WEEK 2 STEADY-STATE OPERATING DATA

Objectives

To continue to observe steady-state performance of the system. To understand any disturbance functions (loads) for the system. Introduction to word processing, equations & graphics for Microsoft Word.

Lab Assignments

248 Position Control

Continue to get the parameters for your system.
Section 001--Get operating curve for unpainted spring.
Section 002--Get operating curve for painted spring.

249 Speed Control

Section 001--Get operating curve for two banks of lights.
Section 002--Get operating curve for one bank of lights.

303 Temperature Control

Section 001--Get operating curve for CWS of 20 GPH.
Section 002--Get operating curve for CWS of 30 GPH.

307 Level Control

Continue to make the measurements mentioned in Week 1 assignments.
Section 001--Get operating curve auxiliary pump left off.
Section 002--Get operating curve for 4000 cc/min inlet.

308 Pressure Control

Section 001--Get operating curve for two open ducts.
Section 002--Get operating curve for three open ducts.

309 Flow Control

Section 001--Get operating curve for the manual valve closed.
Section 002--Get operating curve for the manual valve open.

Results

Plot a graph of the output function versus the input function. Probably five (5) to ten (10) data points will be useful for this. Indicate the error in the output function by putting 95% confidence error bars on the points you plot.

Put a copy of the SSOC and the results of your error analysis on the bulletin board near your laboratory system. These graphs also go in the lab report described below.

Disk File Suggestion: For all your data files that you save this week, start their names with "W2" (meaning week #2)

Word processing assignment

Prepare a lab report following the format on the next page. Each section in a report is to start on a new page.

Double space the text in paragraphs. Put page numbers at the bottom of the pages (except the cover page).

This assignment is due at the beginning of the next scheduled lab meeting.

If the report is lacking some substantial component, it will not receive a grade.

If you are smart, you will save this report on a disk and modify and build from it through the rest of the semester.

Week 3 Report

Report is due at the beginning of Week 3 lab meeting.

REPORT CONTENTS

Title Page
Includes "UTC," "Engineering 329," Title, Your Name, Your partners' names, Date

Introduction
In the first paragraph, it tells briefly what was done and for what purpose.
In the second paragraph, it tells how the report is organized.

Theory and Background
Describes the engineering theory of the lab, including equations and schematic diagrams

Procedure
Describes what was done in the physical lab

Results
Describes what you observed, the data. Includes tables and graphs. Each table and graph must be explained.
It builds on the "Procedure;" the "Procedure" section must describe how all the results in this section were obtained.
It includes results of experiments: estimates of errors of the results, SSOC

Discussion
Tells the significance of the experiment and the results. It builds on the "Results;" the "Results" section must include all the results that are discussed in this section.

Conclusions and Recommendations
Describes what principles were demonstrated by the experimental results.
It builds on the "Discussion;" the "Discussion" section must prepare the reader for all conclusions that are mentioned in this section.

Appendices
Includes raw data, references & other things that interrupt the "flow" of the report. Anything that is in an appendix (except "references") must be mentioned someplace in the report.

Attachments
Include a sheet for each team member that describes the contribution to the work in the laboratory.

Disk File Suggestion: For all your report files that you save this week, start their names with "RW3" (meaning report for week #3)

WEEK 3 STEP RESPONSE TESTING

Week 3 Report

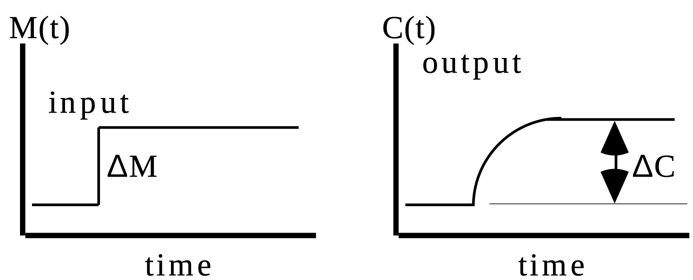
Submission of report.

