

1 Lab 6: AWOL¹ Plant Identification and Controller Design

1.1 Introduction

The goal of this experiment is to use the tools learned throughout the course to develop and test different controllers, and to analyze their particular characteristics, advantages, and disadvantages. The experiment you will be controlling is a simple solenoid attached to a potentiometer for position feed back. A web application has been create to allow you to control the unit over the internet. It has been given the nickname AWOL (Asynchronous Web Operated Laboratory).

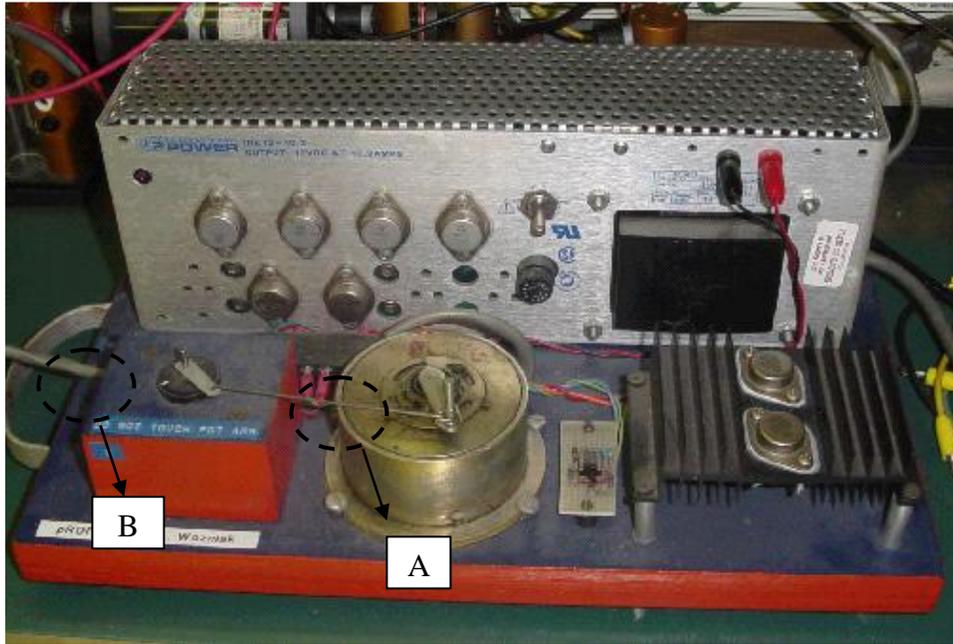


Figure 0: Plant used in the AWOL¹ Laboratory

The plant to be controlled (Figure 0) is located in the Control Systems Laboratory of the Everitt Building. It could be located as well in the engine compartment of an earthmover, controlling engine fuel, hence vehicle speed or power. It is comprised of a 60° travel rotary electromechanical actuator (Center Front of Figure 0, C.F.), a 360° potentiometer position transducer (L.F.), preamplifier and power amplifier (R.F.) and 12 V. Power supply (Center Rear of Figure 0). The input to the Plant is a voltage signal. The resulting output is a rotational displacement of the “arm” (letter A, Figure 0). A rotational potentiometer (letter B, Figure 0) is connected mechanically to the arm. Rotational potentiometers produce a voltage proportional to its shaft’s angular position. The potentiometer will be used as a *sensor* to measure the position of the arm.

1.2 Objectives

By the end of this lab, you will be able to:

- Approximate a transfer function for a non-linear system
- Design proportional and proportional + integral controllers to a specification

¹ Asynchronous Web Operated Laboratory

1.3 Plant Identification and Linearization

The first step in analyzing the system will be to determine whether the analytical tools available are applicable to the system in question. Recall that all the tools developed in class assumed that the system is *linear*. In reality most systems have inherent nonlinear behavior. Examples of common nonlinearities are hysteresis, saturation, and D.C. gain variation with operating point. In Figure 1.a we show an example of a system with a *constant* D.C. gain and in Figure 1.b we show a system with *varying* D.C. gain. A varying D.C. gain indicates that the system is *non-linear*. The plot in Figure 1.b is similar to the AWOL's system response.

