ECE-521 Control Systems II
Laboratory 2

In this Lab you will again obtain a second order model of your spring/mass/damper system using the log-decrement method, and by estimating the transfer function by looking at the step response of the system. Then you will determine the frequency response of the system by exciting the system with sinusoids of various frequencies and measuring the amplitudes of resulting oscillations. These frequency response measurements will then be compared with the frequency response predicted by the estimated transfer functions. Finally, the parameters of the estimated transfer function will be used as initial guesses in an optimization routine to try and improve the fit to the frequency response measurements. *You are strongly encouraged to do all of the analysis for one system in lab before you move to the next system. It is very easy to make mistakes in recording the data which will be difficult to correct after you have changed the configuration.*

You will go through the following steps:

1. Set up a system configuration (you will need three different configurations)
2. Estimate a second order system model using the log-decrement method (the **log_dec.m** program).
3. Estimate a second order system model using the step response and the **fit.m** program. This should be done independently of the results you get from the log-decrement method. Try and match the early part of the step response as well as possible.
4. Excite the open loop system at various frequencies and determine the magnitude of the frequency response.
5. Use the program **process_data.m** to put the data into a nice format.
6. Compare the two time-domain transfer functions with the frequency response using the **fit_bode.m** program.
7. Optimize the fit of the frequency response data and the estimated transfer function using the **opt_fit_bode.m** program.

Pre-Lab

Print out this lab and **read** it.

Time Domain System Identification

0. Starting the software

From Windows, go to **Programs** → **ECP** → **ECP32**

1. Setting up the system

With the control system turned off (push the button on the white and black box, the green **pwr** light should be off), set up the device for you group. You may change the number of masses, add/subtract/change springs, and add/subtract the damper. Be sure all masses/springs are tightened down. If you use the dashpot, be sure the screw on the dashpot (damper) is at least two full turns away from its closed position. If the dashpot exerts too much damping your system will not oscillate.

2. Setting the mechanical zero position

By turning the thumbscrews, set the mechanical zero position indicator. This will help you determine the size of the initial displacement.

3. Turn on the system

Push the button on the white and black box to enable the control system.

4. Set the electrical zero position

Select **Utility** → **Zero Position** to set the current position to zero. You may have to click on this a few times. Look at the **Following Error** readouts, if they are zero or near it you can continue..

5. Set the units

Select **Setup** → **User Units** and set the units to **counts**.

6. Set the trajectory for an initial condition response

Select **Command** → **Trajectory**. Select **Step** and click on **Setup**. Select **Open Loop Step** and set **Step Size** to **0 (zero)** volts. This is important, we do not want the system trying to move the cart! Set the **Dwell Time** to something like 2000 ms, this is the time the system will be recording data. Finally click **OK**, then **OK** and you should be back to the main menu.

7. Prepare to collect data

Select **Data** → **Setup Data Aquisition**. Set the **Sample Period** to every 1 servo cycle. Be sure you are recording from all of the encoders (if you need to change this, see me). Click **OK** to get back to the main menu.

8. Prepare to plot the data

Select **Plotting** → **Setup Plot** You'll want to remove **Encoder 3 Position** and add **Encoder 1 Position**. The click **OK** and get back to the main menu.

9. Collecting initial condition data for log-decrement analysis

Select **Command Execute**. A menu box will come up with a number of options, and a big green **Run** button. At this point one person should displace the first cart and try and hold it still (so there is no initial velocity, only an initial position). One partner should then click on the **Run** button, and a short time later the person holding the cart should release it. You want to record the initial position and the subsequent motion of the cart. **If the motor is on, release the mass at once!** When the system has finished collecting data, a box will appear indicating the how many sample points of data have been collected. (If you have hit a stop, the system stops recording data.) Click on **OK** to get back to the main menu.

10. Plotting the data

Select **Plotting** → **Setup Plot**,then **Plot Data**. You should look at the data before you export it.

11. Exporting the data

Select **Data** → **Export Raw Data**. When asked where to put the data, put it into the **ECE 521** folder or any folder you want to in the **ECE 521** folder.

12. Set the trajectory for a step response

Select **Command** → **Trajectory**. Select **Step** and click on **Setup**. Select **Open Loop Step** and set **Step Size** to a voltage level below 3 volts. You may want to try various voltages. Be sure to record this voltage! Set the **Dwell Time** to something like 2000 ms, this is the time the system will be recording data. Finally click **OK**, then **OK** and you should be back to the main menu.

