WASIT UNIVERSITY
COLLEGE OF ENGINEERING
ELECTRICAL ENGINEERING DEPARTMENT
ELECTRICAL MACHINES LABORATORY
SECOND CLASS

FIRST SEMESTER

MG-5211

EXPERIMENT NO-6

LOAD CHARACTERISTICS OF DC COMPOUND GENERATOR

BASIC THEORY

A shunt field Winding or a series field Winding is wound on a single Pole piece. This is true even when there are two or four Poles in the machine. Two types of Compound generators are available: Cumulative Compound and Differential Compound

CUMULATIVE COMPOUND:

This type of generator is designed to maximize voltage regulation by arranging the magnetic fields from the shunt and series, Windings in the same <direction. Because the two fields are oriented in the same <direction, the shunt and series fields can complement each other. For example, when there is no load, the shunt field ensures that the output voltage is maintained constant. As the generator is loaded toward the full rating, the voltage drop due to the property of the shunt generator is compensated by the series field which has the opposite characteristics. Therefore a commutative compound generator can be optimized to maximize the voltage regulation performance.

Cumulative compound generators can be classified into three different types

Over Compounded	Output's higher at full load than at no load.
Flat Compounded	Output is same between no load and full load.
Under Compounded	Output is lower at full load than at no load.

Output adjustments in a compound generator are done by adjusting a variable resistor which is in series with the shunt field.

DIFFERENTIAL COMPOUND:

Contrary to a Cumulative Compound generator, the output of a Differential generator decreases rapidly as the load increases. The field arrangement inside is done in such a way that the shunt and series magnetic fields cancel each other. Therefore, under a heavy load, the series field reduces the shunt field, resulting in a reduced output. This type of generator is found in an arc welder, and in some other special applications. Also, a Differential Compound generator can be designed to deliver a constant current output.

PREPARATION

Equipment needed: MG-5211 set

(1) Keep the motor Main and generator Output switches off. Check the mechanical coupling between the motor and generator.

(2) Connect all the meters in the motor and generator as indicated in the circuit diagram. Set the range of M - 3 to 10 A.

(3) Turn RH-l (shunt field) of motor circuit fully counterclockwise, and RH-2 (armature) fully clockwise.

(4) Set Series/Shunt selector switch to Shunt.

(5) Connect the No.1 terminal of the series field in the generator to M-1, and No.2 terminal to M-2.

(6) Set RH-l of the generator in middle, and turn all the load switches off.

(7) Connect the DC O-120V Source terminals and the" +, -" input terminals.

   a. Turn the DC Source Adjust fully counterclockwise (OV).

(8) Keep the Motor switch off. Turn the Main switch on.

(9) Make sure there are no objects in the rotating path of the motor and generator. Double check the accuracy of all connections.

OPERATION AND MEASUREMENTS

1. Turn the Motor SW on, and press the Start button. Adjust the DC Source so that the motor speed is 1800 RPM. Fill in the information in Table 6-1 for "NO LOAD" and "MOTOR" section.

2. Turn the generator Output switch on. With the generator at no load, adjust RH-l (generator) to obtain 120V at the output terminal. Fill in the information in Table 6-1 for "NO LOAD" and "GENERATOR" section.

Table 6-1

------------		NO LOAD	1/4 LOAD	1/2 LOAD	FULL LOAD
MOTOR	INPUT VOLTAGE (E)				
	INPUT CURRENT (I)				
	SPEED (RPM)				
GENERATOR	OUTPUT TERMINAL VOLTAGE (Vo)				
	LOAD CURRENT (I_L)				
	FIELD CURRENT (I_{GF})				

3. Turn the generator load switch S-l on. Fill in the information in Table 6-1 for "1/4 LOAD" section.

4. Turn the load switch S-l and S-2 on. Repeat step (3) and fill in the information in Table 6-1 for "1/2 LOAD" section.

5. Turn S-l and S-2 off, and turn S-3 on. Repeat step (3) and fill in the information in Table 6-1 "FULL LOAD" section.

6. Adjust RH-2 of the motor or DC input voltage at each load to maintain 1800 RPM, and fill in the information in Table 6-2 (a) for each load.

Table 6-2 (a) 1800 RPM

		NO LOAD	1/4 LOAD	1/2 LOAD	FULL LOAD
MOTOR	INPUT VOLTAGE (E)				
	INPUT CURRENT (I)				
GENERATOR	LOAD CURRENT (I_L)				
	FIELD CURRENT(I_{GF})				

7. Connect RH-2 of the generator in parallel with the series field winding as indicated by the dotted lines, and set RH-2 in the middle position. Repeat step (6) and fill in the information in Table 6-2 (b) for each load.

Table 6-2 (b) 1800 RPM

		NO LOAD	1/4 LOAD	1/2 LOAD	FULL LOAD
MOTOR	INPUT VOLTAGE (E)				
	INPUT CURRENT (I)				
GENERATOR	OUTPUT TERMINAL VOLTAGE (Vo)				
	LOAD CURRENT (I_L)				

8. When the measurement is over, turn all switches off. Turn down DC Source adjustor to minimum before turning the Main switch off.

EXPERIMENT REVIEW

1. Plot the obtained data points on the charts provided in Figures 6-3 and 6-4.Figure 6-3 is for the motor speed vs. the load, and Figure 6-4 is for the generator output vs. the load

2. Efficiency is defined as the generator output (Pc) for a given motor input (P;) :

$$\eta = \frac{P_G}{P_i} * 100$$

Where $P_G = V_o . I_L$

$P_i = E . I = E . (I_F + I_a)$

Using the data in Table 6-2(a), calculate the efficiency at each load, and plot the results in Figure 6-5. Also draw a curve in Figure 6-6 which shows a relationship between the output voltage and the load currents

3. Using the data in Figure 6-2(b), plot the data in Figure 6-6. Connect the points in dotted line. Compare the two curves. Explain the difference between two curves.
4. The voltage regulation, VR, of the generator is defined as

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} X100(\%)$$

Where V_{NL} is the no load output voltage

V_{FL} is the full load output voltage

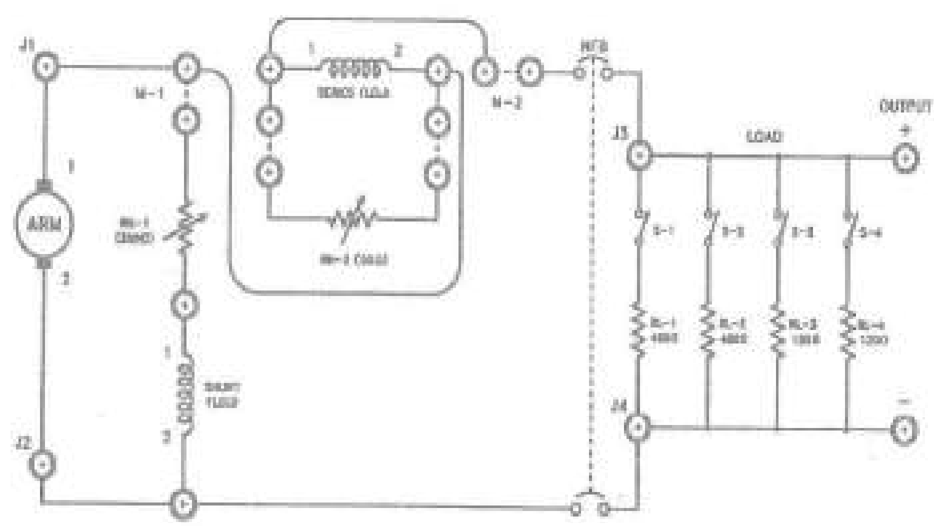
EXPERIMENT NO-7

Comparison between a Cumulative Generator and a Differential Generator

[Note] The generator in the previous experiments in 6 was a Cumulative generator.

PREPARATION

1. Keep the motor Main and generator Output switches off. Check the mechanical coupling between the motor and generator.
2. Connect all the meters in the motor and generator as indicated in the circuit diagram. Set the range of M - 3 to 10 A.
3. Turn RH-l (shunt field) of motor circuit fully counterclockwise, and RH-2 (armature) fully clockwise.
   Set Series/Shunt selector switch to Shunt.
5. Wire the series field winding, No.1 and No.2 terminals of MG-5211 generator as indicated in Figure 6-7 (Differential Compound generator).



6. Set RH-l of the generator in middle, and turn all the load switches off.
7. Connect the DC O-120V Source terminals and the" +, -" input terminals.
    b. Turn the DC Source Adjust fully counterclockwise (OV).
8. Keep the Motor switch off. Turn the Main switch on.
9. Make sure there are no objects in the rotating path of the motor and generator. Double check the accuracy of all connections.