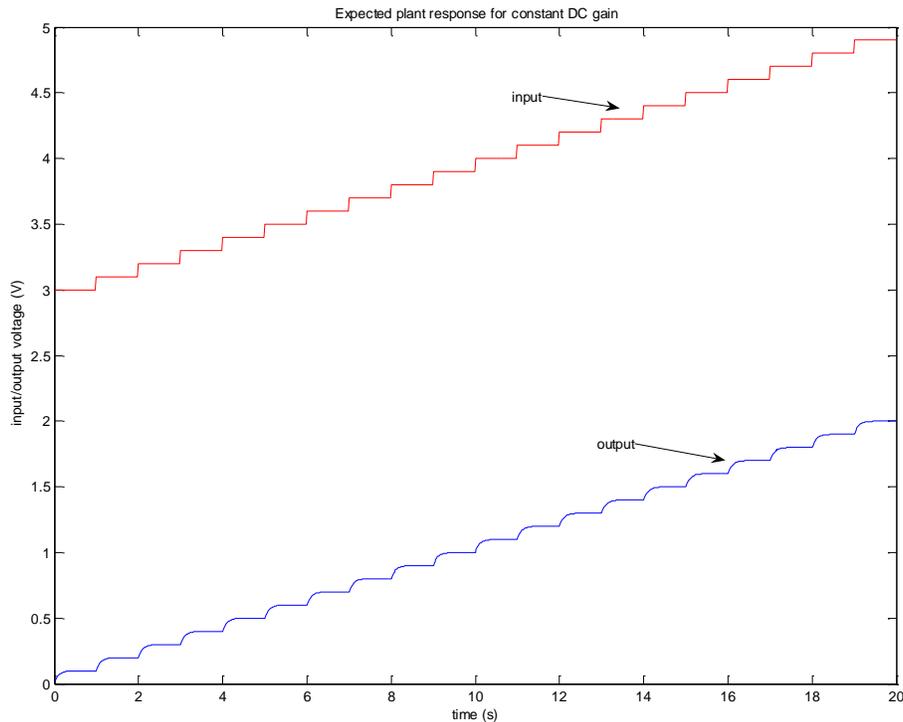


Figure 1.a

A common approach to design analysis for the type of non-linear system shown in Figure 1.b and the AWOL is to determine an operation point and an operating region where the system can be approximated as linear (Figure 1.c).

If the system travels too far outside of the operating region the linear approximation will no longer hold. The control design achieved will be performing to specifications only where the linear plant approximations hold. Different control gains need to be found for different operating points of the system if a large travel range is desired.

This particular target plant can be considered composed of a series of locally 'linear' regions. In order to determine one such region, small steps of increasing amplitude will be inputted to the plant and the steady-state response will be analyzed. The input signal will be a staircase like function, as will be the steady-state output.

