SPRING MASS DAMPER SYSTEM

1. Open ECP32 from desktop

2. Setup → Control Algorithm → Continuous time & State Feedback (default) →ok

3. Command → Trajectory→ Step → Setup →Open loop Step → ok

Step Size = 0V, Dwell time = 3000 ms, No. of resp = 1

4. Data → Setup data acquisition → Sample Period = 2, Selected items : Encoder 1 Position → ok

5. Utility → Zero position

6. Command →Execute → Displace and hold the carriage to 2.5 cm (or any desirable distance) → Click Run & then leave the carriage.

7. Plotting → Setup plot →Encoder 1 Position (in left axis)→Plot Data

Case I

Without mass, with Spring, Without damper

- From plot calculate time period of Oscillation (t_{osc1})
- Calculate $\omega_{n1} = \frac{2\pi}{t_{osc1}}$
- $\omega_{n1}^2 = \frac{k}{m}$ .... (i)

  m : Carriage mass

Case II

With mass and spring, without damper

- Calculate t_{osc2}
- Calculate $\omega_{n2} = \frac{2\pi}{t_{osc2}}$
- $\omega_{n2}^2 = \frac{k}{m+M}$ ....(ii)

  M : Known mass added

  From Equn. (i) & (ii) Calculate k and m

Case III

With Spring and damper, with / without mass

- From plot calculate time period t_d
- $\omega_d = \frac{2\pi}{t_d}$
- $\xi = \frac{1}{2\pi n} l_n(\frac{Xo}{X_n})$ Find X_o, X_n, n from graph
- $\omega_n = \frac{\omega_d}{\sqrt{1+\xi^2}}$
- $2\xi\omega_n = \frac{c}{Total\ mass} = \frac{c}{m+M}$

Transfer function :

$$\frac{X(s)}{F(s)} = \frac{1/M}{s^2+\left(\frac{c}{M}\right)s+k/M}$$

Where

k = spring constant

c = damping coefficient

6. Experiments/ Labs

This chapter outlines experiments which identify the plant parameters, implement a variety of control schemes, and demonstrate many important control principles. The versatility of this software / hardware system allows for a much broader range of experimental uses than will be described here and the user is encouraged to explore whatever topics and methodologies may be of interest – subject of course to your school and laboratory guidelines and the safety notations of this manual. <u>The safety portion of this manual, Section 2.4, must be read and understood by any user prior to operating this equipment.</u>

The instructions in this chapter begin at a high level of detail so that they may be followed without a great deal of familiarity with the PC system interface and become more abbreviated in details of system operation as the chapter progresses. To become more familiar with these operations, it is strongly recommended that the user read Chapter 2 in its entirety prior to undertaking the operations described here. Remember here, as always, it is recommended to save data and control configuration files regularly to avoid undue work loss should a system fault occur.

There are four labs for SD352 Control Systems course. Labs section and experiment titles are given below:

Section 6.1- Lab No.1 - **System Identification**

Section 6.2 – Lab No.2 – **Rigid Body PD & PID Control**

Section 6.4 – Lab No.3 - **Collocated PD Control With 2 DOF Plant**

Section 6.5 – Lab No.4 - **Noncollocated PD Plus Notch Filter Control**

For more information please visit the following lab page at:

http://www.eng.uwaterloo.ca/~tnaqvi/courses/syde352.html

6.1 System Identification – SD352 Lab No.1

This section gives a procedure for identifying the plant parameters applicable to Eq's (5.1-1 through 5.1-8). The approach will be to indirectly measure the mass, spring, and damping parameters by making measurements of the plant while set up in a pair of classical spring-mass configurations.

<u>Procedure:</u>

1. Clamp the second mass to put the mechanism in the configuration shown in Figure 6.1-1a using a shim (e.g. 1/4 inch nut) between the stop tab and stop bumper so as not to engage the limit switch (see Section 2.2). Verify that the medium stiffness spring (nominally 400 N/m (2.25 lb/in.)) is connecting the first and second mass carriages.
2. Secure four 500g masses on the first and second mass carriages.

3. With the controller powered up, enter the Control Algorithm box via the Set-up menu (Continious System) and set $T_s = 0.00442$. Enter the Command menu, go to Trajectory and select Step, Set-up. Select *Open Loop Step* and input a step size of *0 (zero)*, a duration of *3000 ms* and *1 repetition*. Exit to the background screen by consecutively selecting OK. This puts the controller in a mode for acquiring 6 sec of data on command but without driving the actuator. This procedure may be repeated and the duration adjusted to vary the data acquisition period.

