 1 A = 120 W) of the DC generator.

☑ 11. a. Adjust the load resistance to obtain each of the values listed in Table 27-2 while maintaining the nominal I_F value found in procedure 10.

b. Measure and record E_A and I_A for each of the resistance values listed in the Table.

Note: *Although the nominal output current rating of the generator is 1 A dc, it may be loaded up to 1.5 A dc (50% overload) without harm.*

R_L (ohms)	I_A (amps)	E_A (volts)	POWER (watts)
∞	0	136	0
600	0.1	134	13.4
300	0.45	131	58.95
200	0.65	130	84.5
150	0.8	124	99.2
120	1.0	121	121
100	1.08	117	126.36
80	1.35	112	151.2
75	1.45	110	159.5

Table 27-2.

☑ 12. a. With the load resistance adjusted for an output current I_A of 1.5 A, turn the field current I_F on and off by removing the connecting lead from terminal 6 to the DC generator.

b. Do you notice that the driving motor is obviously working harder when the generator is delivering power to the load?

☑ Yes ☐ No

c. Return the voltage to zero and turn off the power supply.

☑ 13. Calculate and record the power for each of the values listed in Table 27-2.

☐ 14. a. Place a dead short across the armature (terminals 1 and 2).

b. Make sure that the power supply voltage control knob is turned down for zero field current.

c. Turn on the power supply.

d. Gradually increase the field current I_F until the motor stalls.

If I recall correctly, I attempted this step but had issues getting the motor to stall fast enough to safely/comfortably take a reading. I was concerned, so I skipped over it.

CAUTION!

Do not leave the motor in the stalled condition for more than a couple of seconds.

e. What value of shunt field current I_F is needed to stall the motor?

I_F = ______ mA

f. Turn off the power supply.

Note: *With a short-circuit across the armature, its current becomes very large; this produces a strong braking effect sufficient to stall the driving motor.*

REVIEW QUESTIONS

1. State two ways by which the output polarity of a shunt DC generator can be changed.

Reverse the direction of current through the shunt field, or reverse the direction the generator is driven

2. If a DC generator delivers 180 W to a load, what is the minimum mechanical power (in watts) needed to drive the generator (assume 80% efficiency)?

225 W

2. If a DC generator delivers 180 W to a load, what is the minimum hp needed to drive the generator (assume 100% efficiency)?

0.241

3. Plot the E_A vs I_F characteristic curve for your DC shunt generator on the graph of Figure 27-4. Use the data from Table 27-1. Note that the curve "bends over" as the field current increases. Can you explain why this happens?

The generator can only produce so much power. As the current increases linearly the voltage will begin to drop.

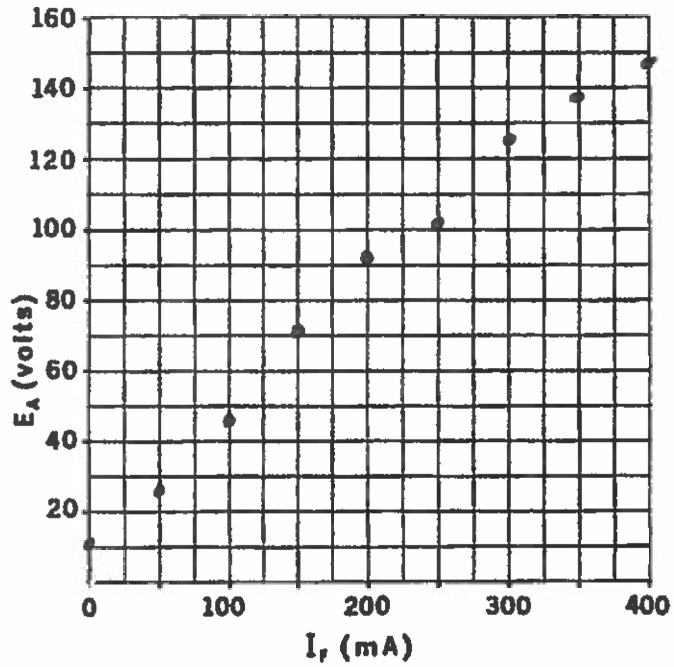


Figure 27-4.

4. Plot the E_A vs I_A regulation curve on the graph of Figure 27-5. Use the data from Table 27-2.

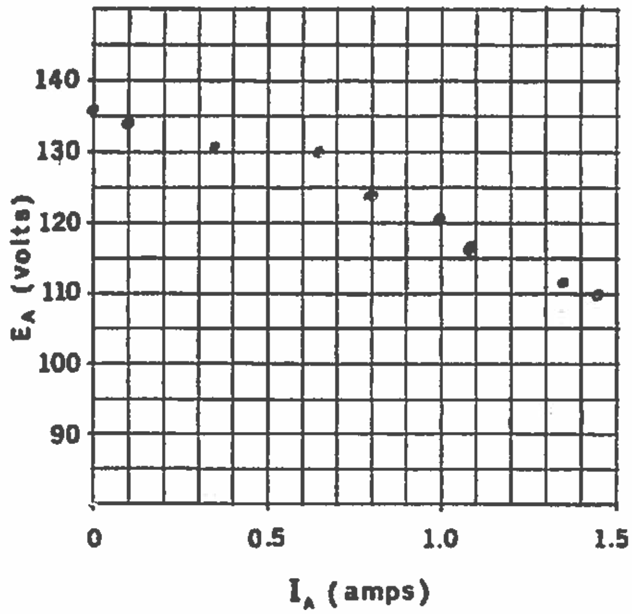


Figure 27-5.

5. Calculate the regulation from no-load to full-load (1 A dc).

$\frac{136-121}{121} = 0.123967$

Regulation = 12 %

Experiment 28

The DC Self-Excited Shunt Generator

OBJECTIVE

- To study the properties of the self-excited DC shunt generator under no-load and full-load conditions.
- To learn how to connect the self-excited generator.
- To obtain the armature voltage vs armature current load curve of the generator.

DISCUSSION

The separately-excited generator (Experiment 27) has many applications. However, it does have the disadvantage that a separate direct current power source is needed to excite the shunt field. This is costly and sometimes inconvenient; and the self-excited DC generator is often more suitable.

In a self-excited generator, the field winding is connected to the generator output. It may be connected across the output, in series with the output, or a combination of the two. The way in which the field is connected (shunt, series or compound) determines many of the generator's characteristics.

All of the above generators can have identical construction. Self-excitation is possible because of the residual magnetism in the stator pole pieces. As the armature rotates a small voltage is induced across its windings. When the field winding is connected in parallel (shunt) with the armature a small field current will flow. If this small field current is flowing in the proper direction, the residual magnetism will be reinforced which further increases the armature voltage and thus, a rapid voltage build-up occurs.

If the field current flows in the wrong direction, the residual magnetism will be reduced and voltage build-up cannot occur. In this case, interchanging the shunt field leads will correct the situation. It is the purpose of this Experiment to show these major points.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Because of its constant running speed, the synchronous motor will be used to mechanically drive the DC generator. Using your Power Supply, AC Ammeter and Three-Phase Synchronous Motor/Generator, connect the circuit shown in Figure 28-1.

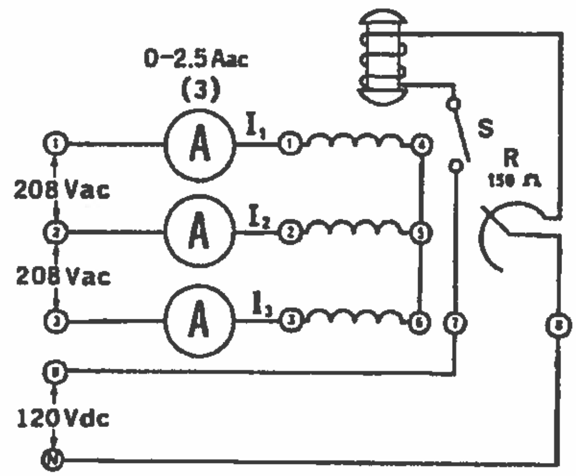


Figure 28-1.

DO NOT APPLY POWER AT THIS TIME!

☑ 2. Terminals 1, 2, and 3 on the power supply provide fixed three-phase power for the three stator windings. (Three-phase power will be covered in later Experiments). Terminals 8 and N on the power supply provide fixed DC power for the rotor winding.

Set the rheostat control knob to its proper position for normal excitation (Experiment 23, procedure 6).

☑ 3. a. Using your DC Motor/Generator, DC Voltmeter/Ammeter and Resistive Load, connect the circuit shown in Figure 28-2.

b. Couple the synchronous motor and the DC generator with the timing belt.

c. Turn the DC generator field rheostat control knob full cw for minimum resistance.

d. Make sure the brushes are in their neutral position.

e. Place the resistance switches for no-load (all switches open).

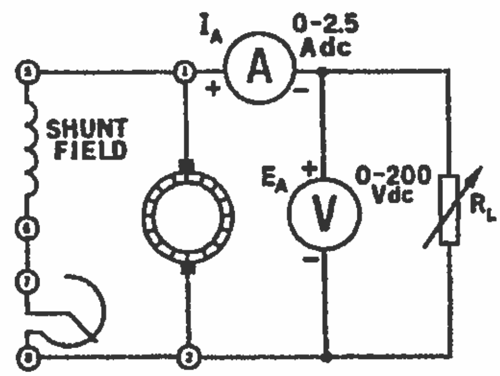


Figure 28-2.

CAUTION!

The switch in the excitation circuit of the synchronous motor should be closed (I) only when the motor is running.

☐ 4. a. Turn on the power supply. The synchronous motor should start running.

b. Close the switch S.

c. Not if voltage E_A builds up.

☐ Yes ☐ No

d. If not, turn off the power supply and interchange the shunt field leads at terminals 5 and 6.

e. Measure the open circuit armature voltage.

E_A = 178 V dc

☐ 5. Vary the field rheostat and notice if the armature voltage E_A changes. Explain.

☑ Yes ☐ No

Greater resistance reduces voltage because it reduces current through the shunt field.

☑ 6. a. Place the resistance switches so that the total load resistance is 120 Ω. Adjust the field rheostat until the generator is delivering an output voltage of 120 V dc. The ammeter I_A should indicate 1 A dc.

b. This is the correct setting of the field rheostat control for the rated power output 120 V x 1 A = 120 W) of the DC generator.

Do not touch the field rheostat control for the remainder of the Experiment!

☑ 7. a. Adjust the load resistance to obtain each of the values listed in Table 28-1.

b. Measure and record E_A and I_A for each of the resistance values listed in the Table.

R_L (ohms)	I_A (amps)	E_A (volts)	POWER (watts)
∞	0	155	0
600	0.25	149	37.25
300	0.5	142.5	71.25
200	0.65	134.5	87.4
150	0.8	125.5	100.4
120	1	120	120
100	1.05	108	113.4
80	1.15	94.5	108.7
75	1.15	88.5	101.8

Table 28-1.

Note: *Although the nominal output current rating of the generator is 1 A dc, it may be loaded up to 1.5 A dc (50% overload) without harm.*

c. Turn off the power supply.

d. Calculate and record the power for each of the resistance shown in Table 28-1.

☑ 8. a. Reverse the rotation of the driving motor by interchanging any two of the stator lead connections (terminals 1, 2, or 3) to the synchronous motor.

b. Remove the generator load by opening all of the resistance switches.

c. Turn on the power supply.

d. Does the generator voltage build up? Explain.

☐ Yes ☑ No

No, -4.6V is as far as it gets.
The generated voltage is in the opposite direction from the residual magnetic field, so they fight each other.

e. Turn off the power supply.

REVIEW QUESTIONS

1. If a self-excited generator has lost all of its residual magnetism, can it build up an output voltage?

☐ Yes ☑ No

2. How would you get a generator to work after it had lost all of its residual magnetism?

Temporarily run it as a seperately excited generator until it builds up residual magnetism.