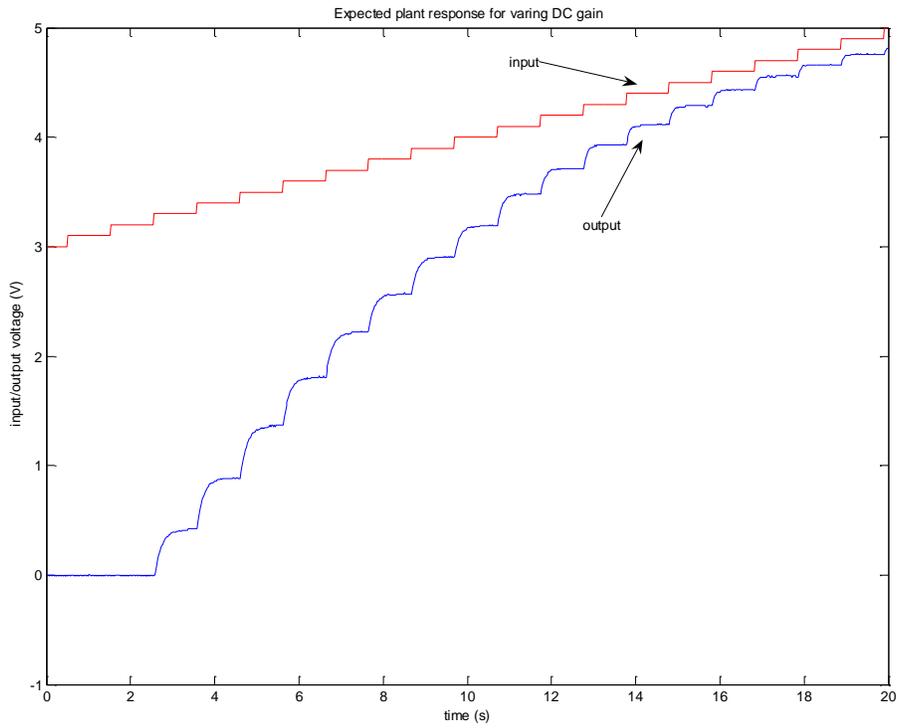


Figure 1.b

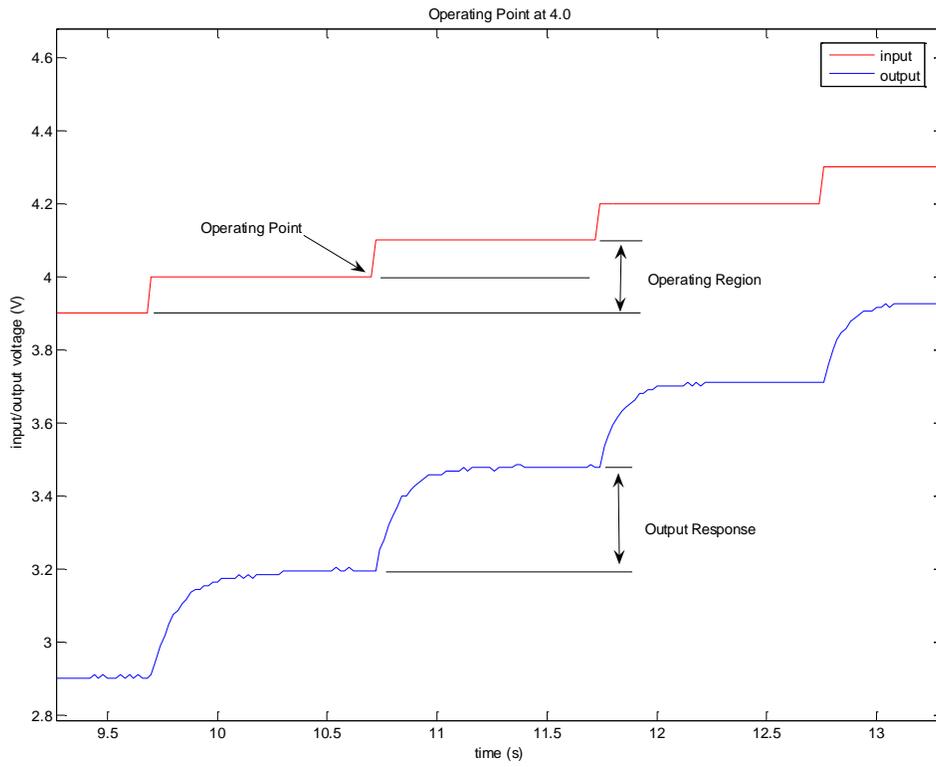


Figure 1.c

The webpage used for this experiment has been designed for most modern browsers, like Google Chrome.

1. Open your web browser and go to URL: <http://coecs120.ews.illinois.edu>
2. Choose Linearity Estimation from the navigation menu on the upper left corner of the page.
3. You will be asked to login. Use the login and password given by your TA.
4. First click on “Download m-file to view plant nonlinearity”. In Google Chrome the text of the m-file will be displayed in a new window. Copy and paste the text into a new m-file in MATLAB and save it as “nonlinearDCG.m” to a directory on your computer. You will run this m-file in MATLAB when you have completed Part1.
5. Then click “Part 1: Observe entire region of operation”
6. A sample webpage is shown in Figure 2.

