ELEC 302-81
Lab 5
Motor Torque, Speed, Losses, and Efficiency

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Date Performed:	February 25, 2013
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1 Purpose of Experiment

In this experiment, the Prime Mover (PM) and Dynamometer (Dyno) modules were used to measure torque, speed, power, and efficiency of a DC motor. This experiment consisted of three parts. Part 1 involved only the PM module, and the basic operation of the PM was studied and the friction torque generated without a load was measured. Part 2 involved the Dyno acting as a load to the PM, and the changes in torque due to the addition of the Dyno were studied. Part 3 involved an experimental study of the PM power losses and efficiency.

2 Procedure

2.1 EMS Workstation Set-up

The main power switch and voltage control knob were verified to be OFF and turned fully CCW, respectively. The voltmeter selector switch was set to position 7–N. The Low Power Inputs for the PM/Dyno module and the Data Acquisition Interface (DAI) were connected to the 24-V supply, which was then turned on. The DAI USB was connected to the computer. On the computer, the file for Lab 05 was opened in the EMS application, and the metering window was set to continuous refresh.

2.2 Prime Mover Operation

The circuit represented by Figure 4 was constructed. Special, low-power connection wires were used to connect the torque (T), speed (N), and ground terminals from the PM/Dyno modules to the DAI module. On the PM/Dyno control switches, the mode switch was set to PM and the display switch was set to Speed (n). The main voltage supply was turned ON and the DC supply voltage was adjusted to 30-V. Both the installed analog EMS voltmeter and the metering window were monitored for proper indications. The DC voltage (E_1), the speed (n), indicated on the PM digital display, and the speed (N) and direction of rotation were measured and recorded in Table 1. On the PM/Dyno module, the Display switch was set to the Torque position. The friction torque (T_f), indicated on the PM digital display and the torque (T), indicated in the metering window were measured and recorded in Table 1. On the PM/Dyno module, the Mode switch was set to the Dyn. position. After a few seconds, the Mode was set back to the PM position. The main power switch was set to OFF the voltage control knob was turned fully CCW. The polarity of the leads at the PM input was then reversed. The main power switch was turned ON and the voltage supply was adjusted to 30-V. The DC voltage (E_1), the speed (n), indicated on the PM digital display, and the speed (N) and direction of rotation of the PM were recorded in Table 1. The main power switch to was set to OFF and voltage control knob was was fully CCW. The leads were then connected to their original polarity.

The power supply was set to ON. On the computer application, the Data Table Applications window was opened. The PM Voltage (E_1), speed (N), and torque, (T), were checked as the values to be recorded in the table. Using the voltage control knob, the PM speed was increased in approximately 300-rpm increments from 0–2100-rpm. At each 300-rpm increment, the values for E_1, N, and T were recorded into the Data Table. This data is shown in Table 2. The voltage control knob was set fully CCW, and the main power switch set to OFF. On the computer application, the Graph window was opened. The Graph window was set to obtain a plot of PM Speed (N), vs. PM Voltage (E_1). The graph was created and then saved. This graph is shown in Figure 1. The graph window was then set to obtain a plot of PM friction torque (T), vs. PM Speed (rpm), shown in Figure 2.

2.3 Dynamometer Operation

A timing belt was used to couple the two modules of the PM/Dyno together. The module on the left acted as the PM, and the module on the right acted as the Dyno. The circuit represented by Figure 5 was constructed. The smaller sized leads were connected to the T and N meters on the Dyno side. The 24-V supply was connected to the PM/Dyno and the DAI modules. On the PM module, the Mode switch was set to PM, and the Display switch was set to Speed. On the Dyno module, the Mode switch was set to DYN, the Display switch was set to Torque, the Load Control Mode switch was set to Man., and the Load Control knob was set to Min. (fully CCW). The main power switch was set ON and the voltage control knob was adjusted until the PM rotated at a speed of 1500-rpm. On the PM module, the Display switch was set to Torque. The opposition torque was then measured and recorded. This data is shown in Table 3. The Display switch was returned to Speed. On the Dyno module, the Load Control knob was slowly adjusted clockwise until the torque on the digital display indicated 2.0 Nm. The voltage control knob was then adjusted so that the PM rotated at 1500-rpm. The opposition torque (T_{PM}), indicated by the PM digital display and the non-corrected output torque (T_{NC}), in the metering window were measured and recorded. These values are shown in Table 3. On the computer in the metering window, the torque correction function (mode C) for the torque meter was selected. The meter was then set to read the PM output torque corrected for belt friction and windage. The voltage control knob was then adjusted so that the PM rotated at 1500-rpm. The corrected torque (T_C) was then indicated in the metering window. This value was recorded in Table 3. The voltage supply was set fully CCW and the main power switch to OFF.

