Electric Power / Controls

DC Machines

Student Manual
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Lab-Volt®

ELECTRIC POWER /CONTROLS

DC MACHINES

by
the Staff
of
Lab-Volt (Quebec) Ltd

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Foreword

Electricity has been used since more than a century and the number of applications requiring electricity is increasing constantly. As a result, the electrical power demand has been rising since the early use of electricity. Many reasons explain why electricity is so popular.

One reason is the great versatility of electricity. We use it every day for cooling, heating, lighting, driving (through electric motors) etc. Furthermore, many apparatuses that are part of our everyday life, such as telephones, televisions, personal computers, etc., require electrical power.

Another reason that explains the constantly rising demand for electricity lies in the fact that it is a highly reliable source of energy.

The Lab-Volt 0.2-kW Electromechanical Training System and related courseware offer a comprehensive program in the field of electrical power technology. It is an ideal tool for preparing the students to the realities of the contemporary job market.

The program was developed by educators to satisfy educational requirements that include industrial applications of electric power technology. The design objective was to develop a low-power educational system with equipment that operates like industrial equipment.

The student manuals explain electrical principles as well as specific industrial applications of the phenomenon discussed in each exercise. Hands-on exercises carried out with the training system reinforce the student's knowledge of the theory being studied.

The method of presentation is unique in its modular concept and places emphasis upon electrical laboratory procedures performed by the individual student.

Symbols and Abbreviations

The user of this Student Manual may find some unfamiliar symbols and abbreviations. In general, Lab-Volt Educational System has adopted the "Letter Symbols for Units" IEEE Standard Number 260/USA Standard Number Y10.19, dated October 18, 1967.

The abbreviations have been adopted by Lab-Volt following a thorough study of available abbreviations and guidelines published by the Institute of Electrical and Electronic Engineers (IEEE) and are consistent in nearly all respects with the recommendations of the International Organization for Standardization (ISO) and with the current work of the International Electrotechnical Commission (IEC).

The symbols and abbreviations used in this manual are listed below. Each symbol derived from a proper name has an initial capital letter. Singular and plural forms are identical.

alternating current	ac	frequency	f
American wire gauge	AWG	greater than	>
ampere	A	ground	gnd
ampere-turn	At	henry	H
applied voltage	V_A	hertz	Hz
average	avg	horsepower	hp
British thermal unit	BTU	hour	h
capacitance	C	impedance	Z
capacitive reactance	X_C	inch	in, ″
clockwise	cw	inductance	L
cosine	cos	inductance - capacitance	LC
coulomb	C	kilohertz	kHz
counterclockwise	ccw	kilohm	kΩ
counter electromotive force	CEMF	kilovar	kvar
current	I	kilovolt	kV
cycles per second	Hz	kilovolt-ampere	kVA
decibel	dB	kilowatt	kW
degree Celsius	°C	kilowatthour	kWh
degree Fahrenheit	°F	less than	<
degree (plane angle)	...°	load (resistance)	R_L
direct current	dc	logarithm	log
divide	÷,/	magnetomotive force	MMF
effective value (ac)	rms	maximum	max.
electromotive force	EMF	megahertz	MHz
farad	F	megavolt	MV
foot	ft, ′	megawatt	MW

Symbols and Abbreviations (cont'd)

megohm	MΩ
microampere	μA
microfarad	μF
microhenry	μH
microsecond	μs
microwatt	μW
mile	mi
milliampere	mA
millifarad	mF
millihenry	mH
milliohm	mΩ
millisecond	ms
millivolt	mV
milliwatt	mW
minimum	min.
minute (time)	min
minus	–
negative	neg, –
ohm	Ω
peak	pk
phase	φ
picofarad	pF
positive	pos, +
potential	E
pound-force	lbf
pound-force inch	lbf·in
pound-force foot	lbf·ft
power (active)	P
power (apparent)	P
power (instantaneous)	S
power (reactive)	Q
power factor	PF
reactance	X
reactance (capacitance)	X_C
reactance (inductance)	X_L
reactive power	var
resistance	R
resistance-capacitance	RC
resistance-inductance	RL
revolutions per minute	r/min
revolutions per second	r/s
root-mean square	rms
second (time)	s
sine	sin
source (current)	I_S
source (voltage)	E_S
tangent	tan
temperature	T
time	t
total current	I_T
total power	P_T
volt	V
voltage (applied)	V_A
volt-ampere	VA
watt	W
watthour	Wh

Table of Contents

Introduction IX

Experiment 1 **Prime Mover and Torque Measurement** 1-1

To learn how to connect a three-phase synchronous motor. To learn how to connect the electrodynamometer. To learn how to use the Prony brake.

Experiment 2 **The Direct Current Motor – Part I** 2-1

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 winding.

Experiment 3 **The Direct Current Motor – Part II** 3-1

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

Experiment 4 **The DC Shunt Motor** 4-1

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

Experiment 5 **The DC Series Motor** 5-1

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

Experiment 6 **The DC Compound Motor** 6-1

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

Experiment 7 **The DC Separately Excited Shunt Generator** 7-1

To study the properties of the separately excited DC shund 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.

Experiment 8 **The DC Self Excited Shunt Generator** 8-1

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.

Table of Contents (cont'd)

Experiment 9 **The DC Compound Generator** 9-1

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.

Experiment 10 **DC Motor Starter** 10-1

To examine the construction of a DC motor starter. To observe the operation of a 3-point DC starter. To observe the operation of a 4-point DC starter.

Experiment 11 **Thyristor Speed Controller** 11-1

Completing this exercise will give you an introduction to thyristor speed controllers. You will learn how to control the speed of a DC motor by varying the armature voltage using a thyristor speed controller.

Experiment 12 **Thyristor Speed Controller with Regulation** 12-1

In this exercise, you will be introduced to thyristor speed controllers operating in the closed-loop mode of control. You will learn how the closed-loop mode of control regulates the motor speed by detecting the armature voltage and current. You will learn how to control the acceleration of the DC Motor/Generator. You will also learn how to limit the current and the torque of the DC Motor/Generator.