Objectives

To observe experimentally the time response of the output function of the system to a step function input. To observe the system's s.s. gain, the system's response time and the system's dead time (if any). To make the observations for a number of different values for the size of the input function and the initial s.s. values. To make the observations for a variety of system configurations, if appropriate.

Reference: Smith & Corripio, problem 2-8 & pp 216-220

The purpose of this lab is to get step response data as shown in Figure 8. Figure 8(a) shows a graph of the input step function, M(t). Notice the input function is not at zero when the step occurs. This is called the base line value of M(t). At a certain time, the "start" time, the input function makes a step increase, ΔM.



(a) Step Input (b) Step Response (output)

Figure 8. Step response input and output functions

The system takes a certain time to respond to this input step. A typical response curve is shown in Figure 8(b). From this graph you can get these characteristics of the system: steady-state gain, response time and dead time. These are called the First-Order Plus Dead Time (FOPDT) parameters of the system.

Procedure for getting step response data

Prepare system for operation

Open LabVIEW program labeled "(Step)". This program emulates a programmable logic controller (PLC). It is programmed to provide a step input to the system, You should get a panel somewhat like the one shown in Figure 9, below.

Choose a value of the "input" variable that you want to be the base line value. Choose a value that you want to be the step height of the "input" variable. Click on the RUN arrow. The chart on the right of the screen emulates a strip chart recorder.

After the system reaches steady state at the input base line condition, click on the "Step" switch to initiate the step input function.

When you want to stop, click on the STOP button. As before, it will ask if you want to save the data on a disk file and if you want to draw a time-response graph of the data. If you've just been playing around, click "NO" to all of these requests.
You'll probably want to play around a bit before taking any serious data. You'll want to try different values of the step parameters: base line value and step height.