OPERATION AND MEASUREMENTS

1. Turn the motor on, and press the Start button. Adjust the DC Source for 1800 RPM on the motor

2. Turn the generator output on. Adjust generator RH-1 to obtain 120V at no load. Fill in the information in Table 6-3 "NO LOAD" section

Table 6-3 (1800 RPM)

	NO LOAD	1/4 LOAD	1/2 LOAD	FULL LOAD
SHUNT FIELD CURRENT(IF)				
OUTPUT TERMINAL VOLTAGE (Vo)				
LOAD CURRENT (I_L)				

3. Turn the load switch S-l on. Adjust motor RH-2 to obtain 1800 RPM. Fill in the information in Table 6-3 "1/4 LOAD" section
4. Turn load switches S-l and S-2 on. Adjust motor RH-2 to obtain 1800 RPM. Fill in the information in Table 6-3 "1/2 LOAD."
5. Turn S-l and S-2 off. Turn S-3 on. Repeat step (4) and fill in the information in Table 6-3 "FULL LOAD."
6. In step (5), connect RH-2 in parallel to the series field winding. Set the RH-2 in the output voltage (Vo) and fill in the space provided below Table 6-3.
7. Turn all switches off. Turn down the DC source adjust before turning the Main switch off

EXPERIMENT REVIEW

1. Using the data in Table 6-3, draw a curve showing the output as a function of the load in Figure 6-8. Find the Voltage Regulation, VR as defined in the previous section

$$VR = \frac{\text{No Load Output Voltage - Full Loaded Output Voltage}}{\text{Full Loaded Output Voltage}}$$

2. Find the voltage regulation using the Vo value as obtained in step (6). Compare the two voltage regulation values.
3. Compare the voltage regulation data obtained m Section 6-1 (Cumulative generator). Explain the difference.

EXPERIMENT NO-8

SPEED AND OUTPUT CHARACTERISTICS OF A COMPOUND GENERATOR

The output characteristics of a compound motor are investigated as a function of the generator speed in this section.

PREPARATION

1. Keep the motor Main and generator Output switches off. Check the mechanical coupling between the motor and generator.
2. Connect all the meters in the motor and generator as indicated in the circuit diagram. Set the range of M - 3 to 10 A.
3. Turn RH-l (shunt field) of motor circuit fully counterclockwise, and RH-2 (armature) fully clockwise.
4. Set Series/Shunt selector switch to Shunt.
5. Connect the No.1 terminal of the series field in the generator to Mr I, and No.2 terminal to M-2.
6. Set RH-l of the generator in middle, and turn all the load switches off.
7. Connect the DC O-120V Source terminals and the" +, -" input terminals.
    c. Turn the DC Source Adjust fully counterclockwise (OV).
8. Keep the Motor switch off. Turn the Main switch on.
9. Make sure there are no objects in the rotating path of the motor and generator. Double check the accuracy of all connections.

OPERATION AND MEASUREMENTS

1. Turn the generator Output switch on. Turn the Main and Motor switches on. Check the DC Source. It should be av. Press the motor Start button.

2. DC source voltage slowly to obtain the speed as specified in Table 6-4 (no load). Fill in the information in Table 6-4 for each speed. Notice that the armature voltage is obtained by measuring the voltage across J-l and J-2.

Table 6-4 (No Load)

	RPM					
SHUNT FIELD CURRENT	1000	1200	1400	1600	1800	2000
ARMATURE VOLTAGE						
OUTPUT TERMINAL VOLTAGE						

3. Turn the load switches S-1 and S-2 on for 1/2 load. Repeat step (2) with the 1/2 load, and fill in the information in Table 6-5 0/2 load).

Table 6-5 1/2 load)

	RPM					
SHUNT FIELD CURRENT	1000	1200	1400	1600	1800	2000
ARMATURE VOLTAGE						
OUTPUT TERMINAL VOLTAGE						

4. Turn all the switches off. Reduce the DC source voltage to minimum before turning the Main switch off.

EXPERIMENT REVIEW

l. Draw curves in solid lines in Figure 6-9 (IF vs. speed), 6-10 (Va vs. speed) and 6- 11 (V O vs. speed) using the data in Table 6-4.

EXPERIMENT NO-9

EFFICIENCY AND LOSSES OF A COMPOUND GENERATOR

BASIC THEORY

A generator requires some form of rotating mechanical energy at the input to convert the mechanical energy to an electrical energy. A variety of energy sources are available for the input: an electric motor, a gasoline or diesel powered engine, or a windmill.

In this section, a generator is driven by a DC motor. The efficiency of a generator refers to the ratio of the input to output energy. The difference between the input and output energy is the loss of the generator itself. The main elements of the generator losses are mechanical friction, the armature and field winding losses and the stray power loss. The armature winding loss is considered to be a variable loss, while the field winding loss is considered to be a fixed loss.

For a separately excited machine, the power supplied to the field coil is not considered to be a part of the generator loss. The generator efficiency is
Expressed in the following formula:

$$\text{Effeciency (\%)} = \frac{\text{Output power (W)}}{\text{Input power (W)}} \times 100$$

PREPARATION

Equipment needed: MG-5211 set and a DC voltmeter (or a multimeter)

(1) Check the mechanical coupling between the motor and generator. Keep all the switches off.

(2) Connect the meters M-1, M-2 and M-3 in the motor to their locations as indicated. Set M-3 for 10 A range.

(3) Connect a voltmeter across the generator armature terminals (J1 - 12). Set the meter in 200V range.

(4) Turn the motor RH-l fully counterclockwise, and RH-2 fully clockwise.

(5) Set the Series/Shunt switch to Shunt.

(6) Connect the meters M-l through M-3 in the generator to their locations as indicated.

(7) Set the generator RH-1 in the mid position, and RH-2 fully clockwise.

(8) Connect the No.1 terminal of the generator series field winding to M -1, and No.2 terminal to M-2. Make sure all the load switches are off.

(9) Connect between the DC 120V sources terminals and input terminals using the cords. Turn the Main switch on. Adjust the DC source to obtain 115V.

(10)Make sure there are no foreign materials in the rotating paths of the motor and generator. Make sure all the connections are correct.

OPERATION AND MEASUREMENTS

(1) Turn the Motor switch on, and press the start button. Bring the motor speed to 1800 RPM by adjusting RH-l. Fill in the information in Table 6-6 "MOTOR" section.

(2) Turn the generator Output switch on. Adjust RH-1 of the generator to obtain DC120V output at no load. Fill in the information in Table 6-6 "GENERA TOR" section.

Table 6-6 (No Load 1800 RPM)

	MOTOR	GENERATOR
INPUT VOLTAGE (E)		
FIELD CURRENT (IF)		
ARMATURE TERMINAL VOLTAGE (V A)	----	
ARMATURE VOLTAGE (IA)		
LOAD CURRENT (Id)	--	
OUTPUT TERMINAL VOLTAGE (Vo)	------------	

(3) Turn only the load switch S-3 on. Adjust RH-2 of the motor to obtain 1800 RPM. Adjust RH-1 of the generator to obtain 120V output at the generator. In case the RPM is off from 1800, adjust for 1800.

(4) Fill in the information in Table 6-7 MOTOR and GENERATOR respectively.

Table 6-7 (Full Load 1800 RPM)

	MOTOR	GENERATOR
INPUT VOLTAGE (E)		
FIELD CURRENT (IF)		
ARMATURE TERMINAL VOLTAGE (V A)		
ARMATURE VOLTAGE (IA)		
LOAD CURRENT (Id		
OUTPUT TERMINAL VOLTAGE (V_o)		

(5) Turn all the switches off. Turn the DC Source down before turning the Main switch off.

EXPERIMENT REVIEW

1. Generator loss $P_{GL} = P_{SL} + P_{FL} + P_{AL}$

- Stray Power Loss $P_{SL} = P_{MG} - P_M$

Where $P_{MG} =$ Motor input power with a generator coupled, but not loaded.
$P_M =$ Motor input power without a generator coupled.

[Note] P_{MG} from Table 6-6 "Generator and No load": $P_{MG} = E\ (I_F + I_A)$
P_M from Table 4-1 "Motor and No load" : $P_M = E\ (I_F + I_A)$

- Loss due to the generator field winding resistance $P_{FL} - V_A \,.\, I_F$

[Note] Calculate P_{FL} using Full Load/Generator data from Table 6-7.

- Loss due to the generator armature winding resistance P_{AL}

Where $I_L =$ Generator load current at full load
R_A =Armature winding resistance

[Note] Use the RA value from Table 2-1.

