ENGS 26 CONTROL THEORY

DC Servomotor Laboratory

Equipment and Software Required:

Thayer School DC Motor/Tachometer board
DT9802 USB Data Acquisition Board and PC
Oscilloscope
Connectors (1 BNC-BNC, 3 BNC-Banana, 4 to 6 pairs banana-banana)
+10 V power amplifier (white box)
Voltmeter
Signal generator
+15 V DC power supply (silver box)
DT VEE software
Breadboard and analog control component kit

Note: You should complete this experiment during the first week of the lab session, and write the report during the second week of the lab session.

1. Objective

The objective of this lab is to implement a lead/lag compensator to control motor shaft position and to determine the closed-loop bandwidth of the system.

2. System modeling

As in Lab 2, the DC motor is driven by a voltage through a power amp. An integrated tachometer provides a voltage proportional to shaft angular velocity, and a “three turn” potentiometer provides a voltage proportional to shaft position. In Lab 2, we identified an open-loop transfer function of the motor-tach-power amp based on the open-loop system response to step input voltages. With the potentiometer in the system, we cannot “lump” the tachometer transfer function in the system gain. We will represent the motor together with the power amp by

\[
\frac{\theta(s)}{V_{in}(s)} = \frac{K_1}{s(Ts + 1)}
\]

\(\theta\) is the motor shaft position (rad), \(V_{in}\) is the input voltage to the power amp (volts), \(T\) is the motor time constant in seconds identified in Lab 2, and \(K_1\) the overall gain of the power amp and motor (rad/volt). \(K_1\) is determined based on the power amp gain (which was set to 1 in Lab 2 for open-loop transfer function identification), overall gain measured in Lab 2 (the variable we called \(K\) in Lab 2), and tachometer gain (\(K_t\)). \(K_t\) is given in manufacturer specs as 2.4 V/1000 RPM (or 2.4/104.2 V/rad/s).

Before Lab: From the open-loop system parameter \(K\) determined in Lab 2, compute the portion of the motor gain attributed to the tachometer (\(K_t\)) and that attributed to the motor/power amp (\(K_1\)). Assuming that you had the power amp gain set to 1 in Lab 2, \(K_1\) represents the motor gain.
The potentiometer transfer function depends on its supply voltage. For example, if the supply voltage across the potentiometer is 0 - 15 V, the gain is approximately $15/3 = 5$ V/rev or 0.795 V/rev. The block diagram describing the open loop system is shown in Figure 1. It lumps the gains associated with the motor into $K_1$, assumes a system time constant $T$, and assumes gains $K_t$ and $K_{pot}$ for the tachometer and potentiometers, respectively. The power amplifier, which provides the voltage $V_{in}$ to the motor, is assumed to have a gain of one.

**In Lab:** Connect the tubing between the motor and potentiometer shafts. Apply +15V and 0V across the potentiometer’s positive and negative terminals. **Make sure you do not apply a voltage to the slide! Do not use the -15V side of the power supply!** Ask the lab TA for assistance, if necessary. Verify $K_{pot}$. To do this, make sure that you read between 0 V and +15 V from ground to the slide when you turn the potentiometer 3 full turns. The slide voltage should increase by 5 V for each turn as you turn the pot by hand.

3. **Position control of the DC motor**

We will design a control system such that the following closed-loop specifications are met:

- $ts \leq 0.15$ sec (2% settling time)
- steady-state error $\leq 0.1$, for step input or step disturbance
  (Note: Steady-state error is defined as the reference input voltage - the potentiometer voltage)
- closed-loop damping ratio $\geq 0.5$
- closed-loop bandwidth $\geq 5$ Hz.

The open-loop system is type 1, which implies that there is zero steady-state error for a step input. However, due to static friction, or 'stiction', which is effectively a disturbance, steady-state error is not zero for this system when a proportional, lead, or PD compensation is used. Therefore, a lag compensator or integral control must be used in conjunction with the lead or PD compensator. Since we implemented PI compensators in lab 2, here we will implement a lead/lag compensator.
Since the level of static friction is unknown \textit{a priori}, we will test the steady-state error specification by considering the error response for a unit disturbance input $D(s)$ in Figure 1.

