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ECE 492

Motor Controller + Modeling

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Dynamic Characterization Results

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I. Introduction

The purpose of this report is to characterize and understand the behavior of the Electric Vehicle motor operating in dynamic conditions. Data was collected and analyzed to determine if the hypothesis of a revised motor model can be accepted or rejected. The aim of this study is to be able to relate inputs and outputs of the motor and controller system by either equation or lookup table including a term for acceleration.

II. Hypothesis

Previous static characterization analysis has shown that the friction coefficient f normally seen in the steady state DC motor equation below

$$T_L = K_T i - fw$$

was actually a term which varied linearly with torque at the motor. For this reason, the suspicion has arisen that the controller in this black box motor + controller setup has been developed to control torque. Therefore, the hypothesis for this report is that moment of inertia will also be a term which varies with torque.

In order to prove this hypothesis true, it will be necessary to show that the data reflects the behavior detailed below in the equation for a DC motor [2]:

$$J\frac{dw}{dt} = K_T i - fw - T_L$$

where T_L is the load torque (hydraulic torque seen above)

K_T is the torque constant

i is the power supply current input

f is the friction constant

w is the motor speed in RPM

J is the moment of inertia

This equation details the type of behavior that would be preferable to see in the black box motor + controller setup, but previous static characterization of this system has already strayed from the DC motor model equation. The equation which was found that well characterized the system in steady state is as follows:

$$w = \frac{768.75i}{TL} - 178.57$$

Modifying this equation to include the moment of inertia * acceleration term which is necessary for dynamic characterization, the equation now becomes

$$J\frac{dw}{dt} = \frac{768.75i}{T_L} - 178.56 - w$$

The aim of this report is to calculate J's constant value, or in the non constant case find some way to relate acceleration to the other three parameters in this equation.

III. Data Collection

After several preliminary data collection experiments were run in order to shape the hypothesis and direction of this report, a few large, final data collection experiments were formulated in order to obtain all data required for characterization.

The following experimental data was collected using the available dynamometer and sensors. All system operations are outlined and described in Appendix A. It is important to note that the maximum achievable sampling rate for measuring RPM in the current lab setup is 10Hz.

A. Experiment 1 Protocol

The aim of collecting this data was to illustrate a picture of the motor's transient behavior with several stepped throttle settings at several separate load settings. With each throttle step, motor RPM data was collected and power supply current measured. The sensors and setup for this experiment are detailed in **Appendix A** of this report. Likewise information on calibration and accuracy of the sensors and systems in this experiment are available in the reference section (**Appendix B**).

For each throttle setting (15% - 35% in increments of 5%), the team:

1. Set the load setting to 100% (no load)
2. Being logging data for motor RPM on the 1314 PC Programming software
3. Ensure that a current sensor is connected to the power supply current line, and hooked up to an oscilloscope which will trigger and save data upon stepping the system.
4. Step up the throttle from 0% to its specified setting
5. After recording all data, decrement load setting down by 10% (to a minimum of 60%) and repeat steps 1-4
6. Increment throttle ceiling by 5% (to a maximum of 35%) and repeat steps 1-5

The analysis of this experiment is detailed below, and led the group to perform a second data collection experiment in order to understand the effects of stepping throttle down from its high value to zero.

B. Experiment 2 Protocol

The aim of collecting this data was to illustrate a picture of the motor's behavior in deceleration. This test was completed due to some noticed regenerative braking in the earlier experiment. THe protocol for this experiment is as follows:

For five different power settings:

1. Slowly increment the throttle and load to obtain desired electrical power.

2. Ensure that a current sensor is connected to the power supply current line, and hooked up to an oscilloscope which will trigger and save data upon stepping down the throttle.
3. Instantly step the throttle down from its current setting to 0%.
4. Repeat steps 1-3 for four different electric power settings

IV. Data Analysis

The data collected from both of the above-described experiments was analyzed and plotted in order to obtain a picture of current and RPM transient responses to s stepped throttle. Graphs for RPM response are shown in **Figure 1,** and power supply current responses are shown in **Figure 2.**

