Laboratory Assignment 6
System Identification using frequency response measurements

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1   Purpose

- System Identification

- Use of the HP3562A dynamic signal analyzer

2   Equipment

- HP3562A dynamic signal analyzer

- Protoboard with RC filter

3   Introduction

There are two approaches to obtaining models of the physical systems that we aim to control :

- Theoretical models using physical laws

- Experimental models

Theoretical models are very useful in that they provide you with a physical understanding of the operation of the system. However, theoretical models are usually obtained by recourse to idealization of actual system behavior. Such models prove to be very good at low frequencies and usually break down at higher frequencies. In such cases, recourse is usually made to experimental models of the plant. Also, most often before a final control design is made, it is prudent to verify the theoretical model with experimental data. Theoretical modeling is not to be belittled. In fact a sound understanding of the theoretical principles can lead to good experimental techniques and aid

in obtaining good models of the system. Modeling of most physical systems is done by systematic application of physical laws such as Newton's laws of motion, Kirchoff's laws, etc.

The process of obtaining models of physical systems using experimental techniques is termed system identification. System identification is a very important task and has matured into an important research area in its own right. This is all the more important in the current day scenario where a given system has to perform consistently in spite of changes in parameters and environment. In such cases the controller is tuned continuously to adapt to changes in operating parameters/environment leading to *adaptive* control. While, we do not want to get involved in the finer aspects of system identification, we want to provide you with a basic understanding of what system identification entails and what the common approaches to system identification are.

4   System Identification

System identification is usually performed by injecting known signals into the plant to be characterized (measured) and measuring the output. This leads to the input/output characteristics or the transfer function of the plant. Experimental data for generating such a model/transfer function are usually of four kinds :

- Transient (Step, Impulse etc.)

- Sinusoids of various frequencies and amplitudes

- Stochastic signals - from normal closed loop control signals etc.

- Pseudorandom (white) noise

Each of these kinds of data has its own advantages and disadvantages. We have already done the transient and the frequency response measurements in Lab 4 when we measured the inductance of the transformer.

Transient responses are usually used for first and second order systems. Transient response data is usually quick and relatively easy to obtain. It is also representative of the natural signals to which the system is subjected and a model based on such data can be a reliable basis for the design of a control system. A very popular method for tuning PID controllers called *Ziegler Nichols* tuning is based on the step responses of the plant. One of the prime disadvantages is that the data is not in a form suitable for standard control-system designs and the model must be computed from the data.

Frequency response measurements are more useful for most systems and are hence the preferred choice for many an application. Also, frequency response methods yield the model of the plant in just the right form for us to use frequency domain design techniques for controller design.

Normal operating records are the most attractive basis for obtaining system models (in fact this is the only choice when performing adaptive control where system identification takes place under closed loop control) since such tests are nondisruptive. However, in such cases, all modes of the system might not be excited (lack of persistent excitation) and the covariance matrices used to obtain model parameters might be close to being singular leading to numerical problems.

System identification using pseudorandom noise signals is also very commonly done since the noise is usually rich in all frequencies and hence excites all modes of the plant being measured

leading to good estimates of the model parameters. However, for the purposes of this lab, we shall stick to frequency response measurements using sinusoids of various frequencies and amplitudes.

In lab 4 we did frequency response measurements on the inductor using the function generator as the source and measured both the input and the output signals on an oscilloscope. The range of frequencies measured was varied manually and the ratio of the output/input signals and the phase difference was measured manually. An instrument which automates this process and plots the bode plot of the system over a specified range of frequencies is the HP3562A Dynamic Signal Analyzer from Hewlett Packard. This instrument consists of a signal source capable of producing swept sines (sinusoids with varying frequencies), white noise etc. and two channels for collecting the input and output data to the plant. It can also fit transfer functions to the measured bode plots and obtain a system model as poles, zeros and gains.

