ME 576 Lab. 11 & 12 for Modeling and Control of Servo Systems

1. Experiment 1 with the Servo Trainer

Introduction

The purpose of this experiment is to accurately determine the continuous-time model of a real system (see Figure 1) and to use this model to design a controller. The system parameters will be determined by using a step response with known controller gains in a closed loop configuration.

The servo system with a PD controller is schematically shown in Figure 2 and has the output/input transfer function:

$$C(s) = \frac{q(s)}{R(s)} = \frac{k_p k_{hw} / J}{s^2 + \left(c + k_d k_{hw} / J\right)s + k_p k_{hw} / J}$$

which has the form of the classical second order system:

$$C(s) = \frac{q(s)}{R(s)} = \frac{w_n^2}{s^2 + 2Vw_n s + w_n^2}$$

where

$$w_n \cong \sqrt{\frac{k_p k_{hw}}{J}}$$

is called the system natural frequency, and

$$V \cong \frac{1}{2w_n}\left(\frac{c + k_d k_{hw}}{J}\right)$$

is the system damping ratio.

Te hardware gain, k_{hw} of the system is comprised of the product:

$$k_{hw} = k_c k_a k_t k_e k_s$$

where

- k_c, the DAC gain, =10V/32,768 DAC counts
- k_a, the Servo Amp gain = approx. 2 (amp/V)
- k_t, the Servo Motor Torque constant = approx. 0.1 (N-m/amp)
- k_e, the Encoder gain, = 16,000 pulses (counts) / 2π radians
- k_s, the Controller Software gain, = 32 (controller input counts/encoder or ref. input counts)

Hence, k_{hw} has the dimensions of torque, but is more precisely expressed in units of [N-m/rad*(controller input count)/(DAC count)].