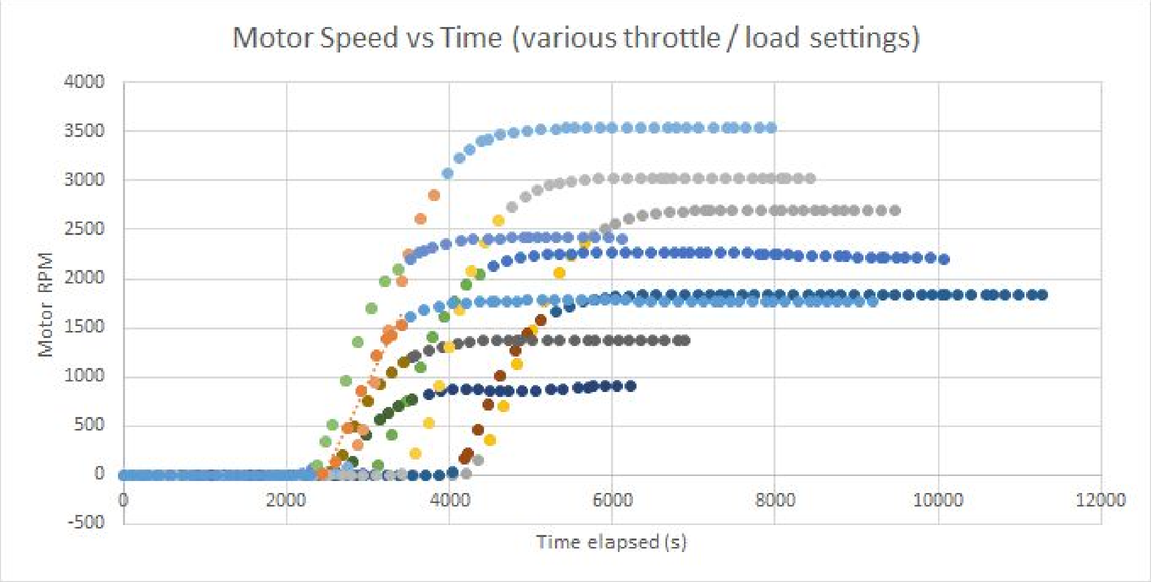

Figure 1

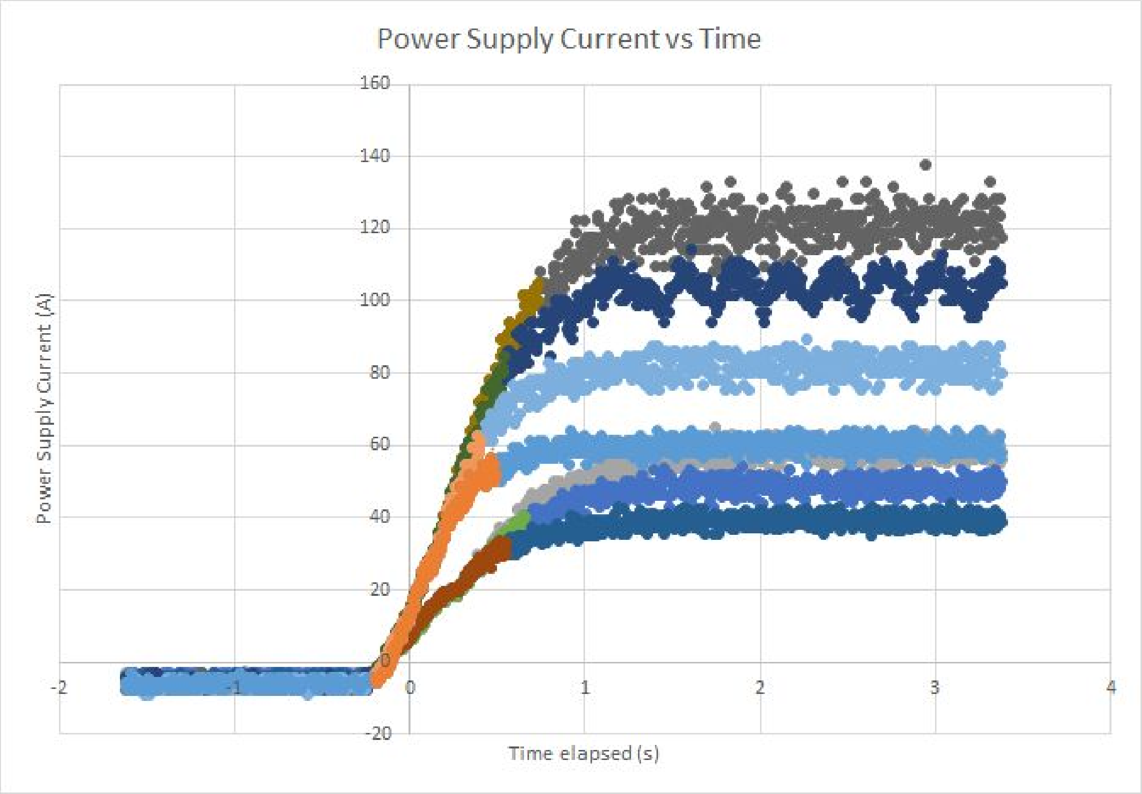

Figure 2

In order to use this data to characterize the transient response of the motor + controller setup, individual response graphs were plotted and their linear slopes were fitted to trendlines in order to obtain values for motor speed acceleration (RPM vs. time). One example of this type of graph can be seen below in **Figure 3.** Additionally, power supply current was plotted in a similar way in order to find a slope for rate of current increase (example in **Figure 4)**, which was then used for generating a table of of results (**Figure 5**).