Appendices **A** **Equipment Utilization Chart**
B **Impedance Table for the Load Modules**
C **Performing the Electrical Power Technology Courseware Using the Lab-Volt Data Acquisition and Management System**
D **SCR Speed Control – Part I**
E **SCR Speed Control – Part II**

We Value Your Opinion!

Introduction

The subject matter in this manual, *DC Machines*, covers the study of direct current machines. The motor and generator characteristics, whether they are shunt, series or compound connected, are explained in details. The starting and speed control of the DC motors are some subjects also covered.

The exercises in this manual provide a systematic and realistic means of learning the subject matter. Each exercise contains:

- an OBJECTIVE that clearly defines the objectives of the exercise;
- a DISCUSSION of the theory involved;
- a detailed step-by-step laboratory PROCEDURE in which the student observes and measures important phenomena. Schematic diagrams facilitate connecting the components;
- some REVIEW QUESTIONS to verify that the material has been well assimilated.

The exercises can be carried out using either conventional instruments (AC/DC voltmeters and ammeters, power meters, oscilloscope, etc.), or the Lab-Volt Data Acquisition and Management (LVDAM) System. Appendix C of this manual provides useful guidelines to perform the exercises using the LVDAM system.

As a reference manual, we suggest to consult *Electrical Machines, Drives, and Power Systems* written by Theodore Wildi and published by Prentice Hall.

Note that the highlighted text in the manual only applies to the Imperial system of units.

Experiment 1

Prime Mover and Torque Measurement

OBJECTIVE

- To learn how to connect a three-phase synchronous motor.
- To learn how to connect the electrodynamometer.
- To learn how to use the Prony brake.

DISCUSSION

The synchronous motor has the special property of maintaining a constant running speed under all conditions of load up to full load. This constant running speed can be maintained even under variable line voltage conditions. It is, therefore, a useful motor in applications where the running speed must be accurately known and unvarying.

In this Experiment, you will learn how to use this motor as a stable driver for generators. The complete study of its characteristics will be taken up in later Experiments. It should be noted that, if a synchronous motor is severely overloaded, this operation (speed) will suddenly lose its synchronous properties and the motor will come to a halt. The synchronous speed of your motor is 1800 r/min.

The load imposed on a motor can be measured by two different means; these two torque measuring devices are the Prony brake and the electrodynamometer. The Prony brake is an entirely passive device (no electrical power is required) while the electrodynamometer requires external power.

The Prony Brake is a friction brake which is used to act as a load for any type of motor and to measure the torque developed by these motors. This brake is entirely mechanical, and consists of a spring balance mounted in a standard full size module. It is built to accurately measure the torque developed by any rotating machine placed on its left-hand side.

A self-cooling friction wheel is slipped over the shaft of the machine under test, and attached to its output pulley by means of two screws. The friction belt of the Prony Brake is then removed from inside the module and slipped over the friction wheel. The braking torque applied to the machine can be varied by turning the knurled wheel (LOAD) in the upper left corner of the module. A second knurled wheel (TORQUE PRESET) in the upper center allows the spring balance to be brought back into equilibrium by aligning the red line in the right-hand window (ZERO) with the black line; the torque can then be read directly on the 0-3.4 N·m [0-30 lbf·in], 360° circular scale, in steps of 0.02 N·m [0.2 lbf·in].

The accuracy is better than 2% and the torque is continuously adjustable over the full range from no load to locked rotor. When one wants to apply a known torque to the machine, the TORQUE PRESET wheel must first be set so that the calibrated circular scale reads exactly the desired torque value and the LOAD wheel must then be turned in such a way that the red line in the ZERO window is aligned with the black line.

The electrodynamometer is a device used to accurately measure the torque developed by motors of all kinds. It is actually an electrical brake in which the braking force can be varied electrically rather than by mechanical friction. The electrodynamometer is a more stable, easier to adjust, device than the mechanical friction brakes.

The electrodynamometer consists of a stator and a squirrel-cage rotor. The stator, unlike other electromechanical devices, is free to turn, but its motion is restricted by a helical spring.

In normal operation, DC current is applied to the stator winding. This sets up a magnetic field which passes through both the stator and the rotor. As the rotor turns (being belt-coupled to the driving motor), a voltage is induced in the rotor bars, and the resulting eddy currents react with the magnetic field causing the stator to turn in the same direction as the rotor.

The stator rotation is limited by the helical spring and the amount that it turns is marked off on a scale attached to the external stator housing.

The electrodynamometer is calibrated from -0.3 to 3 N·m [3 to 27 pound-force·inches (lbf·in)] which is more than adequate for the testing of 0.2 kW [1/4 hp] motors even when they are tested at overload conditions.

The power output of a motor depends upon its speed and the torque it develops. This relationship is given by the following equation:

$$P_{out}\ (W) = \frac{2\pi \times N \times T}{60} \qquad (1)$$

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

$$P_{out}\ (hp) = \frac{1.59 \times N \times T}{100\ 000} \qquad (1)$$

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)

Prime Mover and Torque Measurement

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!

Synchronous Motor

☐ 1. Examine the front face of the Three-Phase Synchronous Motor/Generator. (The entire Three-Phase Synchronous Motor/Generator will be fully described in a later Experiment.)

a. Note the three separate windings connected to terminals (1 and 4, 2 and 5, 3 and 6. These windings are identical and are actually located in the stator or stationary part of the motor. The three windings carry AC current and will connect to a three-phase power source.

b. Identify these three windings and their corresponding connection terminals.

c. The winding on the rotor or rotating part of the motor, is connected to connection terminals 7 and 8, through a 150 Ω rheostat and a toggle switch. This winding will carry DC current, whose value can be controlled by means of the rheostat.

d. Identify the winding, the rheostat, the toggle switch and their corresponding connection terminals.

☐ 2. Using your Power Supply, and AC Ammeter, connect the circuit shown in Figure 1-1.

Terminals 1, 2 and 3 on the power supply provide fixed three-phase power which is required 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 which is required for the rotor winding.