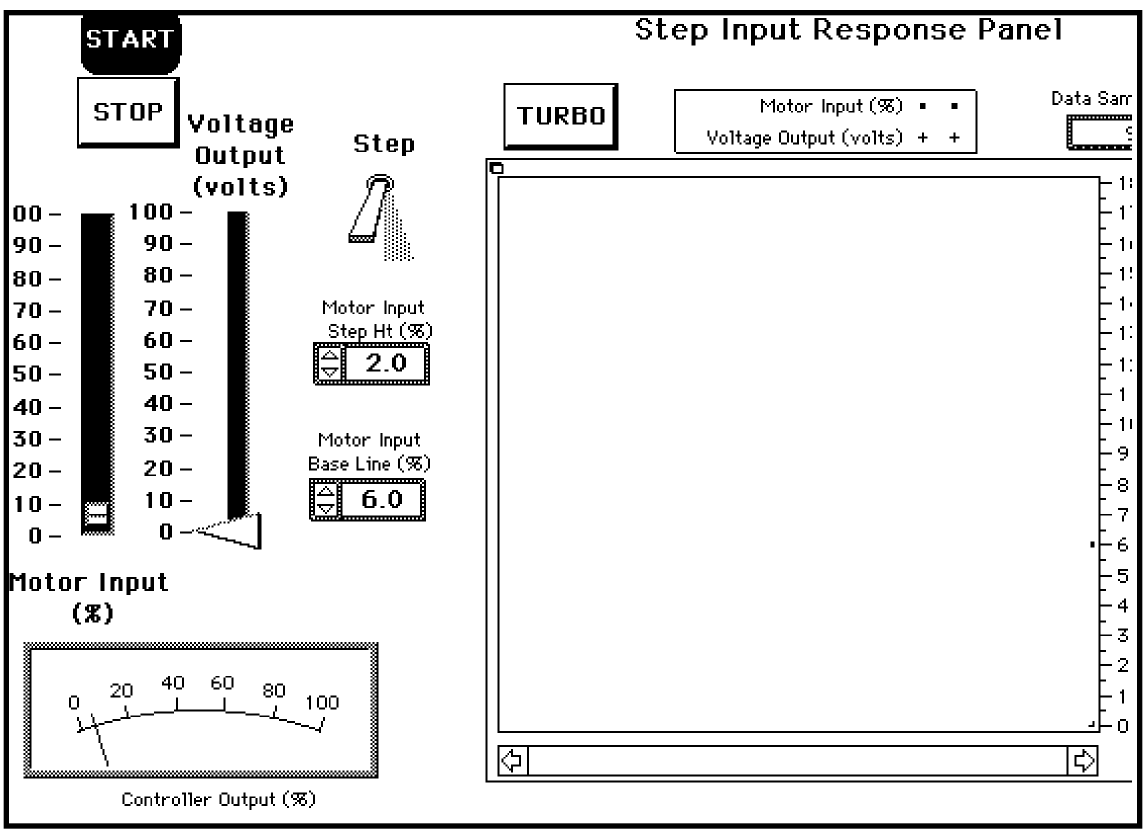


Figure 9. Step function programmed controller panel

When you are ready to get some good data, set the parameter values and start the instrument (click on the RUN arrow). After the step response has ended, click the STOP button and save the data, if you wish, and make the time-response graph.

If you want more frequent data points to complete your analysis, click the "Turbo" button just before you click the "Step" switch. In "Turbo" mode, the strip chart is turned off while all other data saving and plotting is the same.

Lab Assignments

For all stations, get step response data for the same conditions as Week 1 & 2.

For the "fast" systems (Motor Speed, Air Pressure & Water Flow) you are to obtain the system parameters for steps in the "up" direction as well as steps in the "down" direction. Also, obtain system parameters for different size steps and at different parts of your operating range.

Results

The time-response graph should look similar to the one in Figure 8(b). S&C (p 220) describes three different ways to get the parameters (K, τ and t_o). These are called Fit 1, Fit 2 and Fit 3. Another way is the Schonblom technique: Plot $\ln(C^{\Delta}/K-1)$ versus t; the slope will be $1/\tau$ if it is first order. The Cunningham extension of this is to get the slope and intercept of this curve with linear regression. You are to use any of these methods to find the parameters for your system.

If none of the first-order fit methods work very well, try a second order fit. See Coughanowr's book for how to handle higher order systems.

As the experimental measurement of your output variable has error associated with it, so too does the experimental determination of gain, dead time and time constant (K, t_o, τ). You are to get an estimate of these errors, also. A good way to do this is to make several measurements and then use Student's T statistics after your analysis by the different fits. The poster in Grote 213 (credit to Dr. Schonblom) and in the Freshman lab can help you with this.

Week 4 report described below will present and discuss the fits.

Optional Method for Temperature & Level Projects: Run the "Step Train" programs with LabVIEW. Talk with Dr. Cunningham or Dr. Henry for details.

Disk File Suggestion: For all your data files that you save this week, start their names with "W3" (meaning week #3).

Week 4 Report

A draft of Week 4 Report is due the second school day before the next scheduled lab meeting.

WEEK 4 REPORT CONTENTS
STEADY STATE AND STEP RESPONSE

Introduction

Theory & Background
Description & explanation of system components & connections.
Schematic diagram (like S&C, Fig. 5-1). Input function(s) and output function
Theory & governing equations for components and system (like S&C, equations 3-1 & 3-2)
Laplace domain descriptions in terms of deviation variables, OLTF (like S&C, equations 3-7 & 3-10)
Block diagram (like S&C, Figure 3-19)

Procedure
Results
Calibrations. Steady state performance curves. Experimental results for step input (curves, gain, time constant & dead time for different conditions) (like S&C, Figure 6-17). Include the various Fits.
Estimates of error in measurements and calculated results.
Include a table which clearly presents your results.

Discussion
Comparison with theory. Observations about the SSOC of the system

Conclusions

Recommendation

Appendices
Physical properties (dimensions, etc.) of components & system

Attachments
Include a sheet for each team member that describes the contribution to the work in the laboratory since last reported.