MG5212

6. Load Characteristics of External-Exciting DC Generator

<Preliminary Knowledge>

The no-load output at the DC external-exciting generator becomes constant as long as its rotation speed and field exciting current are uniform. However, when there is a load at the output of the generator, the output voltage changes. That's because there occurs a strong voltage drop due to the armature winding resistance like other generators. Therefore, the output terminal voltage is as follows.

$$\text{Output terminal voltage} = \text{Generation voltage} - R_A \cdot I_L$$

Here, the RA is an Armature winding resistance and the IL is a load current. In case of a self-exciting shunt generator, the output terminal voltage will be different from the formula above. That's because the exciting current of the generator field changes right after the output terminal voltage changes by load. The external-exciting generator has the following characteristics in comparison with the self-exciting one.

1. The external-exciting generator does not produce a magnetic field from the output voltage like the self-exciting generator. Therefore, as long as the external-exciting voltage does not change at all, it has a less voltage output in comparison with the self-exciting generator. The voltage regulation VR(%) is as follows.

   $$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

   Here, V_{NL} : No-load terminal voltage

   V_{FL} : Full-load terminal voltage

2. As it does not follow the self-exciting mode, you do not have to worry about the loss of residual magnetism. It generates electricity even during reverse rotation. However, the +,− of the output voltage changes during reverse rotation.

<Preparation for Operation>

Equipment : MG-5212 Set

1. First of all, check if the motor of the practice equipment is connected to its generators properly, and turn OFF the main switch and motor switch.
2. Connect the M-1, M-2 and wattmeter of the motor circuit to each terminal indicated.
3. Connect the input terminal of the AC 0~110V source terminal by using the connecting cord. And, connect the J3~J4 and J5~J6 as shown in dotted lines so that the winding of the motor circuit can be connected to the circuit.
4. Connect the M-1~M-4 Meters of the generation circuit to each terminal indicated. And, turn the RH-1 to the maximum in the clockwise direction.
5. Turn ON the main and motor switches, and turn the AC 0~110V source knob beside the left side of the equipment to reach about 100V. And, adjust the exciting source DC 0~120V knob to reach 110V, and turn OFF the motor switch.
6. Turn ON the exciting switch and output switch of the generation circuit, and turn OFF the load switch S-1~S-4 all together.
7. Check if there is any obstacle to the motor and generator rotating part, and check if the circuit configuration is normal, again.

<Operation & Measurement>

1. Turn ON the Motor switch, run the motor by pressing the Start button, and adjust the AC source to the AC 110V for its normal rotation. Measure the RPM and check if a speed is 1750RPM. (It is normal as long as it is within 1750±1%.)
2. Adjust the RH-1 of the generation circuit so that the output voltage can reach 120V. And, read the M-1~M-4 Meter indicators and record results to the

no-load box of the Table 6-1.

3. Turn ON the load switch S-1 of the generation circuit, and measure the motor RPM again. If not sufficient, make it a normal RPM by adjusting the AC 0~110V source knob beside the left side of the equipment. And, read the M-1~M-4 Meter indicators and record results to the 1/4 load box of the Table 6-1.

4. Then, turn ON the S-1 and S-2, read the M-1~M-4 Meter indicators, and record results to the 1/2 load box of the Table 6-1.

<Table 6-1 (RPM: 1750)>

	No-Load	1/4 Load	1/2 Load	Full Load	Over Load
Armature both end voltage (V_A)	120 V				
Load Current (I_L)					
Field Current (I_F)					
Output Voltage (V_o)					
Speed (RPM)	1750	1750	1750		?

5. Turn ON the S-1, S-2 and S-3 for full load, carry out measurement like the No.(4), and record results to the full-load box of the Table 6-1.

6. Turn ON the S-1~S-4 all together, read the M-1~M-4 Meter indicators with the RPM while the RPM is not adjusted, and record results to the over-load box of the Table 6-1.

7. After finishing this practice, stop the motor by pressing the Stop button, and turn OFF the Motor switch. In case of not continuing this practice, turn OFF the main switch.

<Practice Evaluation>

1.Indicate the characteristics of the output voltage vs. load in the Fig. 6-1 by using the data in the Table 6-1. And, calculate the voltage regulation of generator output voltage during full-load.

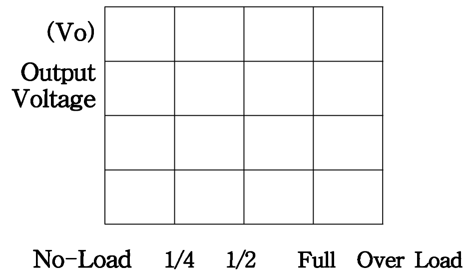


Fig. 6-1

[Note] $VR = \dfrac{\text{No}-\text{load output voltage} - \text{Full}-\text{load output voltage}}{\text{Full}-\text{load output voltage}} \times 100$ ......(%)

2. **Measure the Armature winding resistance, and calculate a voltage drop caused by the Armature winding at the 1/4, 1/2 and full loads.**

[Note] Turn OFF the output switch of the generator when it stops, and measure the resistance between J1 and J2, both ends of the Armature. Carry out measurement about three times while moving the rotational axis of the generator slightly, and set its average to R_A. At this time, the voltage drop by Armature winding is $R_A \times I_L$.

<Summary>

1. **The voltage regulation at the external-exciting generator increases in proportion to the load current. (However, there is no change in RPM and field current.)**
2. **The voltage drop by Armature winding is a kind of generation loss. The output terminal voltage is indicated as 「Generation voltage-Armature winding voltage drop」.**

7. Saturation Characteristics of External-Exciting DC Generator

<Preliminary Knowledge>

The output voltage of a generator varies depending on the generator's rotational speed, the intensity of magnetic field, and load resistance. In this case, it is only the rising rotational speed and magnetic field that can increase the output voltage actively. However, the rising speed of the generator has a mechanical limitation of the prime motor or generator itself. And, due to the saturation characteristics of the field core, the intensity of generator magnetic field will not increase beyond a certain limit in spite of increasing the field current.

In this practice, we are going to have a practice on how the saturation characteristics are indicated while the generator is under a no-load status. You should be careful that the field winding becomes hot because the exciting current flows to the generator field winding more than the rated current. Therefore, the time for flowing the over-exciting current for saturation must be as short as possible. (Within 10 seconds when the exciting current of the field is 0.7~1A)

<Preparation for Operation>

1. Execute the No.(1)~(4) of the preparation for operation in the "6. Load characteristics of external-exciting DC generator."
2. Turn the RH-1 of the generation circuit back to the middle position between right and left, set the Exciting Source 0~120V to the minimum, and turn ON the switch.
3. Turn ON the main and motor switches, and turn the AC 0~110V source knob beside the equipment to reach about 100V. And, turn OFF the Motor switch again.

4. Turn OFF all the load switch S-1~S-4 of the generation circuit, and turn ON the output switch.
5. Check if there is any obstacle to the motor and generator rotating part, and check if the circuit configuration is normal, again.

<Operation & Measurement>

1. Turn ON the Motor switch, run the motor by pressing the Start button, and adjust the AC source to AC 110V for normal rotation. And measure the RPM and check if it is normal.
2. Increase the voltage of the power supplier connected to the generator field slowly to reach the field current in the Table 7-1, and record the output terminal voltage to the following table accordingly.

<Table 7-1 (No-Load)>

Field Current (A)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1A
Output Terminal Voltage (V)										

3. Turn the Exciting Source back to 0V, and turn ON the S-1, S-2 and S-3. And, check the motor's RPM again.
4. Increase the field current of the generator slowly like the No.2 above, and record the output voltage to the Table 7-2 accordingly.

<Table 7-2 (FULL Load)>

Field Current (A)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1A
Output Terminal Voltage (V)										
Rotation Speed (RPM)										

5. After finishing measurement, turn OFF the power switch of the external power supplier, and stop the motor by pressing the Stop button. And turn OFF the Motor switch, and remove the external power supplier connected to the field of

the generator. In case of not continuing this practice, turn OFF the main switch.

<Practice Evaluation>

1. By using the data in the Table 7-1, indicate the characteristics of the output voltage vs. no-load field current in a full line to the graph of the Table 7-3.