2.4 Motor Losses and Efficiency

The circuit represented by Figure 5 was kept connected on the EMS workstation. On the PM module, the Mode switch was set to Prime Mover, and the Display switch was set to Speed. On the Dyno module, the Mode switch was set to

Dyn., the Display switch was set to Torque, the Load Control Mode switch was set to Man., and the Load Control knob was turned fully CCW. On the metering window, the torque correction function (mode C) for the torque meter was selected. The voltage supply knob was then adjusted so that the PM rotated at 1500-rpm. On the Dyno module, the Load Control knob was adjusted until the digital display indicated 1.0-Nm. The Dyno speed (N), and the corrected output torque (T_C), from the metering window were measured and recorded. These values are shown in Table 4. The PM mechanical output power (P_{mech}), indicated on meter, P_m, the PM electrical input power (P_{in}), indicated on meter PQS_1, and the PM efficiency (η), indicated on meter A were measured and recorded. These values are shown in Table 5.

On the Dyno module, the Load Control knob was slowly adjusted CCW until the indicated torque display read 0-Nm. The voltage control knob was then adjusted until the PM rotated at 1500-rpm. The Data Table Application was opened on the computer. The PM voltage (E_1), current (I_1), electrical input power (PQS_1), speed (N), output torque (T), mechanical output power (P_m), and efficiency (A), were set to be recorded in the Data Table. On the Dyno module, the Load Control knob was adjusted so that the torque indicated on its digital display increased from 0–2.0-Nm in 0.2-Nm increments. For each increment value, the values to be recorded were entered into the Data Table. These values are shown in Table 6. The voltage control knob was set fully CCW and the main power switch to OFF. The Graph window on the computer was then opened. It was set to obtain a plot of PM efficiency vs. PM mechanical output power. This graph was created and saved. It is shown in Figure 3. The 24-V power supply was then turned OFF and the timing belt removed.

3 Results

3.1 Prime Mover Operation

Voltage	**Speed**		**Direction**	**Friction**	**Torque**
E_1 V	n rpm	N rpm	CW/CCW	T_f Nm	T Nm
30.10	503.0	509.6	CW	-0.18	-1.60
-30.19	-508.0	-513.0	CCW	—	—

Table 1: PM friction torque; PM polarity reversal

Voltage E_1 V	**Torque** T N-m	**Speed** n rpm
0.04	0	0.43
18.84	-0.15	308.54
35.60	-0.17	607.85
53.00	-0.18	913.84
70.23	-0.19	1220.52
86.02	-0.20	1502.90
102.99	-0.21	1807.37
119.92	-0.22	2107.53