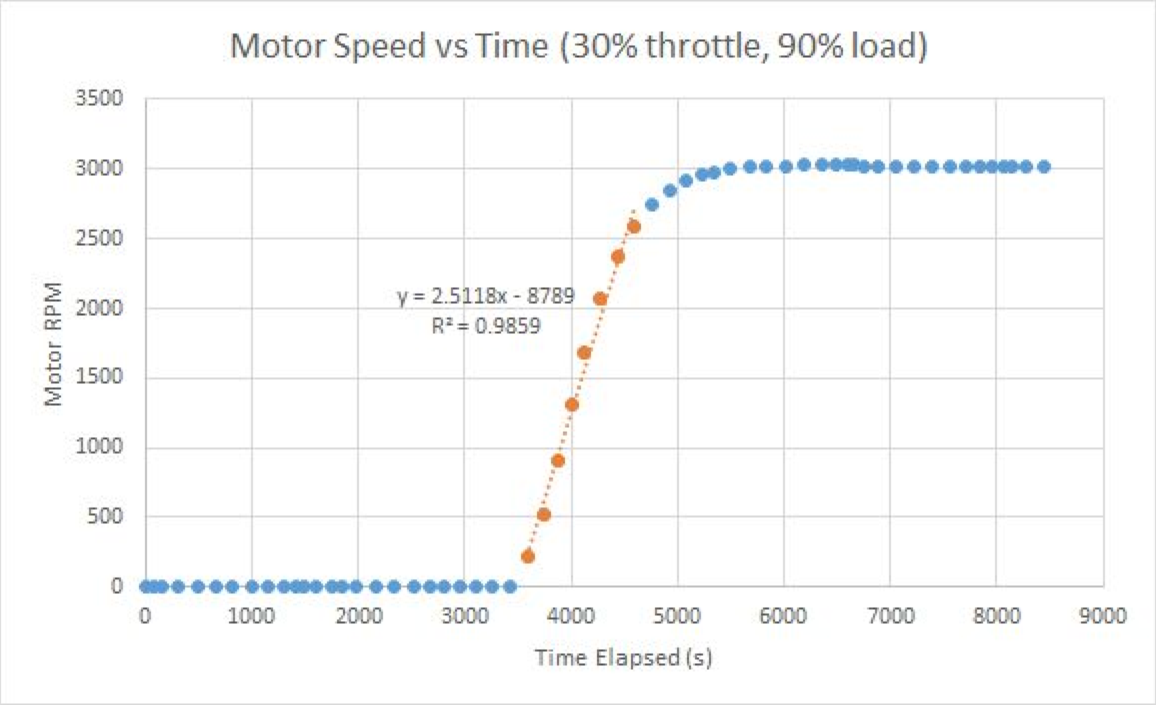

Figure 3

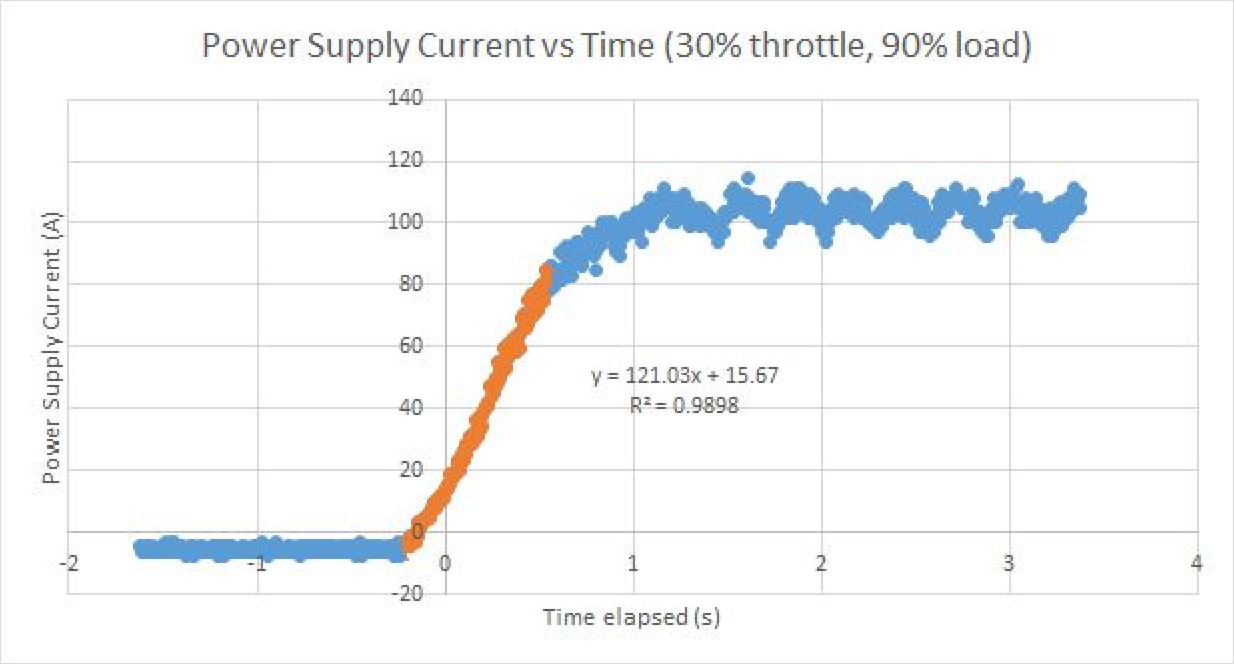

Figure 4

Time (s)	Motor RPM	PS Current (A)	Torque (Ft-lb)	Acceleration (RPM/s)
0.161	8	19.48583	80.2901421	2.5118
0.331	215	40.06093	78.24996808	2.5118
0.489	523	59.18367	64.85090057	2.5118
0.617	906	74.67551	52.93046858	2.5118
0.74	1308	87	44.99031327	2.5118
0.856	1680	95	39.29432305	2.5118
1.012	2071	100	34.17319754	2.5118
1.178	2370	102	30.76725379	2.5118
1.332	2587	103	28.63107786	2.5118

Figure 5

Due to the unavailability of transient torque data the torque values seen in the table above are simulated. That is, they are generated using the previously obtained equation which relates motor torque, RPM, and power supply current [2]. Using these calculated values, a graph for Torque vs. Time was also able to be generated **Figure 6.** In the future, to further improve the results of dynamic characterization, it would be preferable to use actual experimental torque data collected by using an oscilloscope connected to the load cell in the lab setup. Using all of the data listed above, the values for parameter J were calculated and plotted in order to determine if the value was constant across all cases. As a reminder, J is from this above-listed equation:

$$J\frac{dw}{dt} = \frac{768.75i}{T_L} - 178.56 - w$$

What was found that the value for J changed, and could actually be related to acceleration using a polynomial fit (**Figure 7**).