Disk File Suggestion: For all your report files that you save this week, start their names with "RW4" (meaning report for week #4)

WEEK 4 MODELLING

Week 4 Report

Submission of final report and brief oral presentation (5 min limit).

Objectives

To learn how to program and produce graphs in Excel. To observe the dynamic response of the approximate linear FOPDT model for a system. To observe the impact of parameter values on the dynamic response.

FOR NEXT WEEK

Bring with you the results of the steady state and step response experiments. Specifically, you must have

Gain

τ

t_o

at your chosen operating point (both for step up and step down) and the values of the steady-state input and output parameters at the operating point.

For the level-control system and position-control system, you must have the parameters necessary for the approximate linear FOPDT model of your system.

Post these results also on the bulletin board in your area in the laboratory.

WEEK 5 MODELLING -- APPROXIMATE LINEAR FOPDT MODEL

Objectives

To learn how to model first-order-plus-dead-time (FOPDT) with Excel. To observe the dynamic response of the approximate linear FOPDT model for a system. To observe the impact of parameter values on the dynamic response. To adjust the linear FOPDT model parameters to get the model results to agree with the experimental results.

Modelling Assignments

Approximate FOPDT Method

Reference: Smith & Corripio, pp 216-220

Disk File Suggestion: For all your model & results files that you save this week, start their names with "W5" (meaning week #5).

Week 6 Report

A draft of Week 6 Report is due the second school day before the next scheduled lab meeting.

<u>WEEK 6 REPORT CONTENTS</u>
STEP RESPONSE MODELLING

Introduction

Theory & Background
Description & explanation of system components & connections.
Schematic diagram (like S&C, Fig. 5-1). Input function(s) and output function
Theory & governing equations for components and system (like S&C, equations 3-1 & 3-2)
Laplace domain descriptions in terms of deviation variables, OLTF (like S&C, equations 3-7 & 3-10)
Approximate FOPDT model (like S&C, example 6-9)
Block diagram (like S&C, Figure 3-19)

Modelling
Equations

Procedure

Results
Steady state performance curves (SSOC's). Experimental results for step input (curves, gain, time constant & dead time for different conditions) (like S&C, Figure 6-17).
Modelling results for step input (curves)
Direct comparison of experimental and modelling results.
Description of errors in results and estimates of magnitudes of error

Discussion
Comparison with theory, modelling & experiments

Conclusions

Recommendation

Appendices
Physical properties (dimensions, etc.) of components & system
Modelling diagram, equations

Attachments
Include a sheet for each team member that describes the contribution to the work in the laboratory since last reported.

Disk File Suggestion: Use file names beginning with "WR6"

WEEK 6 FREQUENCY RESPONSE

Week 6 Report

Submission of final report and oral presentation (10 min limit).

WEEK 6 ORAL PRESENTATION CONTENTS
Background
Brief description of system, "input" and "output"
Brief description of performance curves (SSOC)
Objective of controller design
Theory
Brief review of system transfer function (FOPDT) (include parameter values)
Modelling
Model & parameters
Results
Sample time-response graphs for experiment & approximate model
Conclusions
"The experimental results showed ____________________
The approximate model results showed ________________."

Some suggested slides for Week 6 Report

Background
Theory
Modelling
Results
Conclusions

Theory
Transfer function
Parameters

Results
Time response
Experimental
Approximate model

Background
System
Input
Output
SSOC
Operating Range

Modelling
Model equations
Parameters

Conclusions

Objectives

To observe experimentally the time response of the output function of the system to a sine function input. To observe the system's amplitude ratio and the system's phase lag. To make the observations for a number of different values for the amplitude and the average value of the input sine function. To make the observations for a variety of system configurations, as appropriate.

Reference: Smith & Corripio, pp 95, 292-295

The purpose of this lab is to get frequency response data as shown in Figure 12.