13. Collecting step response data

Select **Command Execute**. A menu box will come up with a number of options, and a big green **Run** button. Click on the **Run** button. When the system has finished collecting data, a box will appear indicating the how many sample points of data have been collected. (If you have hit a stop, the system stops recording data. This usually means you're input amplitude in step 12 was too large. Got back to step 12 and choose a smaller voltage.) Click on **OK** to get back to the main menu.

14. Plotting the data

Select **Plotting** → **Setup Plot**, or just **Plotting Data** → **Plot Data**. You should look at the data before you export it.

15. Exporting the data

Select **Data** → **Export Raw Data**. When asked where to put the data, put it into the **ECE 521** folder or any folder you want to in the **ECE 521** folder. You should give this file a name similar to the name you gave to the corresponding initial condition response so you will remember they go together.

16. Preparing the data for analysis

At this point you need to locate the files you have exported, and edit out the first line and the '[' at the beginning of the second line. Save the files as type '.dat'. If you screw up you'll still have the original files, and the GUI's expect files to have the suffix '.dat'.

17. Log-Decrement Analysis

Start Matlab and set the default folder to the **ECE 521** folder. Type log_dec to start the log-decrement analysis. You will need to compare the estimated transfer function with the measured step response. Be sure to print out a figure of your final estimate of the step response.(See subsequent page for a description of this program)

18. Step Response Analysis

From Matlab, type **fit**, which starts a routine to help you find a second order estimate of a transfer function using the settling time and the damping ratio directly. Be sure to print out a figure of your final estimate of the step response.
(See subsequent page for a description of this program)

NOTE The *log-decrement* and *fit* programs are to be use *independently*. Do not just take the estimates from the *log-decrement program* and type them into the *fit* program. You may want to have one partner operate one program and the other operate the other program and then compare the answers.

log_dec Program

You should generally go through the following steps in the following order:

1. Load IC Response Click here to load the file with the initial condition response.

2. Encoder In this lab we will be looking at the displacement of the first mass, so enter **1** for the first encoder.

3. Plot IC Response This will plot the initial condition response from the file you chose. If you don't get anything you may have entered the filename wrong or chose the wrong encoder. Other possibilities are that you did not record all of the encoders in the default order, or that you did not edit the data file properly.

4. Final Time This lets you choose a different final time to display the IC response. You may want to change this and then plot the IC response again since you are interested in only the first few cycles.

5. Peak Separation This is a parameter that determines the minimum number of samples between peaks. It is important that peaks be numbered consecutively (at least the peaks after the initial displacement).

6. Compute + Peaks/ Compute - Peaks The log-decrement looks at what happens from one set of peaks to another. You have the choice of looking at positive peaks or negative peaks. In some instances, where there is alot of damping, you may not get much oscillation. Then you may want to use the negative peaks to do the log-decrement.

7. Make + Figure/ Make - Figure This will print out a figure with the peaks numbered. This is useful for your lab reports.

8. Low and High Once the peaks have been identified, you need to choose the peaks to use for the log-decrement analysis. Here you enter the lowest number (for the starting peak) and the highest number (for the ending peak). Note that it is not necessary to use all of the peaks, and that, in fact, you are usually better off using the first few peaks and ignoring the others.

9. Estimate TF Click on this box to estimate the transfer function parameters (ζ and ω_n) based on the log-decrement analysis and your chosen peaks.

10. Load Step Response Click here to load the step response file into the program.

11. Encoder Enter the encoder for the mass we are looking at (enter 1 for encoder 1)

12. Plot Step Response Plot the step response.

13. Final Time Determine the final time for the step response plot. Note that since the system step response is both "on" then "off" you usually choose a final time where the step is still "on".

14. Gain Here you guess at the system gain. At this point we have a model of the system but we don't know the system gain. It won't take long to iterate and get it pretty close.

15. Compute Fit Click on this to see the step response of the true system and the step response of your model. Note that these may not be very close since we didn't model the motor/rack/pinion very well. To get the system gain iterate between 14 and 15 a few times.

16. Make Figure This will produce a figure of the step response of the real system and your model. The important system parameters will be printed out. This is a good figure to have in your report.

fit Program

1. Encoder In this lab we will be looking at the displacement of the first mass, so enter **1** for the first encoder.

2. Load Step Response Click here to load the step response file into the program.

3. Plot Step Response Plot the step response of the system.

4. Final Time Determine the final time for the step response plot. Note that since the system step response is both “on” then “off” you usually choose a final time where the step is still “on”.

5. Settling Time Enter your estimate of the settling time. We want to match the early part of the step response, so your estimate of the settling time will probably end up being smaller than you think it should be based on the step response.

6. Damping Ratio Enter the damping ratio. Again, we want to match the early part of the step response.

7. Gain Here you guess at the system gain. At this point we have a model of the system but we don’t know the system gain. It won’t take long to iterate and get it pretty close.

