LAB #11: SPEED CONTROL OF A D.C. MOTOR
MOTOR CHARACTERIZATION

INTRODUCTION

The primary goal of this semester-long project is to develop a speed controller for a D.C. motor. Whenever the motor is to be operating at a given speed, the controller should react to changes in motor loading to correct the speed as quickly as possible. If the motor is told to change speeds, this change should likewise occur as quickly as possible. In both cases, there should be minimal overshoot of the target speed, and no "hunting" for the correct speed. No two motors are identical, and one of the benefits of feedback control is reduced sensitivity to plant (controlled system) variations. On the other hand, controller design should take into account certain motor parameters to produce optimal responses to changes of load or speed setting. The purpose of this lab session is to experimentally measure parameters of our D.C. motor that can influence the speed control algorithm.

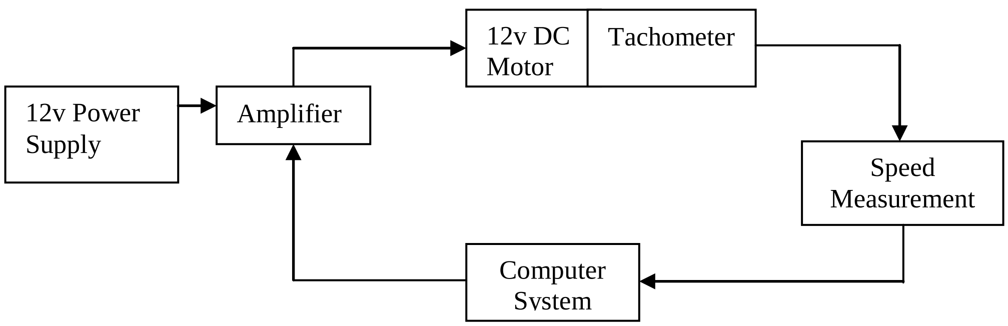


Figure 1. Motor control system hardware block diagram.

MOTOR CONTROL SYSTEM MODEL

A motor, its load, its controller, and all associated electronics can be modeled as a feedback control system, as illustrated in Figure 2. The system input is a signal related to the desired motor speed; it is also known as the reference or setpoint, $R(s)$. The system output is the actual speed of the motor. The load on the motor is unknown at controller design time. Therefore, a *controller* is needed to compensate for changes in the load or the setpoint, either of which can change at any time. The controller, implemented in software on the computer, is represented by a transfer function $C(s)$. The input to the controller is the error, $E(s)$, which is the difference between the setpoint, $R(s)$, and the measured signal, $Y(s)$. The *actuator* (or *amplifier*) includes the H-bridge (or transistor switch) and associated electronics, and is represented by its transfer function, $A(s)$. The actuator converts the control action computed by the controller into the voltage applied to the motor. The motor is represented by its transfer function, $M(s)$, which is the ratio of its output (speed) to its input (applied voltage). The *sensor* includes the tachometer and its associated electronics, and is represented by its transfer function $H(s)$. The measured signal, $Y(s)$, is the sensor output that is related to motor speed. In this project, $Y(s)$ and $R(s)$ could be either time period or voltage of the conditioned tachometer output.

