**Lab Report 5: Electric Motor Performance Analysis**

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**Nomenclature**

= torque

= input power to motor

= shaft output power

= current

= moment of inertia for flywheel

= angular velocity of the flywheel

= shaft revolutions per second

= electric motor efficiency

1. **Introduction**

This experiment was carried out on November 5, 2019 in the subsonic wind tunnel labs at NC State. Two electric motors were analyzed for this experiment and three trial runs were used to collect data for each motor. Provided by the experimental setup was all the necessary information needed to calculate the input power, output power, and thereby the efficiency for each motor. Detailed in this report is the experimental setup, the process of analysis, and a discussion of the results of the experiment. The goal of the experiment was to familiarize the students with the process of gathering electrical motor data and the interpretation of that data for testing and approximation purposes.

1. **Methodology**
2. **Experimental Setup**

LabVIEW was used to change the input parameters for the motor. From the interface, throttle instructions were sent to a myDAQ converter and then to the electronic speed controller for the brushless motor. Measurements were collected from the motor using a dynamometer. Represented below is the visual representation of the process.

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| **Figure 1. Lab 5 Block Diagram.** *Above is the visual representation of the experimental process, including the variables sent between components and ultimately to data processing.* |
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1. **Procedure**

Students each performed the action of changing throttle input settings on the computer interface at least once. After the throttle setting was entered, the students lowered the throttle as quickly as possible by changing the input to a low percentage (roughly ten percent) throttle setting before eventually lowering the throttle to zero. The throttle was intended to be lowered after it had reached its maximum setting, and this was done by listening to the motor. As no student was perfectly accurate with the timing of this, there is a possibility for some error. Three trials were completed for each of the two motors tested to reduce the effects of this error on the results.

1. **Calculations**

Torque for the electric motor was calculated using the readings from the dynamometer. Below is shown the calculation of the moment of inertia multiplied by the angular acceleration of the flywheel. Torque was supplied in the data files and was not calculated in the code.

|  |  |  |
| --- | --- | --- |
|  |  | (1) |
|  |  |  |

Output power from the shaft was calculated by multiplying the torque by two pi and the rotations per second, which was converted from the rotations per minute measured in the experiment.

|  |  |  |
| --- | --- | --- |
|  |  | (2) |
|  |  |  |

Input power to the motor was calculated by multiplying the input voltage and current to the motor, as seen below in in Eq. 3.

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

Finally, the efficiency of the motor was calculated by computing the ratio of output power to input power, represented by Eq. 4.

|  |  |  |
| --- | --- | --- |
|  |  | (4) |
|  |  |  |

1. **Results**

Plots included in this section include all runs for both motors. Each has a legend included to distinguish the data points from each other, as well as a line connecting each data point to better visualize the trend, as the data points are cluttered and not always distinguishable.

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| **Figure 2. Torque vs. RPM.** Motor one had a higher torque output than motor two. All runs were relatively consistent for the two motors, with the exception of the second run for motor one. Note that it is a more complete curve and has a lower maximum than the rest of the runs for motor one. |

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| **Figure 3. Input Power vs. RPM.** Motor one can be seen here to have require a higher power input than motor two. All runs are consistent, but again the second run from motor one deviates more than the rest. |

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| **Figure 4. Shaft Output Power vs. RPM.** Motor one had a higher power output than motor two, as shown above. |
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| **Figure 5. Motor Efficiency vs. RPM.** With slight deviance, the efficiencies are consistent for their respective motor. Motor two had a higher efficiency than motor one until about 6000 RPM, but then motor one exceeded the maximum efficiency for motor two, peaking at about 9500 RPM. |

1. **Discussion**

From the results section, it is clear that motor one is the more powerful motor. It had a higher torque, input power, and output power. As the throttle was reduce for each run after reaching its maximum, as seen in the input power plots of Fig. 3, the maximum torque for each motor follows the same trend. This means that the maximum torque will occur at the same moment as maximum input power, which is full power for the motor. Torque reaches its maximum here because the motor has just started, and the torque then declines after reaching this value because the power supplied to the motor was reduced (by changing the throttle setting). Fig 2 verifies these ideas, showing that the torque maximum occurs at roughly the same value for RPM as the maximum input power does. Motor one, run two shows a slightly different at the start of the experiment with regards to the trend for the input power and torque. Judging by Fig 3, it the second run for the first motor started at an RPM greater than zero, and the maximum input power was received by the motor at an earlier RPM than the other runs for both motors. Observing Fig 2, the maximum torque for motor one does not match the maximum power input value, and instead continues to increase. From the lack of data points, it is possible that the RPM at which motor one reaches its maximum torque is later than the second data point collected by trial two for that motor. Motor one may have not had enough time to start up and the throttle value on the computer interface was changed too soon during the experiment, resulting in the maximum power value being delivered to the motor earlier than that of the other motors. The figures for torque and input power corroborate these ideas, but it is possible that the motor experienced a minor fluctuation in performance during that trial. Regardless, the other two trials for motor one were consistent with each other and are the best fitted candidates to evaluate its performance.