3.1 Lead/Lag compensator

The following lead/lag compensator was developed in class to meet specifications:

$$G_c(s) = \frac{s + 35}{s + 62} \frac{s + 0.1}{s + 0.01}$$

**Before Lab:**
Determine, using MATLAB, the frequency response of the lead-lag compensator only.

Choose values of resistors and capacitors to implement this compensator. First put the compensator in Bode form. Note than it may be convenient to move the pole at $s = 0.01$ to $s = 0.00909$ in order to allow for use of components in the kit.

**In Lab:** Build the compensator. (Do not add the summing junction or close the loop yet.) Verify that it works by determining the magnitude of the frequency response. To do this, subject the compensator to sine waves from below the lowest corner frequency (if viable) to above the highest corner frequency. If it is not viable to start at the lowest corner frequency, then start somewhere between the first two corner frequencies. Also, subject the compensator to a step input to find the DC gain or 'Bode gain.'

Record amplitude ratio information at each frequency. To do so, you may use the oscilloscope and printers, or you may use DT-VEE. The 'Store' button on the oscilloscope starts storage mode. The 'Save' button captures the trace, and the print button on the side of the scope sends the trace to the printer. To use DT-VEE, record the input once to obtain an accurate input amplitude, and record the output at each frequency tested. You will have to set the sample frequency and number of samples for each frequency tested.

You should use a log scale to choose frequencies at which the compensator frequency response is evaluated experimentally. Choose the amplitude of the input sine wave such that the output does not saturate at any frequency. Compare the experimental and simulated frequency responses in your report.

3.4 Closed-loop system implementation

**In Lab:** Construct the summing junction and construct a buffer circuit for the potentiometer slide output, as shown in Figure 2. Create a reference input between 2 and 7 V using the signal generator, i.e., 5 V amplitude, 2 V offset from zero volts. Connect the reference input and buffered slide output to your summing junction, and connect the output of the summing junction to the input of the lead-lag compensator circuit. Connect the output of the compensator circuit to the input of the power amp, and connect the output of the power amp to the motor. Set the power amplifier gain to one.
Check the operation of the position control system for inputs ranging from zero frequency (i.e., a square wave at 0.1 Hz from 2 V or 7 V or a step input $V_{ref} = \begin{cases} 2 \text{ V} & t < 0 \\ 7 \text{ V} & t \geq 0 \end{cases}$) to sinusoidal inputs at frequencies up to the bandwidth of the system (i.e., $V_{ref} = 4.5 + 2.5 \sin \omega t$). Construct the closed-loop frequency response. Compare the experimental and simulated frequency responses in your report, and compare the simulated and experimental step response in your report.

**MAKE SURE THAT YOUR CIRCUIT WORKS BEFORE YOU START THE CLOSED-LOOP SYSTEM!** Note that if the motor shaft slips in the tubing when you operate the closed-loop system, you have done something wrong! Turn off the power amp immediately, and correct the problem in your circuit if this happens!

**NOTE ON SELECTING REFERENCE INPUT AMPLITUDE:**
Note that you cannot record position commands over the full range of the potentiometer (0 to 15V), since the A/D converter records voltages between +10V. When choosing your input amplitude, consider the angle that the motor will move through. For example, for a 5V input, you should expect 1 full turn, while for a 1V input, you will expect a fraction of a turn. Do not choose an input amplitude outside of the 0 to 10V range, and be aware that if your system overshoots, you will not “see” the overshoot recorded on the A/D channel, if it exceeds 10 V or goes below 0 V. For example, for a 5V input, you may want to choose the minimum voltage as 2 V and the maximum voltage as 7 V.

**PLEASE TURN OFF INSTRUMENTS AND MAKE SURE ALL MATERIALS ARE RETURNED TO YOUR KIT BEFORE LEAVING THE LAB.**

**PLEASE LEAVE YOUR STATION NEAT.**

[Diagram of Lead-lag compensator for position control with potentiometer feedback.]

Figure 2  Lead-lag compensator for position control with potentiometer feedback.