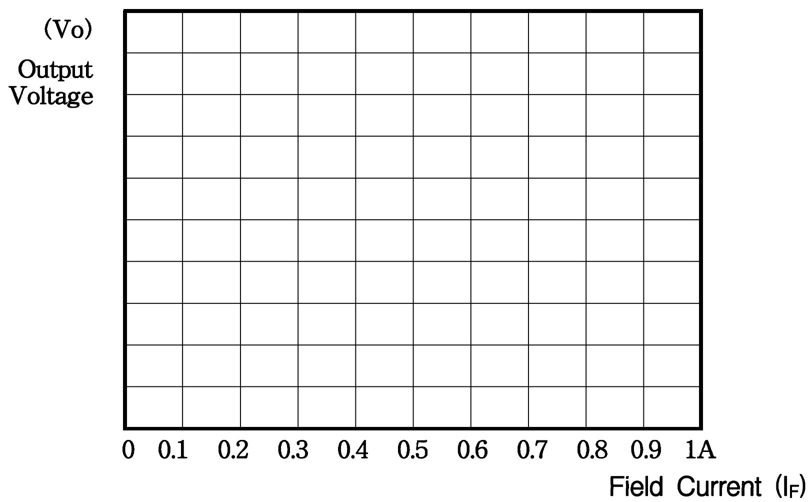


Table 7-3

2. By using the data in the Table 7-2, indicate the characteristics of the output voltage vs. full-load field current in a full line to the graph of the Table 7-3.

<Summary>

1. Looking at the full line in the Table 7-3, you can see that the output voltage remains constant without rise in its line when the field current reaches a certain level or higher. That's because it shows the no-load saturation characteristics.
2. The Table 7-3 indicates that the dotted line shows a different change from the full line. When the load current flows, the saturation characteristics of the generation output show different changes in comparison with no-load.

8. Loss & Efficiency of External-Exciting Generator

<Preliminary Knowledge>

The generator needs power supply from an external motor in any case. This outside force includes an electric motor, gasoline, diesel engine, water mill or windmill. It is the generator that converts those mechanical forces into electric energy.

In this practice, the generator is driven by the AC motor. The efficiency of this generator varies depending on how much the output energy comes from the generator in comparison with force applied to the generator. Then, let's think about the causes of inefficiency that deteriorates the efficiency.

The causes are classified roughly into the mechanical abrasion loss, heat loss at the Armature winding resistance, heat loss at the field winding resistance, and stray power. In particular, the loss at the Armature winding resistance that varies depending on the generator loads is called a variable loss, and the loss at the field winding is called a fixed loss.

In case of the generator with the AC motor, the efficiency of the generator can be calculated as follows.

$$\text{Generation efficiency (\%)} = \frac{\text{Output power(W)}}{\text{Input power(W)}} \times 100$$

Let's calculate the generator efficiency during the maximum load by determining a stray power loss and calculating a copper loss (by winding resistances). For your reference, the stray power loss is known as one of fixed losses, including mechanical loss and air resistance. All the losses caused by winding resistance is considered as copper loss.

<Preparation for Operation>

Equipment : MG-5212 Set, Ohmmeter (or Multimeter)

1. Execute the No.(1)~(3) of the preparation for operation in the "6. Load characteristics of external-exciting DC generator."
2. Connect the M-1~M-4 Meters of the generator circuit to each terminal indicated.
3. Set the Exciting Source DC 120V knob of the generation circuit to the minimum in the counterclockwise direction, and turn the RH-1 to the minimum in the counterclockwise direction.
4. Turn OFF the load switch S-1~S-4 all together, and turn ON the output switch.
5. Turn ON the main and motor switches, turn the AC 0~110V source knob beside the left side of the equipment to reach about 100V, and turn OFF the Motor switch, again.
6. Check if there is any obstacle to the motor and generator rotating part, and check if the circuit configuration is normal, again.

<Operation & Measurement>

1. Turn ON the motor switch, run the motor by pressing the Start button, and adjust the AC source to AC 110V. And, measure the RPM and check if it is a rated speed.
2. Adjust the output voltage to 120V while turning the Exciting Source DC 0~120V knob in the clockwise direction slowly. And, read the M-1, M-2 and Wattmeter of the motor, and M-1~M-4 Meter indicators of the generator, and record results to the no-load box of the motor and generation in the Table 8-1.
3. Then, turn ON the load switch S-1, S-2 and S-3, and adjust the Exciting Source DC 0~120V again so that the output voltage can reach 120V. And,

read the M-1, M-2 and Wattmeter of the motor, and M-1~M-4 Meter indicators of the generator, and record results to the full-load box of the motor and generation in the Table 8-1.

<Table 8-1>

	Motor			Generator			
	M-1	M-2	W-Meter	M-1	M-2	M-3	M-4
No Load							
Full Load							

4. Stop the motor by pressing the Stop button, and turn OFF the Motor switch. And, turn OFF the output switch of the generation circuit, and measure the winding resistance between J1 and J2 of the Armature winding of the generation circuit by using the ohmmeter (or multimeter). At this time, carry out measurement three times while rotating the generation slightly with its rotational axis fixed, and set its average to RA.

<Table 8-2>

	1	2	3	Average (R_A)
Armature winding resistance				

5. In case of not continuing this practice after measurement, turn OFF the main switch.

<Practice Evaluation>

1. Calculate the stray power loss PSL of the generator by using the data of the Table 4-2 and 8-1 in the "4. Load characteristics & torque of induction motor." In this case, let's consider the stray power loss as PSL.

   [Note] PSL=(Motor input when connecting the no-load generator)-(Input with the motor running only)

2. Calculate the generator's loss by Armature winding resistance, exciting loss

and total generator loss, and calculate the generator efficiency.

[Note] • Armature loss $P_{AL} = R_A \cdot I_L^2$ Here, R_A : Armature winding resistance

I_L : Load current

• Total loss $P_{TL} = P_{SL} + P_{AL} + P_{FL}$ Here, P_{FL} : Generator exciting loss

• Generator efficiency $\eta_{(G)}$ =

$$\frac{\text{Generator output}}{\text{Generator Full-load motor input} - \text{Input with the motor running only}} \times 100$$

$$\text{or } \eta_{(G)} = \frac{\text{Generator output}}{\text{Generator output} + \text{Total generator loss}} \times 100$$

Here, the generator output is 「Output voltage×Load current」.

3. Calculate the efficiency of the generation system including the motor by using the data in the Table 8-1.

[Note] System efficiency $\eta_{(MG)} = \dfrac{\text{Output during generator}}{\text{Motor input during generator full-load}} \times 100$

In case of the external-exciting generator, do not calculate the generator field input in the input power.

<Summary>

1. To enhance the generator efficiency, you must make the loss as little as possible in this practice. The less a void gap between field pole and Armature rotational pole is, the more output you can obtain thanks to lower magnetic field resistance.

2. Not the efficiency of the generator itself, but the efficiency of the generation system, is calculated from the efficiency of the motor, which rotates the generator, and that of the generator itself. Therefore, at this time, it requires a better output efficiency of the motor vs. its input energy. In general, the efficiency here refers to that of the generator.

SECOND SEMESTER

MG-5211

EXPERIMENT NO-2

LOAD CHARACTERISTICS OF A DC SHUNT MOTOR

BASIC THEORY

DC shunt motors are popular due to their superior stability in speed. This type of motor exhibits better speed regulation against load the changes, from no load to full load, when compared to a series or a compound motor.

The magnetic field strength in a motor is proportional to the field current. This field strength, along with the armature current, determines the torque of a motor. However, as can be seen in the coming discussions, the increase in the field current actually decreases the motor speed. In contrast to a series winding motor which has a field current proportional to the load, a shunt winding motor maintains constant shunt field current regardless of the load. However, the torque developed in a shunt motor is less than in a series winding motor.

For a shunt winding motor with no load, small amount of torque is still needed to overcome the mechanical as well as electrical losses of the rotating machine itself. As the motor is loaded, the torque is increased following the relationship between the armature speed and Counter EMF (CEMF). This relationship is described as the following. First of all, the armature speed is reduced due to the load. The reduced speed causes the CEMF to decrease, which in turn increases the armature current. As the armature current is increased, the torque is increased also. The increased torque compensates for the speed which was reduced due to the load.

Although this seems to a complex chain of events, the process described above occurs in a short period of time, and the speed of the motor appears to be constant. The opposite process takes place when the load is removed from the motor

PREPARATION

Equipment Needed: MG-5211 Set and an Ohmmeter (or a Multimeter)

1. Make sure the connection between the motor and generator is secure and reliable. Keep the Main, Motor and Generator Output switches off.
2. Connect M-1, M-2 and M-3 meters in the motor to the appropriate terminals. Set M -3 for 10A range.
3. Connect between the DC 0-120V Source Terminals and the Motor Input terminals using patch cords. Set the DC Source voltage control on the left of MG'-5211 fully counterclockwise.

Turn RH-1 (shunt field circuit) of the motor circuit fully counterclockwise, and RH-2 (armature circuit) fully clockwise.

