DC Motor-Clutch-Generator Control Workstation

Senior Project Proposal

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Summary:

The project objective is to design a motor-clutch-generator workstation. The plant is a motor-clutch-generator. A DC motor's velocity, torque, acceleration, and other parameters will be controlled. The motor will be attached to an electrical clutch, with the other end of the clutch being attached to another DC motor which will act as a load (DC generator). The clutch can be engaged and disengaged such that the plant will change, and the controller must be able to compensate for these changes. This plant is controlled with software that is implemented on the EMAC 80515 development board using C language programming. Also, non-linear modeling techniques will be used to create an accurate simulation model of the physical system in Simulink. Interfacing between Simulink and the controller will also be accomplished.

Detailed Description:

Goals of the project are as follows:

- A plant controller implemented in C language with the EMAC 80515 development board.
- A user interface that allows for changing control parameters and for motor control; as well as allowing the display of real time operation data.
- Serial communication between the EMAC 80515 development board and a PC using an RS232 serial interface for data sharing.
- Non-linear modeling of the physical system using control theory, Simulink, and Matlab.
- A graphical user interface (GUI) in Simulink for the purpose of easy manipulation of the model for simulation and its data.

The project consists of three primary subsystems; the plant, Simulink model, and a microcontroller development system. The first subsystem, which the other two are dependent on, is the physical system. A GUI will be created to interface Simulink with the microcontroller development system though the serial port. The software-based controller will be implemented on the EMAC 80515 development board. The microcontroller board will allow the user to set control parameters, display the physical system's operation status such as velocity, and also to use control algorithms and feedback data to accurately control the physical system with its PWM signal which will drive the motor. Moreover, the EMAC 80515 development board will be programmed to communicate with a PC running Simulink through serial communication. These systems are combined for an overall system block diagram.

The block diagram of the motor-clutch-generator workstation, with subsystems labeled for reference, is shown in figure 2-1. The motor subsystem consists of the Pittman DC motor with its rotary encoder and the hardware used to interface the motor with the EMAC development board. The motor is controlled by the EMAC 80515 subsystem using a pulse width modulation (PWM) signal. The speed of the motor is then

fed back to the EMAC 80515 subsystem by the rotary encoder which produces pulses proportional to the speed of the internal shaft of the motor. The interface hardware consists primarily of an H-bridge which amplifies the PWM signal from 5 Volts to 20 Volts. The clutch subsystem consists of a clutch that is electronically activated and, when activated, is used to couple the motor shaft to the DC generator shaft, thus changing the plant model. The DC generator subsystem is the DC generator and its variable load. The DC generator is a second Pittman motor. Its load will be determined by a high power rated resistor whose value is selected by the user. This value may be selected either manually or through software. Subsystem four is the external joystick hardware. This joystick will be designed for the user to operate the motor in both closed loop and open loop modes. The x and y directions of the stick will be set up to produce an analog voltage signal to be converted by the A/D converter of the EMAC 80515 subsystem. Other hardware, consisting of pull-ups and protection circuitry, will be implemented in this subsystem.

The EMAC 80515 subsystem will use a liquid crystal display (LCD) for displaying its interface to the user. The LCD will also be used to display real time data of the operation of the physical system. A keypad will be used as the primary user input, allowing the user to enter parameters and choose between options. Another element of the EMAC 80515 subsystem is the software based controller. This controller will be used with feedback to implement a closed loop controller. The controller will be used to control velocity, acceleration, torque, position and other possible operating variables of the motor. Various control theory methods are to be explored for the implementation of this controller such as proportional control, proportional-integral-derivative (PID) control, root-locus design, and frequency domain design. The final component of the EMAC 80515 subsystem is the RS232 serial interface. The microcontroller will take the feedback information from the rotary encoder of the motor and send this data to a PC running Matlab and Simulink using the serial interface. This data can be used to analyze the operation of the physical system without heavy use of lab equipment such as the oscilloscope. Also, the microcontroller will use the serial interface to receive command signals from the PC. The command signal will be stored in RAM and will allow the microcontroller to produce complex command signals without the need for implementing an extensive algorithm in the microcontroller code itself.