5   Low pass filter identification using the HP3562A

In this section, we look at the operation of the HP3562A dynamic signal analyzer. As an example we consider the determination of the transfer function of a simple RC low pass filter given in Figure 1. The resistance is chosen to be $10K\Omega$ and the capacitance chosen to be $0.1\mu F$ to yield a
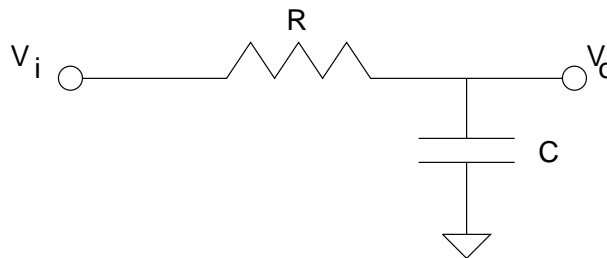

Figure 1: RC Low pass filter

time constant of $1ms$. This yields a first order transfer function of the form

$$\frac{V_o(s)}{V_i(s)} = \frac{1}{0.001s + 1} = \frac{1000}{s + 1000} \tag{1}$$

The RC circuit has already been built for you in the lab on a protoboard and the connections to the signal analyzer are made as follows :

V_i is connected to the source and to channel 1 of the signal analyzer and V_o is connected to channel 2 of the signal analyzer. Thus, we use the signal analyzer to generate test signals V_i and measure both the input and output signals V_i and V_o on channels 1 and 2 of the signal analyzer respectively.

A schematic of the signal analyzer is shown in Figure 2.

For the purposes of this lab and for subsequent experiments to determine the transfer functions of the actuators you will use in your project, we will use the swept sine mode of testing. The swept sine test essentially automates what you did in Lab 4. It sweeps through a range of sinusoids and measures the input and output magnitudes and phase difference and creates a Bode plot. To perform a swept sine test on the RC circuit, we have to do the following :

- Switch on the signal analyzer by depressing the line button found at the bottom left corner.

- Go to the display control area and select *upper/lower* display format so that you can view both the magnitude and phase plots on the screen at the same time. Next, depress the button corresponding to *Active trace A and B*. This activates both the traces. Next, depress the *Meas Disp* button and select *Freq resp* using the menu that appears on the main display.

- Now, set the variables that you want to plot on the two displays. Select trace A and depress the *Coord* button. Choose *Mag dB* from the menu that appears on the display. Then, select trace B and depress the *Coord* button and select *Phase deg* from the menu that appears on the display. Now, the display has been set up properly to proceed with the rest of your experiment.

- Now, move over to the *Measurement* controls. First, select the measurement mode to be *Swept sine*.

- Next set the source level to 1 V pk-pk. You can choose other values too depending on the plant you are testing. This basically sets the amplitude of the sinusoids that the signal analyzer generates.

- Select the frequency span next. In this case we know that the break frequency is 1000 rad/s (159.155 Hz). So, let us choose the start frequency to be 10 Hz and the stop frequency to be 1 KHz. Here is where you need to know something about your plant apriori. It will help you in limiting your experiments to the ranges that are important.

- You are now ready to perform system identification. Move over to the *Control* area and depress the *Start* button. You will notice that the magnitude and phase plots are drawn on the upper and lower displays respectively. The signal analyzer also displays the numeric values of the current value of frequency, magnitude ration and phase difference as the experiment proceeds.

- You are finally ready to obtain a transfer function corresponding to the measurements just made. Move over to the *Operator* controls section and depress the *Curve fit* button. Again, for this operation, you need to know something about the plant that you are testing. A menu appears on the display. Depress the soft key corresponding to the *Number of Poles* and enter 1. Next depress the soft key corresponding to the *Number of zeros* and enter 0. Then depress the soft key corresponding to *Start fit*. The phase plot will disappear and the fitted magnitude plot will be displayed at the bottom of the display. You can compare the values of magnitudes etc. between the experimental plot and the fitted plot by moving the marker around. Use the marker wheel in the *Marker* section to do this. This provides a verification on the accuracy of the fit. You need to perform this operation to convince yourself of the validity of the fit. Do not trust the numbers that the analyzer tells you blindly.

