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

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1 Purpose of Experiment

In this experiment, the Prime Mover and Dynamometer 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 Prime Mover module, and the basic operation of the Prime Mover was studied and the friction torque generated without a load was measured. Part 2 involved the Dynamometer acting as a load to the Prime Mover, and the changes in torque due to the additon of the Dynamometer were studied. Part 3 involved an experimental study of the Prime Mover 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 fully counterclockwise, respectively. The voltmeter selector switch was set to position 7–N. The Low Power Inputs for the Prime Mover/Dynamometer (PM/Dyno) module and the Data Acquisition Interface (DAI) were connected to the 24-V supply. The 24-V supply was 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 cicuit represented by Figure 4 was constructed. The Prime Mover module on the left side of the Prime Mover/Dynamometer workstation was used in Part 1. Special, smaller sized connection wires were used to connect the torque (T) and speed (N) terminals from the PM/Dyno module to the DAI module. The white ground terminal was also connected between the two modules. On the PM/Dyno control switches, the Mode switch was set to Prime Mover (PM) and the Display switch was set to Speed (n). The main voltage supply was turned ON and the DC supply voltage was adjuted to 30-V. Both the installed analog EMS voltmeter and the metering window were monitored for proper indications. The DC voltage E1, the speed n indicated on the Prime Mover digital display, and the speed N indicated on the computer metering window were measured and recorded. The direction of rotation of the prime mover was also recorded. These values are shown 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 Prime Mover digital display and the Torque, T, indicated in the metering window were measured and recorded. These values are also shown 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 voltage control knob was turned fully CCW and the main power switch was set to OFF. The polarity of the leads at the Prime Mover Input were then reversed. The main power switch was turned ON and the voltage supply was adjusted to 30-V. The

DC voltage E1, the speed n indicated on the Prime Mover digital display, and the speed N indicated on the computer metering window were measured and recorded. The direction of rotation of the prime mover was also recorded. These values are shown in Table 1. The voltage control knob was set fully CCW and the main power switch to OFF. 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 Prime Mover 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 Prime Mover speed was increased in approximately 300-rpm increments from 0–2100-rpm. At each 300- rpm increment, the values for E1, 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 Prime Mover Speed, N, vs. Prime Mover 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 Prime Mover friction torque, T, vs. Prime Mover Speed (rpm). The graph was created and then saved. This graph is 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 Prime Mover, and the module on the right acted as the Dynamometer. The circuit represented by Figure 5 was constructed. The smaller sized leads were connected to the T and N meters on the Dynamometer side. The 24-V supply was connected to the PM/Dyno and the DAI modules. On the Prime Mover module, the Mode switch was set to Prime Mover, and the Display switch was set to Speed. On the Dynamometer 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 to Prime Mover rotated at a speed of 1500 rpm. On the Prime Mover 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 Dynamometer module, the Load Control knob was slowly adjusted clockwise until the torque on the digital dispay indicated 2.0 Nm. The voltage control knob was then adjusted so that the Prime Mover rotated at 1500 rpm. The opposition torque, T_{PM}, indicated by the Prime Mover 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 Prime Mover output torque corrected for belt friction and windage. The voltage control knob was then adjusted so that the Prime Mover rotated at 1500-rpm. The corrected torque T_C was then indicated in the metering window. This value was reorded and is shown in Table 3. The voltage supply was set fully CCW and the main power switch to OFF.

2.4 Motor Losses and Efficiency

The cicuit represented by Figure 5 was kept connected on the EMS workstation. On the Prime Mover module, the Mode switch was set to Prime Mover, and the Display switch was set to Speed. On the Dynamometer 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 Prime Mover rotated at 1500 rpm. On the Dynamometer module, the Load Control knob was adjusted until the digital display indicated 1.0 Nm. The Dynamometer 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 Prime Mover mechanical output power, P_{mech}, indicated on meter, P_m, the Prime Mover electrical input power, P_{in}, indicated on meter PQS1, and the Prime Mover efficiency, η, indicated on meter A were measured and recorded. These values are shown in Table 5.
On the Dynamometer 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 Prime Mover rotated at 1500-rpm. The Data Table Application was opended on the computer. The Prime Mover 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 Dynamometer module, the Load Control knob was adjusted so that the torque indicated on its digital display increased from 0 to 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 Prime Mover efficiency vs. Prime Mover 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: Prime Mover friction torque; Prime Mover polarity reversal

Voltage	**Torque**	**Speed**
E_1 V	T N-m	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 Prime Mover speed was increased