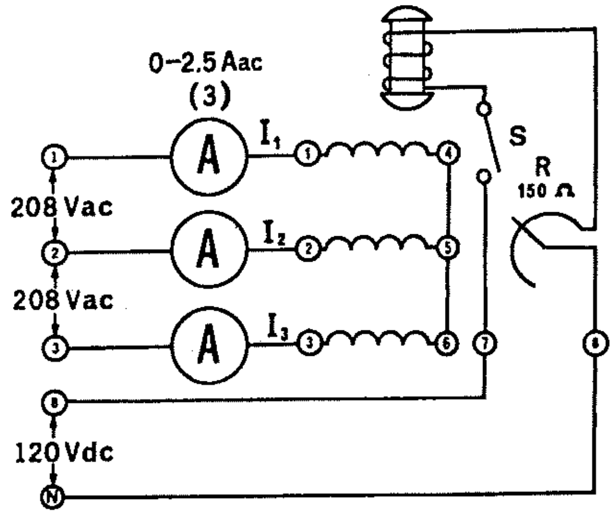

Figure 1-1.

☐ 3. a. Adjust the rheostat for maximum resistance (control knob turned fully counterclockwise, ccw).

b. The motor is supplied with DC current only when switch S is closed. Insure that switch S is open.

c. Have your instructor check your completed circuit.

☐ 4. a. Turn on the Power Supply. The motor should start running immediately.

b. Note the indications on the three current meters.

c. Close switch S.

☐ 5. a. Vary the rheostat control for minimum stator current as indicated by the three current meters (The control knob should be close to its full ccw position).

b. Measure and record the three stator winding currents (at minimum stator current).

I_1 = ______ A I_2 = ______ A I_3 = ______ A

c. Increase the rotor DC excitation by adjusting the rheostat for minimum resistance (control knob turned fully clockwise cw).

d. Measure the three stator winding currents (at maximum rotor DC excitation).

I_1 = ______ A I_2 = ______ A I_3 = ______ A

☐ 6. Reduce the DC excitation until the stator currents are at their minimum values. Note and record the position of the rheostat control knob. (In all future procedures using the synchronous motor, the control knob should be set to this position for normal excitation.)

Control knob scale position = ______

☐ 7. a. Using your hand tachometer measure the running speed of the motor as you vary the DC excitation.

Speed-minimum excitation = ______ r/min

Speed-midpoint excitation = ______ r/min

Speed-maximum excitation = ______ r/min

Does the speed remain constant?

☐ Yes ☐ No

b. Note whether the direction of rotation is clockwise or counterclockwise.

Rotation = ______

☐ 8. a. Turn off the power supply and open switch S. Interchange any two of the AC connection leads at the power supply terminals.

b. Turn on the power supply and note the direction of rotation:

Rotation = ______

c. Turn off the power supply.

d. Disconnect the synchronous motor.

Electrodynamometer

Note: *If your list of equipment does not include an electrodynamometer, proceed to procedure 19.*

☐ 9. a. Examine the construction of the Electrodynamometer.

b. Note the cradle construction for the electrodynamometer housing. (This is also called trunnion mounting.)

c. Note the helical spring at the rear of the machine. This spring has been accurately calibrated against the graduations marked on the front of the housing.

d. Note the mechanical stops that limit the rotational travel of the stator housing.

e. Identify the stator winding that is attached to the inside of the housing. (This winding carries DC current.)

f. Identify the two wire leads that carry DC current to the stator winding. (They enter the housing through the center of the helical spring.)

g. Identify the bridge rectifier located at the rear of the module. (This bridge furnishes DC power for the stator magnetic field.)

h. Identify the variable autotransformer mounted on the front face of the module. The braking effect of the electrodynamometer is controlled by the strength of the stator magnetic field, which is proportional to the DC output of the bridge rectifier, which is varied by the variable autotransformer.

i. Identify the two AC connections terminals mounted on the module face.

☐ 10. a. Connect the electrodynamometer tot the fixed AC output of the power source by connecting the two input terminals of the electrodynamometer to terminal 1 and N of the power source.

DO NOT APPLY POWER AT THIS TIME!

b. Set the electrodynamometer variable transformer control knob to its mid-position.

c. Lower the front face of the module so that you may turn the pulley by hand.

☐ 11. a. Turn on the power supply.

b. Keeping one hand in your pocket, for safety reasons, carefully reach in and try to turn the pulley. Caution is advised because there are several live terminals exposed when the front panel is dropped.

Do you feel a drag when you turn the pulley?

☐ Yes ☐ No

Does the stator housing tend to turn in the same direction as the pulley?

☐ Yes ☐ No

☐ 12. a. Remove your hand from the inside of the module and advance the control knob, thereby increasing the magnetic stator field.

b. Carefully reach in and turn the pulley. Did the drag increase?

☐ Yes ☐ No

c. Repeat (a) but this time reduce the stator magnetic field.

d. Carefully reach in and turn the pulley. Did the drag increase?

☐ Yes ☐ No

e. Turn off the power supply.

☐ 13. a. Couple the synchronous motor and the electrodynamometer with the timing belt.

b. Connect the motor as shown in Figure 1-1.

c. Connect the electrodynamometer to terminals 1 and N of the power supply. (There should now be two connection leads at terminal 1 of the power supply – one to the synchronous motor and one to the electrodynamometer).

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

e. Set the synchronous motor rheostat control knob to its normal minimum stator current position.

☐ 14. Apply power and note if the motor revolves in a cw direction. If not, reverse its rotation (the dynamometer torque can only be measured for cw rotation). Close switch S.

☐ 15. Increase the load on the motor (the dynamometer braking action) by varying the control knob on the dynamometer until the scale marked on the stator housing indicates 1 N·m [9 lbf·in]. (The numeral 1 [9] should be directly beneath the red vertical line on the window beneath the pulley).

☐ 16. a. Measure and record the three AC stator currents with a 1 N·m [9 lbf·in] load on the motor.

I_1 = ______ A I_2 = ______ A I_3 = ______ A

b. Measure and record the motor speed with a 1 N·m [9 lbf·in] load.

Speed with load = ______ r/min

☐ 17. a. Vary the DC excitation to the motor by turning the rheostat control knob, while under the 1 N·m [9 lbf·in] load. What effect does varying the DC excitation have on the three stator currents?

