Cleveland State University
Department of Electrical and Computer Engineering
Control Systems Laboratory

Experiment #4

Empirical Methods for Modeling the Controlled System (Torsion Mechanism)

INTRODUCTION

In Experiment #2 you used the **First Principles Method** to determine a mathematical model of the controlled system or plant in a control loop (in this laboratory the controlled system is the torsion mechanism). An alternative approach to obtaining a model is to use what is called the **Empirical Method** for system modeling, a method that contains two related but different approaches: time domain empirical modeling, and frequency domain empirical modeling. In this experiment you will use both of these empirical modeling methods to model the torsion mechanism, and you will compare the results of each method to the other, and then also to the model of the mechanism you developed using the first principles modeling method studied in Experiment #2.

The first principles method studied earlier is based on (i) looking in detail at the devices and interconnections that make up a system, (ii) using basic physical laws or first principles—Newton's Laws, Kirchhoff's Laws, conservation of mass, conservation of energy, etc.—to guide you in writing the equations that govern the behavior of these devices and interconnections, and then, (iii) devising methods to determine values for the parameters (values for the components) that appear in the equations. When using the first principles method for the very simple torsion mechanism in the lab, the parameter values you had to determine (*through spec sheets, calculations, and/or experimentation*) were values for the inertia (spec sheet and calculation), the damping constant (experimentation), the servo-amp gain (spec sheet), and the motor torque constant (spec sheet). Although useful and therefore widely used, the first principles method can be difficult to apply to large systems with many parts, or to systems in which it will be hard to obtain values for the device parameters that appear in the equations. An alternative approach in these cases is to use the empirical method.

The Time Domain Empirical Modeling Method: The time domain empirical method of modeling a system adopts the point of view that if one is interested only in an overall input-output relationship (or model) for a system, i.e. an overall transfer function or differential equation description (which is what you developed in Experiment #2 using the first principles method), then what's inside the system—the various devices and their interconnections—is unimportant, and what one should do to come up with an overall model—instead of applying first principles to all these various devices and their interconnections inside the system—is to just *apply a simple input* to the system—say, a step—*and observe the overall response at the output*. In many cases this response will look like the response of a first or second order transfer function to the applied input, and therefore a first or second order transfer function can be used to model the system's input-output relationship. The parameter values for *settling time, percent overshoot*, etc. can be measured directly from the characteristics of the response of the actual system. Values for the parameters in the transfer function model so obtained (*gain, poles, zeros, natural frequency, damping ratio, etc*.) are chosen so that the response of the transfer function model to the step input matches the response of the actual system to the step input.

The Frequency Domain Empirical Modeling Method: This method adopts the same point of view and essentially the same approach as the time domain method described above, except that instead of obtaining a step response of the system to be modeled, the method determines the system's frequency response by applying sinusoids of different frequencies to the system's input and observing the *amplitude and phase* of the system's output at each of the applied frequencies. Using this data a Bode plot displaying the system's frequency response is constructed and, as in the case of the time domain method, in many cases this frequency response will look like the frequency response of a first or second order system and therefore a first or second order transfer function (obtained from the first or second order frequency response) can be used to model the system's input-output behavior. Values for the parameters in the transfer function model (*gain, poles, zeros, natural frequency, damping ratio, etc*.) are chosen so that the frequency response of the transfer function model matches the frequency response of the actual system. These values can be determined directly from the characteristics of the frequency response of the actual system as given by the Bode plot.

Controlled System to be Modeled: The controlled system you are to model in this experiment is the same system you modeled in Experiment #2—the torsion mechanism (including its servoamp and servomotor) as shown in Figure 1.

