

# Industrial Emulator / Servo Trainer

The Industrial Servo Trainer design shown in Fig. 1 features brushless DC servo motors for both drive and disturbance generation, high resolution encoders, adjustable inertias and changeable gear ratios. It also has features to introduce coulomb and viscous friction, drive train flexibility, and backlash. The plant is designed to emulate a broad range of typical servo control applications. The Model 220 apparatus consists of a *drive motor* (servo actuator) that is coupled via a timing belt to a *drive disk* with variable inertia. Another timing belt connects the drive disk to the *speed reduction (SR)* assembly while a third belt completes the drive train to the *load disk*. The load and drive disks have variable inertia which may be adjusted by moving (or removing) brass weights. Interchangeable belt pulleys in the SR assembly adjust speed reduction. Backlash may be introduced through a mechanism incorporated in the SR assembly, and flexibility may be introduced by an elastic belt<sup>1</sup> between the SR assembly and the drive disk. The drive disk moves one-for-one with the drive motor so that its inertia may be thought of as being *collocated* with the motor. The load inertia however will rotate at a different speed than the drive motor due to the speed reduction. Also, drive flexibility and/or backlash may exist between it and the drive motor and hence its inertia is considered to be *noncollocated* with the motors.

A disturbance motor connects to the load disk via a 4:1 speed reduction and is used to emulate viscous friction and disturbances at the plant output. A brake below the load disk may be used to introduce Coulomb friction. Thus friction, disturbances, backlash, and flexibility may all be introduced in a controlled manner. These effects represent non-ideal conditions that are present to some degree in virtually all physically realizable electromechanical systems.

All rotating shafts of the mechanism are supported by precision ball bearings. Needle bearings in the SR assembly provide low friction backlash motion (when backlash is desired). High resolution incremental encoders couple directly to the drive ( $\theta_1$ ) and load ( $\theta_2$ ) disks providing position (and derived rate) feedback. The drive and disturbance motors are electrically driven by servo amplifiers and power supplies in the Controller Box. The encoders are routed through the Controller box to interface directly with the DSP board via a gate array that converts their pulse signals to numerical values.

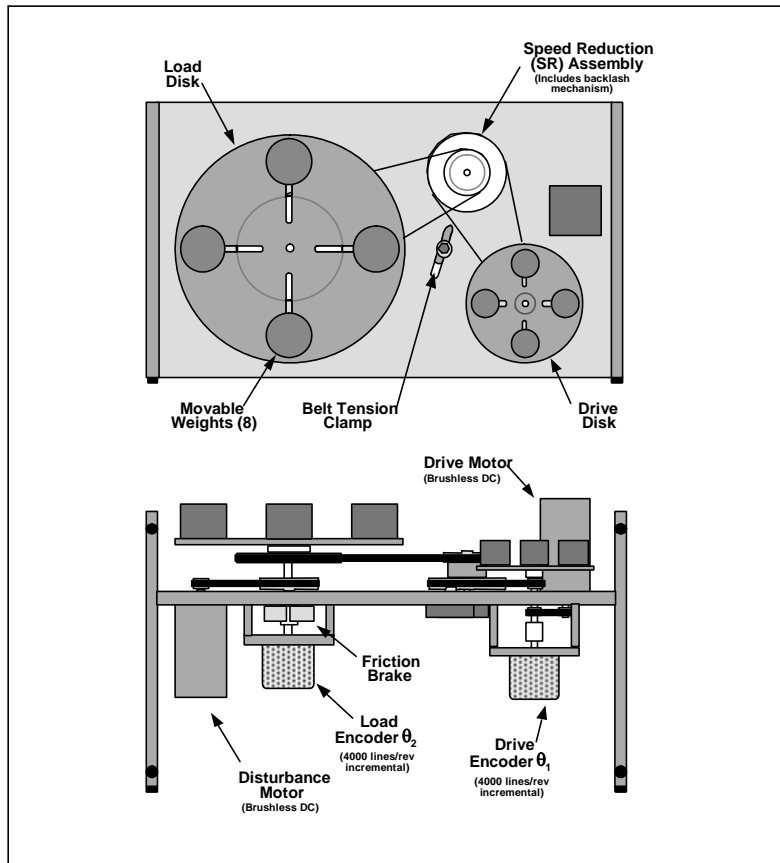
## Checkout Procedure

- Step 1:** With power switched off to the Control Box, enter the ECP program by double clicking on its icon. You should see the Background Screen. Gently rotate the drive or load disk 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 rotate disks freely. Now connect the power cord to the Control Box and 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

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<sup>1</sup>Either a "rigid" or flexible belt may be used between the SR assembly and the load disk.

disabled state. Do not touch the disks whenever power is applied to the Control Box since there is a potential for uncontrolled motion of the disks unless the controller has been safety checked.



**Figure 1: ECP Industrial Servo Trainer**

### Introduction Exercises

- A. Read the safety information for the Industrial Servo Trainer (IST) Experiment in Chapter 2 of the equipment manual (See also Appendix B on the course website).
- B. Identify the control elements and signals in the IST Experiment\*.