Finally, the Simulink subsystem consists of Matlab and Simulink software running on a PC. Simulink is used to model the physical system using control block diagram elements and other functions. The model is non-linear, with its parameters determined using the motor data sheets and experimental data. Also, Simulink is used to generate a GUI for the user to change parameters of the model and other possible options. Matlab will be used both for actual serial communication programming as well as for storing variables such as command signals and control parameters.
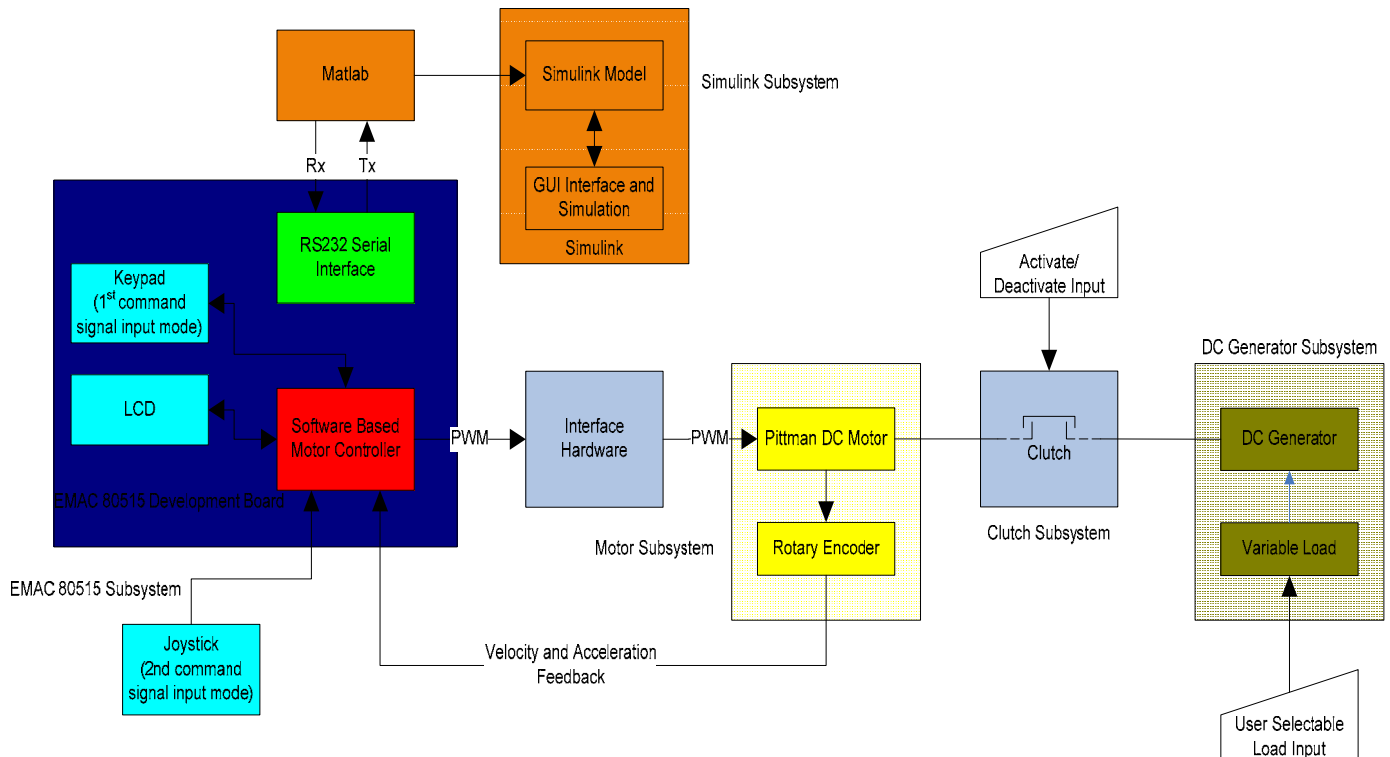
Figure 2-1: System Block Diagram

Project Specifications:

With this project, there are a wide number of specifications that can be made. The specifications have been organized below so that each specification pertains to a specific subsystem of the project. Many specifications have yet to be determined because more preliminary work is needed to get a grasp of the project's capabilities; however, these specifications have been identified, regardless of real figures. The specifications are as follows:

Motor subsystem:
1) Operation temperature: 0 to 40°C
2) Power supply voltage: 30V DC
3) Maximum torque: x N-m **yet to be determined**
4) Analog circuit-hardware protection
5) Printed circuit board implementation
6) Operating direction: clockwise and counter-clockwise (when decoupled from load)

Clutch subsystem:
1) Power supply voltage: 12V DC
2) Maximum torque: 1.7 N-m
3) Operating direction: clockwise

DC generator subsystem:

1) Maximum load: x Ω **yet to be determined**
2) Load power rating: x W **yet to be determined**
3) Maximum torque: x N-m **yet to be determined**
4) Variable load by way of software control
5) Variable load by way of manual user control
6) Operating direction: counter-clockwise

Joystick interface subsystem:
1) D2 button**:** RPM up if trigger is pressed
2) D3 button**:** RPM down if trigger is pressed
3) D4 button (multi-use)**:** (1) Motor brake (2) Exits from closed-loop control. (3) Enable closed-loop control if trigger active, regulate at last commanded velocity
4) Trigger button: Enables D2 and D3 buttons and enables closed-loop control if D4 is active
5) X and Y axis control open-loop RPM
6) Protection circuitry and printed circuit board implementation

EMAC 80515 subsystem:
1) Two line LCD main display: Measured parameters on line 1 including RPM, torque, etc. Control parameters on line 2 including command RPM, PWM generation duty cycle
2) Secondary display of menu which consists of operation mode selection and parameter selections
3) Display refresh rate: 0.5 seconds
4) Motor Velocity: display accuracy $\pm$ 20 RPM
5) PWM: period waveform (1 millisecond), variable duty cycle (0 to 100% in 0.2% or less increments), display accuracy: $\pm$ 0.2%
6) Serviced every 40 ms (default), keypad selectable from 5 to 250ms
7) If system saturates, controller returns PWM to open-loop operation
8) Proportional, proportion-integral, and proportion-integral-derivative controller implementations (more methods optional)
9) Partial RS232 serial interface with use of EMAC 80515 development board UART with rate of 9600 baud.
10) Simulink operation mode: Ability to send physical system data and receive command signals to store in RAM.

Simulink subsystem:
1) System model: Open-loop and closed-loop modeling of the physical system
2) Non-linear modeling: Non-linear modeling for the static, Coulomb, and viscous frictions of the motor, and for the clutch subsystem non-linearity.
3) GUI for changing parameters of the model and other options
4) Serial communication with EMAC 80515 development board for sending command signal variables and for receiving physical system data

5)   Method for comparing and analyzing the physical system with the modeled system, with the goal of method realized in real time

Preliminary Work:

Six days of lab have been used to gather information and to evaluate the project. Simon Benik has researched serial communication using the UART on the EMAC development board. Progress has been made, but more work on serial interfacing has been postponed until more issues have been tackled to make best use of the time available. He has also improved previous work on the user interface and has consolidated the code used to generate pulse width modulation signals. He also has begun the high level design of the software. The high level flow chart is shown below in figure 6-1.
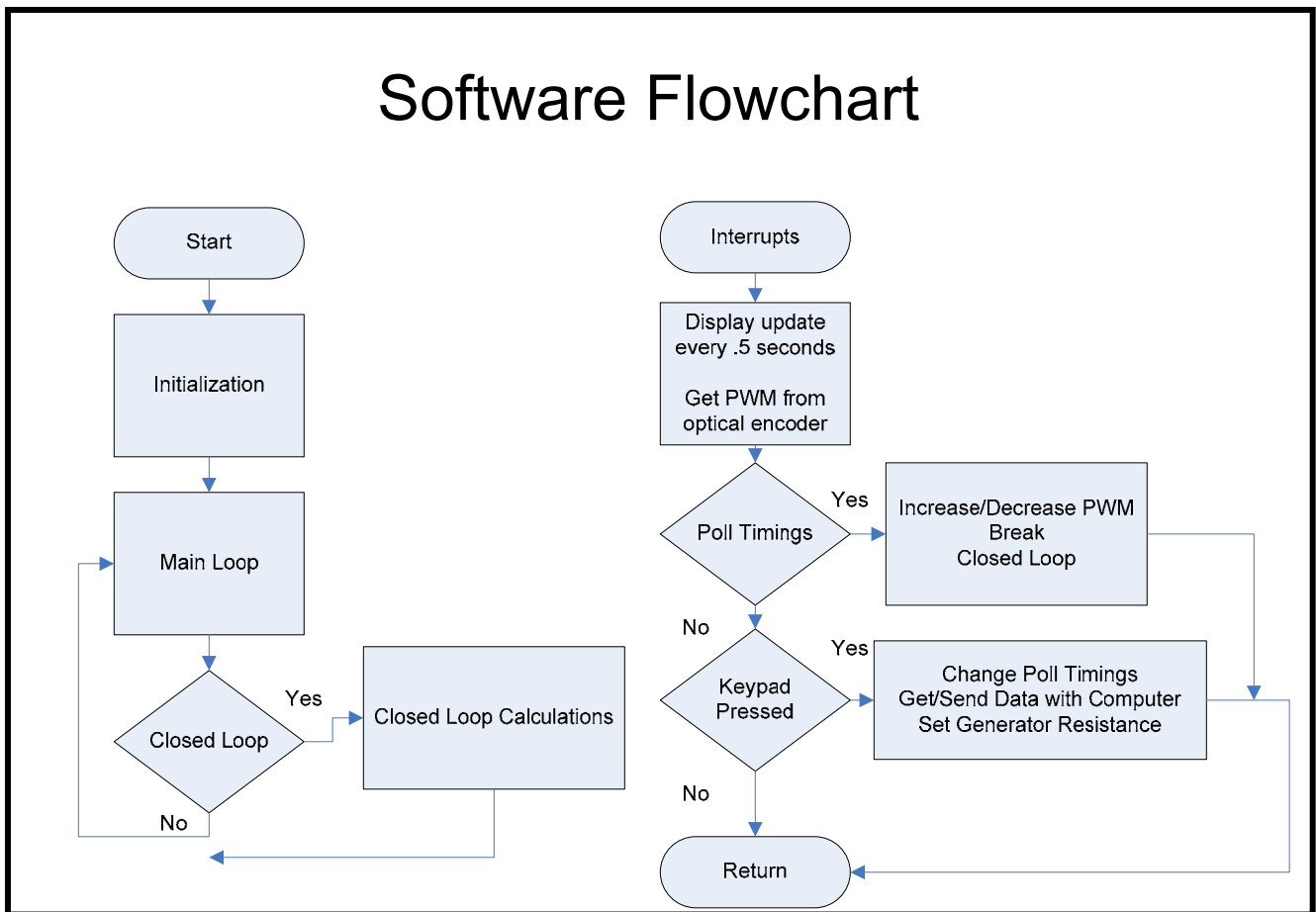