____

____

b. Measure the motor running speed at minimum and maximum DC excitation while under the 1 N·m [9 lbf·in] load.

Speed minimum excitation = ______ r/min

Speed maximum excitation = ______ r/min

c. Does the motor fall out of synchronism when the DC excitation is too low?

☐ Yes   ☐ No

☐ 18. a. Increase the DC excitation to its maximum value. Gradually increase the load on the motor, by advancing the variable autotransformer control knob on the electrodynamometer, until the motor falls out of synchronization. Immediately turn off the power supply. Open switch S.

b. Record the value of this "breakdown" torque.

"Breakdown" torque = ______ N·m [lbf·in]

Prony Brake

Note: *If your list of equipment does not include a Pony Brake, proceed to REVIEW QUESTIONS.*

CAUTION!

The friction wheel may become very hot during this experiment.

☐ 19. a. Examine the construction of the Prony Brake.

b. Remove the friction wheel from inside the module and note the holes in the web of the pulley; they are for cooling purposes. Slip the friction wheel over the synchronous motor shaft and secure it firmly to the motor pulley by tightening the two screws in the grooves of the motor pulley.

c. Note the floating plate inside the module. In operation, this plate is pulled in one direction by the friction belt and in the other direction by a spring which is connected to the fixed frame by means of a rack gear. A pinion gear, driven by the rack, turns the front plastic disc which has a red line to read the torque. The TORQUE PRESET wheel effectively increases the spring tension and consequently, the force which tends to turn the floating plate.

d. The LOAD wheel effectively increases the tension on the friction belt, and tends to turn the floating plate in the opposite direction.

e. Note the friction belt attached at one end to the floating plate and at the other end to the LOAD wheel screw.

f. The complete system constitutes a spring balance.

☐ 20. a. Turn the LOAD wheel downwards to release the tension on the friction belt, and slip the belt over the friction pulley mounted on the synchronous motor. Leave the belt loose.

b. Connect the synchronous motor as shown in Figure 1-1.

c. Set the synchronous motor rheostat control knob to its normal minimum stator current position. Open switch S.

d. Turn on the power supply and note if the motor revolves in a cw direction. If not, reverse its rotation (the Prony brake can only measure torque for cw rotation). Close switch S.

e. Measure the three stator winding currents.

I_1 = ______ A I_2 = ______ A I_3 = ______ A

f. Vary the TORQUE PRESET wheel until the circular scale indicates 1 N·m [9 lbf·in]. This does not impose any torque on the motor and the currents should not change. You have just preset the balance to the indicated torque.

g. Turn slowly the LOAD wheel upwards to tighten the belt over the friction pulley. Note the gradual increase in the motor currents. Keep turning the LOAD wheel until the hairlines in the right-hand window are aligned. The balance is now in equilibrium and is imposing a torque of 1 N·m [9 lbf·in] on the synchronous motor.

h. Measure and record the three AC stator currents with a 1 N·m [9 lbf·in] load on the motor.

I_1 = ______ A I_2 = ______ A I_3 = ______ A

i. Measure and record the motor speed with a 1 N·m [9 lbf·in] load.

Speed with load = ______ r/min

☐ 21. a. Increase the DC excitation to its maximum value. Gradually increase the load on the motor by turning the LOAD wheel. Then bring the balance into equilibrium by turning the TORQUE PRESET wheel until the hairlines are aligned. Repeat successively these last two steps until the motor falls out of synchronism. Immediately turn off the power supply. Open switch S.

b. Record the value of the "breakdown" torque as indicated by the calibrated dial.

"Breakdown" torque = ______ N·m [lbf·in]

REVIEW QUESTIONS

1. How can you reverse the direction of rotation of a synchronous motor?

____

____

2. What effect does varying the DC incitation have on the stator currents of a synchronous motor?

____

____

3. How can you increase the power output of a synchronous motor?

____

____

4. Calculate the developed motor mechanical output power in procedure 16 b) or 20 i).

____

____

Mechanical Output Power [hp]= ______

5. Calculate the developed motor mechanical output power in procedure 18 or 21 (just prior to "breakdown").

____

____

Mechanical Output Power [hp] = ______

6. Which torque measuring device is easier to use, the electrodynamometer or the Prony brake?

____

____

7. Where is the power (heat) dissipated in the electrodynamometer?

____

____

8. Where is the power (heat) dissipated in the Prony brake?

____

____

Experiment 2

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!

☐ 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?

____

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?

____

c. How many brushes are there?

____

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 ______ and ______.

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

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

____

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

☐ 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 ______ and ______.

b. What is its rated resistance value?

$R_{(field\ rheostat)}$ ________ 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 2-1.

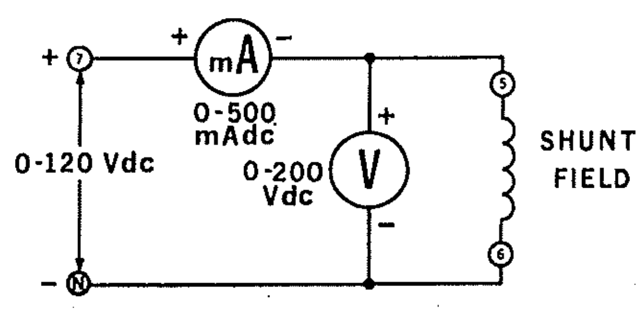

Figure 2-1.

☐ 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.

$E_{(shunt\ field)}$ = ______ V dc

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 = ______ / ______ = ______ Ω

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

$P_{(shunt\ field)}$ = I^2R = ______ X ______ = ______ W

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

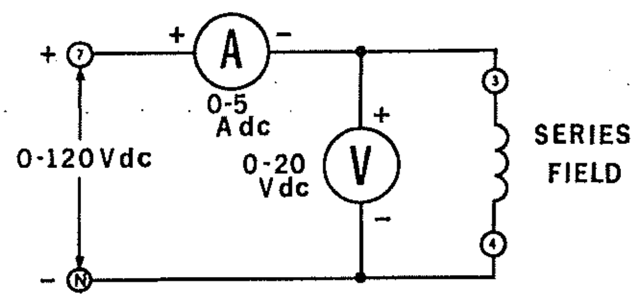

Figure 2-2.

a. This is the same circuit as shown in Figure 2-1 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.