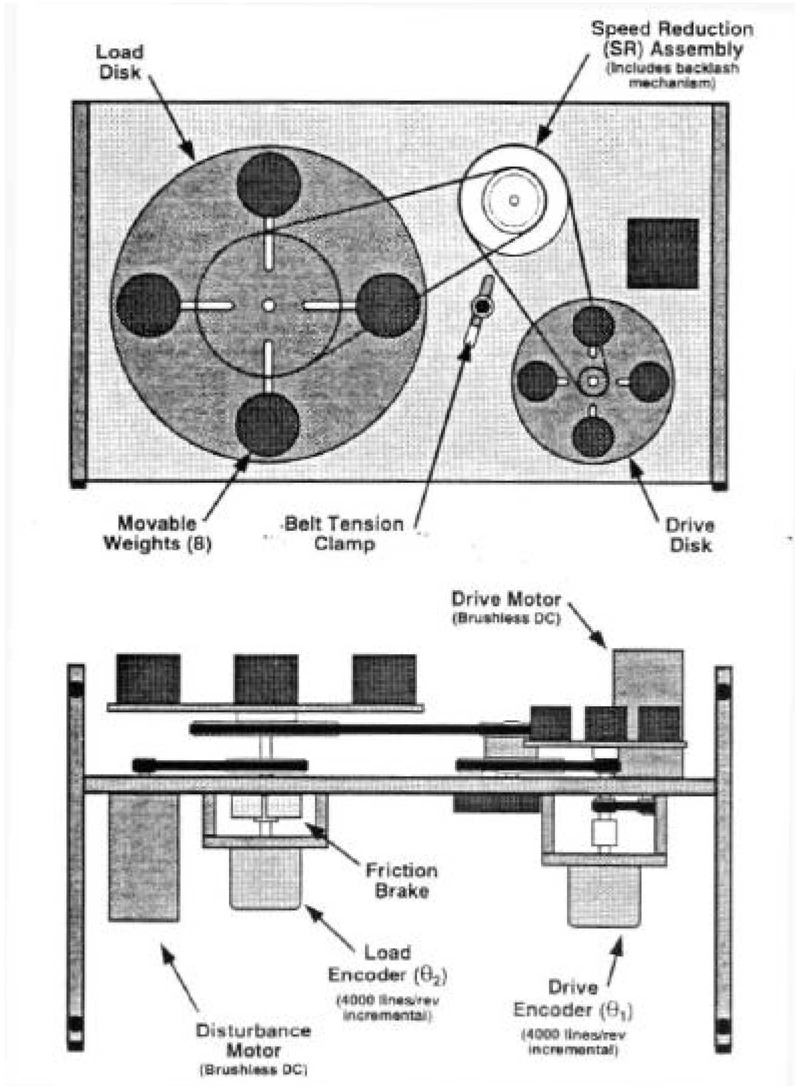

Figure 1 Servo Trainer Configuration

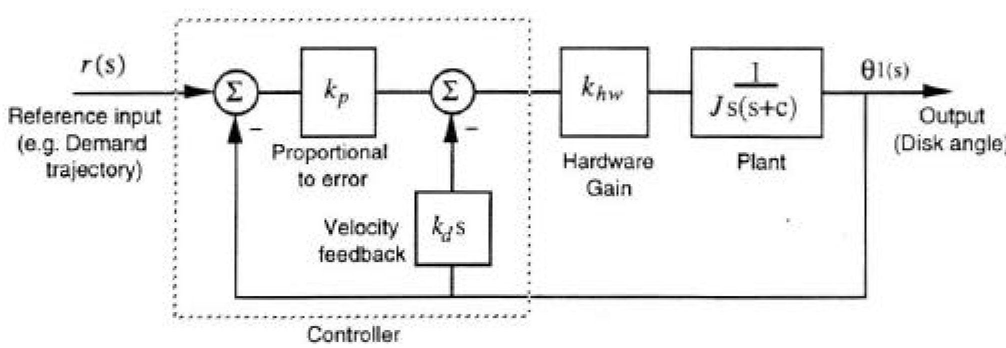

Figure 2 Controller Configuration for Plant Identification

System Identification Procedure

A step response of the system is utilized to determine the natural frequency and damping ratio.

Procedure

1. Enter the **Control Algorithm** box under the **Set-up** menu and set **Ts=0.002652 s** and select **Continuous Time Control**. Select **PI with Velocity Feedback** and **Set-up Algorithm**. Enter $k_p=0.7$ and $k_d=0.002$ (k_i=0) and select OK.

   In this and all future work, be sure to stay clear of the mechanism before doing the next step. Selecting Implement Algorithm immediately implements the specified controller: if there is an instability or large control signal, the plant may react violently.

2. Select **Implement Algorithm** and then **OK**.

   If the system appears stable after implementing the controller, first displace the disk with a light, non sharp object to verify stability prior to touching the plant.

3. Enter the Command menu, go to **Trajectory** and select **Step**, *Set-up*. Select **Closed Loop Step** and input a step size of **1000 counts**, a duration of **1000 ms** and **1 repetition**. Exit the Background Screen by consecutively selecting **OK**. This puts the controller board in a mode for performing a pair of closed loop steps (one forward and then one backward) of one second duration. This procedure may be repeated and the duration adjusted to vary the maneuver and data acquisition period.

4. Go to **Set up Data Acquisition** in the **Data** menu and select **encoder #1** and **Command Position** as data to acquire and specify data sampling every 1 (one) servo cycles, i.e., every Ts. Usually it is not necessary to acquire data at such a high frequency. Here however we wish to have high resolution data to make fairly precise measurements of the response frequencies. Select **OK** to exit. Select Zero Position from the Utility menu to zero the encoder positions.

5. Select **Execute** from the **Command** menu and select **Run**. The drive disk will step, oscillate, and attenuate, then return. Encoder data is collected to record this response. Select **OK** after data is uploaded.

6. Select **Set-up Plot** from the **Plotting** menu and choose **Encoder #1 Position** then select **Plot Data**. You will see the drive disk time response similar to that shown in Figure 3.

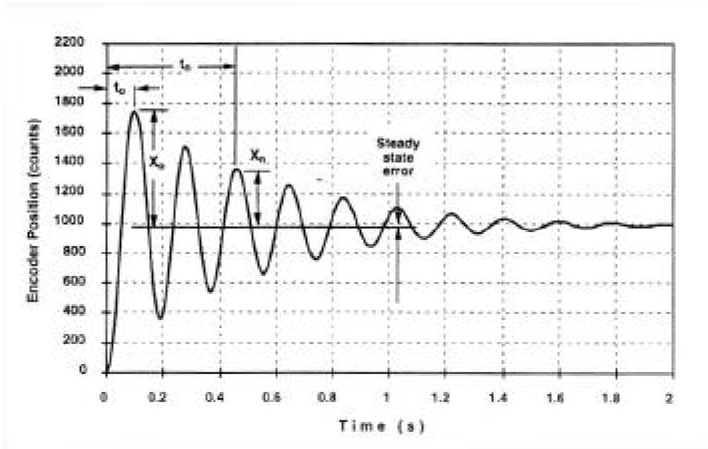

Figure 3 Typical Response to a Step Input

7. Measure the amplitude and time to peak of the first one or two consecutive cycles as shown in Figure 2. Measure the reduction from the initial cycle amplitude X_0 to the last cycle amplitude X_n for the n cycles. For more precise measurements you may "zoom in" to the area of interest in the plot via **Axis Scaling** under **Plotting**.