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

\*Refer to Introduction Literature.

### Experiment 6.1: System Identification

Follow the procedure in Section 6.1.1 of the ECP Manual to determine the hardware gain,  $k_{hw}$ . The following values will need to be determined:

Inertia of the test arrangement,  $J_{dtest} = \underline{\hspace{2cm}}$  ( $\text{kg}\cdot\text{m}^2$ )

The combined gain,  $k_a k_t k_c =$  \_\_\_\_\_  
Hardware Gain,  $k_{hw} =$  \_\_\_\_\_

Include the plot of velocity that was used to determine the acceleration. Pg \_\_\_\_.

Follow the procedure in 6.1.2 and 6.1.3 to determine the inertias of the drive and load disks as well as the plant damping coefficient. The following values will need to be determined:

Drive damping constant,  $\zeta =$  \_\_\_\_\_  
Natural frequency,  $\omega_n =$  \_\_\_\_\_ (rad/s)  
Inertia of Drive Disk,  $J_{dd} =$  \_\_\_\_\_ (kg-m<sup>2</sup>)  
Inertia of Load Disk,  $J_{dl} =$  \_\_\_\_\_ (kg-m<sup>2</sup>)  
Plant Damping Coefficient,  $c_4 =$  \_\_\_\_\_ (N/rad/s)

\*DO NOT DO 6.1.4

### Experiment 6.2: Rigid Body PD and PID Control

This experiment will demonstrate some of the more salient concepts of PD and PID control. Follow the procedures in 6.2.1 to study the effects of  $k_p$  and  $k_d$ . The following values will need to be determined:

In Step 1,  $J =$  \_\_\_\_\_ (kg-m<sup>2</sup>)  
In Step 3,  $k_p =$  \_\_\_\_\_  
In Step 8,  $k_d =$  \_\_\_\_\_

What is the effect of doubling  $k_p$  in Step 7?

What are the units of  $k_d k_{hw}$ ?

Follow the procedures in 6.2.2 and 6.2.3 to create and implement the respective PD and PID controllers. Include all of the requested plots with this report. The following values will need to be determined:

For  $\omega_n = 4$  Hz:  
 $k_p =$  \_\_\_\_\_  
 $\zeta = 0.2, k_d =$  \_\_\_\_\_  
 $\zeta = 1.0, k_d =$  \_\_\_\_\_  
 $\zeta = 2.0, k_d =$  \_\_\_\_\_

$k_i =$  \_\_\_\_\_

Plot of the Under-damped response is on pg. \_\_\_\_\_.

Plot of the Critically Damped response is on pg. \_\_\_\_\_.

Plot of the Over Damped response in on pg. \_\_\_\_\_.

Plot of Critically damped response using integral action is on pg. \_\_\_\_\_.

Plot of response after doubling  $k_i$  is on pg. \_\_\_\_\_.

What is the integral action's effect on steady state error and how does it affect overshoot?

In the control structures that have been presented two approaches have been taken toward the derivative term; in one case the derivative is in the forward path while in another it is in the feedback loop. The effects of this difference will now be investigated. Follow the procedure in 6.2.4 and create all the requested plots. The following values will need to be determined:

In Step 3,  $k_i =$  \_\_\_\_\_

Plot of PI with Velocity Feedback with  $k_i = 0$  response to a ramp is on pg. \_\_\_\_\_.

Plot of PI with Velocity Feedback with  $k_i =$  \_\_\_\_\_ response to a ramp is on pg. \_\_\_\_\_.

Plot of PID with  $k_i = 0$  response to a ramp is on pg. \_\_\_\_\_.

Plot of PID with  $k_i =$  \_\_\_\_\_ response to a ramp is on pg. \_\_\_\_\_.

Describe the error to the ramp trajectory in each case?

Describe what differences you observed between using  $k_d$  in the forward and return paths? Does either case overshoot?

What was the effect of adding integral action with  $k_d$  in the forward and return paths? Why do you think the integral action had this effect?

Finally the frequency response of the closed loop PID controllers will be studied. Follow the procedure in 6.2.5 to investigate the response of the plant and controller to sinusoidal excitations. This procedure will use a “Sine Sweep” or chirp signal to generate the system frequency response. Include all plots that are requested by the procedure.

Frequency Response of the PI with Velocity Feedback for the Under-damped case is on pg.\_\_\_\_.  
Frequency Response of the PI with Velocity Feedback for the Critical Damped case is on pg.\_\_\_\_.  
Frequency Response of the PI with Velocity Feedback for the Over Damped case is on pg.\_\_\_\_.  
Frequency Response of the PID controller for the Critically Damped case is on pg.\_\_\_\_.

What is the resonant frequency of the under-damped case and how does it compare with the theoretical predictions for an under-damped oscillator?

**Skip the part below – Fall 2007**

Compare and contrast the various frequency responses in terms of their asymptotic Bode response characteristics and S-Plane roots (from transfer function).