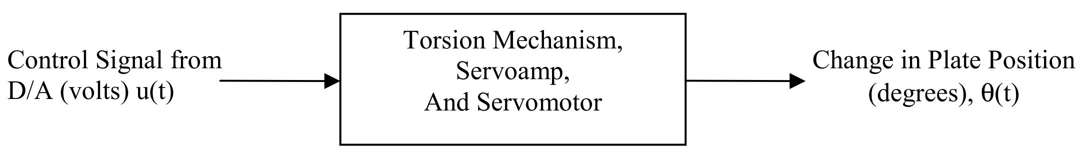
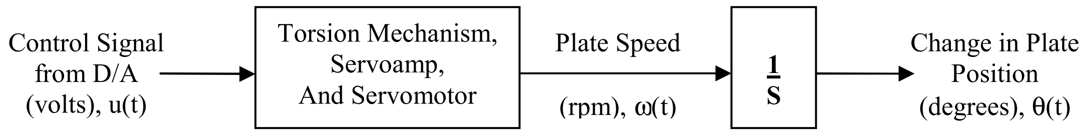


Figure 1: Controlled System to be Modeled

However, the problem of putting a step into this system (as in done to model it using the time domain empirical method as described above) is that the change in plate position is a ramp in response to a step in the control voltage (as seen in Experiment #1) and it's hard to see what the transients look like (i.e. whether they are approximately first order, second order, or neither) when the output is ramping.. A way around this is to recognize that plate position is just the integral of plate speed, and since plate speed doesn't ramp in response to a step in the control voltage (and therefore we stand a chance of seeing what the transients look like by looking at plate speed), we can (i) apply the modeling method to model plate speed response, and then (ii) just add an integrator—a 1/S term—to the model so obtained to make its output plate position rather than plate speed. This is shown in Figure 2, and it's the approach you'll take in this experiment.

Figure 2: <u>Controlled System to be Modeled Showing Speed and Position</u>



PRELAB

You should come into the lab with a clear understanding of what this lab is about and how you are going to proceed, and you should answer the following questions **on a separate piece of paper that you can hand in.**

1. What is the transfer function of a first order system? How many parameters does it have? What are their names?

2. If a step of magnitude A is applied to a first order system, what does the output response look like in the time domain? Sketch it.

3. How are the first order, time-domain response characteristics related to the first order transfer function parameters?

4. What part of the controlled system are you modeling in this experiment? Based on the model of the controlled system that you developed in Experiment #2, what should the transfer function of the part of the controlled system you are modeling in this experiment turn out to be?

5. Sketch (by hand—don't do it with a computer) the frequency response of the following system: (s) = 6280/(s + 628). At what frequency (in Hz) does it cross the 0 dB axis?

PROCEDURE

<u>MAKE SURE ALL POWER IS TURNED OFF</u>.

<u>Part I—Time Domain Empirical Modeling Method</u>: Devise an experimental set-up that will allow you to generate the data necessary to develop a time domain empirical model for the controlled system. Speed responses of the system should be from 0 to 300 rpm so that the model developed in this experiment is for the same system operating range as the operating range used in developing a model for the system in Experiment #2. **WHEN YOU THINK YOU HAVE A GOOD SET-UP, ASK THE INSTRUCTOR TO CHECK IT OUT BEFORE APPLYING POWER TO THE MECHANISM. ALSO, BE PREPARED TO SAY WHY YOU HAVE WHAT YOU HAVE, AND HOW IT WILL LEAD TO DATA THAT ALLOWS THE DEVELOPMENT OF A TIME DOMAIN EMPIRICAL MODEL.**

a) **DO NOT TURN POWER ON BEFORE THE INSTRUCTOR HAS CHECKED YOUR SET-UP.**

b) Record all system responses using the "**To Workspace"** block in Simulink. Use the **"plot"** command in Matlab to generate a graphical figure of the workspace data, then set scales and labels on axes to adequately display your results. Copy the figure to the clipboard and paste into your report.

c) Based on your measurements from part a), develop a model for that portion of the controlled system whose input is control voltage and whose output is plate speed. **Record in your notebook all the calculations and data needed to do this.**

d) Now fine-tune the model you obtained by (i) applying the same step to your model and to the real system, (ii) comparing—on the same Simulink graph—your model's response with the response of the real system, and (iii) seeing if the match can be improved by making adjustments to the model's parameters. Record your observations.

e) Where did you do step d) before? Why did you do it?

f) Now obtain a model for the overall controlled system, i.e. the system whose input is the control signal and whose output is change in plate position.