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

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

e. Calculate the resistance of the series field winding.

$R_{(series\ field)} = E/I =$ ______ / ______ = ______ Ω

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

$P_{(series\ field)} = I^2R =$ ______ X ______ = ______ W

☐ 9. Connect the circuit shown in Figure 2-3.

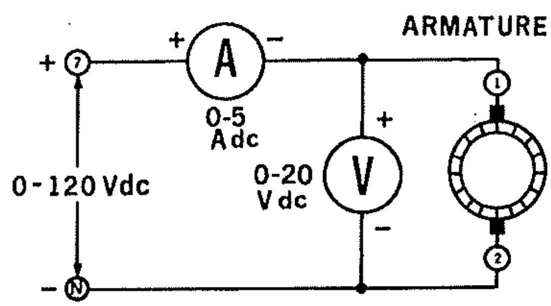

Figure 2-3.

a. This is the same circuit shown in Figure 2-2 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).

$R_{(armature)} = E/I =$ ______ / ______ = ______ 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?

____

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

____

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?

____

$I_{minimum}$ = ______ A dc $I_{maximum}$ = ______ A dc

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

____

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

____

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

   a) What current would flow?

   ____

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

   ____

   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?

   ____

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

   ____

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?

   ____

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

   ☐ Yes ☐ No

   ____

Experiment 3

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!

The Direct Current Motor – Part II

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 3-1. Terminals 4 and N on the power supply will furnish variable 0-120 V ac as the voltage output control is advanced.

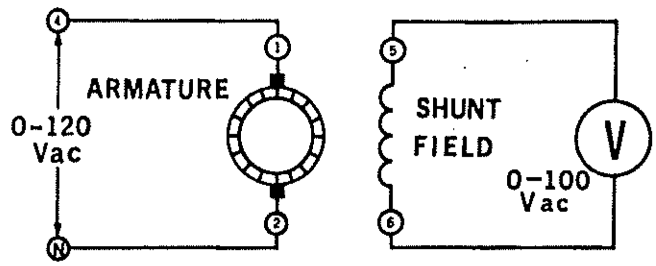

Figure 3-1.

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).

☐ 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.

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 3-2. Notice that the armature is connected in series with the series field winding, across the input voltage.

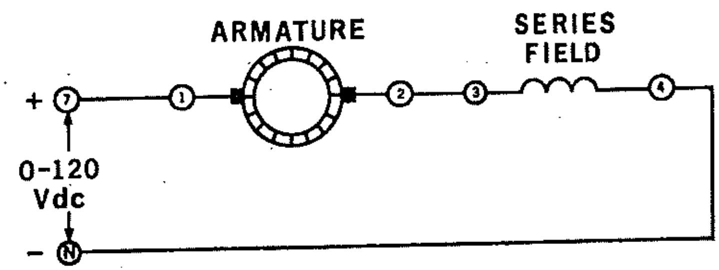

Figure 3-2.

☐ 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 = ______ r/min

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:

____

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

Rotation = ______

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

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

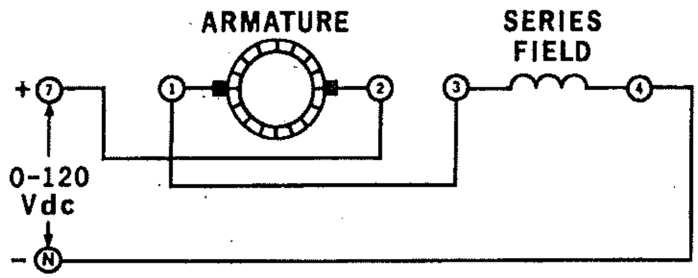

Figure 3-3.

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

Series speed$_{(reversed)}$ = ______ r/min

Rotation = ______

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

____

Shunt Motor Connections

☐ 12. Connect the circuit shown in Figure 3-4. 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.

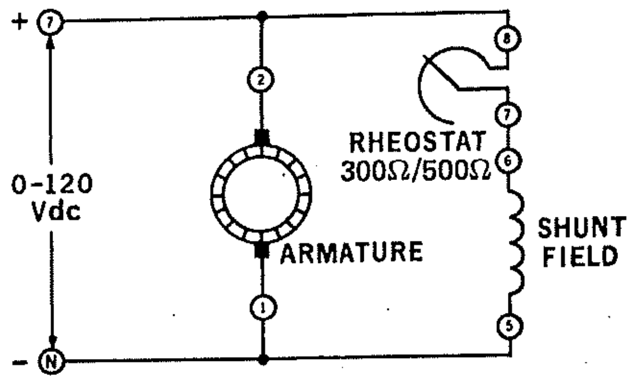

Figure 3-4.

☐ 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$_{(zero\ ohms)}$ = ______ r/min

d. Adjust the rheostat for maximum resistance (approximately 500 Ω).

e. Determine the direction of rotation.

Rotation = ______

☐ 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 3-4. 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 = _____

☐ 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.

____

____

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

☐ Yes ☐ No

____

____

☐ 19. Connect the circuit shown in Figure 3-5. 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).

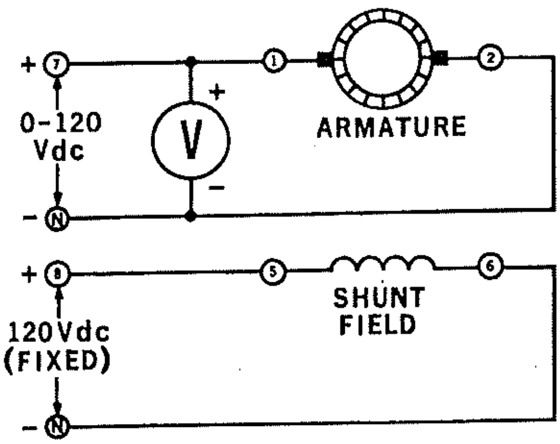

Figure 3-5.

☐ 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 3-1. (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				

Table 3-1.

d. Plot each of the points from Table 3-1 on the graph shown in Figure 3-6. Draw a smooth curve through your plotted points.