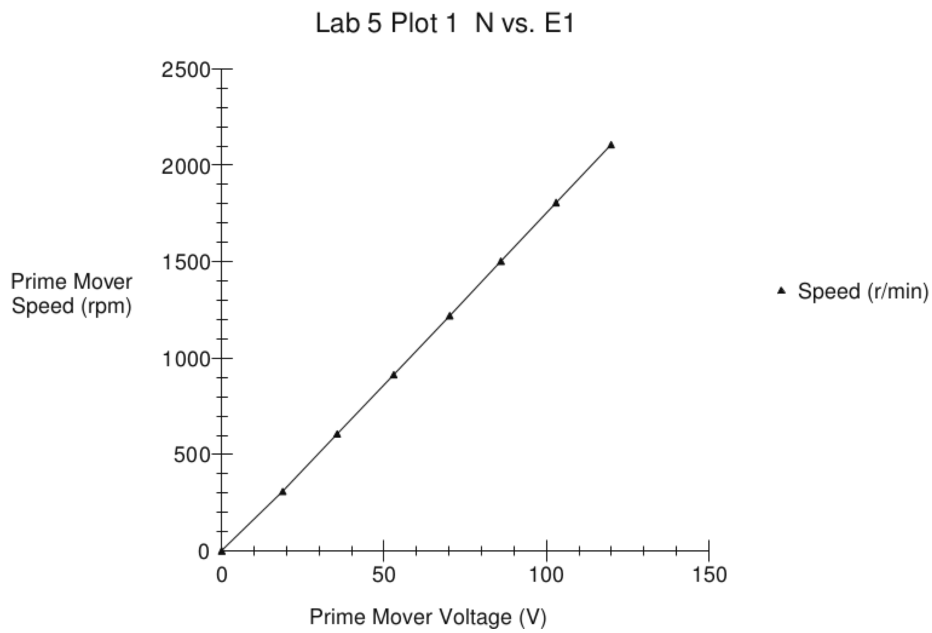

Figure 1: Prime Mover Speed vs. Prime Mover Voltage

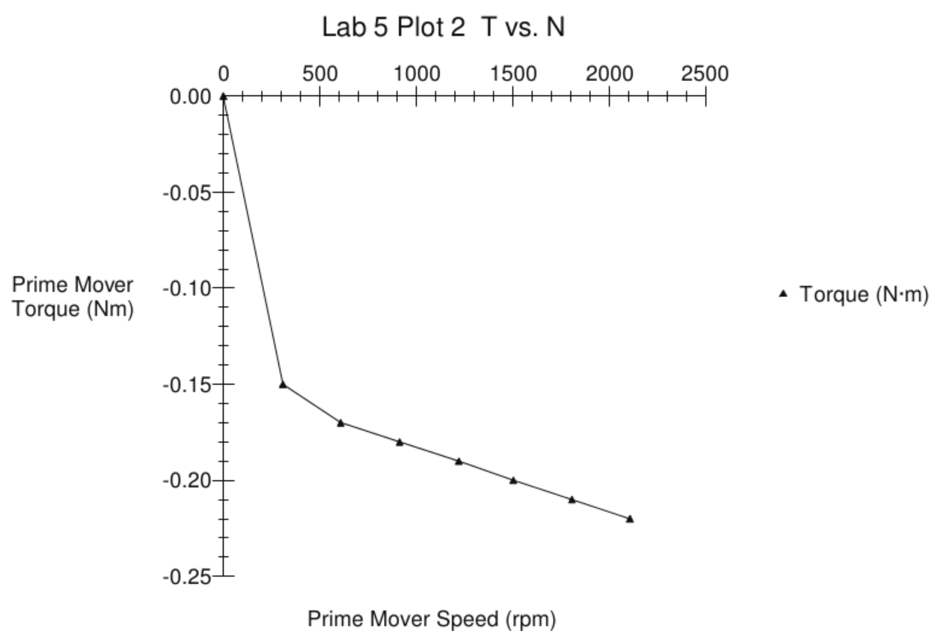

Figure 2: Prime Mover friction torque vs. Prime Mover Speed

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: Prime Mover 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 correceted output torque for a dyno torque of 1.0 Nm

	Measured	Calculated	Percent Deviation
P_{mech} N-m	182.2	183.4	0.65
η %	75.5	75.45	0.60