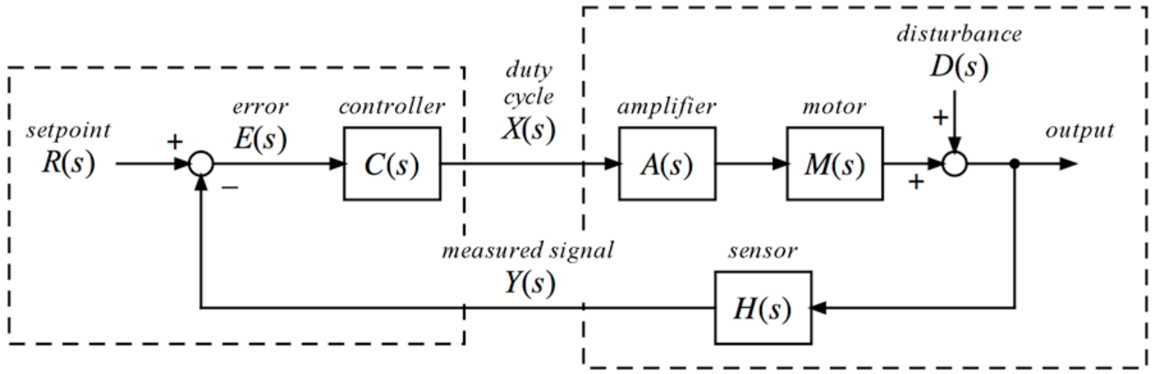


Figure 2. Feedback system transfer function model.

For ease of modeling, we may consider the system from the viewpoint of the computer and the control software and lump all the hardware elements together into a single element called "the plant", whose transfer function is $G(s)$, as illustrated in Fig. 3. The input to the plant is the control action produced by the controller; i.e. the duty cycle $X(s)$ of the pulse width modulated (PWM) signal used to vary the motor speed. The output of the plant is the measured speed of the motor, which is inversely proportional to the optical encoder signal period, measured via the comparator and counter.

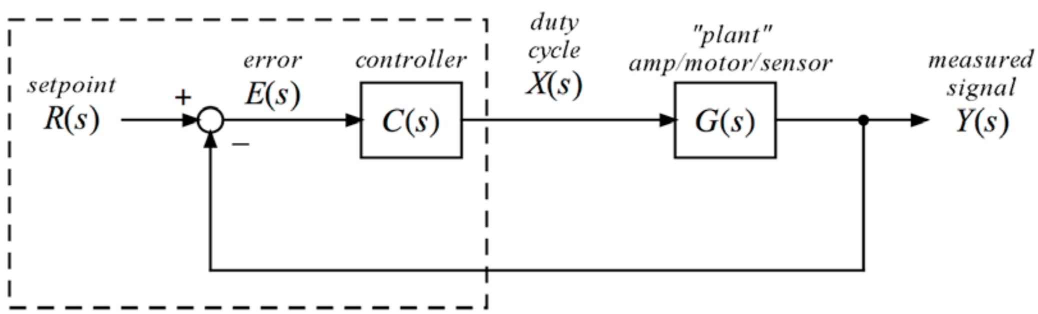


Figure 3. Feedback system with actuator, motor, and sensor consolidated into the plant.

Before a controller can be designed for this system, the transfer function of the plant, $G(s)$, must be determined -- this process is also known as *system identification*. This can be done experimentally by studying the open-loop response of the plant to a step input. The creation of a step input to the motor involves bypassing the controller and forcing an instantaneous change in the control action. Since the D.C. motor in this lab is controlled by a PWM signal generated by the computer, the "control action" is represented by the duty cycle of this PWM signal, selected to produce a desired speed. Application of a step input to the motor therefore involves instantaneously changing the duty cycle $X(s)$ from one value to another. The open-loop response is determined by measuring and plotting the motor's output (its speed) versus time. The parameters needed to determine $G(s)$ can be measured from this plot.

For example, suppose that the open-loop response of the plant to the step input looks like a simple exponential, as illustrated in Figure 4. This suggests that the plant can be modeled as a first-order system with input $x(t)$, measured output signal $y(t)$, time constant τ, and gain K. The model is given by the linear ordinary differential equation:

$$Kx(t) = \tau \frac{dy(t)}{dt} + y(t)$$

Solving this equation produces the step response for time $t > 0$:

$$y(t) = K\Delta x(1 - e^{-t/\tau})$$

where Δx is the step change in the input. The gain K is simply the change in y divided by the change in x, computed when the system has reached steady state (i.e. for large t). The time constant τ is the time needed for the output to make 63.2% (e^{-1}) of the change from its initial to its final value. Knowing the time constant and gain, the transfer function of this first-order system can be written as:

$$G(s) = \frac{Y(s)}{X(s)} = \frac{K}{\tau s + 1}$$

MATLAB/Simulink can be used to verify the experimental data via the model shown in Figure 5, which is that of a first order system driven by a step input. If the experimental data fits a first order behavior, then using the computed values of K and τ in the Simulink model should produce a simulated response that matches the experimental result.