- To find out the poles, zeros and the gains for the fitted plot, depress the soft key corresponding to *Edit Table*. A table of poles and zeros appears and the gain is also given at the bottom of the table. You can edit this table and enter different values for the poles and zeros to study

the effects of changes in pole and zero location on the fitted plot (this is something which can also be done very conveniently in Matlab).

- Your system identification is now complete !

6   Hints on System identification

Note that there is a small quirk to the operation of the signal analyzer. It makes all its measurements (poles, zeros etc.) in Hertz, while we write out transfer functions in radians/s. Failing to remember this can lead to completely wrong models for the system. I find that a convenient way to do things is to take the model, convert all poles, zeros and gains to radians/second in Matlab and obtain the step response in Matlab. Next connect the function generator to the plant input and measure both the plant input and output using the scope. Use a very low frequency square wave of unit amplitude as the input to the plant. Check if the step responses thus obtained correspond to the step responses obtained by simulation of the fitted model in Matlab. This provides a conclusive check on the veracity of your experimental identification procedure and your interpretation of the results !

For the RC circuit that has been set up, I got the following values :

Pole location = -160.507 Hz
Gain = 158.7

which correspond very well to the values predicted by Eq(1).

Please be sure to perform the system identification on the RC circuit first, do this individually, there will be no checkoff on this lab - it is in your own interest to learn to use a dynamic signal analyzer. We request that you complete system identification experiments on the RC circuit by 11/20/96. After that, you might want to start measurements on the actuators.

Take some time to decide on how you would perform system identification on your scanners. Note that you have to use the source on the signal analyzer to drive the power amplifier since the source is limited in the current that it can put out. Decide what your input and output variables are. Determine the frequency ranges of interest and the levels of excitation that you would need. Feel free to discuss these issues amongst yourself (it is supposed to be a team project !) and with the teaching staff.
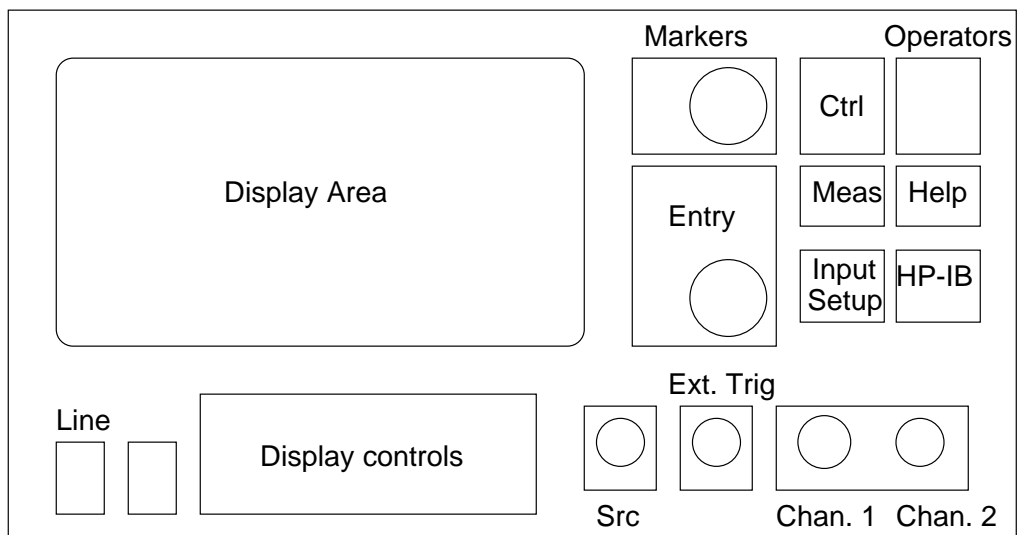
Figure 2: Schematic of the HP3562A Dynamic signal analyzer