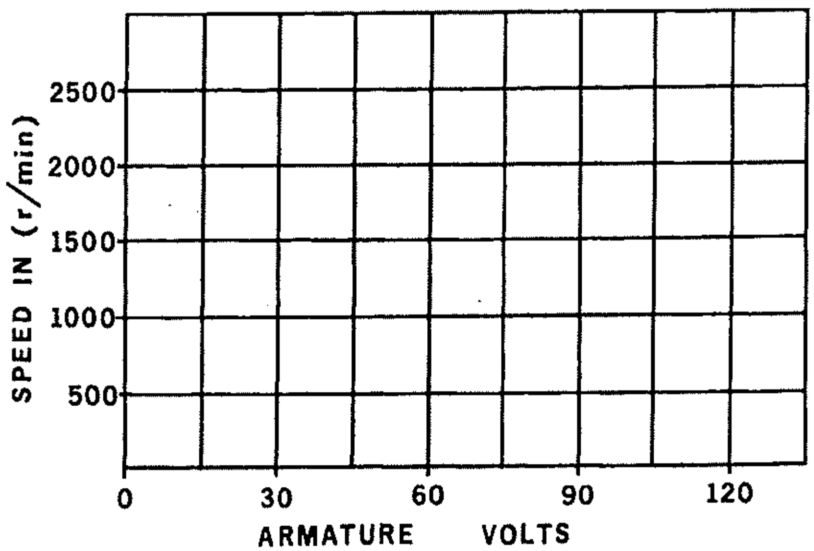

Figure 3-6.

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.

___

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

☐ Yes ☐ No

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

___

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

___

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

____

6. In procedure 20:

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

      ☐ Yes ☐ No

      ____

   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

      ____

7. Draw a circuit showing how you would connect:

   a) a shunt motor to a DC supply.

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) ______________________________

b) ______________________________

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

   a) which method gives the greatest speed range? ______

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

Experiment 4

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.

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 4-1.

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).

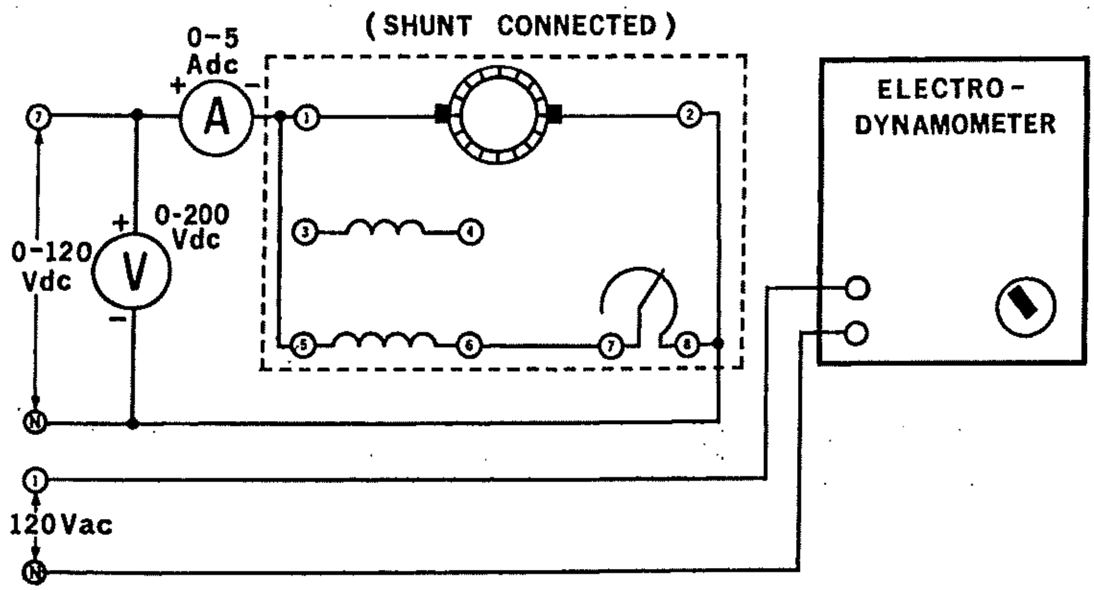

Figure 4-1.

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).

☐ 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 4-1.

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
120			0.3
120			0.6
120			0.9
120			1.2

Table 4-1.

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

Table 4-1.

☐ 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 4-1.

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 4-1 on the graph of Figure 4-2.

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.

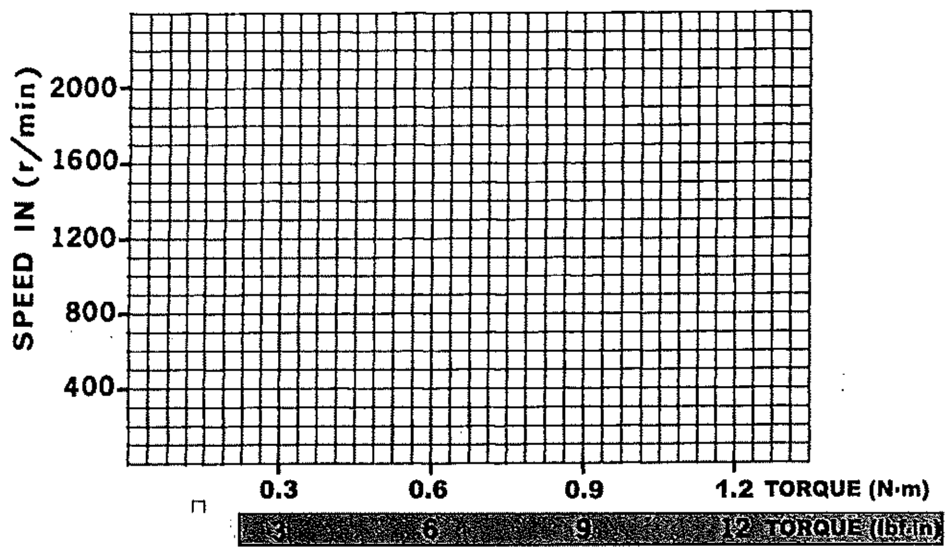

Figure 4-2.