3. Does a generator slowly lose its residual magnetism with time?

☑ Yes ☐ No

4. Plot the E_A vs I_A regulation curve on the graph of Figure 28-3.

The DC Self Excited Shunt Generator

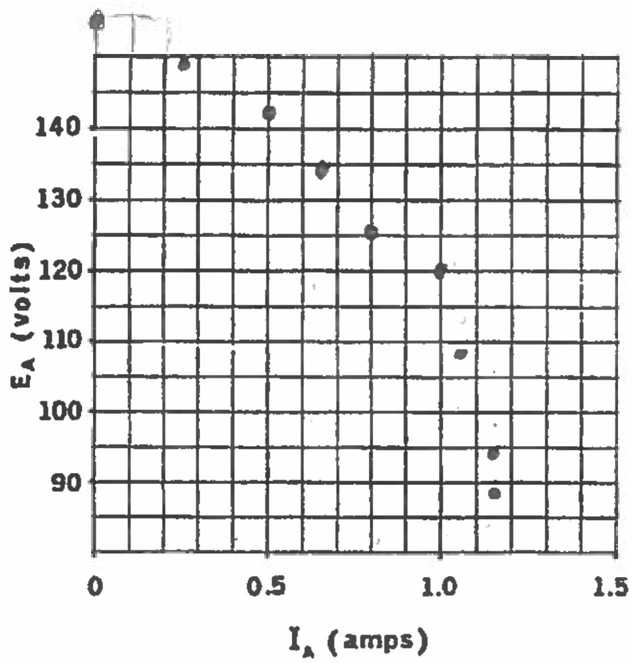


Figure 28-3.

5. Calculate the regulation from no-load to full-load (1 A dc).

$\frac{155-120}{120} = 0.29$

Regulation = 29 %

6. Compare the regulation of the self-excited generator with the regulation of the separately-excited generator (Experiment 27).

Separately excited: 12%
Self-excited: 29%

7. Explain why one of the generators has better regulation than the other.

Unlike the self-excited generator, the separately-excited generator's field current is affected by its load.

Experiment 29

The DC Compound Generator

OBJECTIVE

- To study the properties of compound DC generators under no-load and full-load conditions.
- To learn how to connect both the compound and the differential compound generators.
- To obtain the armature voltage vs armature current load curves for both generators.

DISCUSSION

Self-excited shunt generators have the disadvantage in that changes in their load current from no-load cause their output voltage to change also. Their poor voltage regulation is due to three factors:

a) The magnetic field strength drops as the armature voltage drops, which further reduces the magnetic field strength, which in turn reduces the armature voltage, etc.

b) The armature voltage drop ($I^2 \times R$ losses) from no-load to full-load.

c) The running speed of the driving motor may change with load. (This is particularly true of internal combustion engines and induction motors).

The two field windings (shunt and series) on the compound generator are connected so that their magnetic fields aid each other. Thus, when the load current increases, the current through the shunt field winding decreases, reducing the strength of the magnetic field. But, if the same increase in load current is made to flow through the series field winding, it will increase the strength of the magnetic field.

With the proper number of turns in the series winding, the increase in magnetic strength will compensate for the decrease caused by the shunt winding. The combined magnetic field strength remains almost unchanged and little change in output voltage will take place as the load goes from no-load to full-load.

If the series field is connected so that the armature current flows in such a direction as to oppose the shunt field, we obtain a differential compound generator. This type of generator has poor regulation, but is useful in applications such as welding and arc lights where maintaining a constant output current is more important than a constant output voltage. It is the purpose of this Experiment to show these major points.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

CAUTION!

The switch in the excitation circuit of the synchronous motor should be closed (I) only when the motor is running.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Because of its constant running speed, the synchronous motor will be used to mechanically drive the DC generator. Using your Power Supply, AC Ammeter and Three-Phase Synchronous Motor/Generator, connect the circuit shown in Figure 29-1.

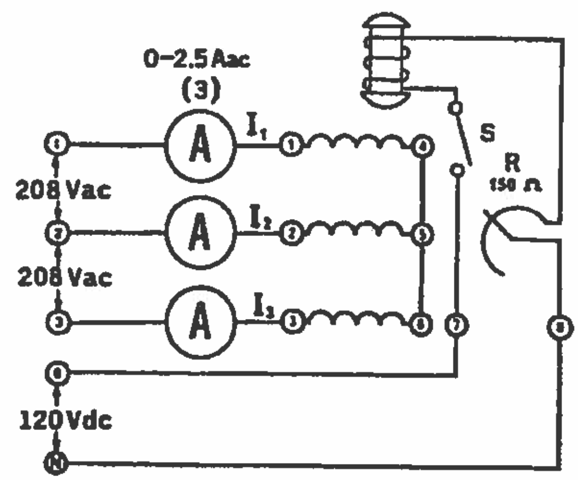


Figure 29-1.

☑ 2. Terminals 1, 2, and 3 on the power supply provide fixed three-phase power for the three stator windings (Three-phase power will be covered in later Experiments). Terminals 8 and N on the power supply provide fixed DC power for the rotor winding. Set the rheostat control knob to its proper position for normal excitation (Experiment 23, procedure 6).

☑ 3. a. Using your DC Motor/Generator, DC Voltmeter/Ammeter and Resistive Load, connect the circuit shown in Figure 29-2.

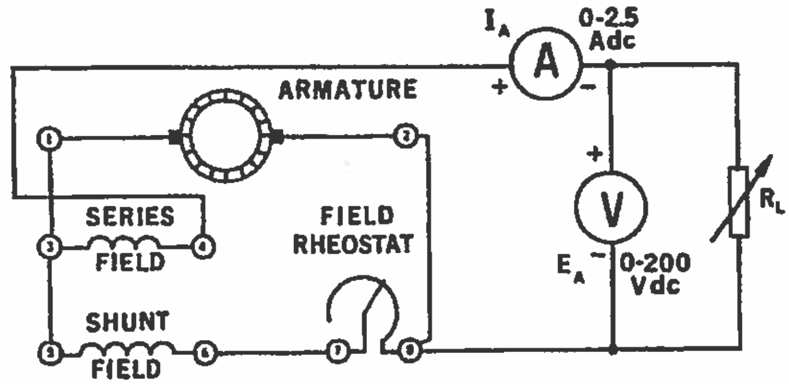


Figure 29-2.

b. Couple the synchronous motor and the DC generator with the timing belt.

c. Turn the DC generator field rheostat control knob full cw for minimum resistance.

d. Make sure the brushes are in their neutral position.

e. Place the resistance switches for no-load (all switches open).

☐ 4. a. Turn on the power supply. The synchronous motor should start running.

b. Close the switch S.

c. Note if voltage E_A builds up.

☑ Yes ☐ No

d. If not, turn off the power supply and interchange any two of the stator connection leads on the synchronous motor.

e. Measure the open circuit armature voltage.

E_A = 178 V dc

☑ 5. Vary the field rheostat and notice if the armature voltage E_A changes. Explain.

☑ Yes ☐ No

Increasing the resistance decreases the current through the shunt winding, decreasing the magnetic field.

☑ 6. Adjust the field rheostat for a no-load current (I_A = 0 A) output voltage E_A of 120 V dc.

Do not touch the field rheostat control for the remainder of the Experiment!

☐ 7. a. Adjust the load resistance to obtain each of the values listed in Table 29-1.

b. Measure and record E_A and I_A for each of the resistance values listed in the Table.

> **Note:** *Although the nominal output current rating of the generator is 1 A dc, it may be loaded up to 1.5 A dc (50% overload) without harm.*

c. Turn off the power supply.

d. Calculate and record the power for each of the resistance shown in Table 29-1.

R_L (ohms)	I_A (amps)	E_A (volts)	POWER (watts)
∞	0	120	0
600	0.2	126	25.2
300	0.45	129.5	58.3
200	0.65	131	85.2
150	0.85	130	110.5
120	1.05	129	135.5
100			
80			
75			

Drawing too much power

Synchronous motor makes sounds, pulls lots of current

Table 29-1.

☑ 8. a. Change the connections to the series field only, so that the armature current flows through it in the opposite direction.

b. Complete the drawing shown in Figure 29-3 showing your proposed circuit change.

c. Have your instructor check your circuit and your drawing.

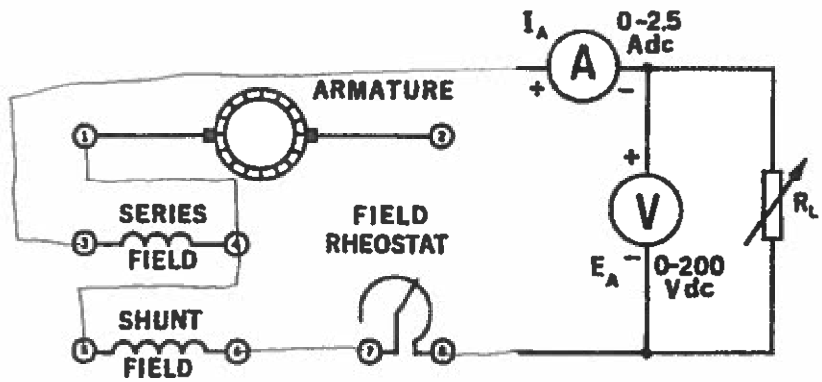


Figure 29-3.

☑ 9. a. Turn on the power supply.

b. Adjust the field rheostat for an E_A of 120 V dc.

c. Do not touch the rheostat after this.

☑ 10. a. Adjust the load resistance to obtain each of the values listed in Table 29-2.

b. Measure and record E_A and I_A for each of the resistance values listed in the Table.

c. Turn off the power supply.

d. Calculate and record the power for each of the resistances shown in Table 29-2.

R_L (ohms)	I_A (amps)	E_A (volts)	POWER (watts)
∞	0	120	0
600	0.13	79	10.3
300	0.1	32.7	3.3
200	0.12	24.5	2.9
150	0.14	20.6	2.9
120	0.15	18	2.7
100	0.16	16.2	2.6
80	0.19	14	2.7
75	0.19	13.5	2.6

Table 29-2.

REVIEW QUESTIONS

1. State which procedure, (7 or 10) is concerned with:

   a) the differential compound generator.

      Procedure 10

   b) the compound generator.

      Procedure 7

2. Plot the E_A vs I_A regulation curve on the graph of Figure 29-4. Use the data from Table 29-2.

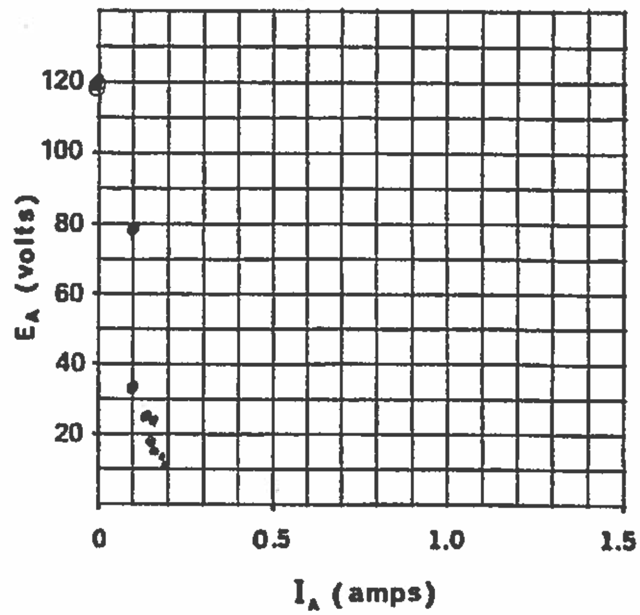


Figure 29-4.

3. Over what voltage range is the armature current nearly constant in the differential compound generator?

From 25 V dc to 0 V dc

4. Plot the E_A vs I_A regulation curve on the graph of Figure 29-5. Use the data from Table 29-1.

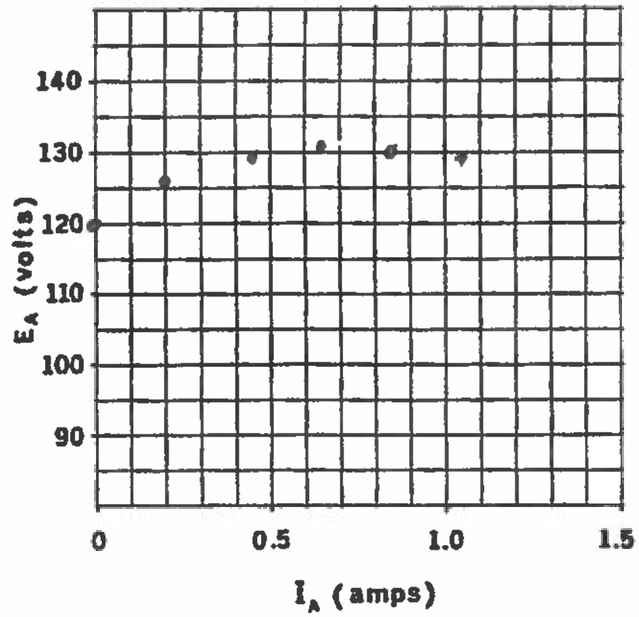


Figure 29-5.

