Laboratory 1: System Identification

In this experiment, you will identify the parameters of the servomotor system, i.e., compute numerical values for the four parameters (K_0, K_1, K_2, K_3) that completely characterize the system. These values will be used in subsequent control design laboratories.

1 Preparation

If you have not done so, read the Introduction to the Control Systems Laboratory, attached to the Laboratory Manual. Pay particular attention to the section entitled *The servomotor system.* Having done so, you should understand the relationship between the physical system, and the block diagram shown in Figure 1. Before the laboratory begins, complete the following steps.

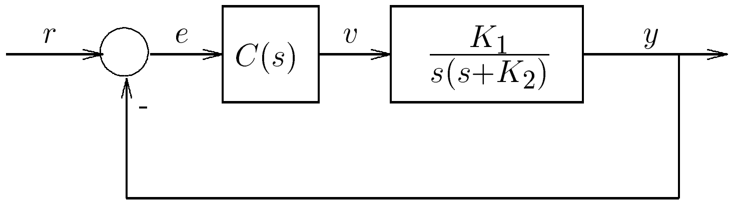

Figure 1: Simplified servomotor block diagram.

1. Let the controller $C(s)$ in Figure 1 be a *positive* gain: $C(s) = K$. What is the closed-loop transfer function $G(s) = \frac{Y(s)}{R(s)}$, in terms of K_1, K_2, K, and s? Be careful of signs!

2. K_1, K_2 and K_3 are all positive, by definition, and $K > 0$ by design. Is $G(s)$ stable?

3. $G(s)$ is a second-order system with no zeros. Thus, it can be expressed

$$G(s) = \frac{G_0 \omega_N^2}{s^2 + 2\delta\omega_N s + \omega_N^2} \tag{1}$$

   for positive constants G_0, δ and ω_N. Compute the relationship between the triples (G_0, δ, ω_N) and (K_1, K_2, K_3).

4. Assuming $0 < \delta < 0.2$, sketch the step response of $G(s)$. What is the relationship between *damped* frequency ω_D, and natural frequency ω_N and damping δ? What is the relationship between *percent overshoot*, and ω_N and δ? Given a step response, show how to *compute* ω_N and δ. Given the same step response, how can you determine values of K_1 and K_2?

5. Sketch a root locus of $G(s)$ as a function of $K > 0$ and $K < 0$, for fixed, positive values of K_1 and K_2. What happens to the poles of the closed-loop system as K is increased from 0?

6. Modify the C program `lab.c`, available on the network in GB347, and the WWW at url

   `http://www.control.toronto.edu/~bortoff/410.html`,

   to implement the constant-gain controller $C(s) = K$. You will determine the numerical value of K during lab. Also, modify the software to implement an step input $r(t)$.

7. Study the source code `lab.c` and determine how the subroutines `Calibrate` and `CheckCalibrate` determine K_3 and K_0.

8. Read the Laboratory Procedure and know what to do before coming to lab.

2 Laboratory Procedure

1. Make sure the servomotor system is wired correctly. Your job is to connect the servomotor box, the power amplifier, and the bench-top interface board. **PLEASE DO NOT ATTEMPT TO CONNECT THE RIBBON CABLE FROM THE BENCH-TOP INTERFACE BOARD TO THE COMPUTER. IT IS VERY EASY TO INSERT THE RIBBON CABLE BACKWARDS, WHICH DAMAGES THE A/D CARD, MAKING THE ENTIRE WORKSTATION UNUSABLE. LET THE TA CONNECT THE RIBBON CABLE TO THE COMPUTER.**

2. Compile and run your modified version of `lab.c`, and determine the parameters K_0 and K_3. It is not necessary for the power amplifier to be driving the motor here, although the power amplifier must be "on," so the POT is biased.

3. Compile and run your controller software for different values of $K > 0$, beginning with small positive values. If the motor vibrates or appears to be unstable, then K is too large. For these experiments, $r(t)$ should be a step of approximately 45 degrees, beginning at a time $t = 1$ second. You should collect the time t, the value of $r(t)$, and the value of $y(t)$, in a data file for later evaluation.

4. Experimentally determine a value of $K > 0$ for which the step response has a percent overshoot of approximately 20%. Because each of the servomotors has a different amount of inertia, each gain K will differ. (Don't copy your neighbor's value.)

5. Load the step response data collected in Step 4 into MATLAB, plot it, and determine ω_N, G_0, δ, K_1, and K_2. Do a good job here, because your measurements will be used in subsequent labs, and your numbers are unique to your workstation. As distributed,

`lab.c` produces a data file called `coollab.m`, which is in the proper ASCII format to load into MATLAB. Its format is

```
0.000  0.000  0.000
0.004  0.000  0.000
 ...    ...    ...
4.000  1.000  0.988
```

where, the first column is time, the second column is r at this time, and the third column is y at this time. Each row is for a different sample time, with time increasing from top to bottom, at increments of 0.004 seconds. To read this data into MATLAB, start MS Windows, then start MATLAB, use the `cd` command to change to the current directory, and type

```
>> load coollab.m
```

(the name of the data file, complete with the .m), at the prompt. This creates array called `coollab`. Then, the commands:

```
>> tdata=coollab(:,1);
>> rdata=coollab(:,2);
>> ydata=coollab(:,3);
```

create vectors that can be plotted. (Note that the `>>` is the MATLAB prompt, and is not typed.)