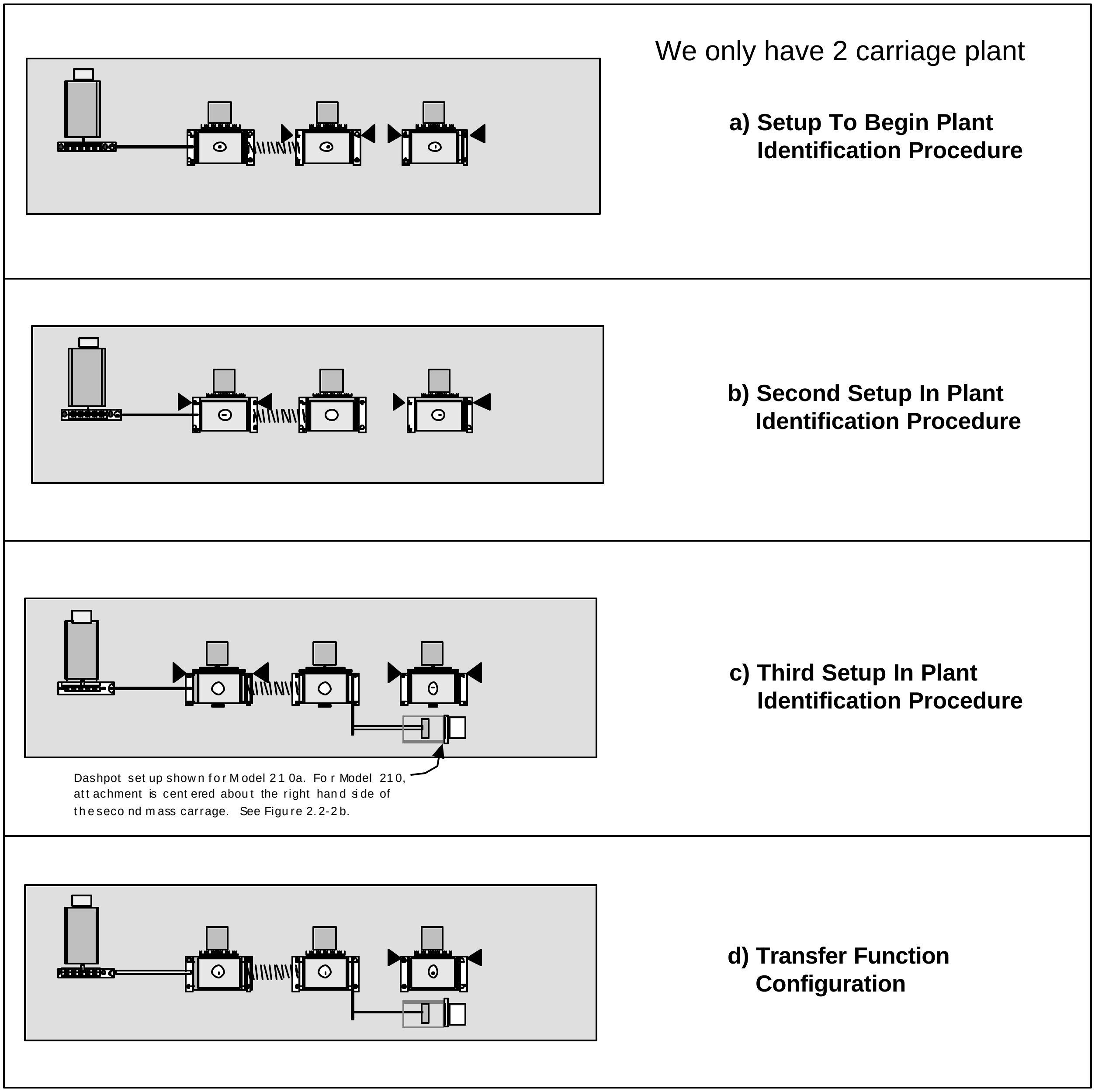

Figure 6.1-1 Configurations For Plant Identification
(Model 210a shown. Four 500 g. weights on each active carriage.)

Duration: Number of sample period (2 servo cycles by default)
1 rep collects 678 samples

4. Go to Set up Data Acquisition in the Data menu and select Encoder #1 and Encoder #2 as data to acquire and specify data sampling every **2** (two) servo cycles (i.e. every 2 T_s's). Select OK to exit. Select Zero Position from the Utility menu to zero the encoder positions.

5. Select Execute from the Command menu. Prepare to manually displace the first mass carriage approximately 2.5 cm. Exercise caution in displacing the carriage so as not to engage the travel limit switch. With the first mass displaced approximately 2.5 cm in either direction, select Run from the Execute box and release the mass approximately 1 second later. The mass will oscillate and attenuate while 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 from the Plotting menu. You will see the first mass time response.