   The following relationship is associated with the logarithmic decrement for underdamped second order systems:

$$\frac{V}{\sqrt{1-V^2}} = \frac{1}{2pn}\ln\left(\frac{X_0}{X_n}\right) \qquad (1)$$

   For small ζ this expression becomes

$$V \cong \frac{1}{2pn}\ln\left(\frac{X_0}{X_n}\right) \qquad (2)$$

   Solve for by first estimating it via Eq. (2) and then solving Eq. (1) by iteration.

8. Divide the number of cycles, n, by the time taken to complete them. Convert the resulting frequency in Hz to radians/sec. This damped natural frequency, ω_d, is related to the natural frequency, , according to

$$w_n = \frac{w_d}{\sqrt{1-V^2}}$$

Close the graph wind by clicking on the left button in the upper right hand corner of the graph. This will collapse the graph to icon from where it may later be brought back up by double-clicking on it.

Lab Report for this part must include the followings:

- Estimated plant dynamics (J and C values) including all the calculations.
- Simulated responses of the system using the estimated parameters and controller gains for a unit step input.
- Design of a new PD controller such that the closed loop system natural frequency w_n = 4 Hz, and the damping ratio of 0.5. Design the controller for both continuous and discrete implementations (Ts=0.00442 sec).

2. High Speed Milling machine

The frequency response of the model will be constructed by generating a series of reference sinusoids and using the sinusoids as inputs to the system. The input/output relationship of these sinusoids will be used to construct the magnitude and phase frequency response plots of the system, which will be used to generate the continuous-time model of the system. Using this model a discrete PID controller will be designed to meet performance criteria given.

A sinusoid of a single amplitude and frequency will be given to the system as an input, the output of the system is recorded, and the resulting magnitude ratio and phase shift of the response will be plotted. This procedure will be continued for various frequencies until accurate frequency response plots are generated.

Hookup Procedure

The horizontal mill should be powered up by the TA. Once this has been completed, the control wires for the table and spindle should be attached as follows:

Table Control Signal	Analog Output 0
Table Feedback Signal	Analog Input 0
Spindle Control Signal	Analog Output 1
Spindle Feedback Signal	Analog Input 1

When all connections have been made TURN THE SELECTOR SWITCH TO MANUAL and turn on the power from the operator console. Press the *Table Start* and *Spindle Start* buttons on the operator console (the green lights should be on). Do not turn on the hydraulics since the spindle will not be running.

Power up the PC, go to the subdirectory *horizmil*, and run the program *sintable*. A user interface screen will appear as in Figure 4.