5. Calculate the regulation from no-load to full-load (1 A dc) for the compound generator.

$\frac{120-129}{129} = -0.07$

Regulation = -7 %

6. Compare the regulation of the compound generator with the regulation of the self-excited generator and the separately-excited generator.

Compound: -7%

Self-excited: 29%

Separately-excited: 12%

7. **Explain briefly why the voltage does not drop with increasing load for the compound generator.**

As the load draws more current the shunt field current is forced to increase as well creating a stronger magnetic field.

Experiment 31

The Split-Phase Inductor Motor – Part I

OBJECTIVE

- To examine the construction of a split-phase motor.
- To measure the resistance of its windings.

DISCUSSION

Some means must be provided for getting two phases from the standard single-phase power supplied to homes if it is to be used to start and run an AC motor. The process of deriving two phases from one is known as phase-splitting and is usually built into the stator circuit of the AC motor. Two-phase power creates the rotating magnetic field.

One method is a special auxiliary winding built into the stator called the start (auxiliary) winding to differentiate it from the actual run (main) winding of the stator. In split-phase AC motors, the start winding is used only for starting the motor and has a high resistance and low inductive reactance. The run winding has low resistance and high reactance. When power is first applied, both windings are energized. Because of their different inductive reactances, the run winding current lags the start winding current, creating a phase difference between the two. Ideally, the phase difference should be 90°; but in practical motors, it is much less. Nevertheless, the windings develop fields that are out of phase, which creates a rotating magnetic field in the stator. This applies torque to the rotor, starting the motor.

When the motor gets up to operating speed, the rotor is able to follow the alternations of the magnetic field created by the run winding without the field of the start winding. The start winding is then switched out of the circuit by a mechanical device called a centrifugal switch, because it is operated by the centrifugal force created by the rotor revolutions. The direction of a split-phase rotating field can be reversed by reversing the connections to the start winding. This changes the direction of the initial phase shift, creating a magnetic field rotating in the opposite direction.

The motor speed depends essentially upon the AC power line frequency and the number of poles on the stator.

The split-phase motor, like a single-phase induction motors, vibrates mechanically at twice the power line frequency.

The Split-Phase Inductor Motor – Part I

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Examine the construction of the Capacitor-Start Motor, paying particular attention to the motor, centrifugal switch, connection terminals and the wiring.

The capacitor, mounted in the rear of the module, is used only when the module is connected as a capacitor-start motor.

☑ 2. Viewing the motor from the front of the module:

a. The main stator winding is composed of many turns of large diameter wire. Identify the main winding.

b. The auxiliary stator winding, wound inside the main stator winding, is composed of fewer turns of smaller diameter wire. Identify the auxiliary winding.

c. Does the auxiliary winding exactly straddle the main winding? Explain.

☐ Yes ☑ No

It appears to be off by about 45°.

d. How many main stator poles are there?

4

e. How many auxiliary poles are there?

4

f. This is a 8 pole motor.

g. Note that there are a number of slots distributed in each pole.

h. Note the construction of the rotor.

i. Note the rotor aluminum end ring.

j. Note that the fan is integrally cast with the end ring.

k. Note the air gap separating the rotor and the stator.

l. Estimate the air gap distance in mm [in].

0,5mm

☑ 3. Viewing the motor from the rear of the module:

a. Identify the centrifugal switch mechanism mounted on the shaft.

b. Pull outward on the centrifugal weights and note the action of the insulated sleeve.

c. Note that the stationary electrical contacts open when the weights are pulled out.

d. If the coiled springs on the centrifugal switch were stiffer, would the electrical contacts open at a lower or higher shaft speed?

Higher speed

☑ 4. Viewing the front face of the module:

a. The main winding (many turns of heavy wire) is connected to terminals 1 and 2.

b. The auxiliary winding (fewer turns of finer wire) is connected to terminals 3 and 4.

c. The centrifugal switch contacts are connected to terminals 6 and 7.

d. The capacitor (not used in the split-phase motor wiring) is connected to terminals 4 and 5.

e. Note that the current rating for the main winding is marked 5 A while the auxiliary winding is marked "intermittent".

Note: *The circuit breaker protecting the auxiliary winding will trip if the winding is left across the input line 120 V) for longer than a few seconds.*

CAUTION!

Always connect the centrifugal switch in series with the auxiliary winding and the input line, unless you are instructed not to do so.

☑ 5. Using your ohmmeter measure and record the resistance of the:

main winding = 2.7 Ω

aux winding = 6.9 Ω

☑ 6. Using your Power Supply, DC Voltmeter/Ammeter and Capacitor-Start Motor, connect the circuit shown in Figure 31-1.

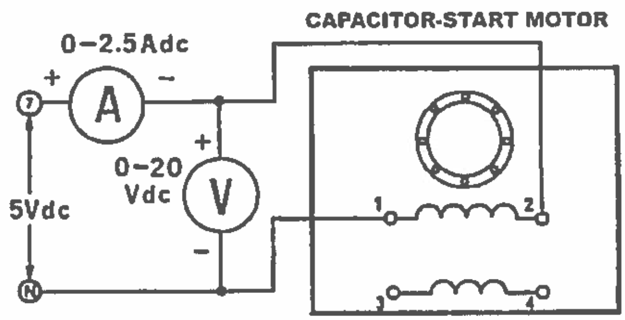


Figure 31-1

☑ 7. Turn on the power supply and adjust for exactly 5 V dc as indicated by the voltmeter across the main winding (terminals 1 and 2).

$I_{main\ winding}$ = 1.75 A dc

$R_{main\ winding}$ = E/I = 2.86 Ω

☑ 8. Return the voltage to zero and turn off the power supply. Connect the circuit shown in Figure 31-2.

☐ 9. Turn on the power supply and adjust for exactly 5 V dc as indicated by the voltmeter across the auxiliary winding (terminals 3 and 4).

$I_{aux\ winding}$ = 0.7 A dc

$R_{aux\ winding}$ = E/I = 7.14 Ω

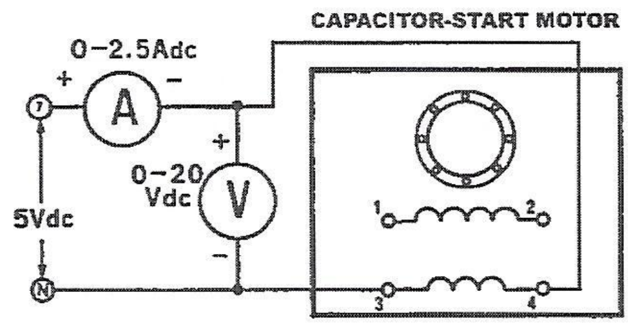


Figure 31-2.

☑ 10. a. Return the voltage to zero and turn off the power supply.

b. Compare the results of procedure 5 with the results of procedure 7 and 9.

They are close to each other, but not identical

c. Note that although the main winding has many more turns of wire than the auxiliary winding, its resistance is lower. Explain why.

The wire is larger, giving it a lower resistance for any given length compared to the auxilory winding.

REVIEW QUESTIONS

1. If a split-phase motor has two poles on the main winding, how many poles are needed for the auxiliary winding?

2

2. How many poles are there respectively on the running and the starting winding of an 8 pole split-phase motor?

Running Winding = 4 poles.

Starting Winding = 4 poles.

3. Why is an auxiliary winding necessary?

It is needed when the motor is started in order to develop a phase shift to get the motor going.

4. Why must the auxiliary winding be different from the main winding in a split-phase motor?

One has more inductance than the other, causing one to lag behind the other.

5. What would happen if the starting and running windings were identical?

There would be no phase difference because the inductance would be identical.

Experiment 32

The Split-Phase Inductor Motor – Part II

OBJECTIVE

- To learn the basic motor wiring connections.
- To observe the starting and running operation of the split-phase motor.

DISCUSSION

When power is applied to a split-phase induction motor, both the running (main) and the starting (auxiliary) windings draw from 4 to 5 times their normal full load current. This means that the heat loss in these windings is from 16 to 25 times higher than normal. As a result, the starting period must be kept short to prevent overheating of the windings.

The high starting currents also produce a proportionally high current in the squirrel-cage rotor, so that the entire motor heats up very quickly during start-up.

The smaller diameter wire employed in the auxiliary winding of split-phase motors is particularly susceptible to overheating and will burn out if it is not disconnected from the power line within 4 to 6 seconds.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Your power supply must be adjusted for an output of 100 V ac to perform the procedures in this Experiment.

a. Connect an AC voltmeter across power supply terminals 4 and N.

b. Turn on the power supply and adjust for an output of 100 V ac as indicated by the voltmeter. Do not touch the voltage output control for the remainder of this Experiment unless told to do so.

c. Turn off the power supply.

☑ 2. a. Connect the main winding of the capacitor-start motor, terminals 1 and 2, to the pre-adjusted 100 V ac output of the power supply, terminals 4 and N.

b. Close the power supply switch for no longer than 3 seconds.

c. Did the motor growl?

☑ Yes ☐ No

d. Did the motor turn?

☑ Yes ☐ No (slowly)

☐ 3. a. Lower the front face of the module. Carefully reach in behind the front face of the module so that you may give the motor shaft a quick turn by hand at the moment of power supply switch closure.

b. Close the power supply switch for no longer than 3 seconds.

c. Did the motor turn?

☑ Yes ☐ No

d. What determined the direction of rotation of the motor?

It spun whichever direction I spun it.

e. Return the front face of the module to its normal position.

☑ 4. a. Disconnect the main winding, terminals 1 and 2, from the power supply.

b. Connect the auxiliary winding, terminals 3 and 4, to the pre-adjusted 100 V ac output of the power supply terminals 4 and n.

c. Close the power supply switch for no longer than 3 seconds.

d. Did the motor make a growling sound?

☑ Yes ☐ No

e. Did the motor turn?

☐ Yes ☑ No

☑ 5. a. Connect the main winding, terminals 1 and 2, in parallel with the auxiliary winding, terminals 3 and 4.

b. Connect the parallel windings to the pre-adjusted 100 V ac output of the power supply.

c. Close the power supply switch for no longer than 3 seconds.

d. Did the motor start?

☑ Yes ☐ No

e. Was the motor noisy?

☑ Yes ☐ No

f. Note the direction of rotation.

Clockwise

☑ 6. a. Interchange the leads connecting the two windings in parallel.

b. Close the power supply switch for no longer than 3 seconds.

c. Note the direction of rotation.

Counterclockwise

d. Give a rule for reversing the rotation of a split-phase motor.

Reverse the direction of current through one of the windings while leaving the other unchanged.

☑ 7. Connect the circuit shown in Figure 32-1. The centrifugal switch is connected in series with the auxiliary winding and both windings are connected in parallel across the 100 V ac power source terminals 4 and N. Note that the capacitor, connected between terminals 4 and 5, is not used when the module is operated as a split-phase motor.

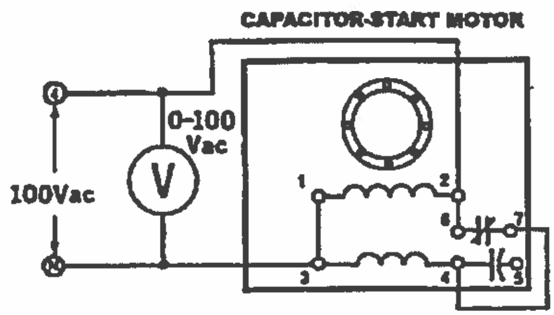


Figure 32-1.

☑ 8. a. Close the power supply switch. The output voltage control should remain at its 100 V setting.

b. Did the motor start?

☑ Yes ☐ No

c. Did the centrifugal switch operate?

☑ Yes ☐ No

d. Estimate the starting time.

T = 0.7 s

e. Using your hand tachometer, measure the running speed.

Speed = 1740 r/min

f. Reduce the input voltage to 80 V ac as indicated by the voltmeter and measure the running speed.

Speed = 1740 r/min

g. Return the voltage to 100 V ac and turn off the power supply.

☑ 9. Connect the circuit shown in Figure 32-2. Note that both windings are connected in parallel and that the centrifugal switch is in series with the parallel connected motor windings and the 100 V ac power supply terminals 4 and N.