DISCUSSION QUESTIONS

1. Show a ***complete*** derivation of your model—**graphical data, numerical data, calculations, final model, and comments on the derivation.** Remember: you initially obtained values for the model's parameters from the system response (Part I-c), and then you fine-tuned the model's parameter values by comparing the model's response to that of the real system (Part I-d). Include here the parameter values for each part, and **include in your discussion comments on whether the fine-tuning in part d) did any good, what values it changed, and why the changes were made.** Remember: the model you should end up with is for the entire torsion mechanism as shown in Figures 1 and 2—servo amp, servomotor, and mechanism—where the input is control voltage into the servo amp, and the output is position change, not speed change.

2. How does the empirical model of the controlled system you obtained above compare to the model of the controlled system you obtained using the first principles method in Experiment #2? Write down both models, discuss similarities and differences in **parameter values,** and **EXPLAIN—FOR THE DIFFERENCES—WHAT YOU THINK THE REASONS ARE FOR THE DIFFERENCES.**

Part II—Frequency Domain Empirical Modeling Method: TURN OFF THE SERVOAMP AND DISCONNECT THE CONTROL SIGNAL (THE D/A OUTPUT) FROM THE

SERVOAMP INPUT. Now devise an experimental set-up that will allow you to produce the data necessary to develop a frequency domain empirical model for the controlled system. However, **DO NOT CONNECT ANYTHING TO THE SERVOAMP INPUT UNTIL THE INSTRUCTOR HAS CHECKED YOU OUT!!!.** Generate any sinusoids you need using the Wavetek signal generator **(DON'T** generate them from Simulink), make sure the sinusoidal amplitude doesn't exceed 2 volts (4 volts peak-to-peak; you can use Simulink to look at amplitude), and **save all recordings in a Matlab workspace file, you may need to plot them later. WHEN YOU THINK YOU HAVE A GOOD SET-UP, ASK THE INSTRUCTOR TO CHECK IT OUT BEFORE APPLYING POWER TO THE MECHANISM. ALSO, BE PREPARED TO SAY WHY YOU HAVE WHAT YOU HAVE, AND HOW IT WILL LEAD TO DATA THAT ALLOWS THE DEVELOPMENT OF A FREQUENCY DOMAIN EMPIRICAL MODEL.**

a) DO NOT TURN POWER ON BEFORE THE INSTRUCTOR HAS CHECKED YOUR SET-UP.

b) For this controlled system you can get the model from the Bode diagram's magnitude and phase plot of input versus output. Since you are interested only in magnitudes and phase, and therefore not interested in making time measurements, you can run the Simulink recorder for short periods.

c) Make sure you measure data for a wide enough frequency range so that the Bode plot will display all the system characteristics that are needed to build the model.

DISCUSSION QUESTIONS

1. Generate a Bode plot of the frequency response of the controlled system, by hand. **THIS PLOT MUST BE DONE CAREFULLY, ACCURATELY, AND *BIG*.** The curve drawn through the data must make sense—**DO IT MANUALLY WITH A FRENCH CURVE OR SPLINE IF YOU HAVE TO—BUT IT MUST MAKE SENSE.** Include all Bode plot data in a table. Remember to look up what the ordinate and abscissa of a Bode plot are, **LABEL THE FREQUENCY AXIS IN HZ NOT RAD/SEC, AND USE THE APPROPRIATE NUMBER OF CYCLES ON THE LOG SCALE SO THAT DETAILS OF THE RESPONSE CAN BE CLEARLY SEEN AND ACCURATELY MEASURED.**

2: Discuss and show thoroughly how you obtained the frequency domain empirical model of the controlled system. Show a ***complete*** derivation of your model**—what information you used from the Bode plot, how you got it, other data, calculations, final model, and comments on the derivation.**

3. Compare your frequency domain model to **both** your time domain model and your first principles model. Discuss—**in detail**—similarities and differences. Which one do you think is the better model? **WHY?**