Table 2: Recorded data when the PM speed was increased

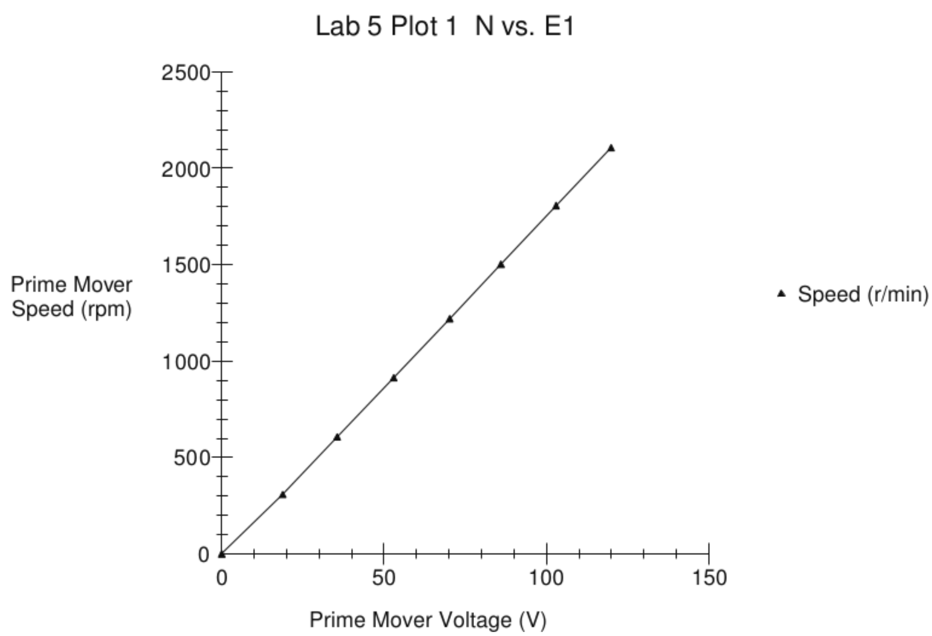

Figure 1: PM Speed vs. PM Voltage

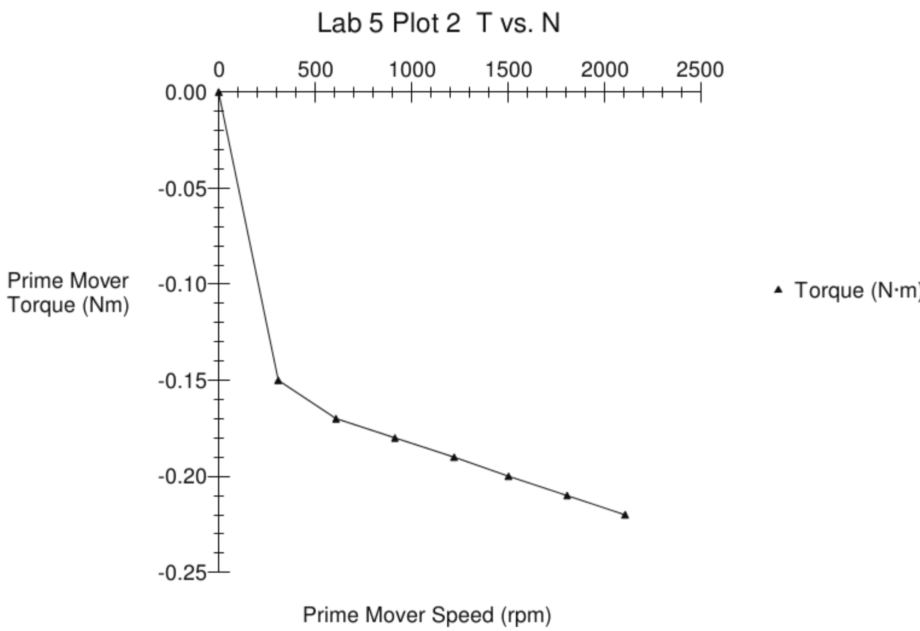

Figure 2: PM friction torque vs. PM Speed

3.2 Dynamometer Operation

n rpm	T_{DYN} N-m	T_{PM} N-m	T_{NC} N-m	T_C N-m
1500	0	-0.66	—	—
1500	2.0	-2.26	1.76	2.33

Table 3: PM non-corrected and corrected torques

3.3 Motor Losses and Efficiency

T_C N-m	N rpm
1.31	1337

Table 4: Dynamometer speed and corrected output torque for a dyno torque of 1.0 Nm

	Measured	Calculated	Percent Deviation
P_{mech} N-m	182.2	183.4	0.65
P_{in} N-m	241.5	—	—
P_{loss} N-m	59.3	—	—
η %	75.5	75.45	0.60

Table 5: Measured and calculated values for mechanical power output, electrical power input, and PM efficiency; computed PM power losses

	Input			**Output**		
Voltage	**Current**	**Electrical Power**	**Torque**	**Speed**	**Mechanical Power**	**Efficiency**
E_1 V	I_1 I	PQS_1 W	T N-m	N rpm	P_m W	A η
88.71	0.94	89.90	0.32	1525.44	51.03	56.76
87.42	1.25	116.22	0.48	1474.08	74.44	64.05
86.08	1.58	144.32	0.67	1436.68	100.54	69.67
84.88	2.02	180.53	0.90	1394.14	131.70	72.96
83.98	2.40	210.73	1.11	1362.04	158.61	75.27
83.21	2.77	239.24	1.31	1340.72	183.39	76.65
82.42	3.13	267.18	1.50	1309.10	205.88	77.06
81.67	3.53	297.42	1.71	1273.63	227.89	76.62
81.01	3.90	325.22	1.92	1256.24	252.54	77.65
80.34	4.24	349.83	2.08	1232.10	268.29	76.69
79.57	4.64	379.02	2.30	1208.88	291.42	76.89