4. Set Series/Shunt SW. to Shunt.
5. Connect M-1, M-2 and M-3 meters of the generator to their positions as indicated in the circuit.
6. Set Rheostat RH-1 of the generator to the middle position, and set RH-2 fully clockwise.
7. Connect the No.1 terminal of the Series Field winding of the generator to M-1, and No.2 terminal to M-2. Turn off all the load switches.
8. Connect between the DC 0 -120V Source terminals of MG-5211 and the motor Input terminals using patch cords. Turn Main and Motor switches on. Do not press Start button yet.
9. Adjust the control on the left side and bring the DC Source voltage to 60V. Turn the Motor switch off.
10. Make sure there are no objects in the rotating paths of the motor and generator. Double check the accuracy of all connections.

[Note] Before turning the Main or Motor power on or off, turn the handle on the left side to minimum position first.

OPERATION AND MEASUREMENTS

(1) Turn the Motor SW on, and verify that the DC input is 60V. If it is, press Start button to start the motor. Adjust the handle on the left side to raise the voltage to 115V. See if the motor is turning.

(2) Turn RH-2 (Motor) fully counterclockwise, and adjust RH-1 to set the motor RPM to 1800. Fill in the information in Table 2-1 "NO LOAD/MOTOR" section. Notice that the input current is the sum of the field and armature currents.

Table 2-1

		NO LOAD	1/4 LOAD	1/2 LOAD	FULL LOAD	OVER LOAD
MOTOR	SPEED (RPM)	1800				
	INPUT VOLTAGE (E)	115V				
	INPUT CURRENT (I)					
	INPUT POWER (P)					
	ARMATURE RESISTANCE (RA)					

(3) Turn the Generator Output and Load switch S-l on. Adjust RH-1 (generator) to obtain 120V at the output. Fill in the information in Table 2-1 "1/4 LOAD/MOTOR" section.

(4)Turn the generator load switch S-2 on also (S-1 & S-2 on). Repeat the same type of Measurements as in (3) and fill in the Table 2-1 "1/2 LOAD/MOTOR" section.

(5) Turn both S-1 and S-2 off, and turn type of measurements as in (3) and fill in the Table 2-1 "FULL LOAD /MOTOR" section.

(6) Press the Motor Stop button and turn Motor SW off. Turn RH-2 (Motor circuit) fully counterclockwise

(7) Using an Ohm meter, measure the armature winding resistance between J3 and J4. Enter is value in the "Armature Resistance”

[Note] The winding resistance measured includes the brush resistance as well. To obtain more reliable data, measure DCR about 3-4 times while turning the motor on by hand slightly each time. Average the measurements for RA

(8) Turn off the Main, Motor, and Generator Output switches off.

EXPERIMENT REVIEW

1. Using the data in Table 2-1, calculate the speed Regulation which is defined by the following expression

$$\text{Speed Regulation (\%)} = \frac{\text{No Load Speed} - \text{Full Load Speed}}{\text{Full load speed}} \times 100$$

No load speed = 1800 RPM

[Note] Ideally, the generator should not be motor when no-load characteristics of the motor measured. However, the generator is left connected to motor for the convenience, and the load of the generator is changed instead.

2. Using the data in Table 2-1, draw a curve in Figure 2-1 (a) and (b) representing the relationships between the speed, input current and the loads.

Figure 2-1 Motor Characteristic Curves

EXPERIMENT NO-3

LOAD CHARACTERISTICS OF A DC SERIES MOTOR

BASIC THEORY

The main advantage of a DC Series motor is its superior torque capability even at low speed. This type of motor generates higher torque as the load increases at the expense of reduced speed. The reason for these characteristics is that the torque output of a motor is proportional to the field and armature currents. In a DC Series motor, these two currents increase C5 the speed is reduced due to an increased load.

The opposite phenomena takes place when the load is reduced in a DC Series motor as the Counter EMF (CEMF) is increased due to an increase in motor speed. This, in turn, reduces the field and armature currents, resulting in reduced torque. The reaction between the torque and motor speed continues until the motor reaches an equilibrium state at which the torque output is just about enough to support the load and its own mechanical losses.

The most popular application of DC Series motors is found in an electrically powered train or in towing applications where a large torque is required at the start with a compromise in speed. As the start stage is over. De motor will provide higher speed with reduced torque.

In theory, an ideal DC Series motor which is defined as a lossless machine can reach an infinite speed at no load. However, in a real motor, an infinite speed does not happen because the loss of the machine itself appears as a load to the motor

PREPARATION

Equipment needed: MG-5211 Set

1. Make sure the connection between the motor and generator is secure and reliable. Keep the Main, Motor and Generator Output switches off.

2. Connect M-1, M-2 and M-3 meters in the motor to the appropriate terminals. Set M -3 for 10A range.

3. Connect between the DC 0-120V Source Terminals and the Motor Input terminals using patch cords. Set the DC Source voltage control on the left of MG'-5211 fully counterclockwise.

4. Turn RH-1 (shunt field circuit) of the motor circuit fully counterclockwise, and RH-2 (armature circuit) fully clockwise.

5. Turn RH-2 (motor circuit) fully clockwise.

6. Set Series/Shunt SW to Series

7. Connect M-1, M-2 and M-3 meters of the generator to their positions as indicated in the circuit.

8. Set Rheostat RH-1 of the generator to the middle position, and set RH-2 fully clockwise.

9. Connect the No.1 terminal of the Series Field winding of the generator to M-1, and No.2 terminal to M-2. Turn off all the load switches.

10. Connect between the DC 0 -120V Source terminals of MG-5211 and the motor Input terminals using patch cords. Turn Main and Motor switches on. Do not press Start button yet.

11. Adjust the control on the left side and bring the DC Source voltage to 60V. Turn the Motor switch off.

OPERATION AND MEASUREMENTS

1. Turn the Main and Motor SW on, and check the input DC voltage which is expected to be 60V.

Table 3-1 Data for DC Series Motor Load Characteristics

		NO LOAD	1/4 LOAD	1/2 LOAD	FULL LOAD	OVER LOAD
MOTOR	SPEED (RPM)	1800				
	INPUT VOLTAGE (E)	115V				
	INPUT CURRENT (I)					
	INPUT POWER (P)					

2. Press the Start button and adjust the handle on the left side to bring the DC voltage to l1SV. Also, adjust RH-2 to bring the motor speed to 1800 RPM. In case the RPM is off, adjust input DC to obtain 1800 RPM. Record the RPM, input voltage and input current into “MOTOR / NO LOAD" section of Table 3-1. Notice that the input current is indicated by M - 3 meter.

3. Turn the Generator Output SW and Load switch S-1 on. Adjust RH-2 (generator) to obtain 120V at the output. Record the RPM and input current into the 1/4 LOAD/MOTOR section of Table 3-1.

4. Turn the generator load switch S-2 on: (S-1 & S-2 on). Repeat the same type of measurements as in (3) and fill in the table "1/2 LOAD/MOTOR" section.

5. Press the Motor Stop button. Turn the motor SW off in case no further experiments are planned

EXPERIMENT REVIEW

1. Using the data in Table 3-1, calculate the speed Regulation which is defined by the following expression:

$$\text{Speed Regulation (\%)} = \frac{\text{No load speed- Full load speed}}{\text{Full load speed}} \times 100$$

2. Draw load characteristics curves.

Draw curves in dotted line showing the relationships between load and speed, and between load and input current into Figure 2-1 (a) and (b). Compare the results with the Shunt motor.

3.The armature current is related to the torque by the following equation.

$$T = K_1\varphi I_a = K_2 I_a2 \text{ ....(N.m)}$$

where K, and K2 are constants

φ = Flux of the series field winding (Wb)

I_a = Armature current

EXPERIMENT NO-5

MOTOR SPEED AND COUNTER EMF

BASIC THEORY

Electromotive force (EMF) is induced in a conductor when the conductor cuts through magnetic lines of force. When an AC voltage is applied to an inductor, the Current through the coil is less than the current which would flow when DC voltage is applied to the coil. The reason for this is that counter EMF is induced in the coil when AC signal is applied. The counter EMF (CEMF in volts) is induced, in general, in a direction to generate currents to oppose the current from the external Source. A transformer is an example of CEMF based device where voltage is induced in the secondary due to the CEMF in the primary inductance.

The CEMF in a DC motor is analyzed in this section. The armature resistance Ra. is calculated by dividing the voltage drop across the armature E by the armature Current Ia with the armature in stationary position. However, the armature current I, decreases as the armature reaches normal speed. This is due to the CEMF. The magnitude of the CEMF is proportional to the RPM of the $(E\text{-}CEMF)/R_a$. Another way to experience CEMF is to turn off the supply voltage from a rotating armature and check the polarity of the voltage across the armature. It should be opposite to the supply Voltage.