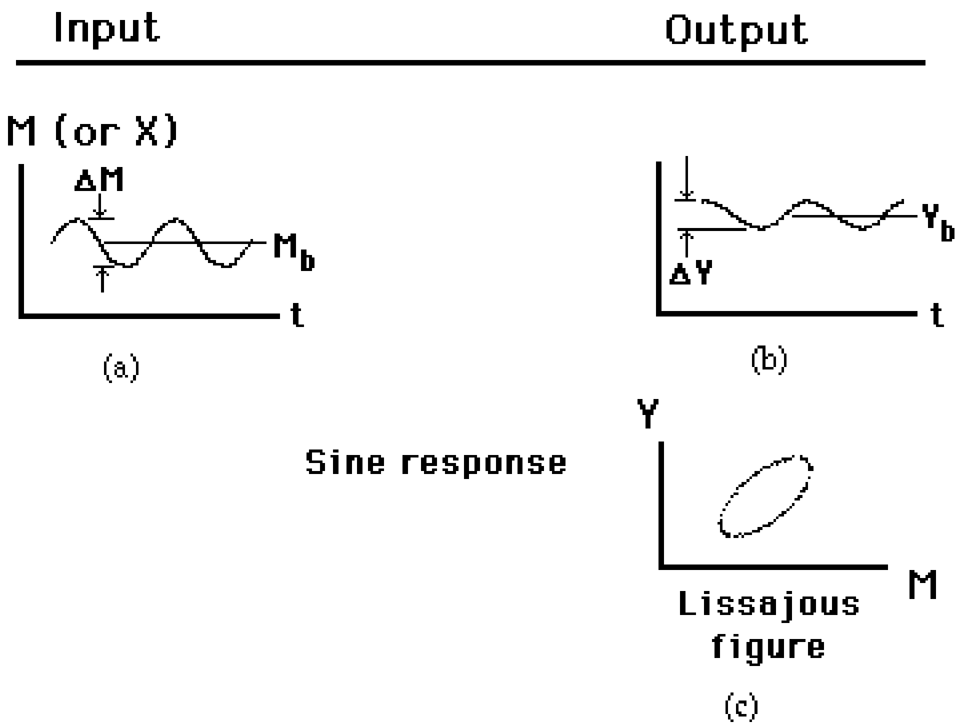


Figure 12. Frequency response input and output functions

Figure 12(a) shows an input to the system that is a sine wave. The input function baseline is M_b. The peak-to-peak amplitude of the sine wave is ΔM. The sine wave has a frequency, *f*, measured in Hertz (Hz). Hertz is the same as cycles per second.

A typical output function is shown in Figure 12(b). The output function will have the same frequency but may have a different peak-to-peak amplitude, ΔC. The output function may also be delayed so that it lags in phase compared to the input function.

A sine-input operating curve can be plotted, also, as shown in Figure 12(c). More about this later.

PROCEDURE FOR GETTING SINE RESPONSE DATA

Prepare system for operation

Open LabVIEW program labeled "(Sine)". This program emulates the operation of a programmable controller. You should get a panel somewhat like the one shown in Figure 13.