☐ 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 = ______ %

☐ 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 = ______ V Torque = ______ N·m [lbf·in]

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 = ______ A

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:

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

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

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

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} = ______ W [hp]

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

____

____

Output power = ______ W

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

____

____

Input power = ______ 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 = ______ %

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

____

Losses = ______ W

5. List where some of these losses occur.

____

____

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

☐ Yes ☐ No

____

7. Give two reasons why losses are undesirable.

____

____

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

____

Experiment 5

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.

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 5-1.

DO NOT APPLY POWER AT THIS TIME!

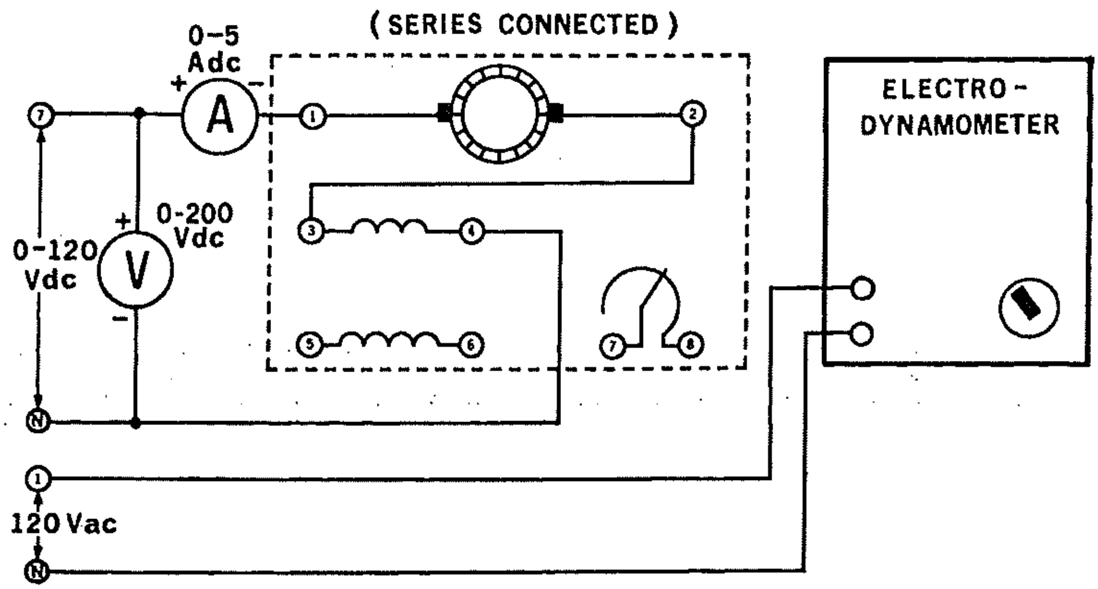

Figure 5-1.

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).

☐ 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 5-1.

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)
120			0
120			0.3
120			0.6
120			0.9
120			1.2

Table 5-1.

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

Table 5-1.

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

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

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.

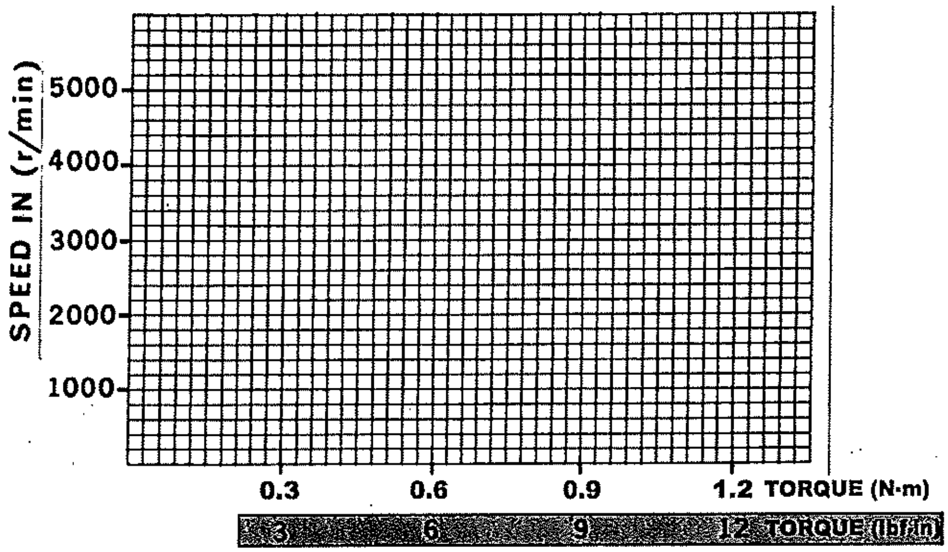

Figure 5-2.

☐ 6. 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 = ______ %

☐ 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 = ______ V Torque = ______ N·m [lbf·in]

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 = ______ 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:

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

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} = ______ W [hp]

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

____

____

Output power = ______ W

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

____

____

Input power = ______ W

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

____

____

Efficiency = ______ %

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

____

____

Losses = ______ W

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

____

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

   a) Starting torque ______________________________

   ____

   b) Starting current ______________________________

   ____

   c) Efficiency ______________________________

   ____

   d) Speed regulation ______________________________

   ____

Experiment 6

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.

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 6-1.

