

Lab 5: Frequency Identification

Introduction

The transfer function (mathematical model) of a plant can be estimated in several different ways. In Lab 2 of this course, the open loop transfer function of the hydraulic motor was found by analyzing its open loop transient step response. The analysis included the assumption that the hydraulic motor behaved as a first order system upon which the defining parameters (time constant and DC gain) could be determined from the measured step response data. Thus, the transfer function was identified in the time domain.

The transfer function can also be determined from a system's frequency response. This is done by exciting the system with sinusoids of varying frequency and then measuring the gain and phase offset of the output signal with respect to the input sinusoid. Plotting gain and phase versus input frequency gives the frequency response of the system. The two plots together are called the Bode plot. A system's Bode plot can be used to determine its transfer function.

In this laboratory exercise, two unknown plants will be identified using frequency response identification. The Parker-Hannifin Hydraulic Trainer will not be used for this experiment. Only the B&R X20 Controller and the Oscilloscope will be used to analyze the mystery systems.

Background

A system's Bode plot is the frequency response of the system's open loop transfer function, see Figure 1.

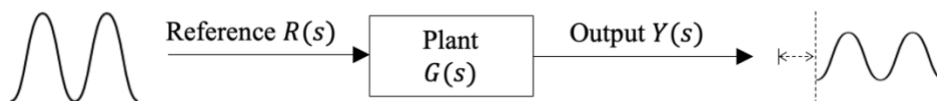


Figure 1: Input/Output of Open Loop Transfer Function

The Bode plot for this system consists of the system gain ($Y(s)/R(s)$ in decibels) and phase lag (in degrees) both plotted against the input sinusoid's frequency ($R(s)$) in rad/s on a logarithmic scale. If the plant's transfer function $G(s)$ is known, the Bode plot can be hand drawn or obtained using the `bode()` function in MATLAB.

Similarly, if the plant's Bode plot is available, a transfer function can be approximated for the plant based on that Bode plot. This is the main concept behind this laboratory exercise. For more background, please read [1], Ogata 5th ed., pages 403 – 422.

Experiment

Frequency Identification of Two Mystery Systems:

1. Perform a frequency sweep of two unknown open loop transfer functions.
2. Create Bode plots using the collected data.
3. Use frequency identification to estimate the transfer function of each unknown plant.
4. For comparison, apply step inputs to the unknown systems and conduct transient response identification.

The mystery plants will both be simulated on the B&R X20 Controller where the plant's outputs are connected to the MW2000's Analog Output Ch. 1 and Ch. 2. The sinusoidal input to the plant can be wired to the

MW2000's Analog Input Ch. 6. The Oscilloscope's function generator will be used to conduct the frequency sweep.

Hardware Setup

1. Wire the electrical connections: Connect *Gen Out* of the Oscilloscope's function generator to both the Oscilloscope's Ch. 1 and the MW2000's Analog Input Ch. 6. Use a T-connector to do this. Additionally, connect the MW2000's Analog Output Ch. 1 to the Oscilloscope's Ch. 2.
2. Press the *Wave Gen* button and use the Oscilloscope's screen function keys to set:
 - a. Waveform to Sine
 - b. Frequency to 1 Hz
 - c. Amplitude to 2.00 Vpp
 - d. Offset to 0.0 V
3. Setup the Oscilloscope's display:
 - a. Change the *Volts/Div* for both Ch. 1 and Ch. 2 to be 500 mV/div. The *Volts/Div* may need to be adjusted during the experiment. Adjust each channel's vertical position so that there is no offset between them. Set the *Time/Div* scale in order to view two or three periods of the sine wave. *Time/Div* will have to be modified as you sweep through frequencies.
 - b. Select *Cursors* under the *Measure* menu on the front panel. Two horizontal and two vertical dotted lines should appear on your display. On the display, use the *Select Cursor* tab to choose between *X1*, *X2*, *Y1*, and *Y2* then use the cursor knob in the *Measure* menu to adjust position of the respective cursor. The values of each cursor are shown in the bottom right corner of the screen, along with values for ΔX , $1/\Delta X$, and ΔY . Use these values when determining your measurements.
 - c. Select the *Horz* button to set the *time mode* to be normal. Set the *trigger level* using the level knob to be somewhere within -1.0 to 1.0 Volts. Select the *Trigger* button and set the *trigger source* to be Ch. 1.

Software Setup

Copy the files *Lab5_ID1.slx* and *Lab5_ID2.slx* from 'N:\HydraulicsLab\ME460' to your own directories: 'C:\ME460_SPxx\ABx\Lab5\FreqIDx'. Open the Simulink file and *Build* the model. Power on the B&R X20 Controller. When you are ready to run the experiment, *Connect to Target* and click the *Run* pushbutton. This will enable the sinusoidal input. Since you will be using the Oscilloscope, you may *Disconnect from Target* after you have clicked *Run*.