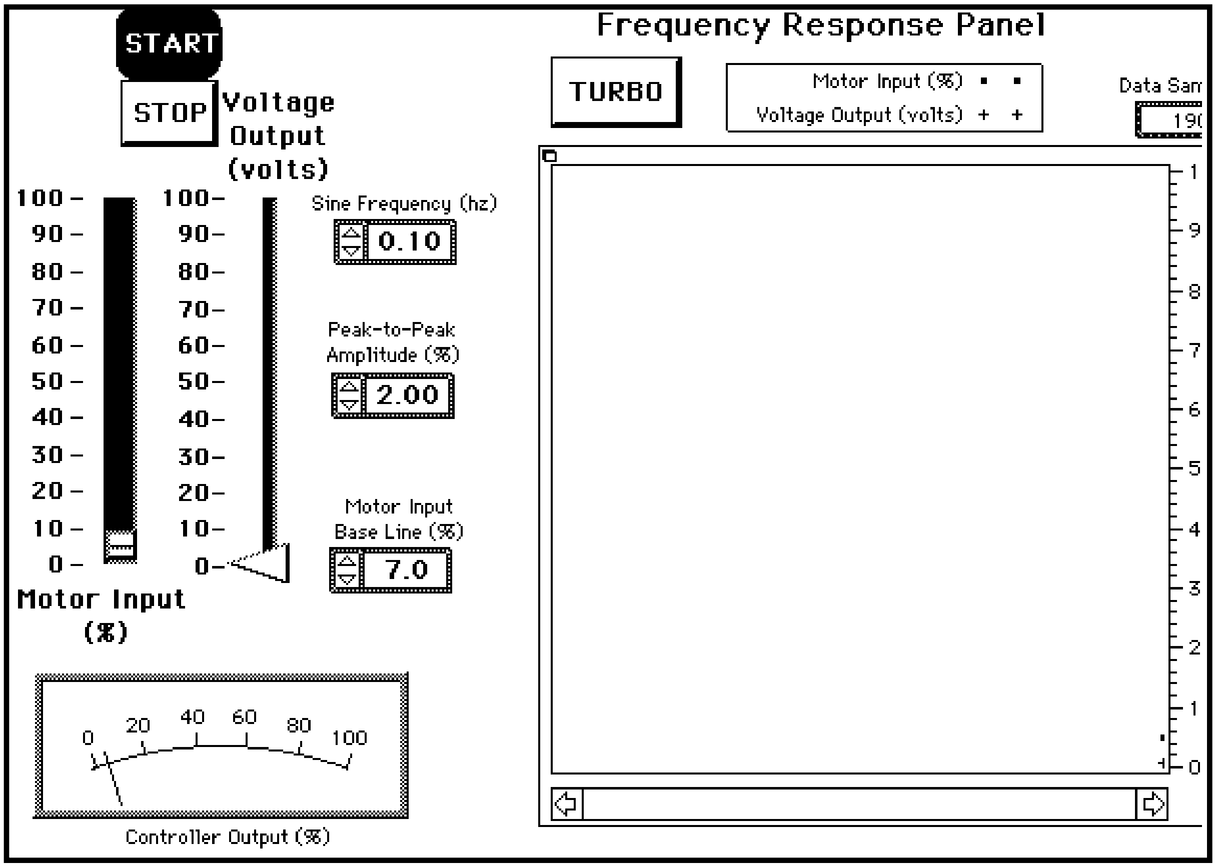


Figure 13. Sine wave input controller panel

Choose a value of the "input" variable that you want to be the base line value. Choose a value that you want to be the sine amplitude height of the "input" variable. Choose the frequency of the sine wave that you want. Set these in the appropriate windows in the panel. Click on the RUN arrow. The chart on the right of the screen is emulating a strip chart recorder.

When you want to stop, click on the STOP button. As before, it will ask if you want to save the data on a disk file, if you want to draw a time-response graph of the data and if you want to draw an input-output graph of the data. If you've just been playing around, click "NO" to all of these requests.

You'll probably want to play around a bit before taking any serious data. You'll want to try different values of the sine parameters: frequency, sine wave amplitude and base line value.

When you are ready to get some good data, set the parameter values and start the instrument (click on the RUN arrow). After the sine response has ended, click the STOP button and save the data, make the time-response graph AND the input-output graph. This latter graph is the famous and useful Lissajous figure.

When you complete a run you will get a graph similar to that in Figure 14. The level-control system will get a different graph due to the "reverse" nature of the system.