Some of the important characteristics of the shunt and series motors as studied in the previous sections are due to the CEMF. In shunt motor, the motor speed was increased as the shunt field current was decreased. However, in the series motor, the armature Current was increased as the motor speed Was decreased due to the increased load.

PREPARATION

Equipment Needed: MG-5211 Set and an Ohmmeter (or a Multimeter)

1. Keep the Main and Motor switches off. Decouple the motor from the generator by removing the rubber coupling. Keep the rubber coupling for future use.
2. Connect M-l, M-2 and M-3 meters to their assigned locations. Make sure M - 3 is connected for l_{OA} range.
3. Connect between DC O-120V Source terminals and the motor input terminals. Turn the DC Source voltage adjusts at the left of MG-5211 fully counterclockwise.
4. Connect the No.1 terminal of the Series Field winding of the generator to M-l, and the terminal No.2 to M-2 respectively. Keep Output switch off.
5. Turn RH-l and RH-2 of the motor circuit fully counterclockwise.
6. Set Series/Shunt SW to Shunt.
7. While keeping the Motor switch off, turn the Main switch on. Turn the voltage adjust to obtain 60V DC.
8. Make sure there are no objects in the rotating paths of the motor. Re-verify all the wiring.
9. Connect M-3 meter of the generator circuit to J3 and J4 of the motor circuit. The meter should be connected in an opposite polarity (+ and reversed) to measure CEMF.

OPERATION AND MEASUREMENTS

1. Turn Main and Motor switches on, and press Start button. Adjust the control on the left side to raise the DC source voltage until the motor RPM reaches 600. Record the input voltage, armature current and field current in the 600 RPM column in Table 5-1.

2. To observe CEMF, disconnect the armature current meter M-3 and observe the voltage across J3 and J4 at the moment. Record the maximum value in the 600 RPM column

Table 5-1 Counter EMF data

	600 RPM	1200 RPM	1800 RPM
INPUT VOLTAGE (E)			
ARMATURE CURRENT (IA)			
FIELD CURRENT (IF)			
CEMF (V_{CEF})			
ARMATURE WINDING RESISTANCE	* ARMATURE RESISTANCE WITH MOTOR STOPPED :		

3. Repeat step 0) and (2) at 1200 and 1800 RPM, and record the data in the corresponding columns.
4. Set motor RPM to 1200. Turn the Field Rheostat RH-1 fully counterclockwise, and record the field current and RPM at this time.
5. Stop the motor. Turn the DC Source down to minimum and turn Main and Motor switches off. Couple the motor and generator using the rubber coupler. Make sure the two shafts are aligned straight.
6. Place the clamp over the motor and generator joint, and tighten the clamp to ensure good coupling.

EXPERIMENT REVIEW

1. Verify that CEMF in a shunt motor is proportional to the RPM of the motor. Compute the CEMF at each RPM values (600, 1200, 1800) using the following formula.
   i. V CEMF = E - $I_a R_a$ volts
   ii. Where E= Input voltage
      1. I_a = Armature current
      2. R_a = Armature resistance

2. The RPM of a DC motor can be calculated from the fOllowing relationship.

$$N = K_3 \cdot \frac{E - I_a R_a}{\varphi} \text{ (RPM)}$$

Where K_3 Constant

$I_a R$ = armature current and resistance

φ = Field flux (Wb)

E = Input voltage

MG-5214

SECTION 2.

LOAD CHARACTERISTICS OF DC (SHUNT, COMPOUND) MOTOR

< Basic theory >

In spite of the excessive speed at no load, a Series motor has an advantage of delivering a high torque at a heavy load. In contrast, a Shunt motor exhibits superior speed regulation over a wide range of loads, although the torque is insufficient at a heavy load. A Compound motor combines the desired features of the two into one.

A Compound motor contains a Shunt field winding as a Series field winding. At no load, the Shunt field winding ensures that the motor does not run at too high speed, while at the rated load, the Series field winding provides the necessary torque.

The characteristics of each type are summarized below :

Shunt Field :

The Shunt field maintains a constant current and hence a constant flux, regardless of the armature current or speed. As the armature speed is increased, the Counter EMF increases in proportion too. The increased CEMF tends to counteract to the increased speed of the armature.

Series Field :

The Series field follows the variation of the armature current in the same direction. Therefore, as the speed of the armature increases at no load, the armature current is decreased due to the increased CEMF. Therefore, the Series field current decreases, following the armature current. The reduced armature current actually causes the armature speed to increase, resulting in an even higher speed. However, the torque generated will be reduced as the field and armature currents are reduced. This process keeps repeating until an equilibrium point is reached where the speed is just about enough to provide a torque to overcome an internal mechanical friction. When a motor is heavily loaded, the armature speed will be reduced considerably, and the armature and field currents will go up instead. This increased current will make the torque higher until an equilibrium point is reached.

< Preparation >

Equipment : **MG-5214 set**

[Note] The preparation procedure here is based on a Compound motor. However, the actual Shunt motor experiments are performed at the <**Operation and Measurements**> section.

(1) Turn Main and Motor switches off. Separate the coupling between the motor and generator. Keep the rubber coupling for future use.

(2) Connect meters M-1, M-2 and M-3 of the motor circuit to their specified terminals. Set M-3 for 10A range.

(3) Connect meters M-1, M-2 and M-3 of the generator to their specified terminals, and connect M-4 meter to any two terminals from J3 through J5.

(4) Turn RH-1 (Shunt field) of the motor fully counterclockwise and RH-2 (armature) fully clockwise.

(5) Connect between DC 0~120V Source terminals and Input terminals using the provided cords. Also, connect from J3 to J4, and from J5 to J6 of the motor circuit. This will configure the motor as a Compound motor.

(6) Turn the Main and Motor switches on, and turn the DC 0~120V Source Adjust at the side of the trainer to obtain DC 60V on the voltmeter. Turn the Motor switch off again.

(7) Make sure there is no objects in the rotating path of the motor, and verify all the connections again.

< Operation and Measurements >

(1) Turn the Motor switch on. Press Start button. Raise the DC Source to 115V DC for normal operation.

(2) Turn RH-2 of the motor fully counterclockwise, and adjust RH-1 to obtain 1800 RPM on the motor. Record the RPM, input voltage and input current, and fill in the information in Table 2-1 "Compound / No Load" section. Notice that the input current is the sum of the Shunt field current and armature current.

Table 2-1

	Compound		Shunt	
	No Load	Full Load	No Load	Full Load
Input Voltage (E)				
Input Current (I)				
Speed (RPM)				

(3) Press Stop button. Open the connection between J3 and J4. Connect J4 to No.1 terminal of the Series field. This will configure the motor for a Shunt operation.

(4) Turn RH-2 fully clockwise, and RH-1 fully counterclockwise.

(5) Press Start button. Turn RH-2 fully counterclockwise. Adjust RH-1 to obtain 1800 RPM motor speed. Record the RPM, input voltage and input current, and fill in the information in Table 2-1 "Shunt / No Load" section. Notice that the input current is the sum of the Shunt current and armature current.

(6) Turn the Motor and Main switches off. Couple the motor and generator using the rubber coupler.

(7) Place a clamp over the motor and generator, and tighten the clamp. Check the coupling and make sure the two shafts are in line. In case they are not straight, correct the situation.

(8) Set the Exciting Source DC 0~120V handle to MIN position, and turn Exciting switch on.

(9) Turn the generator Output switch off, and turn the load switches S-1, S-2 and S-3 on. The equivalent load resistance at this point is approximately 545 .

(10) Connect the meters M-1, M-2 and M-3 of the generator to their specified terminals. Connect M-4 to J3 and J4 of the generator output.

(11) Turn the Main and Motor switches on, and make sure the motor input voltage is DC 60V. Press Start button, and adjust the DC Source to DC 115V.

(12) Turn RH-2 of the motor fully counterclockwise, and adjust RH-1 to obtain 1800 RPM. Turn Output switch on, and adjust the Exciting Source DC 0~120V to 200V at the output.

(13) Check the load current meter of the generator. It should indicate approximately 0.36A at full load. Measure the motor input voltage, input current and RPM, and fill in the information in Table 2-1 "Shunt / Full Load" section.

(14) Press Stop button, and remove the connection between J4 (motor) and Series field No.1 terminal. Connect J3 to J4 to configure to a Compound motor.

(15) Turn the generator Output switch off, and press Start of the motor. Adjust RH-1 (motor) to obtain 1800 RPM.

(16) Turn the generator Output switch on, and adjust the Exciting Source DC 0~120V to obtain 200V output.

(17) Verify that the load current indicator indicates approximately 0.36A. Measure the motor input voltage, input current and RPM, and fill in the information in Table 2-1 "Compound / Full" Load section.