The Split-Phase Inductor Motor – Part II

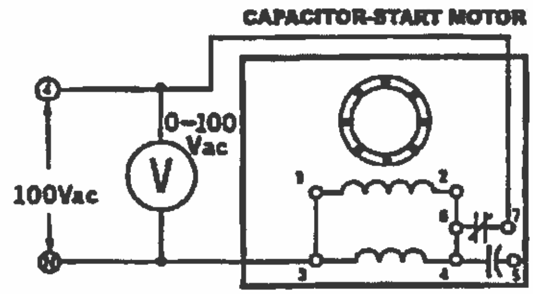


Figure 32-2.

☑ 10. Before applying power to the motor answer the following questions:

a. Will current flow through both windings?

☑ Yes ☐ No

b. Will a starting torque be developed?

☑ Yes ☐ No

c. Will the motor start to turn?

☑ Yes ☐ No

d. What will eventually happen?

The centrifigal switch will cut power and it will slow down until the switch returns, then it will repeat endlessly.

☑ 11. a. Close the power supply switch and note what happens.

b. Observe the operation of the centrifugal switch.

c. At approximately what speed does the centrifugal switch close?

Speed = 1350 r/min

d. Return the voltage to zero and turn off the power supply.

The Split-Phase Inductor Motor – Part II

REVIEW QUESTIONS

1. Will a single-phase induction motor start if only the running (main) or the starting (auxiliary) winding is excited?

   No

2. Will such a motor run on one winding once it has been started?

   ☑ Yes ☐ No

3. How could your reverse the rotation of the motor?

   Reverse direction of curent through one of the windings.

4. What will happen to your motor when power is applied if springs twice as stiff are used on the centrifugal switch?

   It will reach a much higher speed before cutting power to the auxilary winding.

5. Explain in detail the behavior of your motor in procedure 11.

   The centrifugal switch repeatedly cuts and reapplies power whenever the speed crosses its threshold.

6. If the running winding and the auxiliary winding were connected in series, would the motor turn? Explain.

   ☑ Yes ☐ No

   Both windings would be energized, so it would at least begin turning.

The Split-Phase Inductor Motor – Part II

7. Does the speed of a split-phase motor change appreciably with a change in the applied voltage?

   ☐ Yes ☐ No

Experiment 33

The Split-Phase Inductor Motor – Part III

OBJECTIVE

- To measure the starting and operating characteristics of the split-phase motor under load and no-load conditions.
- To study the power factor and efficiency of the split-phase motor.

DISCUSSION

The starting current of a split-phase motor is usually four to five times normal full-load current. This produces two effects: 1) the motor heats very rapidly during start-up; and 2) the high starting current can cause a large line voltage drop so that the starting torque may be seriously reduced.

The no-load current is usually 60% to 80% of the full-load current, which is high compared to three-phase motors. Most of the no-load current is used to produce the magnetic field in the motor, and only a small portion is used to overcome mechanical friction and the copper and iron losses. Because of the large magnetizing current, the power factor of these motors is rarely more than 60%, even at full-load.

Split-phase motors tend to be much noisier than their three-phase counterparts, because of the inherent 120 cycle mechanical vibration. This vibration can be reduced by using resilient rubber mounting supports.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

The Split-Phase Inductor Motor – Part III

Starting Currents

☑ 1. Using your Capacitor-Start Motor, Power Supply and AC Ammeter, connect the circuit shown in Figure 33-1.

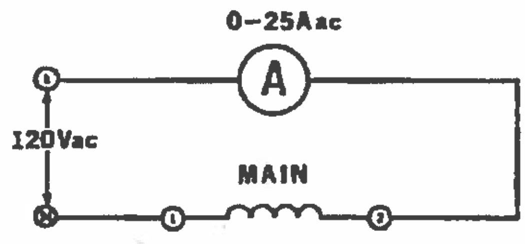


Figure 33-1.

☑ 2. Close the power supply switch and measure the current through the main winding as quickly as possible - within 3 seconds.

$I_{main\ winding}$ = 16 A ac

☑ 3. a. Disconnect your leads from the main winding and connect them to the auxilary winding, terminals 3 and 4 as shown in Figure 33-2.

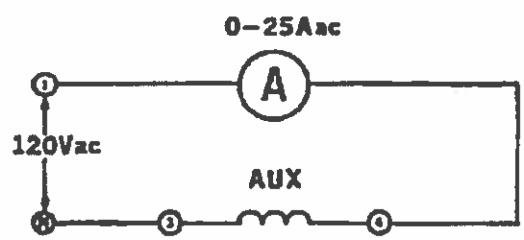


Figure 33-2.

b. Repeat procedure 2. Remember to take your measurement as quickly as possible.

$I_{auxiliary\ winding}$ = 12 A ac

☑ 4. a. Connect both windings in parallel, terminals 1 to 3 and 2 to 4 as shown in Figure 33-3.

The Split-Phase Inductor Motor – Part III

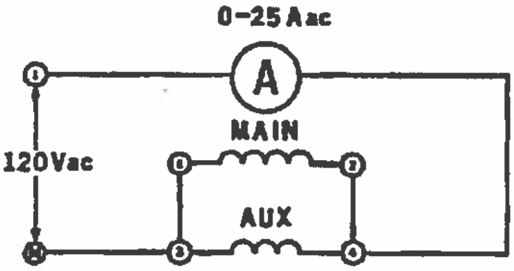


Figure 33-3.

b. Couple the electrodynamometer to the capacitor-start motor with the timing belt.

c. Connect the electrodynamometer to the fixed 120 V ac output of the power supply, terminals 1 and N.

d. Set the electrodynamometer control knob at its full cw position (to provide a maximum starting load for the split-phase motor).

e. Close the power supply switch and measure the starting current as quickly as possible - within 3 seconds.

$I_{starting}$ = > 25 A ac (off the chart)

No-Load Operation

☑ 5. Using your Single-Phase Wattmeter, AC Ammeter and AC Voltmeter, connect the circuit shown in Figure 33-4.

Note that the module is wired as a standard split-phase motor.

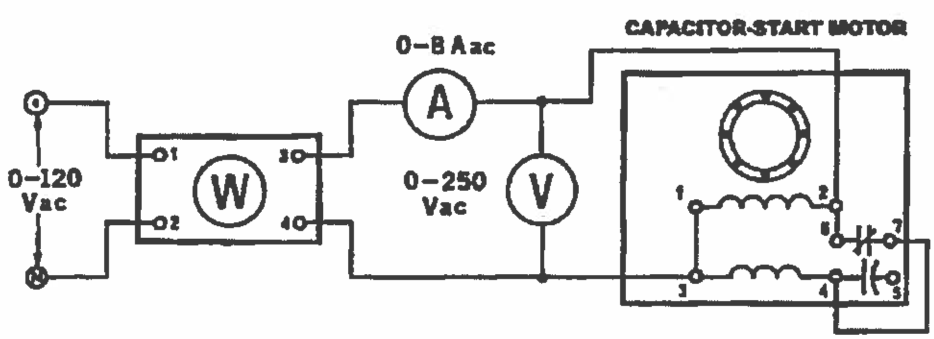


Figure 33-4.

The Split-Phase Inductor Motor – Part III

☑ 6. a. Turn on the power supply and adjust for 120 V ac as indicated by the voltmeter across the motor.

b. Measure and record in Table 33-1 the line current, the power and motor speed. Note and record the relative motor vibration.

c. Repeat (b) for each of the input voltages listed in the Table 33-1.

d. Return the voltage to zero and turn off the power supply.

E (volts)	I (amps)	P (watts)	SPEED (r/min)	VIBRATION
120	4.18	502	1750	Most
90	2.4	216	1760	Less
60	≈1.5	≈90	1750	Less still
30	≈0.5	≈15	1720	Least

Meter scale non linear & ambiguous

Table 33-1.

Watt meters were not working. Watts calculated from voltage and current.

Full-Load Operation

☑ 7. a. Couple the electrodynamometer to the capacitor-start motor with the timing belt.

b. Connect the input terminals of the electrodynamometer to the fixed 120 V ac output of the power supply, terminals 1 and N.

c. Set the electrodynamometer control knob at its full ccw position (to provide a minimum starting load for the split-phase motor).

☑ 8. a. Turn on the power supply and adjust for 120 V ac.

b. Measure and record in Table 33-2 the line current, the power and motor speed.

c. Repeat (b) for each of the torques listed in the Table 33-2, maintaining the input voltage at 120 V ac.

d. Return the voltage to zero and turn off the power supply.

V	lbf·in	TORQUE (N·m)	I (amps)	VA	P_{in} (watts)	SPEED (r/min)	P_{out} (watts)
120	0	0	4.2	504	80	1780	0
119	3	0.3	4.42	526	190	1760	62.5
118	6	0.6	4.75	560.5	260	1740	123.5
117	9	0.9	5.4	632	350	1740	185.3
116	12	1.2	6.1	708	440	1680	238.5

Table 33-2.

TORQUE (lbf·in)	I (amps)	VA	P_{in} (watts)	SPEED (r/min)	P_{out} (hp)
0					
3					
6					
9					
12					

Table 33-2.

☑ 9. a. Calculate and record in the Table 33-2, the apparent power (in VA) delivered to the motor for each of the listed torques.

b. Calculate and record in the Table 33-2, the developed mechanical output power for each of the listed torques. Use the formula:

$$P_{out}\,(W) = \frac{2\pi \times N \times T}{60}$$

where P_{out} = Mechanical Output Power in watts (W)
N = Speed in revolution per minute (r/min)
T = Torque in Newton-meter (N·m)

$$P_{out}\,(hp) = \frac{1.59 \times N \times T}{100\,000}$$

where P_{out} = Mechanical Output Power in horse power (hp)
N = Speed in revolution per minute (r/min)
T = Torque in pound-force·inches (lbf·in)

The Split-Phase Inductor Motor – Part III

☑ 10. You will now determine the maximum starting torque developed by the capacitor-start motor.

a. Disconnect the wattmeter and metering modules from your circuit.

b. Connect the input of your capacitor-start motor to terminals 2 and N of the power supply (fixed 120 V ac).

c. Set the electrodynamometer control knob at its full cw position (for maximum loading).

d. Close the power supply switch and quickly measure the developed torque on the electrodynamometer scale. Open the power supply switch.

Starting Torque = 14 N·m [lbf·in] (1.58 N·m)

REVIEW QUESTIONS

1. From Table 33-2 state the no-load (0 N·m [lbf·in] torque):

a) apparent power = 504 VA = V·I

b) active power = 80 W V·I·cos θ

c) reactive power = 498 var V·I·sin θ

d) power factor = 0.159

$\boxed{12\ lbf \cdot in}$

2. From Table 33-2 state the full-load (1.2 N·m [9 lbf·in] torque):

a) apparent power = 708 VA

b) active power = 440 W

c) reactive power = 555 var

d) power factor = 0.62

e) power delivered = 238.5 W [hp]

electrical equivalent = ____ W

f) efficiency of the motor = 54 %

g) motor losses = 201.5 W

The Split-Phase Inductor Motor – Part III

3. What is the approximate full-load current of your capacitor-start motor?

   I = 6.1 A ac

4. How much larger is the starting current than the full-load operating current?

   It is much larger (beyond 8A, the max the guage shows).

5. Based on procedures 1, 2 and 3, explain why the starting (auxiliary) winding heats much faster than the main winding.

   With less resistance, it has a ton more current flowing through it.

6. Does the no-load speed of a split-phase motor change greatly with changes in the applied voltage?

   ☒ Yes ☐ No

7. How many times greater is the starting torque than the normal full-load torque?

   1.17

Experiment 34

The Capacitor-Start Motor

OBJECTIVE

- To measure the starting and operating characteristics of the capacitor-start motor.
- To compare its starting and running performance with the split-phase motor.

DISCUSSION

When the split-phase rotating field was described, it was stated that the different resistance-reactance ratio of the two windings was designed to give the difference in time phase of the currents in the windings necessary to produce a rotating magnetic field.

In two-phase machines, where the windings are identical but displaced in space by 90°, the ideal time phase displacement of the winding currents is 90°.

For both two-phase and split-phase motors the torque developed at starting can be calculated using the relationship:

$$T = k\, I_1 I_2 \sin \alpha$$

where k is a machine constant, I_1 and I_2 are the currents in the windings, and α is the angle between the currents.