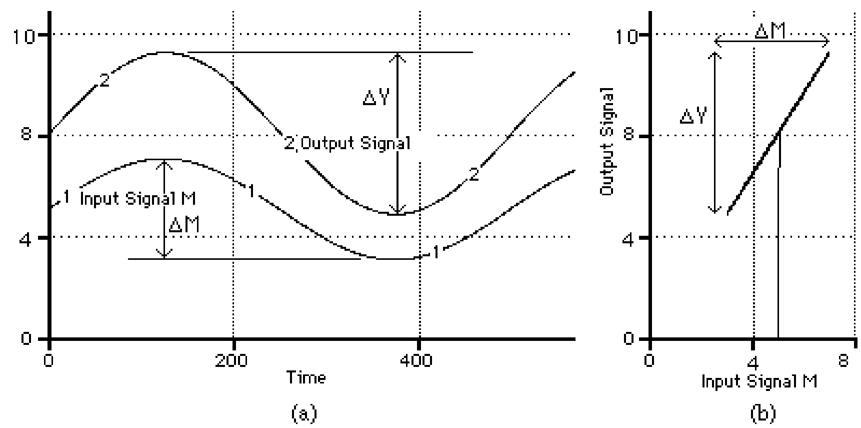


Figure 14. Very low frequency sine response graphs

The very low frequency Lissajous figure is actually a portion of the same curve you got as the steady state operating curve in Weeks 1 & 2. Incidentally, the slope of this line, $\frac{\Delta C}{\Delta M}$, is the s.s. gain.

The amplitude ratio (AR) is the ratio of the vertical height to the horizontal height of the Lissajous figure. When the input and output are exactly in phase, the Lissajous figure is a single line as in Figure 14(b). This means the phase shift is 0.

At a higher frequency, the AR and phase shift are different. A Lissajous figure like Figure 15(b) results. The AR is determined by the ratio of the vertical height to the horizontal height of the oval.

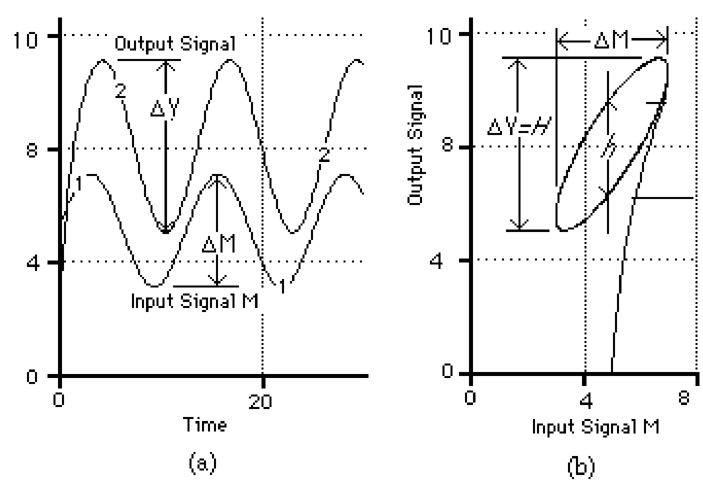


Figure 15. Medium frequency sine response graphs

At an even higher frequency, the phase shift becomes even larger and the Lissajous figure leans over to the left. (To the right for level-control.) An example is shown in Figure 16.

