Rectilinear Control System

The Rectilinear Control Plant shown in Figure 1 is designed to emulate a broad range of real-world applications including 1 DOF rigid bodies, flexibility in linear drives, gearing and belts, and other coupled oscillatory systems. The apparatus consists of three mass carriages interconnected by bi-directional springs. The mass carriage suspension is an anti-friction ball bearing type with approximately +/- 3 cm of available travel. The linear drive is comprised of a gear rack suspended on an anti-friction carriage and pinion (pitch dia. 7.62 cm (3.00 in)) coupled to the brushless servo motor shaft. Optical encoders measure the mass carriage positions – also via a rack and pinion with pinion pitch diameter 3.18 cm (1.25 in).

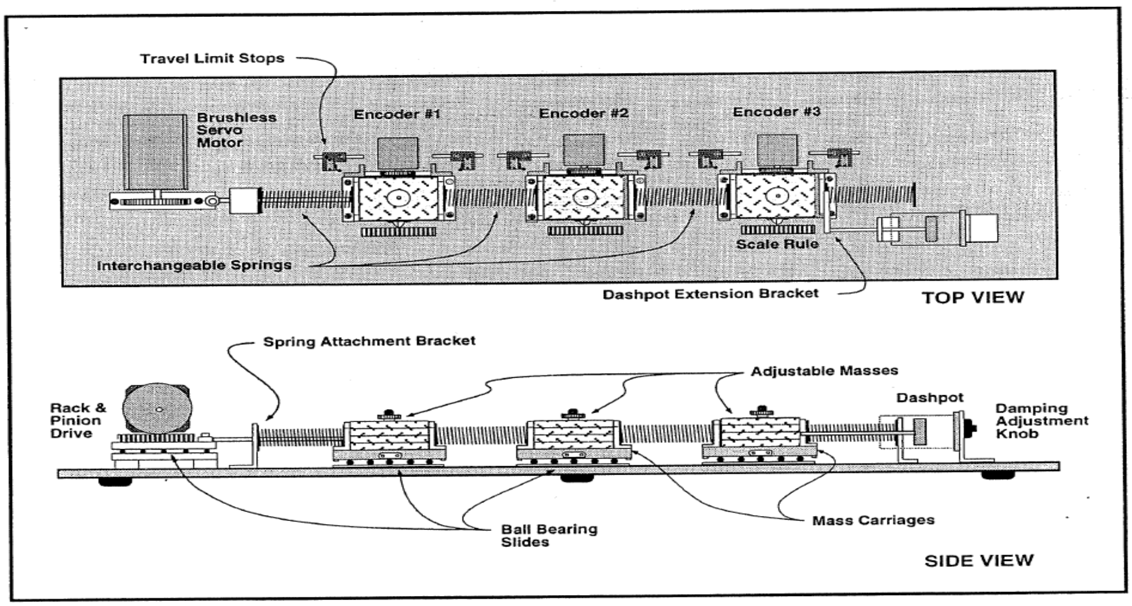

Figure 1: Rectilinear Apparatus

Checkout Procedure

Step 1: Enter the ECP program by double clicking on its icon. You should see the Background Screen. Gently move the first mass carriage by hand. You should observe some following errors and changes in encoder counts. The Control Loop Status should indicate "OPEN" and the Controller Status should indicate “OK”.

Step 2: Make sure that you can oscillate the mass carriages freely. Now press the black "ON" button to turn on the power to the Control Box. You should notice the green power indicator LED lit, but the motor should remain in a disabled state. <u>Do not touch the apparatus</u> whenever power is applied to the Control Box since there is a potential for uncontrolled motion of the masses unless the controller has been safety checked.

Introduction Exercises

A. Read the safety information for the Rectilinear System in Chapter 2 of the equipment manual (See also Appendix B on the course website).

B. Identify the control elements and signals in the Torsion Experiment*.

Sensor:
Actuator:
Controller:
Reference Input:
Actuator Output:
System Output:

*Refer to the Introduction Literature.