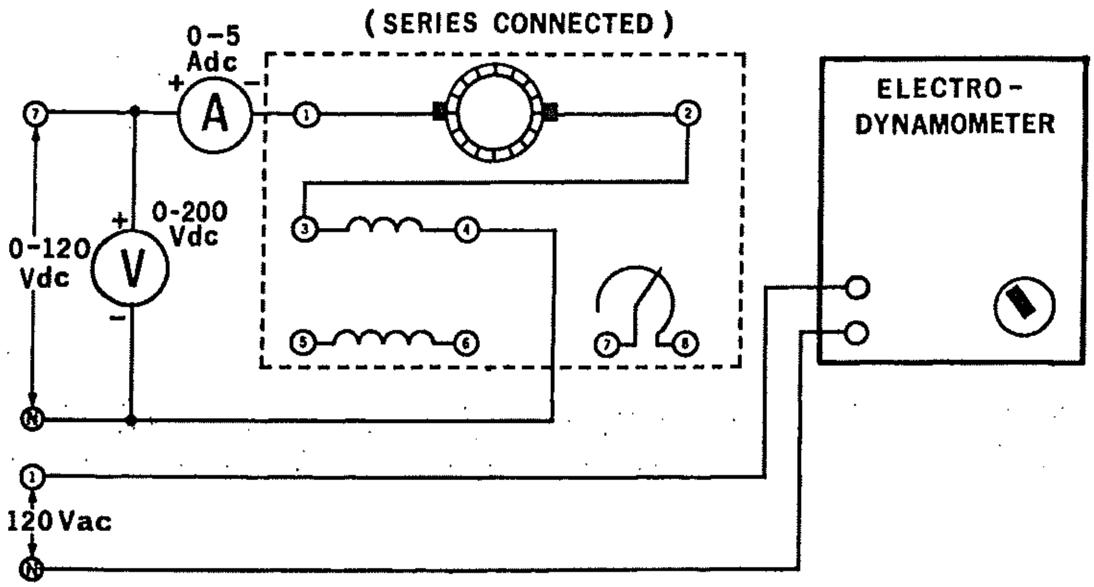

Figure 6-1.

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 6-2.

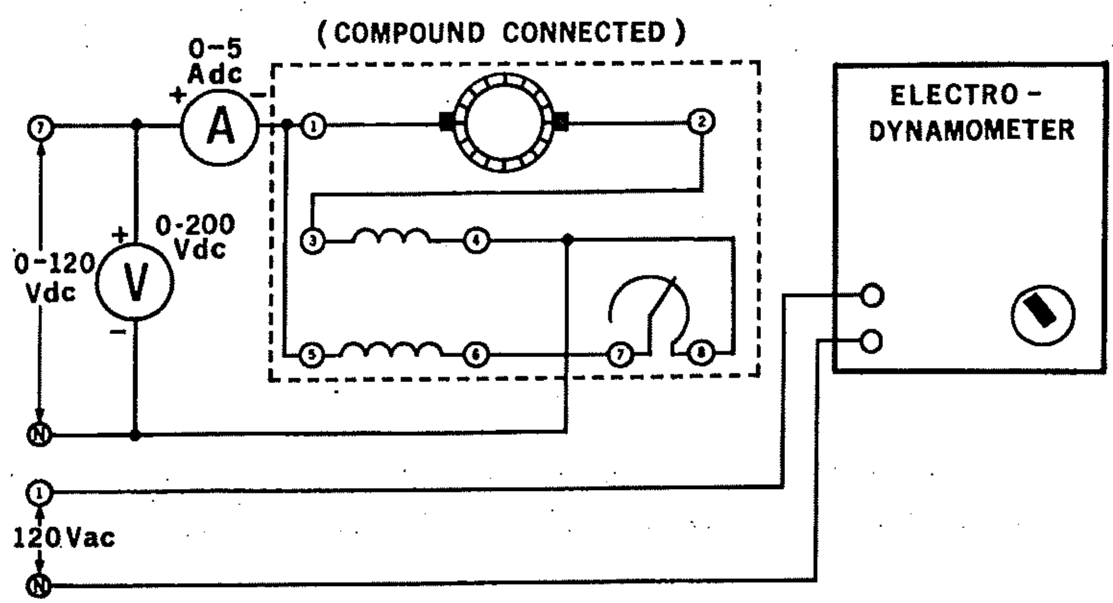

Figure 6-2.

☐ 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).

b. Measure the line current and motor speed. Record these values in Table 6-1.

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)
120			0
120			0.3
120			0.6
120			0.9
120			1.2

Table 6-1.

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

Table 6-1.

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

☐ 8. a. Plot the recorded motor speed values from Table 6-1 on the graph of Figure 6-3.

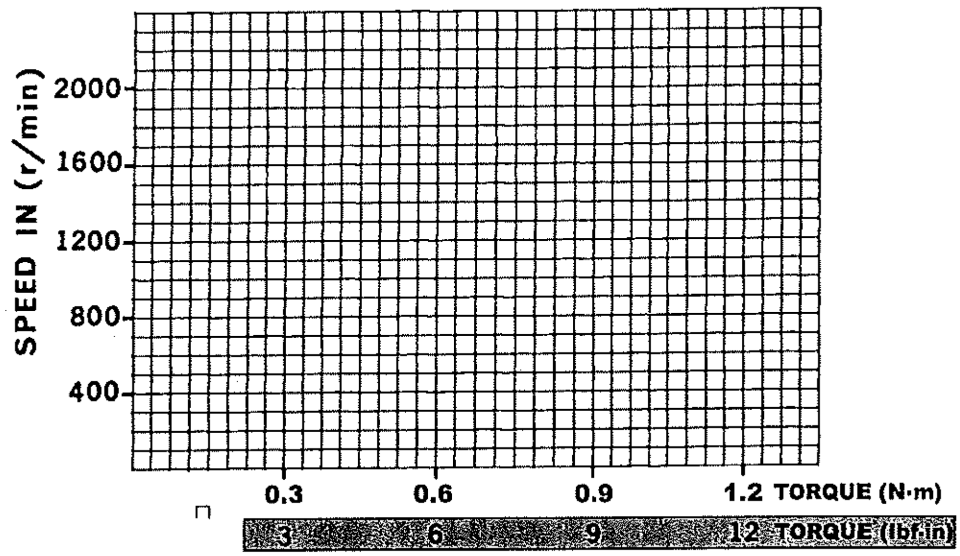

Figure 6-3.

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 [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 = ______ %

☐ 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 = ______ V   Torque = ______ N·m [lbf·in]

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

☐ 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 = ______ A

REVIEW QUESTIONS

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

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

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} = ______ W [hp]

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

____

____

Output power = ______ W

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

____

____

Input power = ______ W

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

____

____

____

Efficiency = ______ %

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

____

____

Losses = ______ W

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

____

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.

____

____

____

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

   a) Starting torque ______________________________________

____

b) Starting current ______________________________

____

c) Efficiency ______________________________

____

d) Speed regulation ______________________________

____