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

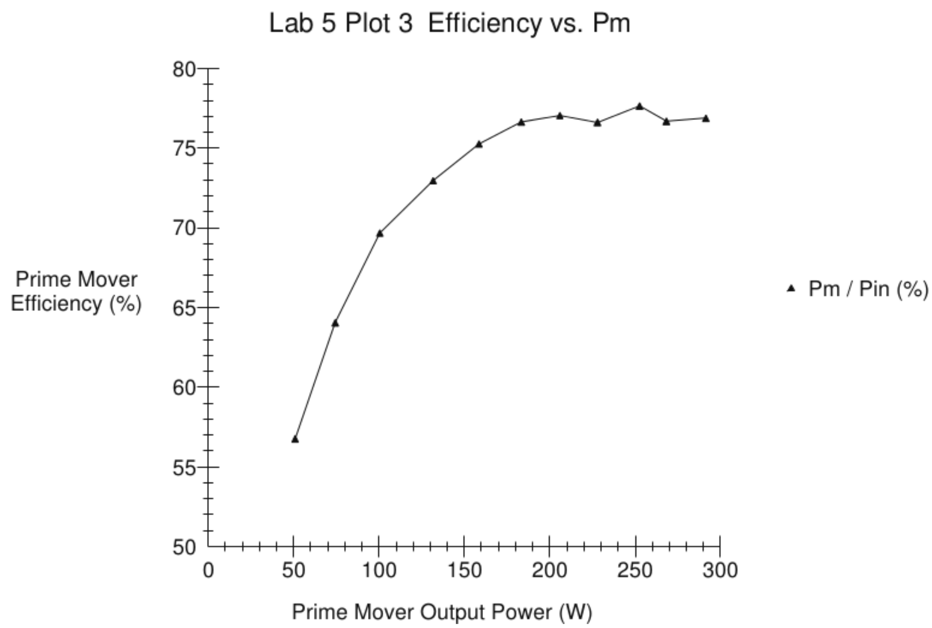

Figure 3: Prime Mover efficiency vs. mechanical output power

4 Conclusions

In Figure 2, as the Prime Mover was first starting to increase there was a large increase in torque in the opposite direction of motion. However, as the Prime Mover 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 Dynamometer was connected to the Prime Mover, the Prime Mover generated a larger torque than it generated without the Dynanometer. This was because of the added belt frition and friction torque of the Dyno bearings. When the Dyno was set to genearate its own magnetic torque of 2 Nm, the Prime Mover rotational speed decreased and thus its opposition torque in the opposite direction of motion increased. The non-corrected torque generated by the Prime Mover 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 Prime Mover. The corrected torque was greater than the non-corrected torque by approximately the same amount that the Prime Mover 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 Prime Mover decreased. However, the current increased as the Prime Mover rotational speed decreased. The mechanical output power was less than the electrical input power. Electric power was being converted to mechanical power.

Equations

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

Circuits Tested

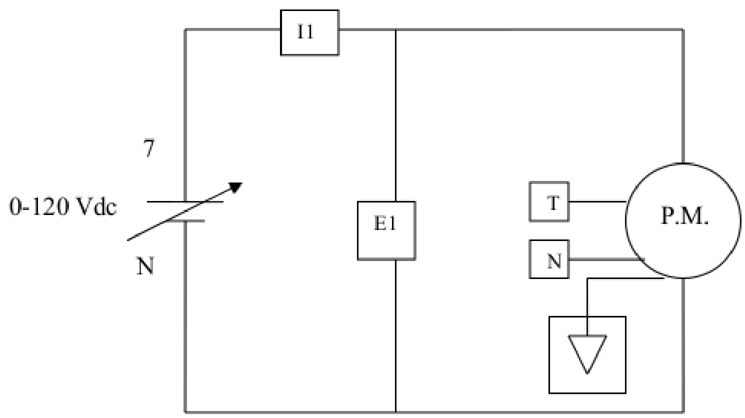

Figure 4: Prime Mover Circuit

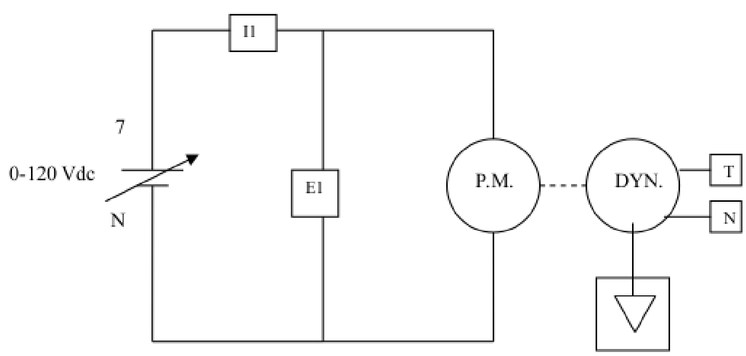

Figure 5: Prime Mover Coupled to the Dynanometer