Because of the small magnitude of α in the split-phase machine the developed torque is relatively low. It is possible to increase α by adding capacitance in series with the auxiliary winding. If too much capacitance is added, the impedance of the winding is increased to the point that there is an unacceptable reduction in the current which more than offsets the benefit gained from increasing α.

The optimum value of C is that where the product of the sine of α and the auxiliary winding current is a maximum.

The capacitor and the start winding are disconnected by a centrifugal switch, just as in the case of the standard split-phase motor. Reversing the direction of rotation of a capacitor start motor is the same as in the case of the split-phase motor, that is, reverse the connections to the start or to the running winding leads.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Using your Capacitor-Start Motor, Power Supply, and AC Ammeter, connect the circuit shown in Figure 34-1. Note that the fixed 120 V ac output of the power supply, terminals 1 and N are being used.

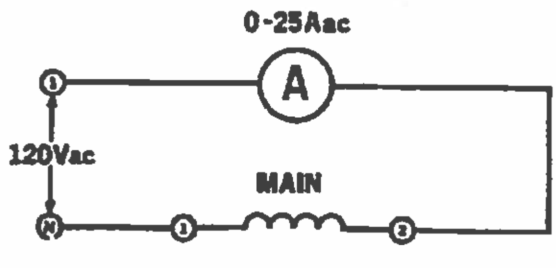


Figure 34-1.

☑ 2. Close the power supply switch and measure the current through the main winding as quickly as possible - within 3 seconds.

$I_{main\ winding}$ = 16.5 A ac

☑ 3. a. Disconnect the leads from the main winding and connect them to the auxiliary winding and capacitor, as shown in Figure 34-2.

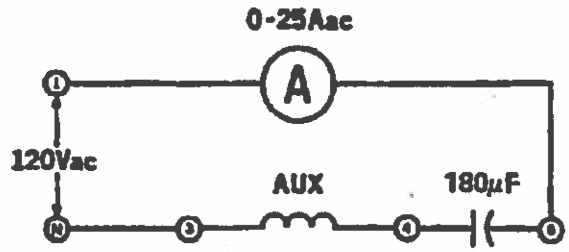


Figure 34-2.

b. Repeat procedure 2.

Note: *Remember to take your measurement as quickly as possible.*

$I_{auxiliary\ winding}$ = 7.8 A ac

☐ 4. a. Connect both windings in parallel, terminals 1 to 3 and 2 to 5, as shown in Figure 34-3.

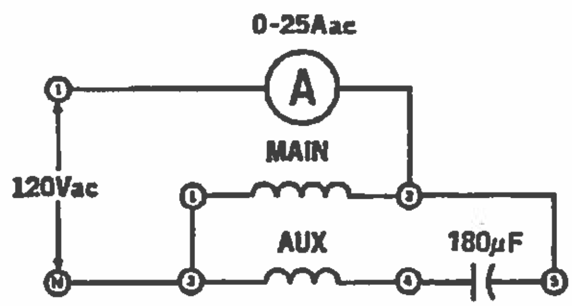


Figure 34-3.

b. Couple the electrodynamometer to the capacitor-start motor with the timing belt.

c. Connect the input terminals of the electrodynamometer to the fixed 120 V ac output of the power supply, terminals 1 and N.

d. Set the electrodynamometer control knob at its full cw position to provide a maximum starting load for the capacitor-start motor.

e. Close the power supply switch and measure the starting current as quickly as possible - within 3 seconds.

$I_{starting}$ = 17 A ac

☐ 5. Compare your results from procedures 2, 3 and 4 with the results from procedures 2, 3 and 4 of Experiment 33.

a. What conclusions can you make about the main winding currents?

The readings are almost identical and theoretically should be.

b. What conclusions can you make about the auxiliary winding currents?

The readings were lower this time due to the presence of the capacitor

c. What conclusions can you make about the starting current for each type of motor?

Starting current is much lower on the capacitor start motor

☑ 6. Using your Single-Phase Wattmeter, Electrodynamometer, AC Ammeter and AC Voltmeter, connect the circuit shown in Figure 34-4.

Note that the module is wired as a standard capacitor-start motor.

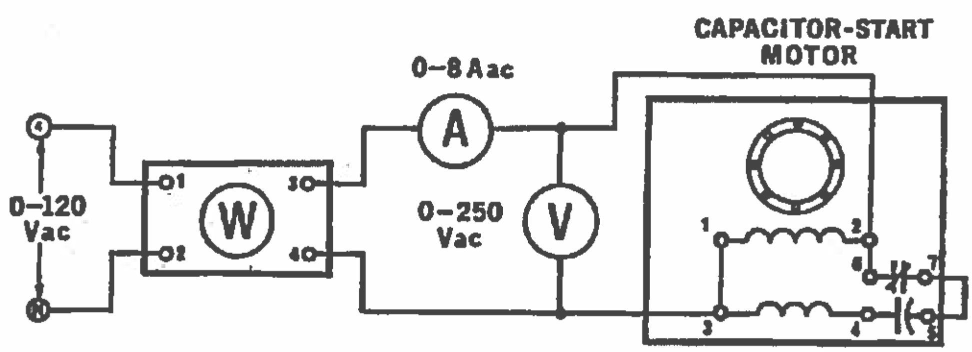


Figure 34-4.

☑ 7. Set the electrodynamometer control knob at its full ccw position to provide minimum starting torque for the capacitor-start motor.

☑ 8. a. Turn on the power supply and adjust for 120 V ac.

b. Measure and record in Table 34-1, the line current, the power and motor speed.

c. Repeat (b) for each of the torques listed in the Table.

d. Return the voltage to zero and turn off the power supply.

TORQUE (N·m)	I (amps)	VA	P_{in} (watts)	SPEED (r/min)	P_{out} (watts)
0					
0.3					
0.6					
0.9					
1.2					

Table 34-1.

V	TORQUE (lbf·in)	I (amps)	VA	P (watts)	SPEED (r/min)	P_{out} ~~(hp)~~ W
119.5	0	4.2	502	80	1780	0
119.5	3	4.4	526	183	1760	62
118.5	6	4.75	563	255	1740	124
117.5	9	5.3	623	340	1690	180
116.5	12	6.1	711	435	1670	237

Table 34-1.

☑ 9. a. Calculate and record in the Table 34-1, the apparent power delivered to the motor for each of the listed torques.

b. Calculate and record in the Table 34-1, the developed power (P_{out}) [horsepower] for each of the listed torques.

☑ 10. Your will now determine the maximum starting torque developed by the capacitor-start motor. This torque is too high to be measured directly by your electrodynamometer. However, you can calculate it by measuring the torque developed when the motor is supplied with a lower voltage, 60 V ac, which is half the rated voltage.

a. Disconnect the Single-Phase Wattmeter, AC Ammeter and AC Voltmeter from your circuit.

b. Set the electrodynamometer control knob to its full cw position (for maximum loading).

c. Turn on the power supply switch and adjust the voltage applied to the motor to 60 V ac. Measure the developed torque on the electrodynamometer scale. Open the power supply switch.

Starting Torque (60 V ac) = 3.8 N·m [lbf·in]

d. Calculate the starting torque developed by the motor when supplied with 120 V ac. The starting torque is nearly proportional to the square of the applied voltage; thus the starting torque obtained at 120 would be four times greater than at 60 V.

Starting Torque (120 V ac) = 15.2 N·m [lbf·in]

REVIEW QUESTIONS

1. From Table 34-1 state the no-load (0 N·m [lbf·in] torque):

a) apparent power = 502 VA V·I

b) active power = 80 W V·I·cosθ

c) reactive power = 496 var V·I·sinθ

d) power factor = 0.159

12 lbf·in

2. From Table 34-1 state the full-load (1.2 N·m [9 lbf·in] torque):

a) apparent power = 711 VA

b) active power = 435 W

c) reactive power = 397 var

d) power factor = 0.612

e) power delivered = 237 W [hp]

electrical equivalent = ______ W

f) efficiency of the motor = 54 %

g) motor losses = 198 W

The Capacitor-Start Motor

3. What is the approximate full-load current of your capacitor-start motor?

   I = 6.1 A ac

4. How much larger is the starting current than the full-load operating current?

   17 − 6.1 = 10.9A

5. Compare these results with those found for the split-phase motor (Experiment 33).

   They are very close, because once the centrifigul switch has opened they are essentially identical. The main difference is the capacitor start motor has a much lower startup current. The startup torque (15.2 lbf·in) was not much more than the starting torque for the split-phase motor (14 lbf·in).

Experiment 35

The Capacitor-Run Motor

OBJECTIVE

- To examine the construction of the capacitor-run motor.
- To determine its running and starting characteristics.
- To compare its running and starting performance with the split-phase and capacitor-start motors.

DISCUSSION

Single-phase motors are all rather noisy because they vibrate at 120 Hz when operated on a 60 Hz power line. Various attempts to reduce this noise, such as resilient rubber mounting, are never totally effective in eliminating this vibration, particularly when the motor is directly coupled to a large resonant-prone fan.

The capacitor-run motor is very useful in this type of application, because the motor can be designed to have low vibration under full-load. The capacitor serves to shift the phase on one of the windings so that the voltage across the winding is at 90° from the other winding, thus making the capacitor-run motor a truly two-phase machine at its rated load. Because the capacitor remains in the circuit at all times no centrifugal switch is required.

When running at no-load the motor is always noisier than at full-load, because only under full-load does it run as a true two-phase machine. If the proper value of capacitance is chosen, the currents through each of the two equal stator windings, under full-load, can be made such that the power factor is close to 100%. However, the starting torque is quite low and the capacitor-run motor is not recommended for severe starting conditions.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Examine the construction of the Capacitor-Run Motor, paying particular attention to the motor, capacitor, connection terminals and the wiring.

☐ 2. Viewing the motor from the front of the module:

a. Both stator windings are composed of many turns of wire. Identify the stator windings.

b. Do the stator windings appear to be identical?

☑ Yes ☐ No

c. Do the windings exactly straddle each other? Explain.

☐ Yes ☑ No

They appear to be off by about 45°

d. How many poles are there? Explain.

4 poles, I think (based on 1715 rpm, 60 Hz power) (60·60/2 = 1800)

e. This is a 4 pole motor.

f. Note that there are a number of slots distributed in each pole.

g. Note the construction of the rotor.

h. Note the rotor aluminum end ring.

i. Note that the fan is integrally cast with the end ring.

☑ 3. Viewing the motor from rear of the module:

a. Note the capacitor and its rating.

b. Is this capacitor electrolytic? Explain.

☐ Yes ☑ No

Electrolytic Capacitors have polarity, so they can only be used in DC circuits

☑ 4. Viewing the front face of the module:

a. Note the two stator windings.

b. One winding is connected to terminals 1 and 2.

c. The other winding is connected to terminals 3 and 4.

d. Note that the voltage and current ratings for each winding are identical.

e. The capacitor is connected to terminals 5 and 6.

☑ 5. Using your Capacitor-Run Motor, Power Supply, Single-Phase Wattmeter, Electrodynamometer, AC Ammeter and AC Voltmeter, connect the circuit shown in Figure 35-1.

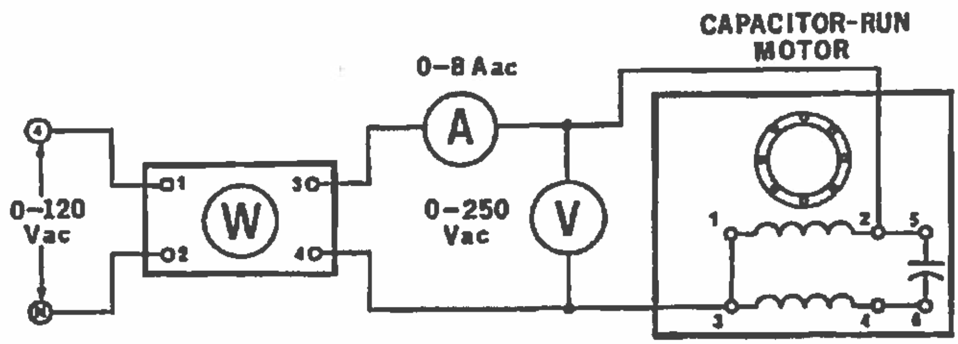


Figure 35-1.