Motor one was the not only the most powerful motor, but overall the most efficient, despite the peak for its efficiency being later than that of motor two. In Fig 5, it can be seen that until about 6000 RPM, motor one is slightly more efficient than motor one, across all trials for each motor. At that point, however, motor one becomes more efficient, continuing to increase past the peak efficiency of motor two until it reaches its peak efficiency around 9500 RPM. The peak efficiency of each motor depends on its design and the effects of both electrical and mechanical losses. Design for the second motor indicates it has a peak efficiency at a lower rotational speed than motor one. Shaft output power follows a similar, but not identical, trend to the efficiency plot. A visual comparison of the output power plot, Fig. 4, with the motor efficiency plot present in Fig. 5 proves this concept. It is possible that the plots would more closely match if the input power was held at a constant value for a longer duration, but as it was near-immediately reduced, the peak output power occurs shifted backwards in terms of RPM with respect to the efficiency plots. Neither motor received full throttle at the indicated maximum efficiency RPM, and as a result the output power begins to decline before those RPM values in Fig. 4, respectively. Motor two had one data point for its maximum output power that corresponds to an RPM very close to its maximum efficiency according to the figures, however. This data point could therefore represent more accurate results for the most efficient power output for the second motor than those that are present for motor one. Fig 4 shows the motor one output power declining prematurely before it reaches the most efficient RPM value for that motor. The throttle was reduced, which governs the input power, and as a result the output power began to reduce correspondingly.

1. **Appendix**

%% Experimental Aerodynamics III Lab 5: Electric Motor Performance Analysis

% Steps

% Load in structure and separate data

% Calculations

% Plotting

%% Preallocation and specifiers

% File structure:

% | RPM (1) | Torque (N-m) (2) | Voltage (V) (3) | Current (I) (4) |

% Unclear if current units are Amps or mA or another derivation of Amp

numMots = 2; % number of tested motors

trials = 3; % number of trials per motor

%data = struct();

legSpec = {'M1 R1','M1 R2', 'M1 R3', 'M2 R1', 'M2 R2', 'M2 R3'}; % legend entries

pSpec = {'bo','g\*','rv'; 'co', 'm\*', 'yv'}; % plot specifier for type of data point ixj = 2x3 matrix

lSpec = {'b','g','r'; 'c','m','y'}; % plot specifier for line color for just line plot

t = ones(2,3); ip = t; op = t; me = t;

%% Loop

% Loop backwards to create entire structure array first

% (so that it does not change size every iteration)

for i = numMots:-1:1

for j = trials:-1:1

file = sprintf('motor%d-run%d.dat',[i j]); % current file to load in

data = importdata(file);

% Temp vars

rpm = data(:,1);

tau = data(:,2).\*0.0010; % N-mm to N-m

volts = data(:,3);

current = data(:,4);

% Calculations

N = rpm./60; % temp var

motor(i).run(j).pout = 2.\*pi.\*N.\*tau./1000; % kW

motor(i).run(j).pin = volts.\*current./1000; % kW

motor(i).run(j).eta = motor(i).run(j).pout./motor(i).run(j).pin;

% Allocation of rest of vars needed for plots

motor(i).run(j).rpm = rpm;

motor(i).run(j).tau = tau;

% Torque vs. RPM

figure(1)

hold on

t(i,j) = plot(motor(i).run(j).rpm, motor(i).run(j).tau, pSpec{i,j}, 'linewidth',1.15);

plot(motor(i).run(j).rpm, motor(i).run(j).tau, lSpec{i,j})

title('Torque vs. RPM')

xlabel('RPM')

ylabel('Torque (N-m)')

% Input Power vs. RPM

figure(2)

hold on

ip(i,j) = plot(motor(i).run(j).rpm, motor(i).run(j).pin, pSpec{i,j}, 'linewidth',1.15);

plot(motor(i).run(j).rpm, motor(i).run(j).pin, lSpec{i,j})

title('Input Power vs. RPM')

xlabel('RPM')

ylabel('Power In (kW)')

% Shaft Output Power vs. RPM

figure(3)

hold on

op(i,j) = plot(motor(i).run(j).rpm, motor(i).run(j).pout, pSpec{i,j}, 'linewidth',1.15);

plot(motor(i).run(j).rpm, motor(i).run(j).pout, lSpec{i,j})

title('Shaft Output Power vs. RPM')

xlabel('RPM')

ylabel('Power Out (kW)')

% Motor Efficiency vs. RPM

figure(4)

hold on

me(i,j) = plot(motor(i).run(j).rpm, motor(i).run(j).eta, pSpec{i,j}, 'linewidth',1.15);

plot(motor(i).run(j).rpm, motor(i).run(j).eta, lSpec{i,j})

title('Motor Efficiency vs. RPM')

xlabel('RPM')

ylabel('Efficiency')

end

end

% Legend entries

phs = {t, ip, op, me}; % plot handles

% Matching the legend to each plot

for plot = 1:4 % number of plots

ph = phs{plot}; % current plot handle

figure(plot)

% Format below tells legend which to plot, format based on legSpec format

legend([ph(1,1), ph(1,2), ph(1,3), ph(2,1), ph(2,2), ph(2,3)], legSpec)

end

% Prevent coplotting for next run of code

hold off all

1. **References**

1Narsipur, Shreyas. “MAE 451 – Experimental Aerodynamics III Lab 5 – Electric Motor Performance Analysis”. *NCSU,* October 29, 2019.