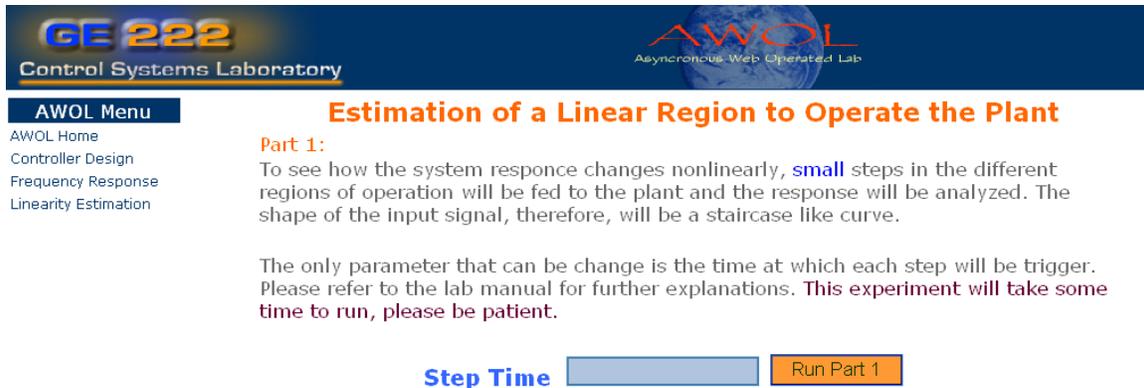


Figure 2: Linearity Estimation Webpage

7. In the webpage text box enter a Step Time of 1 second. The Step Time is the period at which the reference voltage will be increment by 0.1 Volts. The experiment will run for 20 seconds.
8. Click on the “Run Part 1” button.
9. BE PATIENT. The experiment will take several seconds (at least 25) to be executed. Keep in mind that there is only one available plant. Therefore, you might be in a queue waiting for your turn.
10. When the experiment has completed you will get a webpage that looks somewhat like the one shown in Figure 3. You can save the plot by right clicking on it and choosing the appropriate option for your browser.
11. Click on the link that says, “Click here to get the File with the Data Points. Save the file in the same location where you saved the nonlinearDCG.m file and note the name of the data file you just saved.
12. Open MATLAB and change to the directory where you saved your data. At the MATLAB command prompt, type “load <yourdatafile>”. Then plot the data for your report with the command “plot(t,y,t,u)” where (y) is the potentiometer feedback (u) is the control voltage input and (t) is time. As a last step run the m-file you downloaded by typing “nonlinearDCG”. This produces a plot of V_{out} vs. V_{in} . If this were a linear system the plot would be a straight line.

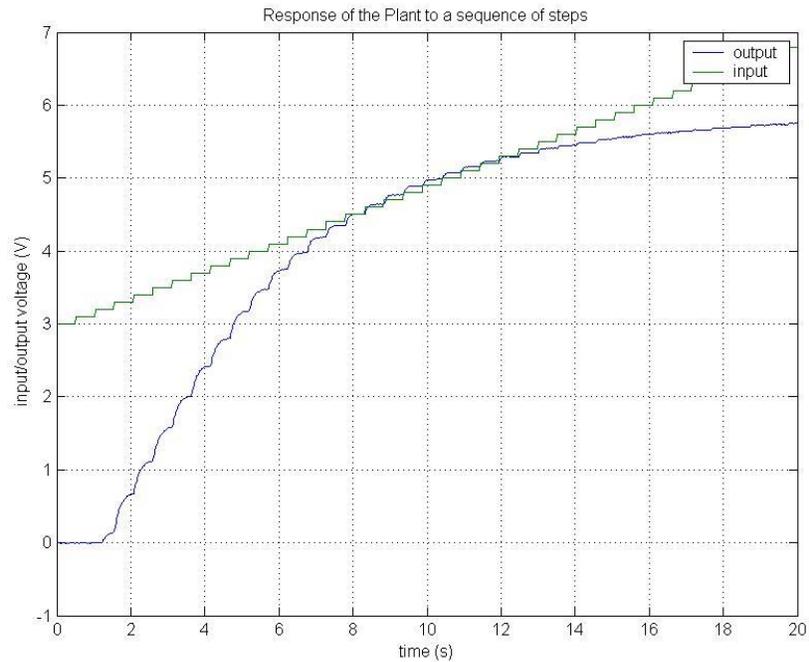


Figure 3: Sample output of the Linearity Estimation Experiment

1.4 Transfer Function Estimation

Now that the nonlinear behavior of the plant has been seen, it is time to approximate a linear model of the system. This linear model will only be valid near the operating region where the model was developed. You will now specify an operating point and obtain several step responses from the system.

1. Choose Linearity Estimation from the navigation menu on the upper left corner of the page.
2. Continue to “Part 2: Obtain system model at operating point”
3. A sample webpage is shown in Figure 4.

GE 222
AWOL

Control Systems Laboratory
Asynchronous Web Operated Lab

AWOL Menu

- AWOL Home
- Controller Design
- Frequency Response
- Linearity Estimation

Estimation of a Linear Region to Operate the Plant

Part 2:
To obtain an estimation of the plant at an operating point, a step response at that point will be examined.

There are three parameters that can be changed in this section, the operating point, the step time, and the step size. The operating point will be the voltage that the reference signal steps up from. Step time is the amount of time between steps (the experiment will run for a total of 20 seconds). The step size will be how high of a step the reference signal will make. For the controller design portion of this lab, the reference signal will make a 0.1 V step.

Operating Point

Step Time

Step Size

Run Part 2

Figure 4: Transfer Function Estimation Webpage

4. Use OP = 4.0 for your operating point. The step time and step size will remain 1 and 0.1, respectively.
5. Read the description of these three variables available on the webpage.

6. Click on the “Run Part 2” button.
7. As before, save the image and data for use in your analysis.
8. Obtain an estimation of the transfer function from your output data. Produce a plot that shows the D.C. gain of the system and its time constant at the desired operating point.