☑ 6. a. Couple the electrodynamometer to the capacitor-run motor with the timing belt.

b. Connect the input terminals of the electrodynamometer to the fixed 120 V ac output of the power supply, terminals 1 and N.

c. Set the electrodynamometer control knob at its full ccw position (to provide a minimum starting load for the capacitor-run motor).

☑ 7. a. Turn on the power supply and adjust for 120 V ac.

b. Measure and record in Table 35-1 the line current, the power and motor speed.

TORQUE (N-m)	I (amps)	VA	P_{in} (watts)	SPEED (r/min)	P_{out} (watts)
0					
0.3					
0.6					
0.9					
1.2					

Table 35-1.

V	TORQUE (lbf-in)	I (amps)	VA	P_{in} (watts)	SPEED (r/min)	P_{out} (hp) W
120.4	0	1.0	120.4	95	1780	0
119.5	3	1.9	127	125	1740	61.8
118.8	6	2.3	273	232	1740	123.5
118.0	9	3.0	354	300	1670	177.8
117.2	12	4.0	469	405	1630	231.4

Table 35-1.

c. Repeat (b) for each of the torques listed in the Table 35-1, maintaining the input voltage at 120 V ac.

d. Was there a noticeable difference in the level of motor vibration between no-load and full-load?

☑ Yes ☐ No

e. Return the voltage to zero and turn off the power supply.

☑ 8. a. Calculate and record in the Table 35-1, the apparent power delivered to the motor for each of the listed torques.

b. Calculate and record in the Table 35-1 the developed mechanical output power for each of the listed torques. Use the formula:

$$P_{out}\ (W) = \frac{2\pi \times N \times T}{60}$$

where P_{out} = Mechanical Output Power in watts (W)
N = Speed in revolution per minute (r/min)
T = Torque in Newton-meter (N·m)

[redacted]

c. Set the electrodynamometer control knob to its full cw position (for maximum loading).

d. Close the power supply switch and quickly measure the developed torque on the electrodynamometer scale and the starting current. Open the power supply switch.

Starting Torque = 2.5 N·m [lbf·in]

Starting Current = 7.5 A ac

REVIEW QUESTIONS

1. From Table 35-1 state the no-load (0 N·m [lbf·in] torque):

   a) apparent power = 120.4 VA   V·I

   b) active power = 95 W   V·I·cos θ

   c) reactive power = 74 var   V·I·sin θ

   d) power factor = 0.789

12 lbf·in

2. From Table 35-1 state the full-load (1.2 N·m [9 lbf·in] torque):

   a) apparent power = 469 VA

   b) active power = 405 W

   c) reactive power = 236.5 var

   d) power factor = 0.864

e) power delivered = 231.4 W [hp]

electrical equivalent = 231.4 W

f) efficiency of the motor = 57 %

g) motor losses = 174 W

3. What is the approximate full-load current of your capacitor-run motor?

I = 4.0 A ac

4. How much larger is the starting current than the full-load operating current?

7.5A - 4.0A = 3.5 A

5. Compare these results with those found for the split-phase and capacitor-start motors (Experiments 33 and 34).

	Split phase	Capacitor start	Capacitor run
Efficiency	54%	54%	57 %
Starting current	>25A	17A	7.5A

6. How can you change the direction of rotation of a capacitor-run motor?

Reverse the direction of current through the windings.

7. Can you explain why oil-filled capacitors must be used for capacitor-run motors instead of the more economical AC electrolytic types?

The capacitors need to be able to cary a heavy curent the entire time the motor is runing and not overheat.

Experiment 49

The Wound-Rotor Induction Motor – Part I

OBJECTIVE

- To examine the construction of the three-phase wound-rotor induction motor.
- To understand exciting current, synchronous speed and slip in a three-phase induction motor.
- To observe the effect of the revolving field and rotor speed upon the voltage induced in the rotor.

DISCUSSION

You have, so far, been introduced to rotating stator fields produced by single-phase power. electric power companies normally generate and transmit three-phase power. Single-phase power for the individual home is obtained from one phase of the three-phase power lines. Three-phase (polyphase) motors are commonly used in industry and electric power companies normally supply three-phase power to industrial users.

The creation of a rotating stator field using three-phase power is similar to the principle of the split-phase or two-phase (capacitor-run) system. In the three-phase system, a rotating magnetic field is generated in three phases instead of two. When the stator of a three-phase motor is connected to a three-phase power source, currents flow in the three stator windings and a revolving magnetic field is established. These three exciting currents supply the reactive power to establish the rotating magnetic field. They also supply the power consumed by the copper and iron losses in the motor.

The speed of the rotating magnetic field is entirely determined by the frequency of the three-phase power source, and is known as the synchronous speed. The frequency of electric power systems is accurately maintained by the electric power companies, therefore, the synchronous speed of the stator field (in r/min) remains constant. (It is, in fact, used to operate electric clocks).

The wound-rotor consists of a rotor core with the three windings in place of the conducting bars of the squirrel-cage rotor. In this case, currents are induced in the windings just as they would be in shorted turns. However, the advantage of using windings is that the wires can be brought out through slip rings so that resistance, and, therefore, the current through the windings, can be controlled.

The rotating stator field induces an alternating voltage in each winding of the rotor. When the rotor is at standstill the frequency of the induced rotor voltage is equal to that of the power source. If the rotor is now rotated by some external means, in the same direction as the rotating stator field, the rate at which the magnetic flux cuts the rotor windings will diminish. The induced voltage and its frequency will drop. When the rotor revolves at the same speed and in the same direction as the rotating stator field, the induced voltage, as well as its frequency, will drop to zero. (The rotor is now at synchronous speed.) Conversely, if the rotor is driven at synchronous speed, but in the opposite direction to the rotating stator field, the induced voltage, as well as its frequency, will be twice the value as when the rotor was at standstill.

Although the rotor will be driven by an external motor in this Experiment, it should be noted that for a given rotor speed the induced voltage value and its frequency will be the same even if the rotor were turning by itself.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. Examine the construction of the Three-Phase Wound-Rotor Induction Motor, paying particular attention to the motor, slip rings, connection terminals and the wiring.

☑ 2. Viewing the motor from the rear of the module:

a. Identify the three rotor slip rings and brushes.

b. Can the brushes be moved?

☑ Yes ☐ No

c. Note that the three rotor windings are brought out to the three slip rings via a slot in the rotor shaft.

d. Identify the stator windings. Note that they consist of many turns of small diameter wire evenly spaced around the stator.

e. Identify the rotor windings. Note that they consist of many turns of slightly larger diameter wire evenly spaced around the rotor.

f. Note the spacing of the air gap between the rotor and the stator.

☑ 3. Viewing the front face of the module:

a. The three separate stator windings are connected to terminals 1 and 4, 2 and 5, 3 and 6.

b. What is the rated current of the stator windings? 1.5A

c. What is the rated voltage of the stator windings? 120V

d. The three rotor windings are (wye, delta) wye connected.

e. They are connected to terminals 7, 8 and 9.

f. What is the rated voltage of the rotor windings? 60V

g. What is the rated current of the rotor windings? 2A

h. What is the rated speed and mechanical output power of the rotor?

Speed = 1500 r/min

Power = 175 W

☑ 4. Using your DC Motor/Generator, Three-Phase Wound-Rotor Induction Motor, Three-Phase Wattmeter, Power Supply, AC Ammeter and AC Voltmeter, connect the circuit shown in Figure 49-1.

☑ 5. a. Note that the DC motor/generator is connected with fixed shunt field excitation to power supply terminals 8 and N, (120 V dc). The field rheostat should be turned to its full cw position (for minimum resistance).

b. Note that the armature is connected to the variable DC output of the power supply, terminals 7 and N, (0-120 V dc).

c. Note that the stator of the wound-rotor motor is wye connected, in series with three ammeters and the wattmeter to the fixed 208 V, 3ϕ output of the power supply, terminals 1, 2 and 3.

d. Note that the 3ϕ input voltage is measured by V_1 and that the 3ϕ rotor output voltage is measured by V_2.

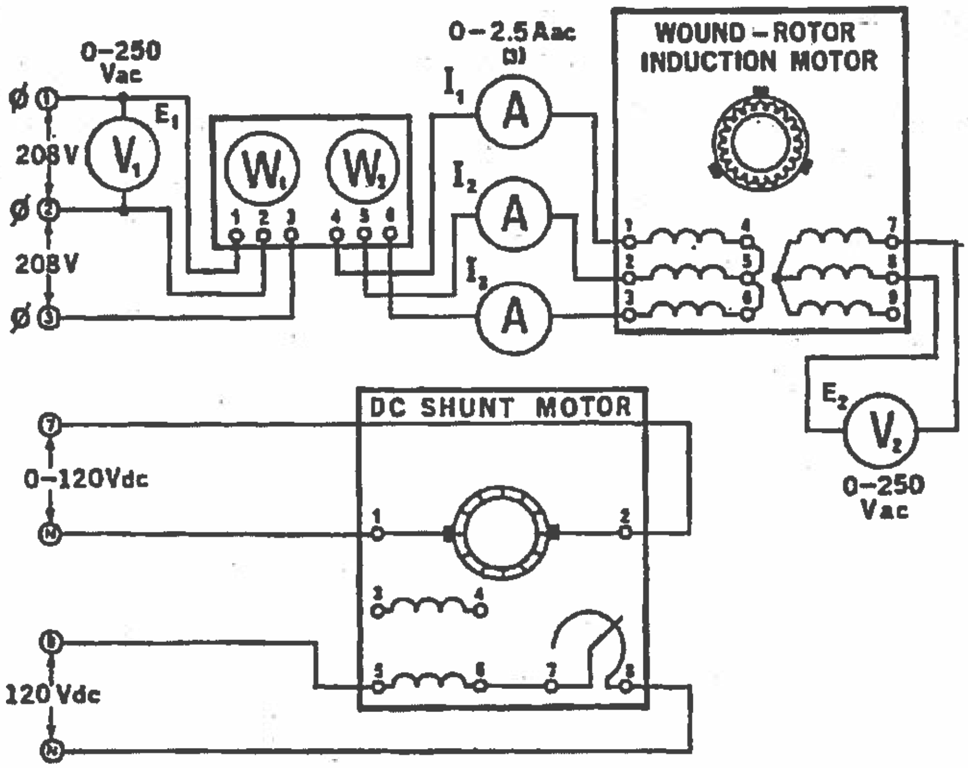


Figure 49-1.

☑ 6. a. Couple the DC motor/generator to the wound-rotor motor with the timing belt.

b. Turn on the power supply. Keep the variable output voltage control at zero (the DC motor should not be turning).

c. Measure and record the following:

E_1 = 208 V ac, W_1 = 59 W, W_2 = 95 W

I_1 = 0.85 A ac, I_2 = 0.72 A ac, I_3 = 0.87 A ac

E_2 = 104 V ac

d. Turn off the power supply.

☑ 7. Calculate the following:

a. Apparent power

0.81A · 208 = 169 — VI

= 169 VA

b. Active power

VI cos θ

59 W + 95 W = 154 W

c. Power factor

$\frac{154}{169} = 0.91$

= 0.91

d. Reactive power

V · I sin θ

= 69.6 var

☑ 8. a. Turn on the power supply and adjust the variable DC output voltage for a motor speed of exactly 900 r/min.

b. Measure and record the following:

Note: *If the value of E_2 is less than in procedure 6, turn off the power supply and interchange any two of the three stator leads.*

E_1 = 206 V ac, W_1 = 69 W, W_2 = 95 W

I_1 = 0.86 A ac, I_2 = 0.72 A ac, I_3 = 0.88 A ac

E_2 = 155 V ac

c. Is the active power approximately the same as before?

☑ Yes ☐ No

☑ 9. a. Increase the variable DC output voltage to 120 V dc and adjust the field rheostat for a motor speed of exactly 1800 r/min.

b. Measure and record the following:

E_1 = 207 V ac, W_1 = 58 W, W_2 = 95 W

I_1 = 0.85 A ac, I_2 = 0.72 A ac, I_3 = 0.88 A ac

E_2 = 210 V ac

c. Return the voltage to zero and turn off the power supply.

d. In procedures 8 and 9 is the rotor being turned with or against the rotating stator field? Explain.