Figure 4. First-order response to a step input.

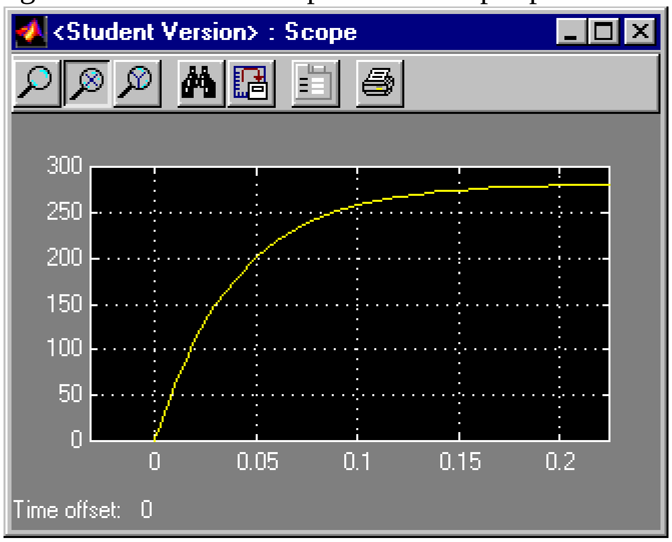
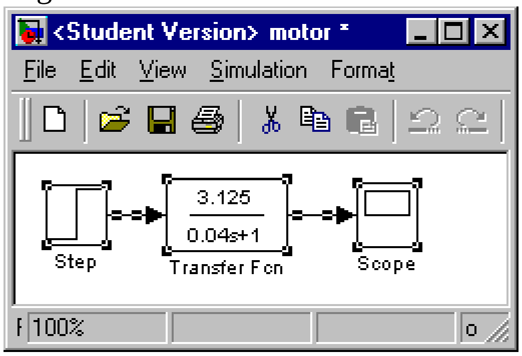


Figure 5. Simulink model.



SOFTWARE DESIGN

As in previous weeks, the test program should be modified to conduct this new experiment. At this point, the program should be able to drive the motor at different operating speeds. For this experiment, it should drive the motor at a low speed, and then instantaneously change the speed to a higher setting, producing the required step input. As soon as the step input is produced, the program should periodically sample the speed and store these values in an array. After the motor has reached steady state, this array of speed values should be uploaded to the host computer. This will allow you to plot the step response (speed vs. time) in MATLAB, Excel, or some other program. The motor time constant and gain parameters can then be measured from this plot.

NOTE: The transistor switch, microcontroller, and other components can be destroyed during these tests, just as easily as in the previous weeks! These devices can be protected by continuing to practice careful design and by observing the guidelines given in the write-ups from previous labs.

LABORATORY EXPERIMENTS

1. As before, you will need to *design experiments* to produce the required data. Be sure to document each experiment in your lab notebook, and summarize the most significant one(s) in your report.

2. Compile and run a test program to generate a step input and measure the open-loop amplifier/motor/sensor response by capturing sampled signal y values in an array. Upload this array to the computer after the motor reaches steady state. It is suggested that this experiment be repeated for different pairs of speeds so that the results can be compared and/or averaged.

3. Use a program such as MATLAB, Excel, etc. to plot the motor response as measured signal y vs. time t. From this plot, measure the motor time constant and gain and write the system transfer function, $G(s)$.

4. Verify the measured time constant and gain by creating and running a Simulink model, as shown in Figures 4 and 5, of a first order system stimulated by a step input. The simulated response should match your experimental results.

FOR FUTURE LABORATORY REPORTS

1. Briefly describe the experiment you designed to collect motor information.

2. Briefly describe your test program and attach a copy of the program. Make sure your program includes descriptive comments.

3. Show (graph) the response curve produced by your experiments.

4. Report the motor time constant and gain measured from the experimental data, and write your system transfer function $G(s)$. Discuss other observed results as appropriate.