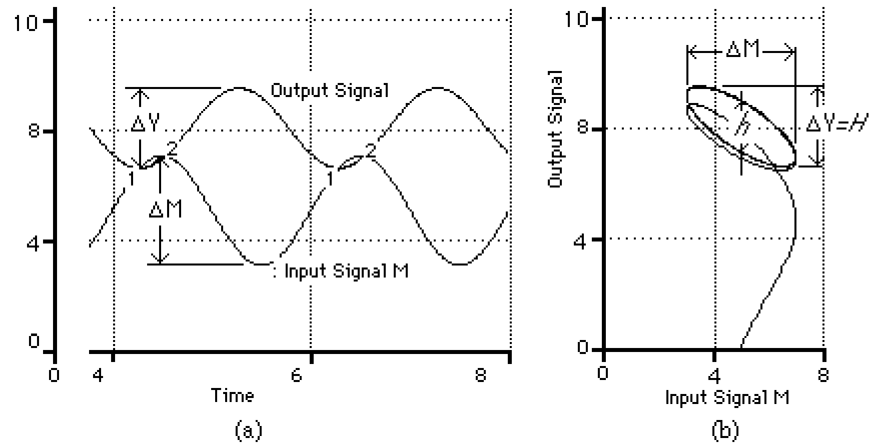


Figure 16. Medium-high frequency sine response Lissajous figure

You will benefit by running experiments at about 10 different frequencies. A good place to start is at a frequency of about $\omega = \frac{1}{\tau}$ (notice that $f = \omega/2\pi$, f is the frequency parameter in the LabVIEW panel). Then you might run experiments at successively lower frequencies by approximately halving the frequency each time. Stop going to lower frequencies when the output is nearly in phase with the input.

Then you might run experiments at higher frequencies by approximately doubling your starting frequency and continue doubling the frequency on successive experiments. Stop going to higher frequencies when the output has no perceptible steady oscillation. "No perceptible" oscillation means that the amplitude in the output is smaller than twice the standard deviation of the output measurements found in weeks 1 & 2.

With Speed, Pressure and Flow systems, the "TURBO" switch allows you to get more data at the higher frequencies. For frequencies greater than about 0.5 Hz, start the experiment with TURBO off and then turn TURBO on for several cycles of oscillation.

After you have AR and phase angle data for a number of frequencies, make two plots like those shown in Figure 17. These are Bode plots. Notice Figure 17(a) is a log-log plot and Figure 17(b) is a semi-log plot. Prepare the results for making the Bode plots by filling in a table of results such as below.

Frequency	Amplitude Ratio	Phase Angle
..(lowest)..	....	....
....	....	....
....	....	....
....	....	....
....	....	....
..(highest).	....	....

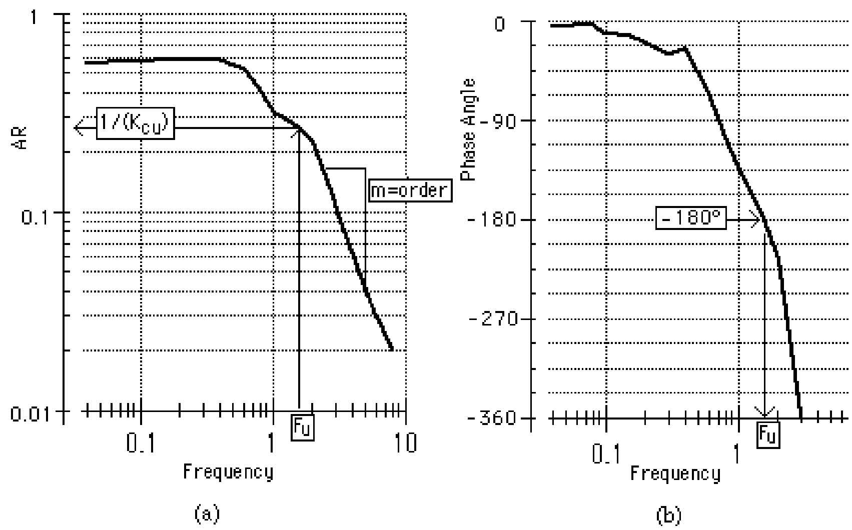


Figure 17. Example Bode plot obtained from experimental data

There are three important values to get from a Bode plot.

1. The order of the system. This is the negative of the slope of the AR vs. Frequency plot at the high frequencies.
2. The ultimate frequency. This is the frequency for which the phase angle is -180°.
3. The K_{cu}. This is the 1/(AR) at the ultimate frequency.

Hints:
XRC/248, SRC/249, PRC/308 & FRC/309 are probably higher than 1st order.
LRC/307 & TRC/303 are probably about 1st order.

Disk File Suggestion: For all your data files that you save this week, start their names with "W6" (meaning week #6)

"The study of how [the amplitude ratio and the phase angle] vary as ω varies is an important part of automatic process control."

––Smith & Corripio, p. 95