It is being turned against the field, and hence is able to produce large voltages

☑ 10. a. Interchange your DC armature connections in order to reverse the motor direction. Turn the field rheostat to its full cw position.

b. Turn on the power supply and adjust the DC output voltage for a motor speed of 900 r/min.

c. Measure and record the following:

E_1 = 207 V ac, W_1 = 60 W, W_2 = 95 W

I_1 = 0.88 A ac, I_2 = 0.73 A ac, I_3 = 0.89 A ac

E_2 = 49 V ac

☑ 11. a. Increase the variable DC output voltage to 120 V dc and adjust the field rheostat for a motor speed of 1800 r/min.

b. Measure and record the following:

E_1 = 207 V ac, W_1 = 62 W, W_2 = 93 W

I_1 = 0.86 A ac, I_2 = 0.73 A ac, I_3 = 0.89 A ac

E_2 = 6 V ac

c. Return the voltage the zero and turn off the power supply.

d. In procedures 10 and 11 is the rotor being turned with or against the rotating stator field? Explain.

It is being turned with the field. This is clear because as the speed goes up the voltage goes down a lot (to about 6 V)

REVIEW QUESTIONS

1. Knowing that the voltage induced in the rotor winding is zero when it is turning at synchronous speed, what is the synchronous speed of your motor?

   Synchronous speed = 1800 r/min

2. Knowing that the equation for synchronous speed is:

   $N_s = 120f/P$

where: N_S = synchronous speed (r/min)
f = power line frequency (Hz)
P = number of stator poles

determine the number of poles in your motor.

= 4 poles

3. Calculate the rotor slip (in r/min) in procedures 6, 8, 9, 10 and 11. (Slip in r/min = sync speed-rotor speed).

   slip (6) = 1800 r/min, slip (8) = 900 r/min

   slip (9) = 0 r/min, slip (10) = 900 r/min

   slip (11) = 0 r/min

4. Calculate the percent slip in procedures 6, 8, 9, 10 and 11.

   slip (6) = 100 %, slip (8) = 50 %

   slip (9) = 0 %, slip (10) = 50 %

   slip (11) = 0 %

5. Does the value of the exciting current of your 3ϕ motor depend upon the rotor speed?

   ☑ Yes ☐ No

6. How much power is needed to produce the magnetic field in your motor?

   = 169 var

7. How much power is needed to supply the losses associated with the production of the magnetic field?

   = 154 W

8. Plot the rotor speed vs rotor voltage on the graph of Figure 49-2. Should it be a straight line?

   ☑ Yes ☐ No

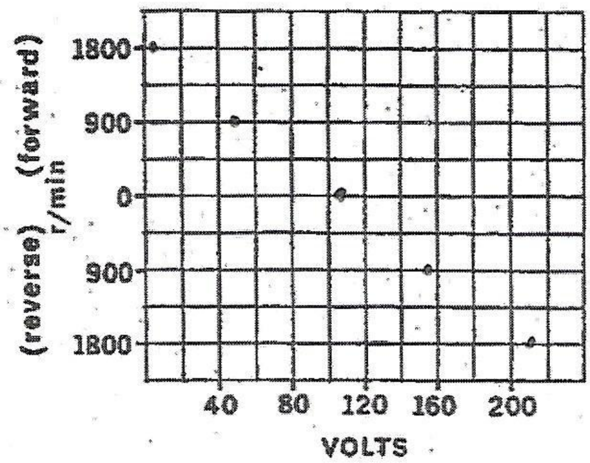

(reverse) r/min (forward)
1800
900
0
900
1800
40
80
120
160
200
VOLTS

Figure 49-2.

Experiment 50

The Wound-Rotor Induction Motor – Part II

OBJECTIVE

- To determine the starting characteristics of the wound-rotor induction motor.
- To observe the rotor and stator currents at different motor speeds.

DISCUSSION

In the previous Experiment we saw that a considerable voltage appears across the rotor windings on open circuit, and that this voltage varies linearly with rotor slip in r/min, becoming zero at synchronous speed.

If the rotor windings are short-circuited, the induced voltage will cause large circulating currents in the windings. To supply this rotor current, the stator current must increase in value above its ordinary exciting current level. The power consumed (VA) in the rotor windings (and associated circuitry) must be supplied by the stator windings. Therefore, we should expect the following:

a) At standstill, or at low speed, the rotor currents, stator currents and torque will be high.

b) At synchronous speed, the rotor current and torque will be zero, and the stator will only carry the exciting current.

c) At any other motor speed, the currents and the developed torque will be between the above extremes.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☐ 1. Using your Three-Phase Wound-Rotor Induction Motor, Electrodynamometer, Power Supply, AC Ammeter and AC Voltmeter, connect the circuit shown in Figure 50-1. Note that the three stator windings are connected to the variable 3ϕ output of the power supply, terminals 4, 5 and 6.

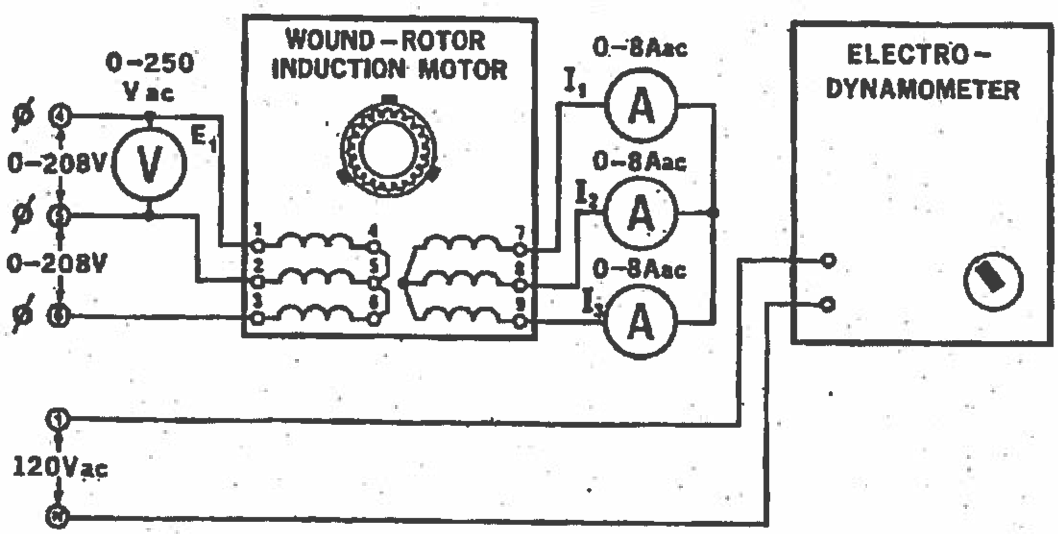


Figure 50-1.

☐ 2. a. Couple the electrodynamometer to the motor with the timing belt.

b. Connect the input terminals of the electrodynamometer to the fixed 120 V ac output of the power supply, terminals 1 and N.

c. Set the dynamometer control knob at its full cw position (to provide a maximum starting load for the rotor).

☐ 3. a. Turn on the power supply and adjust for an E_1 of 100 V ac. The motor should be turning slowly.

b. Measure and record the three rotor currents and the developed torque.

I_1 = 3.5 A ac, I_2 = 2.9 A ac

I_3 = 3.5 A ac, Torque = 3.3 N·m [lbf·in] (lbf·in)

c. Are the three rotor currents approximately equal?

☑ Yes ☐ No

☑ 4. a. Gradually reduce the load on the motor by slowly adjusting the dynamometer control knob. As the load is reduced the motor speed will increase.

b. Do the three rotor currents decrease as the motor speeds up?

Same

☑ Yes ☐ No

c. Do the three rotor currents decrease as the motor speeds up?

☑ Yes ☐ No

d. Measure and record the rotor currents at a torque of 0.2 N·m [1.8 lbf·in].

I_1 = 1.3 A ac, I_2 = 1.2 A ac, I_3 = 1.3 A ac

e. Return the voltage to zero and turn off the power supply.

☑ 5. a. Connect the circuit shown in Figure 50-2. Note that the fixed 3ϕ output of the power supply, terminals 1, 2 and 3 are now being used.

b. Set the dynamometer control knob at its full cw position (to provide a maximum starting load for the motor).

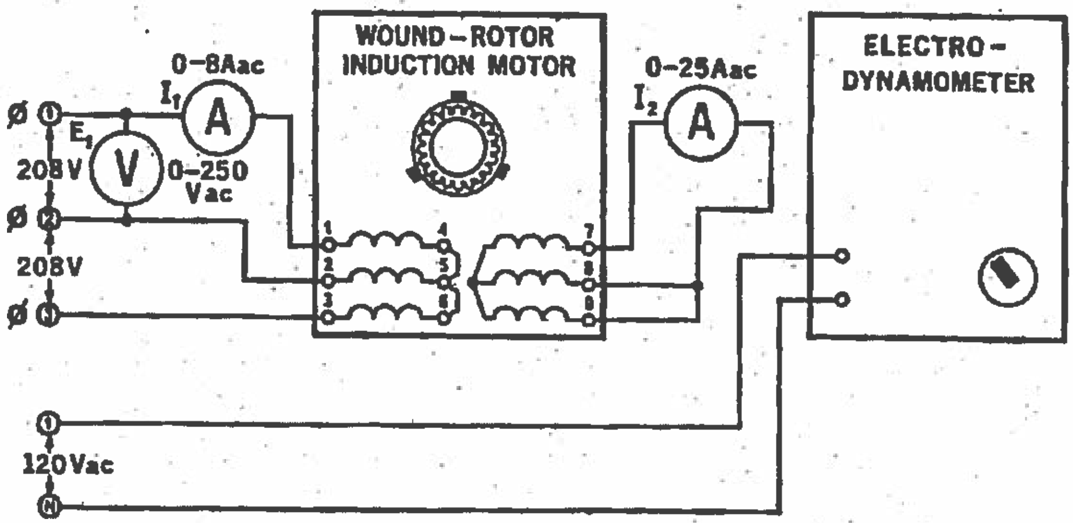


Figure 50-2.

☑ 6. a. Turn on the power supply and quickly measure E_1, I_1, I_2 and the developed starting torque. Turn off the power supply.

I_1 = 4.1 A ac $\qquad$ I_2 = 1.9 A ac

E_1 = 207 V ac, $\qquad$ Torque = 22.8 N·m [lbf·in]

b. Calculate the apparent power to the motor at starting torque.

Apparent power = 849 VA

REVIEW QUESTIONS

1. Assuming the full load 175 W [¼ hp] motor speed is 1500 r/min, calculate the value of the full load torque using the formula for output power:

$$P_{out}\,(W) = \frac{2\pi \times N \times T}{60}$$

where P_{out} = Mechanical Output Power in watts (W)
N = Speed in revolution per minute (r/min)
T = Torque in Newton-meter (N·m)

$\frac{175 \cdot 60}{2\pi 1500}$ = 1.11 N·m lbf·in

$$P_{out}(hp) = \frac{1.59 \times N \times T}{100\,000}$$

where P_{out} = Mechanical Output Power in horse power (hp)
N = Speed in revolution per minute (r/min)
T = Torque in pound-force inches (lbf·in)

2. Calculate the ratio of starting torque to full load torque:

22.8 lbf·in = 2.576 N·m

Torque ratio = 2.32

3. Assuming that the full load stator current is 1.2 A per phase, calculate the ratio of starting current to full load operating current.

$\frac{4.1}{1.2}$

Current ratio = 3.4

4. If the stator voltage of a wound-rotor motor is reduced by approximately 50% of the rated value:

a) By how much is the starting current reduced?

= 50 %

b) By how much is the apparent power reduced?

Only the rotor current (not the stator current) was measured in procedure 3. Thus, it is not possible to calculate from these measurements. The formula would be $\frac{I_1 \cdot V_1}{I_2 \cdot V_2}$

= ______ %

c) By how much is the starting torque reduced?

$1 - \frac{3.3}{22.8} \approx 86\%$

= 86 %

Experiment 51

The Wound-Rotor Induction Motor – Part III

OBJECTIVE

- To observe the characteristics of the wound-rotor induction motor at no-load and full-load.
- To observe speed control using an external variable resistance.

DISCUSSION

The three ends of the three-phase rotor windings are brought out to three slip rings mounted on the rotor shaft. The brushes bearing on the slip rings play an important role in realizing maximum advantage from the wound-rotor motor. By connecting the brushes through rheostats, it becomes possible to develop a higher starting torque than is possible with a squirrel-cage motor. On starting, the full resistance of the rheostats is maintained in the rotor circuit, thus providing the very maximum starting torque.