(18) When measurements are done, stop the motor first, then turn the Motor and generator Output switches off. Turn the main switch off in case no further experiments are planned.

< Experiment Review >

1. From the data in Table 2-1, find the speed regulation, as defined by the following expression, of the Compound and Shunt motor respectively. Explain which motor has better speed regulation.

$$\text{Speed Regulation (\%)} = \frac{\text{No load speed} - \text{Full load speed}}{\text{Full load speed}} \times 100$$

[Notes] No load speed is 1800 RPM. Full load to the generator is considered to be full load to the motor as well because the motor and generator are coupled together.

2. From the data in Table 2-1, find the ratio of the rate change of the input current to the rate change of the motor speed, as defined by the following equation:

$$\text{Input current to speed ratio} = \frac{\text{Full load input current} - \text{No load input current}}{\text{No load speed} - \text{Full load speed}}$$

In case there is a difference in the ratio between the Compound and the Shunt motor, explain why.

< Summary >

1. When compared to a Shunt motor, a Compound motor has poor speed regulation and much higher torque at low speed. At low speed, the Series

field current in a Compound motor increases, resulting in an increased magnetic field.

2. The superior performance of a Shunt motor in speed regulation is demonstrated through the calculations in <**Experiment Review**>. Its shown that the ratio obtained by dividing the rate change in input current by the rate change in speed is much larger in a Shunt motor than a Compound motor.

SECTION 3.

LOSS-EFFICIENCY OF A DC COMPOUND MOTOR

< Basic theory >

In general, the efficiency of a generator system can be defined as the following:

$$\text{Efficiency (\%)} = \frac{\text{Output energy}}{\text{Input energy}} \times 100$$

The efficiency of a motor itself can be defined in a slightly different way. The efficiency η of the motor used in MG-5214 as a energy source is defined as :

$$\text{Motor efficiency } (\eta) = \frac{\text{Delivered power}}{\text{Input power}} \times 100 = \frac{\text{Input power} - \text{Loss in the motor}}{\text{Input power}} \times 100$$

It is clear that, as the power loss in the motor is larger, the efficiency of the motor becomes poor.

The loss elements in a motor are identified as the following :

- Fixed losses : These losses are independent of the load.
  - Shunt field winding copper loss
  - Stray power loss due to mechanical friction and air resistance
- Variable losses : These losses are dependent on the load.
  - Armature winding copper loss
  - Series field winding loss for a Compound motor

< Preparation >

Equipment : MG-5214 set, an Ohmmeter or a Multimeter

(1) Repeat the steps (1) through (7) in <**Preparation**> of Section 2.

< Operation and Measurements >

(1) Turn Motor switch on, and make sure the input voltage is about DC 60V. If it is, press Start button. Raise the input voltage to DC 115V for normal operation.

(2) Turn RH-2 of motor fully counterclockwise, and adjust RH-1 to obtain 1800 RPM motor speed. Fill in the information in Table 3-1 "NO LOAD" section with the RPM, input voltage (E), Shunt field current (I_F), armature current (I_A).

Table 3-1 (1800 RPM)

		No Load	Full Load
MOTOR	Input Voltage (E)		
	Shunt Field Current (I_F)		
	Armature Current (I_A)		
	Armature Winding Resistance (R_A)		
	Series Field Winding Resistance (R_F)		
GENERATOR	Exciting Voltage (V_E)		
	Exciting Current (I_E)		
	Output Voltage (V_G)		
	Load Current (I_L)		

(3) Press Stop to stop the motor. Using an Ohmmeter or a multimeter, measure the Series field winding resistance by measuring the resistance between M-3 and J-3 terminals on the panel. Record the value in the space for Series field resistance (R_F).

(4) Measure the armature winding resistance by measuring the resistance between J4 and J6 terminals. Record the value in the space for armature winding resistance (R_A).

[Note] Because this measurement includes the brush resistance as well, it is better to measure the winding resistance 3~4 times while turning the motor shaft by hand slightly, then average the measurements.

(5) Turn Main and Motor switches off. Couple the motor and generator using the rubber coupler.

(6) Place a clamp over the motor and generator, and tighten the clamp. Make sure the two shafts are in straight line.

(7) Set the Exciting Source DC 0~120V of the generator to MIN position, and turn the Exciting switch on.

(8) Turn generator Output switch off, and turn the load switches S-1, S-2 and S-3 on (equivalent load resistance = 550Ω).

(9) Connect M-1, M-2 and M-3 meters of the generator to their specified terminals. Also connect M-4 to the generator output terminals J3 and J4.

(10) Turn Main and Motor switches on, and make sure the motor input voltage is approximately DC 60V. Press motor Start button, and raise the DC Source to DC 115V.

(11) Turn RH-2 of motor fully counterclockwise, and adjust RH-1 to obtain 1800 RPM motor speed. Turn Output switch on, and adjust Exciting Source DC 0~120V to obtain 200V generator output.

(12) Make sure the load current indication at the generator is about 0.36A at full load. Measure the motor input voltage (E), Shunt field current (I_F), armature current (I_A), and fill in the information in Table 3-1 "MOTOR/FULL LOAD" section.

(13) When all the measurements are done, turn off all the switches.

< Experiment Review >

1. From the data in Table 3-1, calculate the various losses as indicated by the following expressions:

   - Fixed copper loss = Shunt field current × Input voltage
   - Variable copper loss = (Load current)^2 × (Armature winding resistance + series field winding resistance)
   - Stray power loss = (Input voltage × Input current at no load) − (Fixed copper loss + Variable copper loss)
   - Total loss = Power in − Power out ≒ Input voltage × No load input current

2. From the data in Table 3-1, find the efficiency of the DC Compound motor at full load.

$$\text{Motor efficiency } (\eta) = \frac{\text{Input power at full load} - \text{Total loss}}{\text{Input power at full load}} \times 100$$

< Summary >

1. The majority of the losses in a motor is consisted of the copper and stray power losses. The core loss is a minor component. The stray power losses are made of losses due to mechanical and air frictions.

2. Its obvious that in order to improve the efficiency of a motor, the loss of the motor has to be reduced. This can be done by reducing the coil resistance, or design a motor with minimal mechanical friction. Also, reducing the armature resistance, and raising CEMF will help improve the efficiency.

SECTION 4.

CHANGE IN DIRECTION OF ROTATION AND STARTING CURRENT OF A MOTOR

< Basic theory >

In a DC motor, the direction of rotation can be changed by reversing the polarity of either the armature or the field winding. The polarity can be reversed by changing the winding connections. For a DC motor that has permanent magnets instead of field coils, changing the input voltage polarity will make the motor rotate in reverse direction. It is because the polarity of the armature winding is reversed, while the polarity of the permanent magnet remains unchanged.

However, for a self-excited generator which makes use of the residual flux, reversing the rotating direction can cause loss of the generator output. It is because the reversed direction of the motor will erase the residual flux in the core. The generator used in this section is a separately excited AC generator. Therefore, it should not concern us in our experiments.

The motor must be stopped before the direction is changed. Otherwise, large transient current spike may occur and damage the armature coil.

< Preparation >

Equipment : MG-5214 set

(1) Check the coupling between the motor and generator. Keep the Main, Motor, generator Output and load switches off.

(2) Connect the meters M-1, M-2 and M-3 of the motor to their specified terminals. Set M-3 to 10A range.

(3) Connect the meters M-1, M-2 and M-3 of the generator to their specified terminals, and connect M-4 meter to any two terminals from J3 through J5.

(4) Turn RH-1 of motor fully counterclockwise, and RH-2 fully clockwise. Turn the Exciting Source DC 0~120V of the generator to MIN position, and turn the Exciting switch off.

(5) Connect between DC 0~120V Source terminals and Input terminals using the supplied cords, and also connect between J3 and J4, and J5 and J6 of the motor circuit.

(6) Turn the Main switch on. Turn the DC 0~120V Source voltage adjust until the voltmeter indicates DC 60V. Turn the Motor switch off again.

(7) Make sure there is no objects in the rotating path of the motor. Verify that all the connections are correct.

< Operation and Measurements >

(1) Turn the Motor switch on, and verify that the input voltage is DC 60V. Press Start button. Adjust the DC Source to DC 115V to reach normal motor RPM. Draw the direction of rotation in Table 4-1 "FORWARD" section as shown in the example.

(2) Press Stop button and turn Motor switch off. Remove the connections between J3 and J4, and J5 and J6 of the motor circuit. Instead, connect between J3 and J6, and J4 and J5 to reverse the armature polarity.