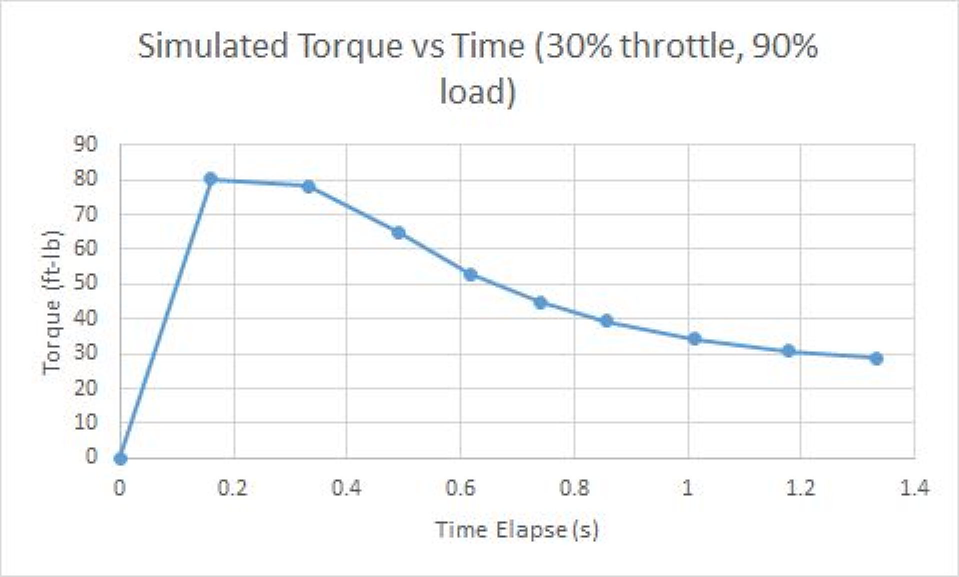

Figure 6

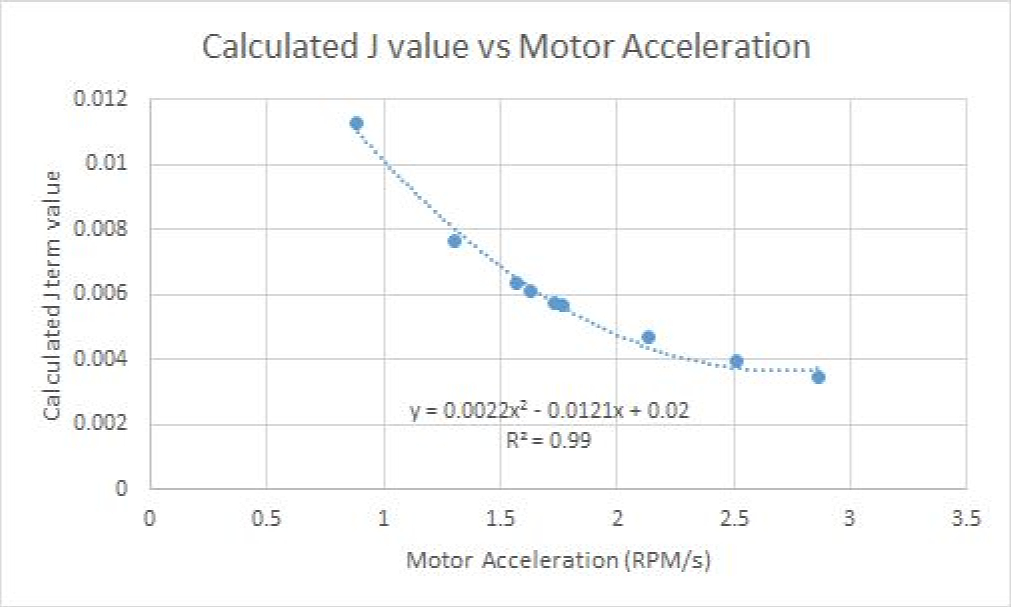

Figure 7

However, this polynomial characterization of the value of J provides for transient response simulations that feature very unrealistic overshoot. Therefore, a linear fit was instead matched to this data. The leftmost point seen above was collected for an acceleration case up to a value less than 1000 RPM. As previously discovered, the controller in this system behaves unpredictably at motor speeds below 1000 RPM [2], so this data point was removed in order to incorporate a reasonable linear fit, as seen below in **Figure 8.**

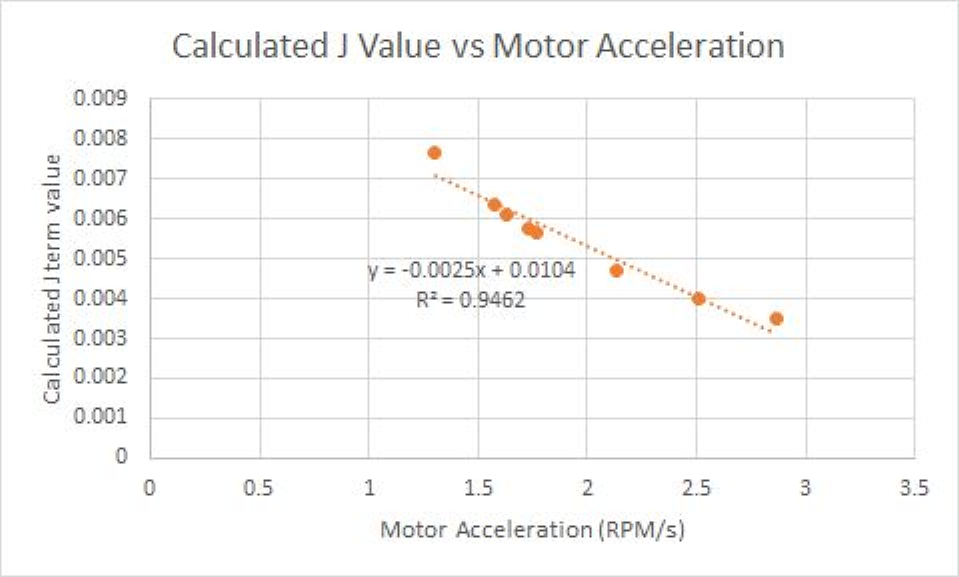
Calculated J Value vs Motor Acceleration
Calculated J term value
Motor Acceleration (RPM/s)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
0.5
1
1.5
2
2.5
3
3.5
y = -0.0025x + 0.0104
R² = 0.9462