Answer the first three questions of the post-lab. Make sure you justify your answers.

1.5 CONTROLLER DESIGN

1.5.1 Proportional Controller

1. Using the plant model you found, design a Proportional Controller to obtain a feedback system with a closed loop DC-Gain of 0.4, 0.5, and finally, 0.6. **YOUR COMPLETE DESIGN PROCEDURE SHOULD BE INCLUDED IN YOUR REPORT.**
2. Test your controller, for a DCG of 0.5, by following steps 3 through 14.
3. Open your web browser and go to the following URL: <http://coecsl20.ews.illinois.edu/>. . Choose Controller Design from the navigation menu on the upper left corner of the page.
4. You should see a webpage similar to the one shown in Figure 5.
5. Select Proportional Controller, using the appropriate radio button in the ‘controller type’ area.
6. Enter your calculated value for K_p that you found and your operating point in the appropriately labeled boxes.
7. Click on the Test Controller orange and blue button.
8. **BE PATIENT.** The experiment might take several seconds to be executed. Keep in mind that there is only one available plant; therefore, you might be in a queue waiting your turn to access the experiment.
9. After the experiment is completed you will be shown a webpage with the plant response plot.
10. Save your plot and data as described previously.
11. Perform the necessary measurements with MATLAB by opening the saved data as discussed earlier. Plot the data for your report with the command “plot(t,y,t,r)” where (y) is the potentiometer feedback (r) is the error between the input and feedback, and (t) is time. Use MATLAB’s zooming capabilities and Data Cursor to optimize measurement accuracy.
12. Did you get the expected results? Why?, why not?
13. Increase the value of the gain in increments of 0.5 until the system becomes unstable.
14. Explain any other observations that do not agree with the theoretical prediction. Your discussion should attempt to explain in a detailed manner the plant behavior. You might want to experiment further with the plant.

Answer the next three questions of the post-lab.

GE 222
Control Systems Laboratory

AWOL Menu
AWOL Home
Controller Design
Frequency Response
Linearity Estimation

Control through the Internet

In this experiment you will be testing the controllers you have design on an actual plant, in the Control Systems Lab.

<p>Select the Type of Controller you want to test</p> <p><input checked="" type="radio"/> Proportional Controller</p> <p><input type="radio"/> Proportional+Integral Controller</p> <p><input type="radio"/> Proportional+Integral+Derivative Controller</p> <p><input type="radio"/> Lead Controller</p> <p><input type="radio"/> Lag Controller</p>	<p>The controller you have selected is:</p> $G_c(s) = Kp$ <p>Test Parameter</p>
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Insert the values for the gains of your controller

Kp

Figure 5: Controller Design Web Page

1.5.2 Proportional + Integral Controller

- Using the plant model already found, design a Proportional + Integral (PI) Controller. The following specifications should be met: 1. Zero steady state error; 2. The fastest closed-loop pole of your new system should be as close as possible to the pole of the proportional controller with 0.5 DC-Gain; 3. Use K_p equal to one half the value you obtained when checking the instability of the P controller (item 13 above). **YOUR COMPLETE DESIGN PROCEDURE SHOULD BE INCLUDED IN YOUR REPORT.**
- Test your controller by following steps 3 to 12 from the previous section. Make sure that you selected a PI controller in step 5.
- Did you get the expected results? Why? Why not?. Explain.
- Try to **tune** your controller. There are a number of techniques available for tuning the controller gains. For lab purposes we are going to use your knowledge and understanding of control systems and of the plant. What is the characteristic of the system's response that does not meet the design goals? What parameter of the controller will have the greater effect on the plant's output?. Fine tune that parameter (increase, or decrease its value in small deviations from the value obtained from theory).
- Include and explain your results.

1.6 Post-lab

1. What seems to be the order of the plant?
2. What plant parameters need to be determined to fully obtain the transfer function for the order you selected?
3. Use any of the methods learned in class to find such parameters. What is the plant transfer function?
4. What value of K_p (for your Proportional Controller) is needed to obtain a closed loop system with a DC-Gain of 0.4, 0.5, and finally, 0.6?
5. According to the transfer function you found can the system turn unstable from a proportional controller? If your answer is 'yes', calculate the theoretical value for K_p that will make the system marginally stable. If your answer is 'no' explain the inconsistency between your theoretical results and your experimental results.
6. What steady state error do you get when you test your proportional controller designed for a D.C. gain of 0.5?
7. Comment on the differences between the P and PI controllers.