Figure 6-1: **Preliminary High Level Flow Chart**

Adam Olson has begun modeling the physical system by collecting experimental data and using it to create models in Simulink. He found the torque of the motor at various speeds and voltages by measuring the current into the motor. Three trials were performed. The types of frictions of a DC motor are shown in figure 7-1.
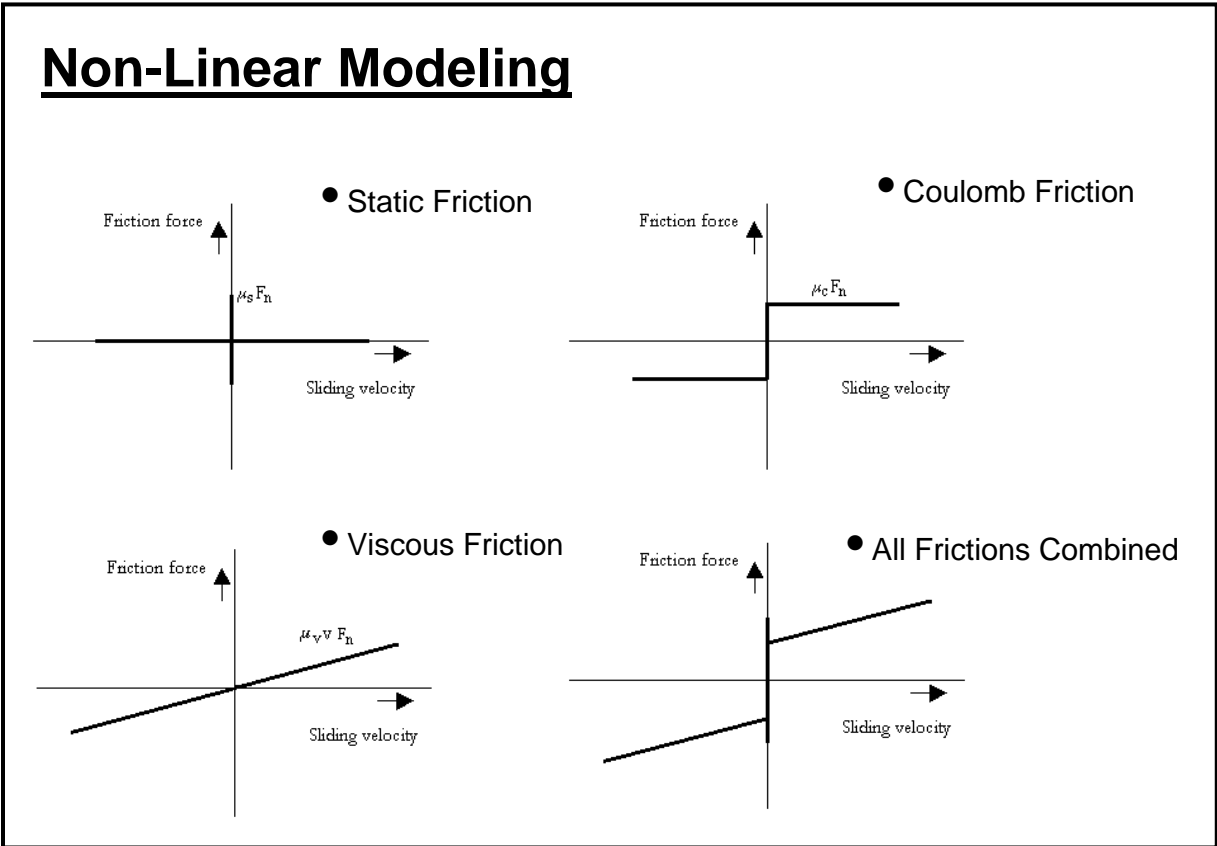
Non-Linear Modeling

• Static Friction

• Coulomb Friction

• Viscous Friction

• All Frictions Combined

Figure 7-1: Non-linear friction characteristics of a DC motor

With this friction data collected, a non-linear model was created. The simulink model of the system is shown in figure 7-2.
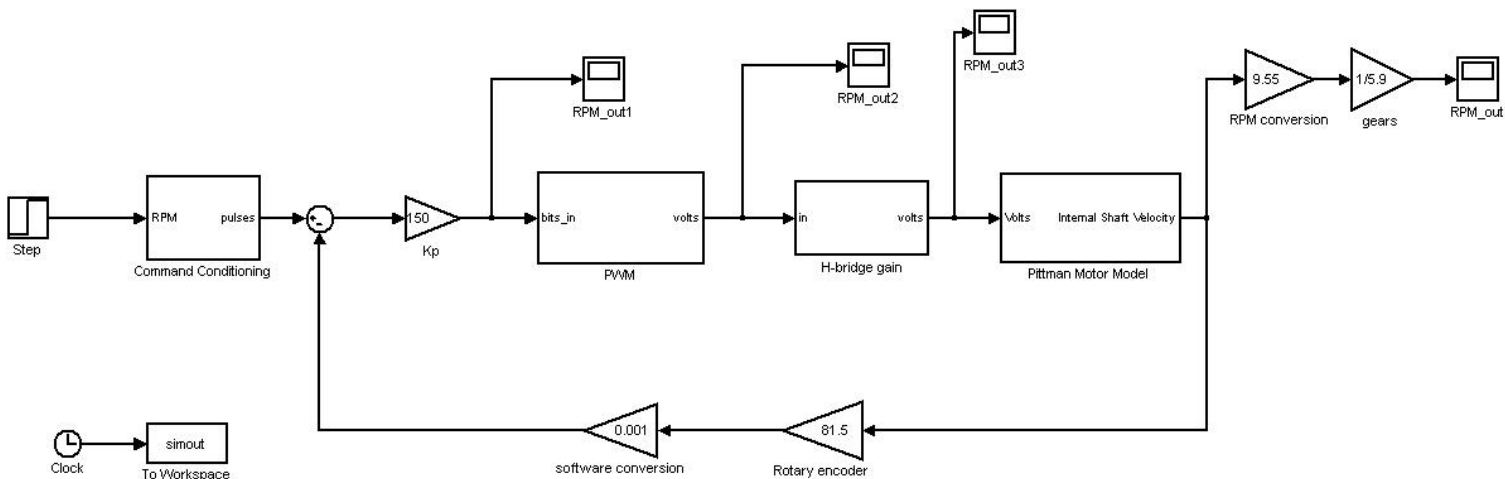
Figure 7-2: **DC motor model in Simulink**