Figure 8

V. Results and Conclusions

From the calculations and plots shown above, it was determined that the original proposed equation for dynamic characterization of this motor + controller system:

$$J\frac{dw}{dt} = \frac{768.75i}{T_L} - 178.56 - w$$

is invalid. Instead, the parameter "J" is actually related to the acceleration (in RPM/s) of the motor by the equation:

$$J = -.0025\frac{dw}{dt} + .0104$$

Substituting this into the original equation gives the final dynamic characterization equation:

$$-.002522\left(\frac{dw}{dt}\right)^2 + .0104\frac{dw}{dt} = \frac{768.75i}{T_L} - 178.56 - w$$

This is an equation which can be plugged into a Simulink model in order to fully realize the predicted behavior of the car's motor system. In generating this equation, the hypothesis for this report is accepted because an equation has been made which is able to relate acceleration to the system's torque, speed, and power supply current.

Appendix A - Dyno System Setup

Electric Vehicle Systems

- HPEVS AC50-51-5X Motor
- Curtis Instruments 1238R-7601 Controller

Battery Simulation - Magna-Power(TSD 100-250/208) D.C. Power Supply

- 20kW P.S. 200A max rms @ ~100 Vdc

Dynamometer System and Sensors - Huff HTH-100 Dyno

- Load Adjustment
    - Oil Valve(CAT HY14-3200)
- Torque Sensor
    - Load Cell (LCCE-250)
    - Strain Gauge Input Module (DataForth - SCM5B38)
- Tachometer
    - Frequency Input Module (DataForth - SCM5B45)
- Throttle
    - Voltage Output Module (DataForth - SCM5B49)
- Data Acquisition Board (MCDAQ-USB7204)

Data Acquisition Software

- Curtis 1314 Programming Software
    - Motor RPM data
- Dyno Software (Proprietary from Class of 2015)
    - Output Data: P.S. Current, Torque
    - Input Data: Load %, Throttle %

Computer

- Dell Precision T1700
    - Accessed through Windows TeamViewer
    - Dyno software is run using a deployment of OpenSuse in Oracle's Virtual Box

Detailed System Description

The Magna-Power power supply takes in 3-phase 208VAC power and is programmed to output 89.6Vdc. With a maximum current output of 200A RMS, it can accurately simulate four battery packs at normal operating conditions. The curtis controller takes in 89.6Vdc from the power supply at convert it to 3-phase AC voltage for the HPEVS AC-50 motor.

The motor is attached to the Huff HTH-100 Dynamometer system with a pump to motor gear ratio of 90:36 or 2.5:1. The Load Cell is attached at the pump and measures torque at the pump. The signal is conditioned by the Strain Gauge Input Module. There are two tachometers measuring motor RPM, one is available through the Curtis 1314 Programming software, providing access to RPM information directly, while the tachometer provides RPM data at the pump. Load Cell data and RPM data (from the tachometer) is collected by the MCDAQ 7204 USB board. The MCDAQ interfaces with the computer using a USB connection. The Curtis Controller communicates over CAN and interfaces with the computer using a USB to CAN interface. The proprietary Dyno software interfaces with the MCDAQ, Curtis Controller and Magna-Power power supply.

Appendix B - References

[1] Calibration Memo:
https://sites.lafayette.edu/ece492-sp16/files/2016/04/CalibrationandAccuracyReport.pdf

[2] Static Characterization Report

https://sites.lafayette.edu/ece492-sp16/files/2016/05/Static_Characterization-1.pdf