ECE-320 Linear Control Systems
Laboratory 2

Frequency domain methods for estimating ω_n and ζ

In this Lab you will first obtain a second order model of your spring/mass/damper system using the log-decrement method. 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 be analyzing **three different systems** in this lab.

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** program). Note that the **log_dec** program only estimates the parameters ζ and ω_n, it does not make the step response.
3. Excite the open loop system at various frequencies and determine the magnitude of the frequency response.
4. Use the program **process_data** to put the data into a nice format.
5. Compare the two time-domain transfer functions with the frequency response using the **fit_bode** program.
6. Optimize the fit of the frequency response data and the estimated transfer function using the **opt_fit_bode** 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 320** folder or any folder you want to in the **ECE 320** 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 320** folder or any folder you want to in the **ECE 320** 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 320** folder. Type log_dec to start the log-decrement analysis. In this case, you do not need to compare the step response to the estimated step response. (See subsequent page for a description of this program)

log_dec Program

0. Select Cart Select cart 1 for this lab.

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

2. Final Time This is initially set to the final time of the data. You can 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.

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. 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. See also (**8. Samples Between Peaks**)

5. Peak X(n) and Peak X(n+N) 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, X(n)) and the highest number (for the ending peak X(n+N)). Note that it is generally a bad idea to use all of the peaks. *For these systems, you will get a better estimate using the first few peaks and ignoring the others.*

6. Estimate Parameters Click on this box to estimate the transfer function parameters (ζ and ω_n) based on the log-decrement analysis and your chosen peaks. If you choose different peaks you will need to click on this again to get the new estimates.

7. Make Log-Decrement Figure This will print out a figure with the peaks numbered and the estimated parameters in the title. This is useful for your lab reports.

8. Samples Between Peaks This is a parameter that determines the minimum number of samples between peaks. The program finds a peak, and then waits this many samples before it finds another peak. It is important that peaks be numbered consecutively (at least the peaks after the initial displacement). You may need to change this parameter if the program is not identifying all of the peaks correctly.

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** (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**. (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** program. This program takes four arguments:

- the measured frequency response (the output from the **process_data** program)
- the estimated gain
- the estimated natural frequency
- 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!**. The resulting plot should be included in your memo

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** to do this. The arguments to this routine are the same as those to the program **fit_bode**. The resulting plot 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.
- The estimates of ζ and ω_n determined from time-domain analysis and the estimates (for the same system) determined from frequency domain analysis.
- A brief comparison of the time-domain and frequency domain estimates (for the same system).
- a list any improvements to the lab you might suggest.

For each system, you should have as an attachment to your memo

- One plot from the log-decrement analysis
- One plot from the Bode plot analysis, with the best guess of the gain you can get (but do not change the time domain estimates of ζ and ω_n
- One optimized Bode plot.