With this model, the physical system can be simulated. Many parameters of the system can be measured in the simulation such as torque, velocity, current, and voltage.

For example, the graph in figure 8-1 shows how closely the simulation models the actual system by displaying both experimental results and simulated results of the system's current with respect to velocity.
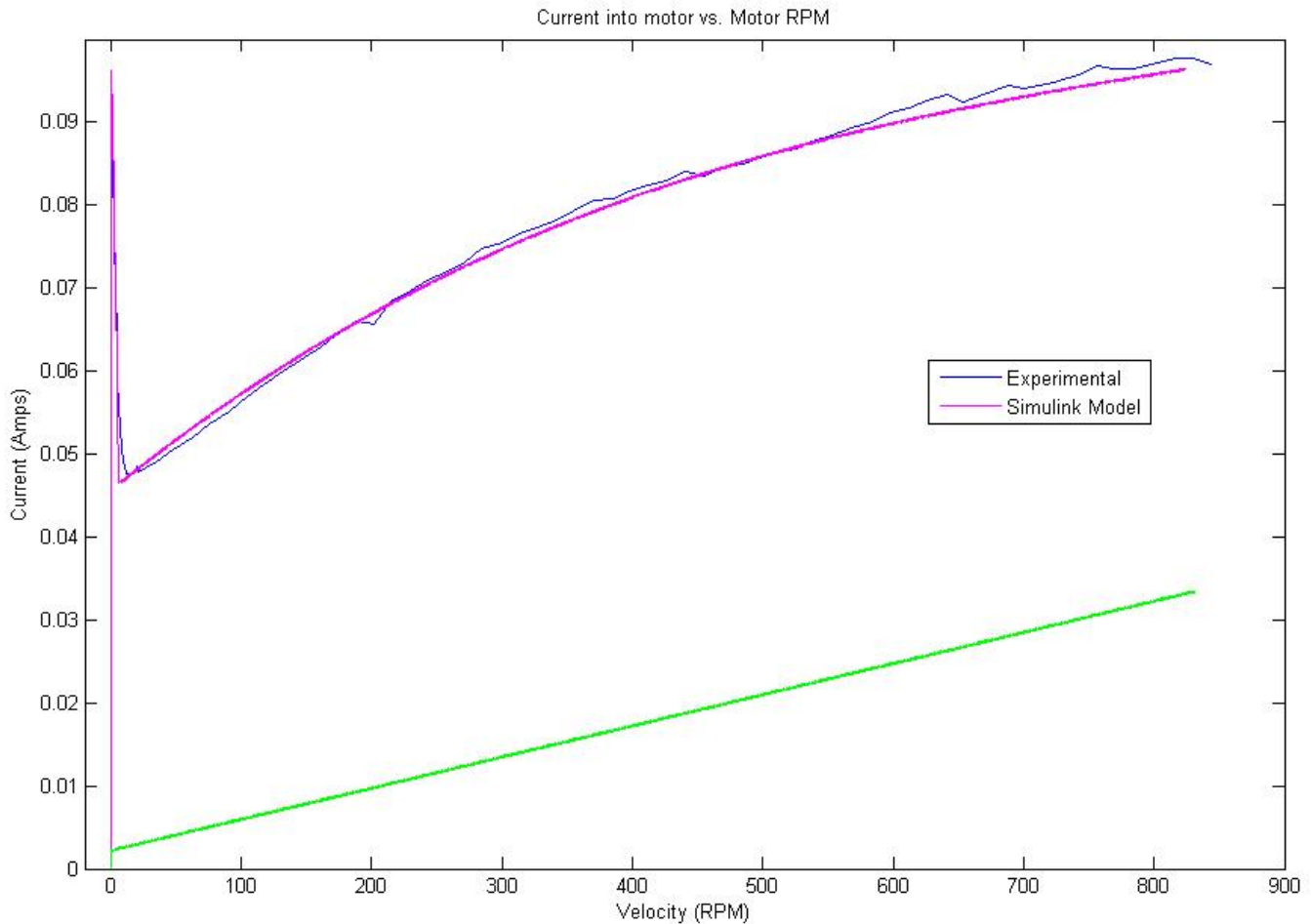