6. Plot in MATLAB the simulated response of $G(s)$ for the identified values of ω_N, δ and G_0. On the the same axes, plot the experimental data. The two plots should be close to one another. Assuming your identified values were $G_0 = 1.0$, $\delta = 0.3$, and $\omega_N = 10.$, and the measured data is in vectors `tdata`, `ydata` and `rdata`, the MATLAB commands would be as follows.

```
>> delta = 0.3;                           % computed value of damping
>> omegan = 10;                           % computed value of natural frequency
>> G0 = 1.0;                              % computed value of gain
>> num=[0  0  G0*omegan^2];               % transfer function numerator
>> den=[1  2*delta*omegan  omegan^2];     % transfer function denominator
>> ysim=lsim(num,den,rdata,tdata);        % simulated step response
>> hold off;
>> plot(tdata,ysim,'-',tdata,ydata,':'); % plot
>> xlabel('Time (seconds)');              % time-axis label - Very Important
>> ylabel('Shaft position (degrees)');    % data-axis label - Very Important
>> title('Actual and simulated servomotor step response');
```

The plot should look similar to Figure 2. (Note the % character is a comment character in MATLAB; everything following the % is a comment.) Can you "tweak" your computed values of δ and ω_N to make the simulated and experimental step responses agree better? **Show this plot to your TA.**

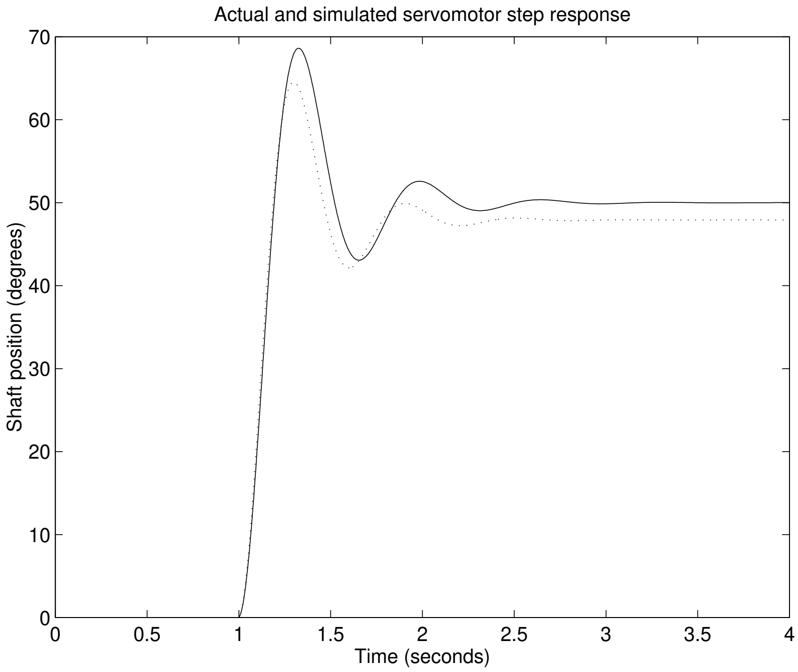

Figure 2: Example of an actual ($\cdots$) and simulated (—) step response for the servomotor system.

3 Before Leaving Lab

Before leaving lab, make sure to do the following.

- Show the TA your pre-lab. The TA will check that it is done, and he/she will check for correctness. He/She may also ask questions to ensure that you know the lab procedure, so make sure you are prepared before coming to lab. (That is for your own good - if you aren't prepared, you won't finish.)
- Demonstrate to the TA the servomotor system closed-loop step response.
- Show the TA the MATLAB step response plots.
- Show the TA your identified K_0, K_1, K_2 and K_3.

4 Laboratory Notebook Write-Up

The laboratory report in your notebook should include a description of the procedure, the work done in the pre-lab, including answers to the questions, a listing of your C code, and a plot similar to that in Figure 2, and should describe the calculations for K_0, K_1, K_2 and K_3. The following questions should be answered.

1. Why use a value of K that gives overshoot of 20%? Can other values work? What if you use a value of K so that the closed-loop system is over-damped? What if you use a value of $K < 0$? What if you use a value that gives 100% overshoot?

2. In MATLAB, create a root locus plot for your servomotor, as a function of K. Show both $K > 0$ and $K < 0$. Mark with an $\times$ the value of K that you used to do the parameter identification.

3. What are some the reasons for discrepancy between the measured step response and the simulated one? A list is not sufficient here. You must *describe* some factors that make simulation of the model different from reality. For example, there is static friction in the motor, which is not modeled by the second - order system. *Why* does static friction make the responses differ? In what way does it affect the experimental step response?

4. Describe how K_0 and K_3 are determined. A graph would be helpful here.