Table 6: Recorded values as the Dynamometer's torque was increased

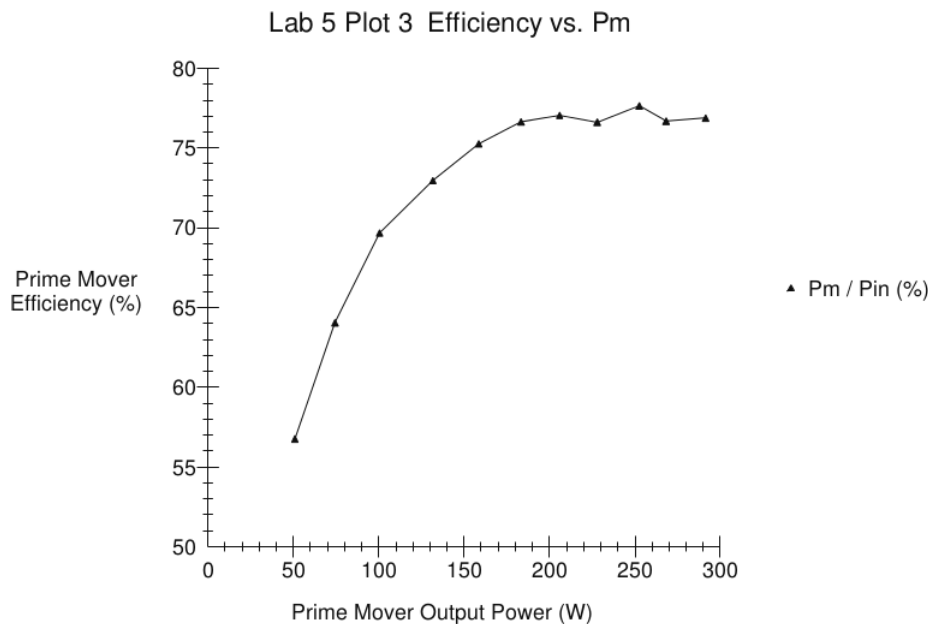

Figure 3: PM efficiency vs. mechanical output power

4 Conclusions

In Figure 2, as the PM was first starting to increase there was a large increase in torque in the opposite direction of motion. However, as the PM gained rotational speed, the opposition torque continued to increase but at a slower rate. In Figure 3, as the mechanical output power increased, the efficiency also increased. This was because of the relationship between output power and input power. As the output power became closer to the value of the input power, then the efficiency of the motor became closer to 1.

In Part 2, when the Dyno was connected to the PM, the PM generated a larger torque than it generated without the Dyno. This was because of the added belt friction and friction torque of the Dyno bearings. When the Dyno was set to generate its own magnetic torque of 2-Nm, the PM rotational speed decreased and thus its opposition torque in the opposite direction of motion increased. The non-corrected torque generated by the PM was without the loading of the Dyno taken into account. When the the corrected torque was generated, the Dyno loading was taken into account and thus this value represented the true torque produced by the PM. The corrected torque was greater than the non-corrected torque by approximately the same amount that the PM generated when the Dyno had not produced its own magnetic torque.

In Part 3, the current was being increased because the PM/Dyno was set up as a motor. As the torque produced by the Dyno increased, the voltage produced by the PM decreased. However, the current increased as the PM rotational speed decreased. The mechanical output power was less than the electrical input power. Electric power was being converted to mechanical power.

Equations

$$P_{mech} = \left(\frac{60}{2\pi}\right)(n \cdot T)$$
$$P_{loss} = P_{in} - P_{mech}$$

Circuits Tested

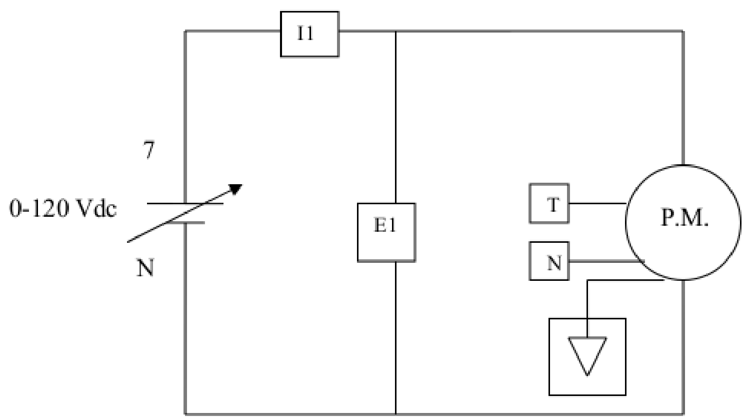

Figure 4: Prime Mover Circuit

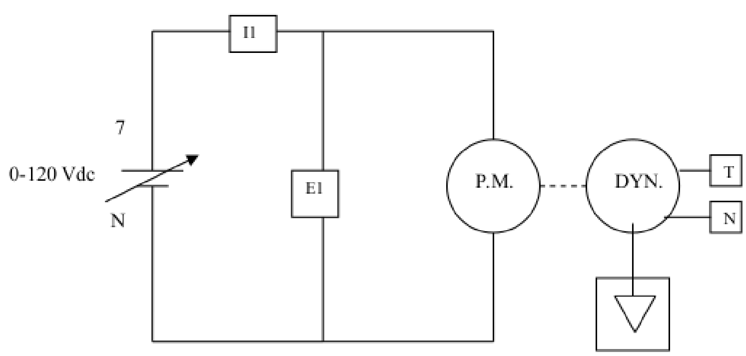

Figure 5: Prime Mover Coupled to the Dynamometer