Figure 8-1: **Experimental results vs. simulated results of the physical system**

The green plot is what the motor's current would be in the model if it were modeled using only linear techniques. The non-linear model is an almost perfect match to the experimental system, and a vast improvement over the linear model.

Schedule of Tasks:

Table 9-1 shows the projected schedule of tasks for both partners. Simon will focus primarily on the EMAC 80515 development board subsystem while Adam will be working mainly on Simulink modeling. Initially Simon will focus on storing feedback parameter variables into the external RAM and also on reading control signals from the RAM to be used by the PWM signal generation code. He will then return to working on the serial communication between the EMAC board and a PC. Simon and Adam will

then work together in a possible automation of the variable DC generator load, in the coding of a Simulink GUI, and then in implementing the closed loop controller designs in C code. Simon will then finish the interface on the board's LCD, keypad, and joystick. Finally, he will test that all functionality is reached for the EMAC development board subsystem.

Table 9-1: Schedule of Tasks

Week #	Simon Benik	Adam Olson
1	Ram Storage	Non-linear modeling
2	Ram Storage	Non-linear modeling
3	Serial Communication	Controller Design and Simulation
4	Serial Communication	Controller Design and Simulation
5	Serial Communication	Controller Design and Simulation
6	Variable Generator Resistance	
7	Graphical User Interface (Simulink)	
8	Closed-Loop Controller Implementation	
9	Closed-Loop Controller Implementation	
10	Closed-Loop Controller Implementation	
11	EMAC User Interface	Closed-Loop Verification
12	Final Testing	

Adam will continue the non-linear modeling and then designing various controllers in Simulink to test them on the model. He will then assist Simon with the DC generator automation, and also will work with Simon on the Simulink GUI. Then, as stated above, he will implement the closed-loop controllers he designed for the EMAC board with Simon. The controllers will be verified and then he will perform final testing to show all subsystems work correctly.

Equipment List:

The equipment list only includes main components of the system. The list is below in table 9-2.

Table 9-1: Equipment List

Parts	Quantity
EMAC 80515 Development Board	1
HP 30V Power supplies	2
LMD18200 H-bridge Motor Controller	1
Pittman DC Motors	2
Reell EC15 Spring Clutch	1
5.6 Ohm, 8.7 Amp Potentiometer	1
Matlab and Simulink Software on a PC	1

The HP 30V power supplies will be used to power the H-bridge, which in turn supplies the DC motor, and also to power the electric clutch. The H-bridge is used to control the motor by increasing the voltage of the PWM signal from the EMAC board.

The DC motors and the clutch are part of the physical system, and the 5.6 Ohm potentiometer serves as the variable load for the DC generator.

Bibliography:

1)   Dr. Gary Dempsey. Advisor in all aspects of research and design.

2)   Pittman Motor Application Notes.
        http://blackboard.bradley.edu/courses/1/EE451_01_06FA/content/_455117_1/220
        000ALL.pdf

3)   Clutch Product Information with Data Sheet.
        http://www.reell.com/products/ec15.htm

4)   Functional Requirements and Performance Specs, Dr. Gary Dempsey, EE450 Electronic Product
        Design.
        http://blackboard.bradley.edu/@@@cb65f20b7d29e2f11466cc12ddf1fae5/courses/1/EE450_01_06
        FA/content/_390634_1/mini_project_figures_diagrams_06.doc