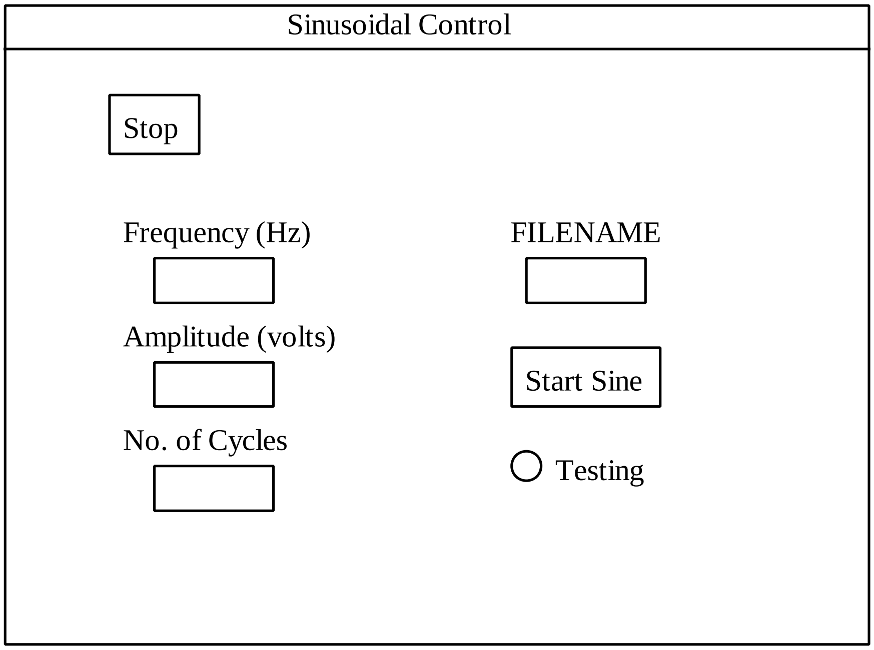

Figure 4 - User Interface Screen for Sinusoidal Input

Sinusoidal Responses

The command signal sent to the table is a voltage which is proportional to the desired velocity. The feedback signal is a voltage level which is proportional to the actual velocity of the table. The experiment will consist of sending a sinusoidal voltage signal at a given frequency to the table and recording the output. Using a series of these responses over a range of frequencies will produce a frequency response curve from which a continuous-time model for the system may be generated.

Enter the desired frequency, amplitude, and the number of cycles desired. Choose a filename for the particular frequency and give it a *.m* extension. An example of an appropriate filename would be *test1.m*. The *.m* extension is used so that the data may be directly imported into MATLAB by typing the filename within the MATLAB environment. To load the data from *test1.m* into MATLAB, one would only have to type *test1* at the MATLAB prompt.

Run the experiment for the following frequencies, amplitudes, and cycles:

Frequency (Hz)	Amplitude (volts)	No. of Cycles
.5	2	3
1	2	6
3	2	8
5	1.5	20
10	.7	20

From the data obtained at the frequencies above, find the magnitude ratio (in dB) and the phase shift (in degrees) for each frequency.

Model Generation

Figure 5 shows the experimentally determined frequency plots for the table. Add your data points from the magnitude and phase responses obtained above.

From Figure 2, determine an acceptable continuous-time model. Assume the system has no zeros.

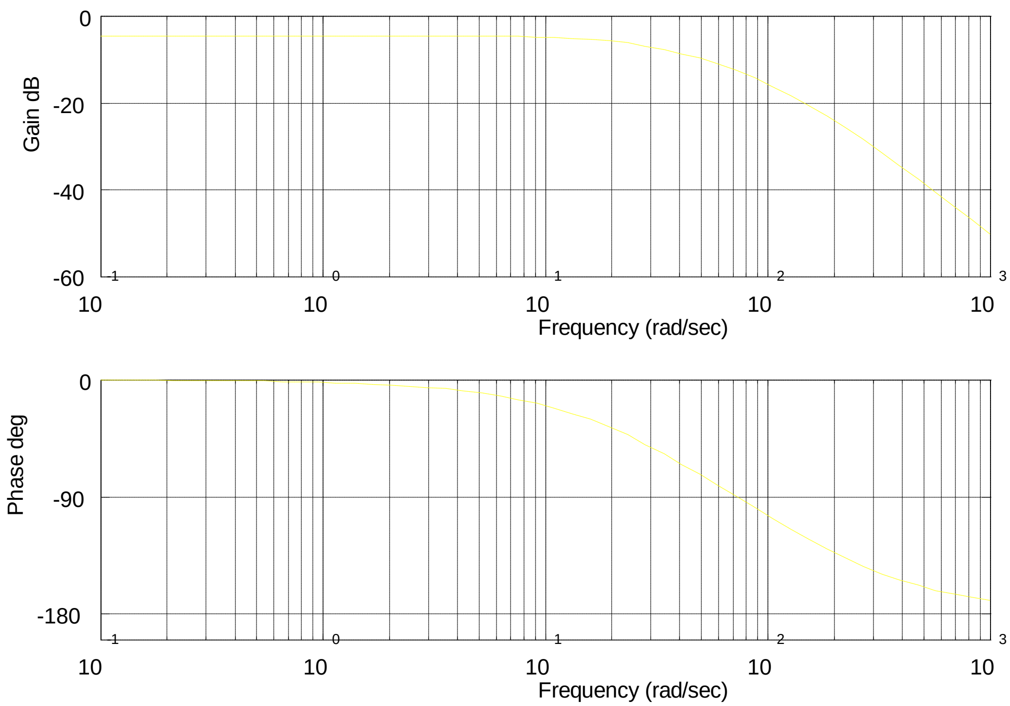

Figure 5 - Frequency Response Plots for Table on Horizontal Mill

PID Control Implementation

The final part of this experiment is to design a PID controller for the table to meet the following performance criteria. The control implementation is shown for continuous and discrete versions in Figure 6. The sampling time interval is 0.01 sec.