7. Choose several consecutive cycles (say ~5) in the amplitude range between 5500 and 1000 counts (This is representative of oscillation amplitudes during later closed loop control maneuvers. Much smaller amplitude responses become dominated by nonlinear friction effects and do not reflect the salient system dynamics). Divide the number of cycles by the time taken to complete them being sure to take beginning and end times from the same phase of the respective cycles.[1] Convert the resulting frequency in Hz to radians/sec. This *damped frequency*, ω_d, approximates the *natural frequency*, ω_n, according to:

$$\omega_{n_{m11}} = \frac{\omega_{d_{m11}}}{\sqrt{1-\zeta_{m11}^{2}}} \cong \omega_{d_{m11}} \quad \text{(for small } \zeta_{m1}\text{)} \tag{6.1-1}$$

   where the "m11" subscript denotes mass #1, trial #1. (Close the graph window by clicking on the left button in the upper right hand corner of the graph. This will collapse the graph to icon form where it may later be brought back up by double-clicking on it.)

8. Remove the four masses from the first mass carriage and repeat Steps 5 through 7 to obtain $\omega_{n_{m12}}$ for the unloaded carriage. If necessary, repeat Step 3 to reduce the execution (data sampling only in this case) duration.

9. Measure the initial cycle amplitude X_o and the last cycle amplitude X_n for the n cycles measured in Step 8. Using relationships associated with the *logarithmic decrement:*

[1] You may "zoom" the plot via Axis Scaling for more precise measurement in various areas. For an even greater precision, the data may be examined in tabular numerical form – see Export Raw Data, Section 2.1.7.3.

$$\frac{z_{m12}}{\sqrt{1-z_{m12}^2}} = \frac{1}{2\pi n}\ln\frac{X_o}{X_n} \longrightarrow \zeta_{m12} \simeq \frac{1}{2\pi n}\ln\frac{X_o}{X_n} \quad \text{(for small } z_{m12}\text{)} \tag{6.1-2}$$

find the damping ratio z_{m12} and show that for this small value the approximations of Eq's (6.1-1, -2) are valid.

10. Repeat Steps 5 through 9 for the second mass carriage. Here in Step 6 you will need to remove Encoder #1 position and add Encoder #2 position to the plot set-up. Hence obtain $\omega_{n_{m21}}$, $\omega_{n_{m22}}$ and ζ_{m22}. How does this damping ratio compare with that for the first mass? Be sure to save this plotted data as it will be used in the next experiment.

11. Connect the mass carriage extension bracket and dashpot to the second mass as shown in Figure 6.1-2c. Open the damping (air flow) adjustment knob 2.0 turns from the fully closed position. Repeat Steps 5, 6, and 9 with four 500 g masses on the second carriage and using only amplitudes > = 500 counts in your damping ratio calculation. Hence obtain ζ_d where the "d" subscript denotes "dashpot".

12. Each brass weight has a mass of 500 ± 10 g. (You may weigh the pieces if a more precise value is desired.) Calling the mass of the four weights combined m_w, use the following relationships to solve for the unloaded carriage mass m_{c2}, and spring constant k.[1]

$$k/(m_w+m_{c2}) = (w_{n_{m21}})^2 \tag{6.1-3}$$

$$k/m_{c2} = (w_{n_{m22}})^2 \tag{6.1-4}$$

Find the damping coefficient c_{m2} by equating the first order terms in the equation form:

$$s^2 + 2z\, w_n s + w_n^2 = s^2 + (c/m)s + k/m \tag{6.1-5}$$

Repeat the above for the first mass carriage, spring and damping m_{c1}, c_{m1} and k respectively.[2] [3]

Calculate the damping coefficient of the dashpot, c_d.

13. Detatch the dashpot from the second mass carriage, replace the medium stiffness spring with a high stiffness spring (800 N/m nominally), and repeat with masses Steps 5 and 6 to obtain the resulting natural frequency ω_{m23}. Repeat this frequency measurement using the least stiff spring (nominally 200 N/m) to obtain ω_{m24}. Calling the value of stiffness obtained in Step 12 above $k_{med\ stiffness}$,

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[1]Note that the calculated masses m_{c1} and m_{c2} will include the reflected inertias of all connected elements – e.g. motor pinion and armature.

[2]Step 12 may be done later, away from the laboratory, if necessary.

[3]The resulting value for k should be very close to that measured when considering the second mass case. You may use the average of the two for your identified k value.