Procedure

Use the function generator to perform a frequency sweep of the mystery plants and record gain and phase data. Record the data at a suitable amount of frequency points in order to identify the transfer function later, see the whiteboard for an example set of input frequencies. A sample table is shown at the end of this lab report for recording data in Excel.

Experiment 1: Mystery System 1

1. If you haven't already, connect to the built Simulink model and run the input sinusoid. You may disconnect after the plant's output is showing on the Oscilloscope in green (Ch. 2). Perform a preliminary frequency sweep without taking data by varying the function generator's frequency from 0 Hz to 200 Hz. Observe the plant's output.

2. Use the starting frequency of 0.1 Hz (this is the minimum frequency output of the function generation). This frequency should be small enough so that there is little to no phase lag in the plant's output. *Hint: This low frequency point will be particularly helpful in identifying the plant's transfer function.*
3. Determine the gain and phase lag of the plant's output at this starting frequency. Make sure the cursors' source signal in Ch. 2 (green). Create an Excel sheet following the sample table below. Record the data into your Excel sheet. Specifically, you only have to record the input frequency in Hz, the plant's output in Volts, and the time difference in milliseconds. All other columns shown in the sample table can be computed from these three measurements. First fill in these three columns and then go back and calculate the remaining columns. You may want to add more columns to perform calculations. Note: For the last column (phase lag), you simply negate the phase measured since the plant's output is "lagging" the frequency input. Use all the significant digits the Oscilloscope provides, do not round or truncate.
4. Increase the input frequency according to the sample set of frequencies on the whiteboard or at intervals of your choosing. You may stop when you feel confident that no further significant information can be gathered at higher frequencies. This should already be known from the preliminary sweep in Step 1.
5. Go back and record more data at frequencies where there is significant change in either the gain and phase lag (*hint: the break-away frequencies*). You will want to know in detail what happens at these points.
6. At this point, you will switch gears and apply a step input to the plant. Change the waveform of the function generator to a square wave. Change the peak-to-peak amplitude to 1.0 Volt, the frequency to 0.1 Hz, and the offset to 0.5 Volts. Use the cursors to measure relevant step response parameters such as overshoot, steady-state, peak time, etc., and record those values somewhere in your Excel sheet.
7. Additionally, record the data from the Simulink scope. You can either save the data logged to the workspace or take a screenshot of the scope plot. Use this plot in your lab report.

Experiment 2: Mystery Plant 2

Open up the second Simulink file (Lab5_ID2.slx) to build, connect, and run the model. Disconnect after the plant's output is shown on the Oscilloscope. Wire Oscilloscope Ch. 2 to the MW2000's Analog Output Ch. 2 for the second mystery system. Repeat all the steps outlined in Experiment 1.

Report Questions

Your individual lab report is due at the beginning of next lab. Your lab report should be typed, though, no formal formatting is required. Please gather all your recorded data (in Excel) and any scope plots and save it to a USB drive or cloud drive so that all partners can access that data outside of lab.

1. Generate Bode plots for the two mystery plants. Make sure to use a logarithmic scale for frequency. This can be done in either Excel (log scale) or MATLAB (`semilogx()`). **IMPORTANT:** *Your phase data may be a bit inaccurate for high frequencies. This is due to a delay in the controller for performing the A/D and D/A conversions. If you would like, you can subtract 3ms from the time difference column in Excel to adjust your data. Please make note of this in your lab report.*
2. Determine the system-type for the two mystery plants.
3. Estimate the transfer functions solely based on the experimentally-obtained Bode plots. Explain in detail how you performed your estimation. This is frequency identification.
4. Compare the experimentally-obtained Bode plots with Bode plots generated with MATLAB using the estimated transfer functions.

5. Additionally, estimate two more transfer functions based on the step responses of the two mystery systems. This is time-domain identification (or transient response identification). You should have a total of four uniquely estimated transfer functions.

$$\hat{G}_{1,freq}(s) = \quad \hat{G}_{1,time}(s) = \quad \hat{G}_{2,freq}(s) = \quad \hat{G}_{2,time}(s) =$$

6. Explain how frequency identification could have been used to identify the transfer function of the hydraulic motor system in Lab 2? How does this compare with the transient response identification in Lab 2?

Table 1: Sample Excel Spreadsheet

Input Frequency [Hz]	Input Frequency [rad/s]	Output Voltage [V]	Input Voltage [V]	Time Difference [ms]	Phase [deg]	Magnitude [--/--]	Magnitude [dB]	Phase Lag [deg]
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					
			2.0					

References

- [1]. K. Ogata, *Modern Control Engineering 5th Edition*. Prentice Hall, NJ, 2009.
- [2]. G. F. Franklin, J. D. Powell, A. Emami-Naeini, *Feedback Control of Dynamic Systems 3rd Edition*. Addison Wesley, MA, 1993.
- [3]. ECE Dept. UIUC, *Control System Laboratory Experiments*. ECE Dept. UIUC, 1997.