(3) Turn Motor switch on, and press Start button. Record the direction of the rotation in Table 4-1 "Reverse" section as shown in the example.

(4) Press Stop to stop the motor. Repeat the step (5) in **<Preparation>** section for forward rotation.

Table 4-1

Forward rotation	Reverse Rotation

Example of direction indication

Table 4-2

	No Load	Full Load
Starting Current		
Steady State Current		

(5) To measure the starting current at no load, press Start button while observing M-3 meter. Read the peak value as well as the steady state current value. Notice that even though the generator is not loaded, and therefore the motor is said to be at no load, the rotating generator itself is in fact a load to the motor. Record the starting and steady state currents in Table 4-2 "NO LOAD" section.

(6) Turn on the load switches S-1, S-2 and S-3 of the generator, and turn on the Output switch as well.

(7) Turn the Exciting switch of the generator on, and adjust the Exciting Source DC 0~120V handle to obtain 100V of excitation voltage.

(8) Turn RH-2 of the motor to obtain 1800RPM. Check the generator output voltage. In case the output is not 200V, adjust the Exciting Source for 200V.

(9) To observe the full load starting current, stop the motor by pressing Stop button. While watching M-3 meter, press Start button. Observe the peak as well as the steady state current, and record the values in Table 4-2 "FULL LOAD" section.

(10) When all the measurements are done, turn off all switches.

< Experiment Review >

1. Calculate the "starting to steady state current ratio" at no load and full load.

[Notes] The starting and steady state currents refer to the input currents of the motor. These currents are the sum of the Shunt field and armature currents. However, in this section, only the armature currents are used for convenience. The starting current of a Compound motor can be calculated by the following formula :

$$\text{Starting Current} = \text{Shunt Field Current} + \left(\frac{\text{Input Voltage}}{\text{Series field resistance} + \text{Armature winding resistance}}\right)$$

< Summary >

1. There are two ways to change the rotating direction of a DC Compound motor :
   - Change the polarity of the armature winding by reversing the connection. or
   - Change the polarity of the Shunt field as well as the Series field windings.

2. The large amount of the starting current in a DC motor is due to the armature current.

$$\text{armature current } I_a = \frac{E - E_C}{R_a} \quad [A]$$

Where E = Input voltage

E_C = Counter EMF voltage

R_a = Armature resistance

At the moment of start, E_C is almost zero volt, making the I_a maximum. The observed peak current is probably less than the calculated value because the ammeter can not respond fast enough.

SECTION 5.

SPEED AND TORQUE OF A DC MOTOR

< Basic theory >

Unlike an AC motor, the speed of a DC motor is proportional to the input voltage once the starting transient is over, and the motor speed increases toward the rated speed. Therefore, the speed control of a DC motor is done by adjusting the input voltage or input current. Another way of controlling the speed is to adjust the Shunt field current. This is based on the fact that when the Shunt field current is reduced, the armature reaction (or the CEMF) is reduced also, resulting in an increased speed. However, this approach reduces the torque of the motor by a large amount.

In a DC Compound motor, the CEMF (E_C), speed (N) and the torque (T) have the following relationship :

$$T = K \cdot \frac{E_C \, I_a}{N} \quad \cdots\cdots\cdots\cdots \quad (N \cdot m)$$

Where N is the speed in RPM

K is air gap dependent constant

[Note] Counter EMF $E_C = E - [I_a (R_S + R_a)]$ ············ [V]

Where E = Input voltage

I_a = Armature current

R_S = Series field winding resistance

R_a = Armature resistance

It is shown that the torque is proportional to E_C and Ia, and inversely proportional to the speed. This explains why a DC Series motor has a superior torque. The term $E_C \cdot I_a$ represents the mechanical output of the motor and is proportional to the speed and torque product.

< Preparation >

Equipment : MG-5214 set

[Note] The torque experiment in this section deals with only the concepts on the torque characteristics. More in depth study is offered in MG-5219 or in MG-5220 trainers. These trainers utilize a Prony brake or a Dynamometer to measure torque and characterize it.

Also, notice that the generator is left coupled with the motor when experiments on the no load characteristics of the motor are performed.

(1) Repeat the steps (1) through (7) in <**Preparation**> of Section 4.

< Operation and Measurements >

(1) Turn Motor switch on, and verify that the input voltage is DC 60V. Press Start button, and adjust the DC Source to DC 115V for normal operation. Turn the DC 0－120V Source voltage handle fully counterclockwise (0V) to halt the motor from rotation.

(2) As the motor stops, turn the DC 0－120V Source Adjust slowly clockwise, and watch for the moment when the motor starts to turn. Also, fill the shunt Field Current, Armature Current and RPM against each input voltage.

(3) Increase the input voltage to 20V, 40V, ..., 120V as specified in Table 5-1, and take the same kind of readings at each input voltage.

(4) Press Stop to stop the motor, and adjust the DC 0－120V Source adjust to DC 100V.

(5) Turn the generator load switches S-1, S-2 and S-3 on. Also turn the Output switch on.

Table 5-1 (Motor no load characteristics)

	Starting Voltage	Input Voltage					
		20 V	40 V	60 V	80 V	100 V	120 V
Shunt Field Current							
Armature Current							
RPM							

(6) Turn RH-1 and RH-2 of the motor circuit fully counterclockwise, and press Start of the motor. Adjust DC 0~120V Source to obtain 1800 RPM motor speed.

(7) Turn the Exciting switch of the generator on, and adjust the Exciting Source DC 0－120V handle to obtain an output voltage of 200V.

(8) Reduce the DC 0－120V Source adjust to 0V to halt motor rotation. Raise the voltage slowly, and repeat the same process as in step (3) above. Fill in the information in Table 5-2 with corresponding data for each column. Also, record the generator output voltage and the load current at each case.

Table 5-2 (Motor full load characteristics)

	Starting Voltage	Input Voltage					
		20 V	40 V	60 V	80 V	100 V	120 V
Shunt Field Current							
Armature Current							
RPM							
Generator Output Voltage							
Generator Output Current							

(9) When all the measurements are done, turn off all the switches.

< Experiment Review >

1. With the data in Table 5-1 and 5-2, complete the chart in Figure 5-1 for speed vs. input voltage characteristics. Draw the no load curve in solid line and the full load curve in dotted line. Explain why there is a difference in speed for a given input voltage.

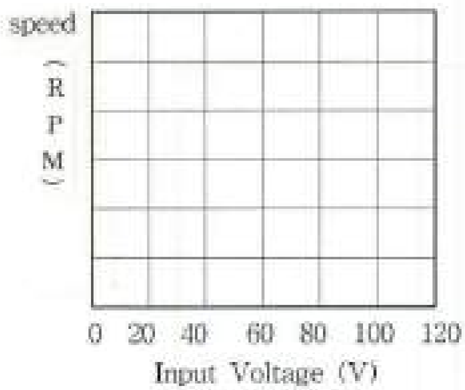


Figure 5-1 (No Load Characteristics)

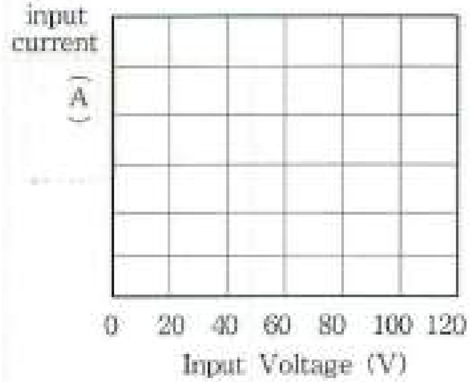


Figure 5-2 (Full Load Characteristics)

2. From the data in Table 5-1 and 5-2, complete the chart in Figure 5-2 for input current vs. input voltage characteristics. Draw the no load curve in solid line and the full load curve in dotted line. Remember that the input current of a motor is the sum of the Shunt field current and armature current. Explain why there is a difference in input current for a given input voltage.

< Summary >

1. From the Table 5-1 and 5-2, it can be seen that there is a threshold voltage for a motor to initiate rotation. This is due to the mechanical friction and the mass of the rotor itself. The generator is a load to the motor with the magnitude being proportional to the speed. In case a motor has to start with a load, the motor will require higher threshold voltage. When a motor is loaded but can not turn because of the low input voltage, the applied input energy is dissipated in the armature winding, and the temperature of

the winding may get too high. This can cause the armature winding to burn.

2. The speed of a motor is very much linear to the input voltage at no load. However, when the motor is loaded, the speed no longer follows the input voltage as shown in Figure 5-1 in dotted line.

3. The torque of a DC Compound motor is proportional to armature current I_a. In a Series motor, the increase of the armature current results in an increased field current also. Therefore, the torque of a Series motor is almost proportional to I_a^2.