As the motor approaches normal operating speed, the rheostat resistance is gradually reduced until it is out of the circuit entirely at full speed. Although the starting torque of the wound-rotor motor is higher, it is not as efficient as the squirrel cage motor at full speed, because the resistance of the rotor windings is always more than that of a squirrel cage motor.

A special feature of the wound-rotor motor is its variable speed capability. By varying the rheostat resistance, it is possible to vary the percentage of slip and thus, vary the motor speed. In such cases, below full speed operation means the motor is running at reduced efficiency and mechanical output power. In addition, because of a high rotor resistance, the motor is made more susceptible to variation in speed as the load changes.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

The Wound-Rotor Induction Motor – Part III

PROCEDURE

CAUTION!

High voltages are present in this Experiment! Do not make any connections with the power on! The power should be turned off after completing each individual measurement!

☑ 1. a. Examine the construction of the Three-Phase Rheostat, paying particular attention to the circuit schematic diagramed on the face of the module.

b. Note that the arms of the three rheostats are separately brought out to terminals 1, 2 and 3. The remaining ends of the rheostats are wired together internally and brought out to the N terminal.

c. Note that the three rheostats are ganged together and that their individual resistances ca be varied simultaneously by turning the single control knob.

d. When the control knob is fully ccw the resistance of each rheostat is 0 Ω. When the control knob is fully cw the resistance of each rheostat is 16 Ω.

☑ 2. Using your Three-Phase Wound-Rotor Induction Motor, Electrodynamometer, Single-Phase Wattmeter, Three-Phase Rheostat, Power Supply, AC Ammeter and AC Voltmeter, connect the circuit shown in Figure 51-1. Do not couple the motor to the electrodynamometer at this time!

☑ 3. a. Set the speed control rheostat knob at its full ccw position for zero resistance.

b. Turn on the power supply and adjust E_1 to 208 V ac. The motor should be running.

c. Measure and record in Table 51-1, the three line currents, the two wattmeter indications (remember, to observe the polarities) and the motor speed.

d. Return the voltage to zero and turn off the power supply.

The Wound-Rotor Induction Motor – Part III

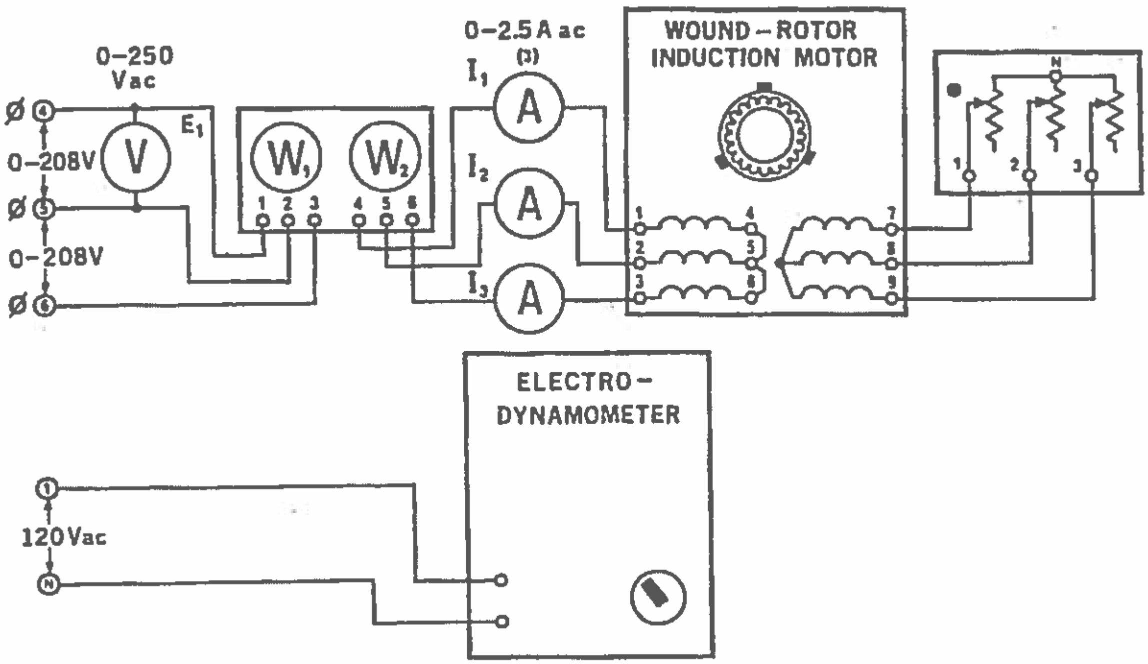


Figure 51-1.

☑ 4. a. Couple the motor to the electrodynamometer with the timing belt.

b. Set the dynamometer control knob at its full ccw position.

c. Repeat procedures 3 for each of the torques listed in Table 51-1, maintaining the input voltage at 208 V ac.

d. Return the voltage to zero and turn off the power supply.

TORQUE (N·m)	I_1 (amps)	I_2 (amps)	I_3 (amps)	W_1 (watts)	W_2 (watts)	SPEED (r/min)
0						
0.3						
0.6						
0.9						
1.2						

Table 51-1.

The Wound-Rotor Induction Motor – Part III

TORQUE (lbf·in)	I_1 (amps)	I_2 (amps)	I_3 (amps)	W_1 (watts)	W_2 (watts)	SPEED (r/min)
0	0.9	0.75	0.85	49	99	1760
3	0.98	0.8	0.95	0	152	1760
6	1.12	0.92	1.08	-41	187	1610
9	1.3	1.06	1.27	-76	226	1560
12	1.52	1.26	1.5	-115	270	1480

Table 51-1.

☑ 5. a. Set the speed control rheostat knob at its full cw position for maximum resistance.

b. Uncouple the motor from the electrodynamometer.

☑ 6. a. Turn on the power supply and adjust E_1 to 208 V ac. The motor should be running.

b. Measure and record in Table 51-2, the three line currents, the two wattmeter indications and the motor speed.

c. Return the voltage to zero and turn off the power supply.

lbf·in	~~TORQUE (N·m)~~	I_1 (amps)	I_2 (amps)	I_3 (amps)	W_1 (watts)	W_2 (watts)	SPEED (r/min)
0	0	0.87	0.72	0.86	52	100	1830
3	0.3	0.97	0.8	0.93	5	150	1470
6	0.6	1.08	0.91	1.06	-37	182	1220
9	0.9	1.26	1.07	1.23	-78	220	940
12	1.2						

Table 51-2.

TORQUE (lbf·in)	I_1 (amps)	I_2 (amps)	I_3 (amps)	W_1 (watts)	W_2 (watts)	SPEED (r/min)
0						
3						
6						
9						
12						

Table 51-2.

☑ 7. a. Couple the motor to the electrodynamometer with the timing belt.

b. Set the dynamometer control knob at its full ccw position.

c. Repeat procedure 6 for each of the torques listed in Table 51-2, maintaining the input voltage at 208 V ac.

d. With a developed torque of 0.9 N·m [9 lbf·in], rotate the speed control rheostat knob from full cw to full ccw.

e. Does the motor speed change?

☑ Yes ☐ No

f. Does the developed torque change?

☑ Yes ☐ No

g. Return the voltage to zero and turn off the poser supply.

☑ 8. a. Connect the circuit shown in Figure 51-2. Note that the fixed 3ϕ output of the power supply, terminals 1, 2 and 3 are now being used.

b. Set the dynamometer control knob at its full cw position (to provide a maximum starting load for the motor).

c. Set the speed control rheostat knob at its full cw position (to provide maximum resistance).

The Wound-Rotor Induction Motor – Part III

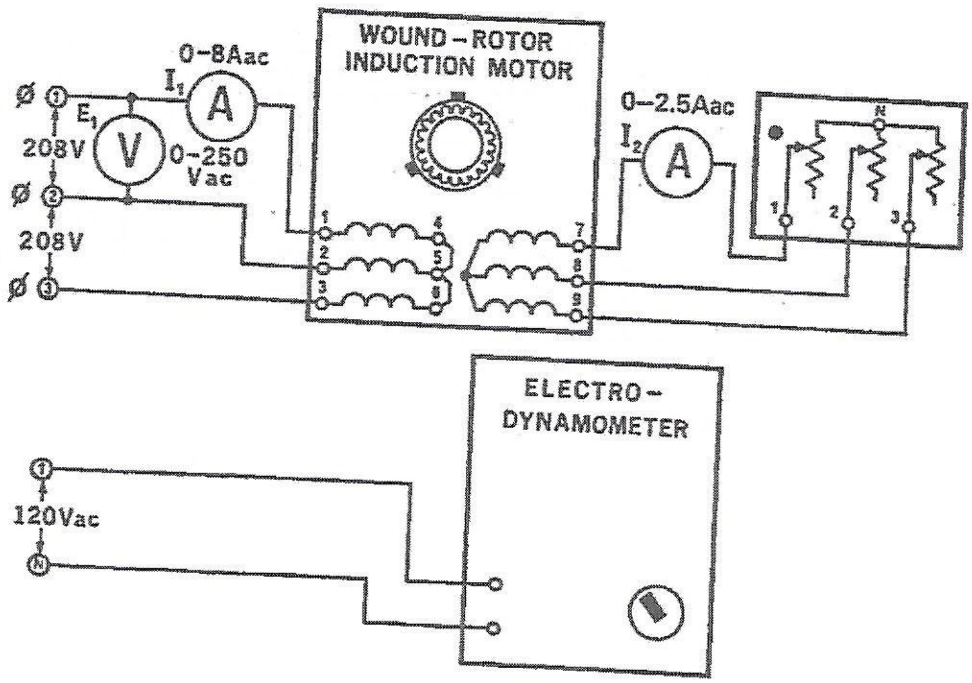


Figure 51-2.

☐ 9. a. Turn on the power supply and quickly measure E_1, I_1, I_2 and the developed starting torque. Turn off the power supply.

I_1 = 1.5 A ac, I_2 = 2.1 A ac

E_1 = 208 V ac, Torque = 16.1 N·m [lbf·in] lbf·in

b. Calculate the apparent power to the motor at starting torque.

Apparent power = 312 VA

REVIEW QUESTIONS

1. Using the results of Table 51-1, calculate the no-load characteristics of the wound-rotor motor.

a) average current

____

_______________ = 0.83 A ac

b) apparent power

0.83·208 = 173 VA

= 173 VA

c) active power

99+49 = 148 W VA cosθ

d) reactive power

VA sin θ

= 89.6 var

e) power factor

148/173 = 0.86

2. Using the results of Table 51-1, calculate the 0.9 N·m [9 lbf·in] characteristics of the wound-rotor motor (with 0 Ω external rotor resistance).

a) average current $\frac{1.3+1.06+1.27}{3}$

= 1.21 A ac

b) apparent power

1.21A · 208V = 251.7 VA

c) active power

-76 + 226 = 150 W

d) reactive power

_______________ = 195.6 var

e) power factor

150/251.7 = 0.60

f) mechanical output power

$\frac{2\pi \cdot 1560 \cdot 1.01\ N \cdot m}{60}$ = 165 W [hp]

(This is impossible and clearly a mistake)

g) efficiency

165/ = 110 % (impossible)

3. Using the results of Table 51-2, calculate the 0.9 N·m [9 lbf·in] characteristics of the wound-rotor motor (with 16 Ω external rotor resistance).

a) average current

_______________ = 1.19 A ac

b) apparent power

208·1.19 = 247.5 VA VA

c) active power

220−78 = 142 W VA cosθ

d) reactive power

_______________ = 202.7 var   V A sin θ

e) power factor

142/247.5 = 0.57

f) mechanical output power $\frac{2\pi \cdot 940 \cdot 1.01}{60}$

_______________ = 99.4 W [hp]

g) efficiency

99.4/149 = 0.7 %

4. Using the results of procedure 9 and Table 51-2, make the following ratio calculations (use the 0.9 N·m [9 lbf·in] characteristics for the full-load values).

These are unitless ratios.

a) starting current to full-load current

1.5/1.19 = 1.26 ~~A ac~~

b) starting torque to full-load torque

16.1/9 = 1.79 ~~N·m [lbf·in]~~

c) full load current to no-load current

1.19 /0.817 = 1.46 ~~A ac~~

5. The efficiency of the motor is much lower when the external resistance is in the motor circuit. Explain.

The rehestat greatly increases the resistance in series with the windings and burns up a lot of power, which results in waste heat.

6. The power factor improves with loading. Explain.

As the load increases the active power increases much more than the reactive power.