8. Recompute Fit Click on this to see the step response of the true system and the step response of your model. Note that these may not be very close since we didn’t model the motor/rack/pinion very well. Try to model the early part of the step response as well as you can. You will probably need to iterate between steps 5 through 8 a few times.

9. Make Figure This will produce a figure of the step response of the real system and your model. The important system parameters will be printed out. This is a good figure to have in your report.

Determining the Frequency Response

You will need to do the following for frequencies of 1, 2, 3, 4, 5, 6, and 7 Hz and then *at least* four more frequencies near the resonant frequency. These frequencies should be at intervals of 0.25 Hz. Hence, if you believe the resonant frequency is near 4 Hz you should also collect data at 3.5 Hz, 3.75 Hz, 4.25 Hz and 4.5 Hz.

1. Prepare a table In your lab memo you will need to need to include a table which includes (a) a column indicating the the frequency the system was excited at, (b) the amplitude (in volts) of the input sinusoid (this is what you put into the system, you cannot measure this on the graph!), and (c) the magnitude (in counts) of the output sinusoid. The frequencies should go from low to high. This data also needs to be entered into the program **process_data.m** (see below).

2. Set the electrical zero position Select **Utility** → **Zero Position** to set the current position to zero. You may have to click on this a few times. Look at the **Following Error** readouts, if they are zero or near it you can continue.

3. Prepare for a Sinusoidal Input Select **Command** → **Trajectory**. Select **Sinusoid** and click on **Setup**. Select **Open Loop Move**.

- Enter the desired amplitude (in volts). We want an input amplitude large enough that the system can overcome friction, but not so large it smashes into the limiters. Try something like 1.0 volts for most frequencies.
- Enter the frequency of the input sinusoid (in Hz)
- Enter the number of repetitions (cycles) the sinusoid should go through. This needs to be large enough the system has reached steady state. You will have to make this larger as you get near resonance.
- Click **OK** and **OK** to get back to the main menu.

4. Run the System Select **Command** → **Execute** and then click on **Run**. If the input voltage is not too large the system will not hit its limits and everything will be fine.

5. Examining the Data Select **Plotting** → **Plot Data** to look at the position of the first cart.

6. Determine output magnitude Determine the magnitude of the output sinusoid when the system is in steady state. You may need to change the axis on the plot to get a good estimate.

7. Prepare data for analysis Enter the input frequency (in Hz), the input amplitude (in volts), and the amplitude of the steady state output (in counts) into the program *process_data.m*. (You have to edit this program to input these values.) Be sure the frequencies go from lowest to highest.) Run this program and save the output into a variable like 'data', i.e., at the Matlab prompt type **data = process_data**.

Comparing the Time Domain/Frequency Domain Results

To compare the measured frequency response with the predicted frequency response, use the **fit_bode.m** program. This program takes four arguments: the measured frequency response (the output from the **process_data** program), the estimated gain, the estimated natural frequency, and the estimated damping ratio. You should use the values of ω_n and ζ that you got from the time-domain estimates of the transfer function. You will have to run this program a few times to adjust the gain to get as good a fit as you can. **Do not change the values of ω_n and ζ!** For each system you should get two plots to put into your memo, one using the values from **log_dec** and one using the values from **fit**.

Optimizing the Estimated Transfer Function

At this point we will use the estimated parameters (K (the gain), ω_n, and ζ) as starting points to an optimization program that tries to minimize the squared error between the measured frequency response and the frequency response of the estimated transfer function. Use the program **opt_fit_bode.m** to do this. The arguments to this routine are the same as those to the program **fit_bode**. You should run this program twice, once with the initial guesses determined from the log-decrement estimates, and once with the initial guesses determined from fitting the step response. Hopefully the program will converge to very similar estimates for both models. The resulting two plots should be included in your memo.

Your (brief) memo for this lab should indicate:

- a brief description of the three systems you analyzed. The three systems should somehow be identified (such as systems A, B, and C) so the captions to the attached figures can be referenced to them.
- which of the two different methods of estimating the transfer function in the time domain seemed to match the frequency response better (they may work equally well). We are only concerned with the estimated of ω_n and ζ here, not the gains.
- a list any improvements to the lab you might suggest.

You should have as attachments to your memo (though all in the same document file) six plots for each system (one from **log_dec**, one from **fit**, two comparing the measured frequency responses with the estimated transfer functions, and two showing the optimized transfer functions.) These figures should all have captions and figure numbers, and indicate which system they are for. Also, for each system there should be a table indicating the input frequency, the input voltage, and the output amplitude (in counts).