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

INTRODUCTION

The technical goal of this semester-long project is to develop a speed control system for a dc motor, as illustrated in Fig. 1. The controller should react to motor load changes, correcting the speed as quickly as possible. If the desired speed is changed, the response should likewise occur as quickly as possible. In both cases, there should be minimal overshoot of the target speed, and no "hunting" (oscillations) around the correct speed. No two motors are identical, and one of the benefits of feedback control is reduced sensitivity to plant variations. A well-engineered controller design usually considers a plant model to produce optimal responses. The purpose of this lab session is to experimentally derive a plant model. In theory, the plant model would be used to design a better speed control algorithm.

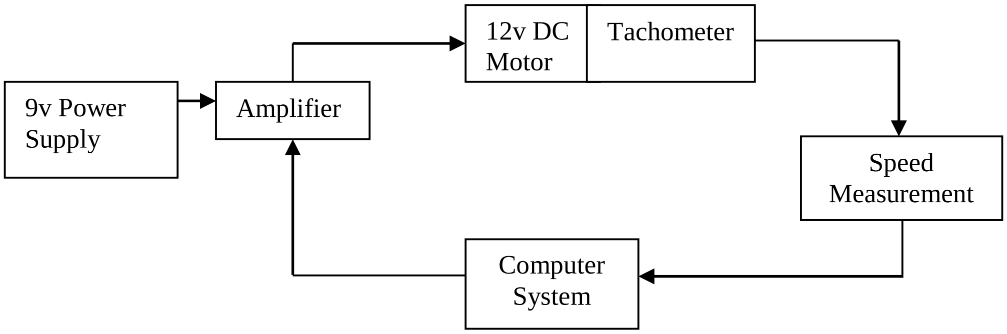


Figure 1. Motor control system hardware block diagram.

MODEL OF THE PLANT (amplifier, dc motor, and sensor)

The plant or process model $G(s)$ includes the amplifier, the dc motor, and the sensing electronics. The plant *input* is the duty cycle of the pwm signal that drives the amplifier, and the plant *output* is either the period or the amplitude of the tachometer output signal (either signal is related to the actual motor speed).

In this lab, the transfer function will be estimated by extracting key parameters from a measured step response. The plant input will be a step function (a change in duty cycle of the pwm signal). The step change in duty cycle is produced by the microcontroller. The resulting response at the plant output is also recorded by the microcontroller and stored in an array of its internal memory, which can be examined by the debugger.

For example, suppose the plant's step response looks like a simple exponential, as illustrated in Figure 1. This suggests that the plant can be modeled as a first-order system with input $x(t)$, measured output signal $y(\mathrm{t})$, 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. Alternatively, the time constant can be estimated as being 1/4 or 1/5 of the settling time (the time between the start of the response to the point of reaching the 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 Fig. 2, 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 1. First-order response to a step input.

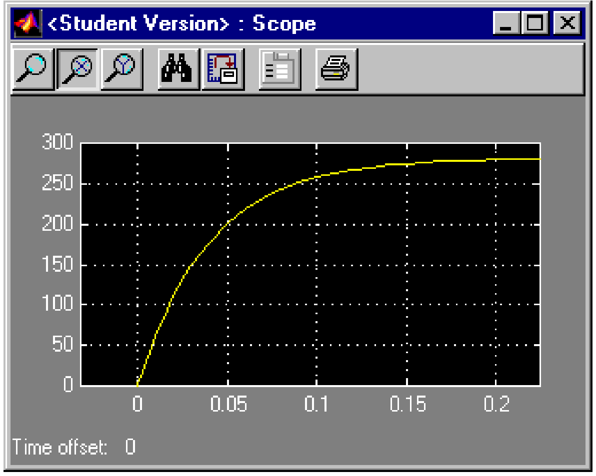
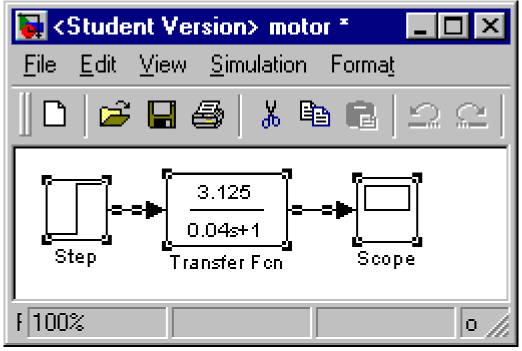


Figure 2. Simulink model.



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, the program should drive the motor at a low speed, and then instantaneously change the desired speed to a higher setting, thus producing the required step input. As soon as the step input is produced, the program should periodically sample the plant output (either the period or amplitude of the tachometer signal) 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 allows one to plot the step response (“speed” vs. time). The motor time constant and gain parameters can then be extracted from the 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.

PRE-LAB ASSIGNMENT

As before, you will need to <u>*design experiments*</u> to produce the required data. Prior to lab, design an experiment to generate a step input (change in duty cycle) and measure the open-loop response of the amplifier/motor/sensor, by capturing the sampled signal values in an array. Record this test plan in the engineering notebook.

LABORATORY EXPERIMENTS

1. Be sure to document each experiment in your lab notebook, and summarize the most significant one(s) in your report.

2. Follow your test plan 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 combinations of speed changes 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 <u>experiment you designed</u> to collect motor information.

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

3. 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.