Experiment 6.1: System Identification

Follow the procedure in the ECP Manual to identify the parameters of the system plant. Include all the necessary plots used to determine the parameters and show any required calculations on the plots. The following values will need to be determined from experimentation:

Mass 1 Trial 1 Natural Frequency, ω_{nm11} = _______________ (rad/s)
Mass 1 Trial 2 Natural Frequency, ω_{nm12} = _______________ (rad/s)
Mass 1 Trial 2 Damping Constant, ζ_{m12} = _______________
Mass 2 Trial 1 Natural Frequency, ω_{nm21} = _______________ (rad/s)
Mass 2 Trial 2 Natural Frequency, ω_{nm22} = _______________ (rad/s)
Mass 2 Trial 2 Damping Constant, ζ_{m22} = _______________
Dashpot Damping Constant, ζ_d = _______________
Mass 2 Trial 3 Natural Frequency, ω_{nm23} = _______________ (rad/s)
Mass 2 Trial 4 Natural Frequency, ω_{nm24} = _______________ (rad/s)

Plot of Mass 1 Trial 1 is on pg._____.
Plot of Mass 1 Trial 2 is on pg._____.
Plot of Mass 2 Trial 1 is on pg._____.
Plot of Mass 2 Trial 2 is on pg._____.
Plot of Mass 2 Trial 3 is on pg._____.
Plot of Mass 2 Trial 4 is on pg._____.

Use the values and plots created above to determine the system parameters in Exercise A. The following values will need to be determined; attach a separate sheet that shows your hand calculations.

Mass of Brass Weights, m_w = __________________ (kg)
Mass of Carriage #1, m_{c1} = ____________________ (kg)
Mass of Carriage #2, m_{c2} = ____________________ (kg)
Mass of Carriage #3, m_{c3} = ____________________ (kg)
Mass 1 Damping Coefficient, c_{m1} = ________________ (N/m/s)

Mass 2 Damping Coefficient, c_{m2} = _______________ (N/m/s)
Mass 3 Damping Coefficient, c_{m3} = _______________ (N/m/s)
Dashpot Damping Coefficient, c_d = _______________ (N/m/s)
Low Stiffness Spring Constant, k_{low} = _______________ (N/m)
Medium Stiffness Spring Constant, k_{med} = _____________ (N/m)
High Stiffness Spring Constant, k_{high} = _______________ (N/m)

Using Eqs. (6.1-7 and 6.1-8) in conjunction with the measured m_1 and $\ddot{x}_{1e}$, determine

The five-term product $k_a k_t k_{mp} k_e k_{ep}$ = ___________

Then using the above value and the given values for k_c and k_s, determine

Hardware Gain of the System k_{hw}, k_{hw1} = ______________ (N/m)

Use Eq. (6.1-6) to calculate another k_{hw}, k_{hw2} = ______________ (N/m)

Note the difference of the two (should be reasonably close).

Write your calculations below

Experiment 6.2: Rigid Body PD and PID Control

In this section, the effects of adding PD and PID controllers to the system will be investigated. Follow the procedure in this section; generate all the requested plots and include them with this report. The following values will need to be reported as well:
(Note that frequency needs to be converted to rad/s in the calculation of k_p etc.)
(Also note a typo in Eq. (6.2-2): the term $k_d s$ in the numerator should not be there)

In Step 3, k_p = ________________
In Step 7, for k_p, ω_n = ___________ (Hz)
For $2k_p$, ω_n = ____________ (Hz)
In Step 8, k_d = _______________
In Step 11, k_p = ________________
(under-damped) k_d = ______________
(critically damped) k_d = ______________
(over-damped) k_d = ______________

Plot of Encoder #1 Position for k_p = ___________ is on pg.____.
Plot of Encoder #1 Position for $2k_p$ = __________ is on pg.____.
Plot of Under-Damped Step Response is on pg._____.
Plot of Critically Damped Step Response is on pg._____.
Plot of Over-Damped Step Response is on pg._____.

How does increasing k_p affect the dynamics of the system?

Follow the procedure in the Frequency Response section and create the requested plots. It is only necessary to include the Logarithmic plots with this report.

Bode Plot of Under-Damped Frequency Response on Logarithmic Axes is on pg._____.
Bode Plot of Critically Damped Frequency Response on Logarithmic Axes is on pg.____.
Body Plot of Over-Damped Frequency Response on Logarithmic Axes is on pg._____.

Comment on the three Bode plots above in terms of (1) breakaway (or corner) frequency at which the response of the system visibly starts to decline as the frequency further increases, and (2) the rate of decline as damping increases.

Continue following the procedure to investigate the effects of adding integral action to the system controller. Produce the requested plots and include them with this report. The value of k_i will also need to be calculated in Step 18.

In Step 18, k_i = _________________
In Step 19, k_i = _________________

Plot of Step Response with k_i = ________ is on pg.______.
Plot of Step Response with k_i = ________ is on pg.______.

How do you feel/observe the integral action affect the system behavior/response? Does this effect become stronger or weaker when the value of k_i is increased?

In Step 19, what happens when you let go of the mass?