Specifications: $e_{ss} \leq 5\%$

$T_s \leq 0.2$ sec

% Overshoot $\leq 10\%$

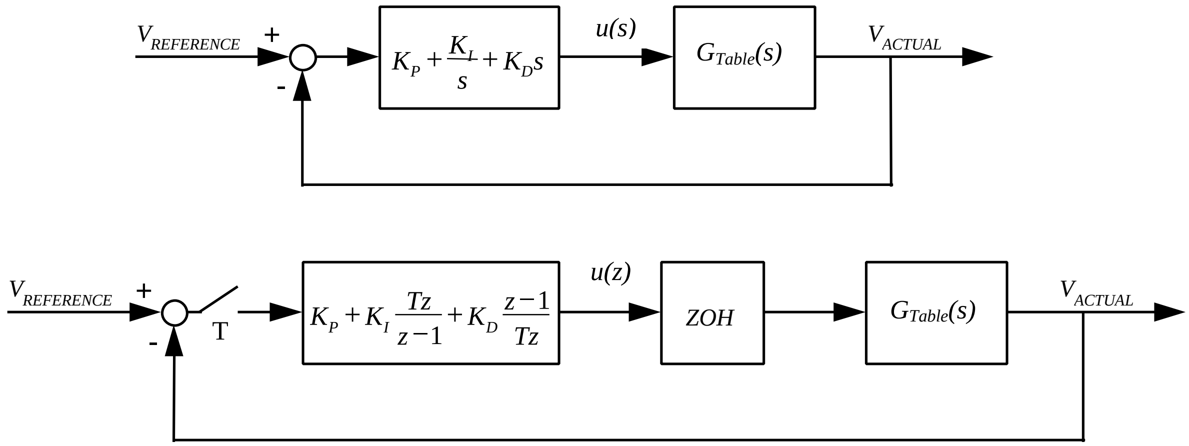

Figure 6 - Block Diagrams for PID Control

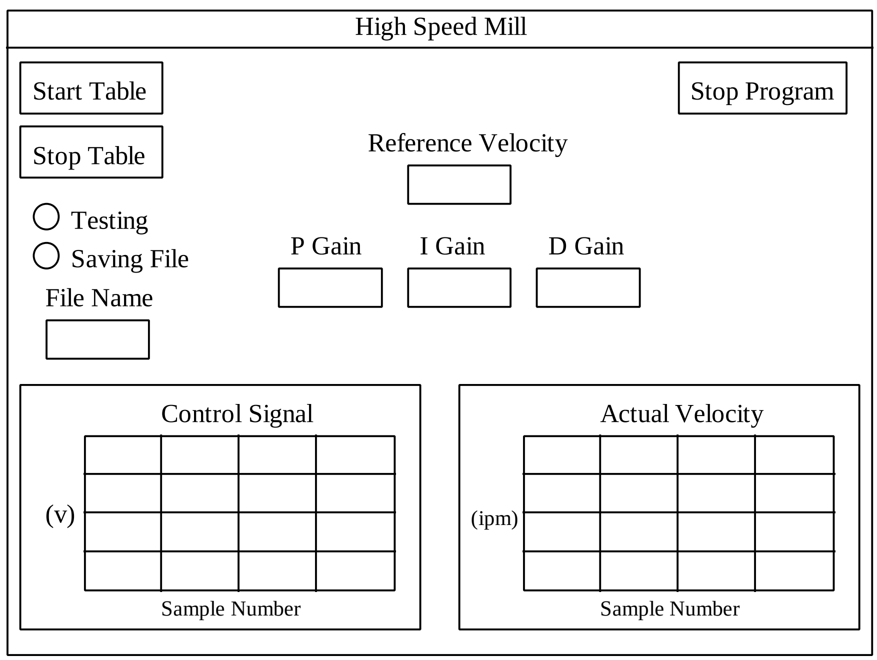

Figure 7 User Interface for Digital Controller Implementation.

Lab Report must include the followings:

- Estimated plant dynamics in Transfer function form.
- Design of a digital PID controller to meet the given specifications, including the design procedure.