

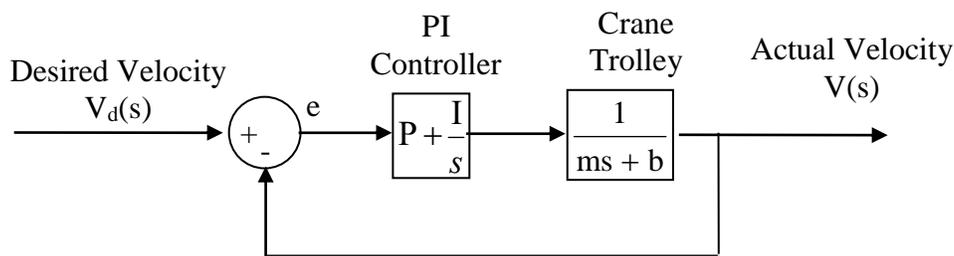
## ME6404 – Fall 2016 Lab 2

### Objectives:

- Use feedback control to track a desired trolley velocity profile
- Use feedback control to track the same velocity profile, but with reduced payload swing

### Background:

The trolley motion of the portable bridge crane is regulated by a velocity controller built into the motor drives. The trolley velocity dynamics can be modeled as a first-order system that is controlled by the motor drive with a proportional-integral (PI) controller. A block diagram of the entire system is shown in Figure 1. The PI controller gains are P and I, and the crane trolley first-order plant is characterized by constants m and b.



**Figure 1: Bridge Crane Velocity Control Block Diagram**

#### Proportional Control:

With only proportional control (setting  $I=0$ ) the closed-loop system is reduced to a first-order system. The open loop transfer function is:

$$G_{op}(s) = \frac{P}{ms + b} \quad (1)$$

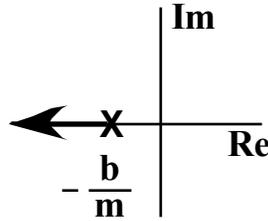
The closed loop transfer function is:

$$G_{cl}(s) = \frac{V(s)}{V_d(s)} = \frac{P}{ms + (P + b)} \quad (2)$$

The error signal used for feedback control is:

$$e(s) = V_d(s)(1 - G_{cl}(s)) = V_d(s) \frac{ms + b}{ms + (P + b)} \quad (3)$$

The effects of the proportional gain are shown in the root locus diagram in Figure 2.



**Figure 2: Root Locus for P Control**

From the locus it is clear that increasing the proportional gain moves the system pole to the left, thereby creating a faster response. The root locus shows the system will never go unstable. In addition, the final value theorem can be applied to find the steady-state error of the system to a unit step input i.e.

$$V_d(s) = \frac{1}{s}$$

$$e_{ss} = \frac{b}{P+b} \quad (4)$$

From this equation we see that as P increases, the steady-state error approaches zero. The above theoretical results suggest that P can be increased without bound to yield optimal results. However, noise and unmodeled dynamics can cause stability issues that prevent very large values of P from being implemented in practice.

Proportional-Integral Control:

With proportional-integral control, the closed-loop system is second-order. The open-loop transfer function is:

$$G_{op}(s) = \frac{Ps + I}{ms^2 + bs} \quad (5)$$

The closed loop transfer function is:

$$G_{cl}(s) = \frac{V(s)}{V_d(s)} = \frac{Ps + I}{ms^2 + (P+b)s + I} \quad (6)$$

The error signal used for feedback control is:

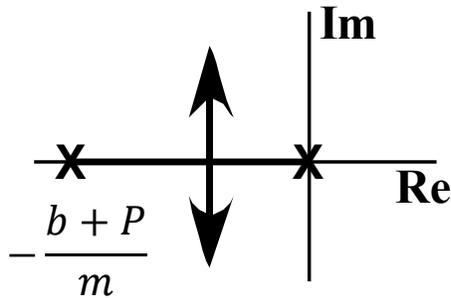
$$e(s) = V_d(s)(1 - G_{cl}(s)) = V_d(s) \frac{ms^2 + bs}{ms^2 + (P+b)s + I} \quad (7)$$

The benefit of having an integral component is its ability to eliminate steady-state errors without using extremely large gains. Applying the final-value theorem, the steady-state error to a step command,  $\lim_{s \rightarrow 0} s e(s) = \frac{1}{I}$ , becomes:

$$e_{ss} = 0 \quad (8)$$

However, integral gain also has its drawbacks. We can use a root locus to plot the closed-loop poles as a function of increasing I (while holding P constant), as shown in Figure 3 (hint: rearrange the characteristic equation to get  $1 + \frac{I}{ms^2 + (P+b)s} = 0$ ). The locus suggests that using integral control can

create oscillations by moving the poles off the real axis. Therefore, the value of I must be chosen with care.



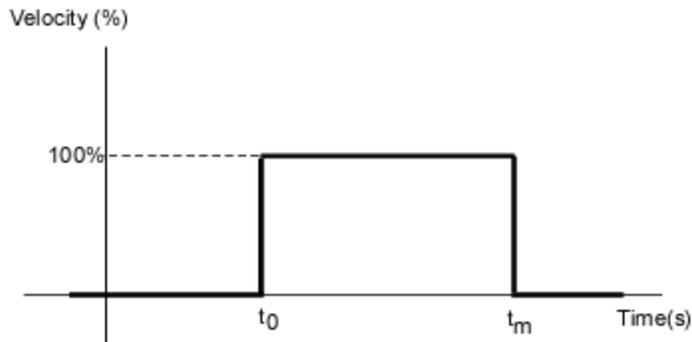
**Figure 3: Root Locus for PI Control**

***Lab Tasks:***

The goals of this lab are to tune the PI controller gains to track a) a desired velocity profile, and b) track the same velocity profile but at the same time, minimize the payload swing.

Desired Velocity Profile:

The shape of the desired velocity profile is shown in Figure 4. The desired profiles are the same for the trolley and bridge axis. The desired move time for both axes,  $t_m$ , is 1s.



**Figure 4: Desired Velocity Profile.**

Part 1: Tracking the Desired Velocity Profile

This is a qualitative, non-exact process to tune the gains. In each case, try to find the best gains using only 5 trials.

1. **Trolley** axis/direction
  - a. Using zero I gain, optimize the P gain to achieve the best tracking of the desired velocity profile. **The P gain must lie between 0.001 and 0.700.** Set suspension length to **100 cm** (**measured** from center of hoist drum to center of payload).
  - b. Using the optimized P gain from 1.a, find the optimal I gain to achieve the best trajectory tracking. **The ‘I gain’, the inverse of the reset time (see Lab Procedure), must lie between 0.05 and 1000.**

## Part 2: Minimizing Payload Oscillation While Still Tracking the Desired Velocity Profile

This is a qualitative, non-exact process to tune the gains. In each case, try to find the best gains using only **5** trials. This part only involves moving in the trolley axis/direction. Try to make the trolley follow the desired velocity profile, but **prioritize minimizing the residual payload oscillation**. That is, sacrificing the velocity following performance to reduce residual swing amplitude.

1. Find the optimal P and I gains with the suspension length set to **100 cm** (measured from center of hoist drum to center of payload). You may use the data from 1a to determine the appropriate P gain.
2. Without changing the gains from step 1, repeat the same movement but change the suspension length to **60cm, 80cm, and 120cm** (Use the buttons on the big yellow pendent on the table and measure the height with a tape measure.)
3. Without changing the gains from step 1, repeat using the same suspension length (100cm) but vary the velocity profile. Use  $t_m = 0.7s, 1.3s, \text{ and } 1.6s$ .

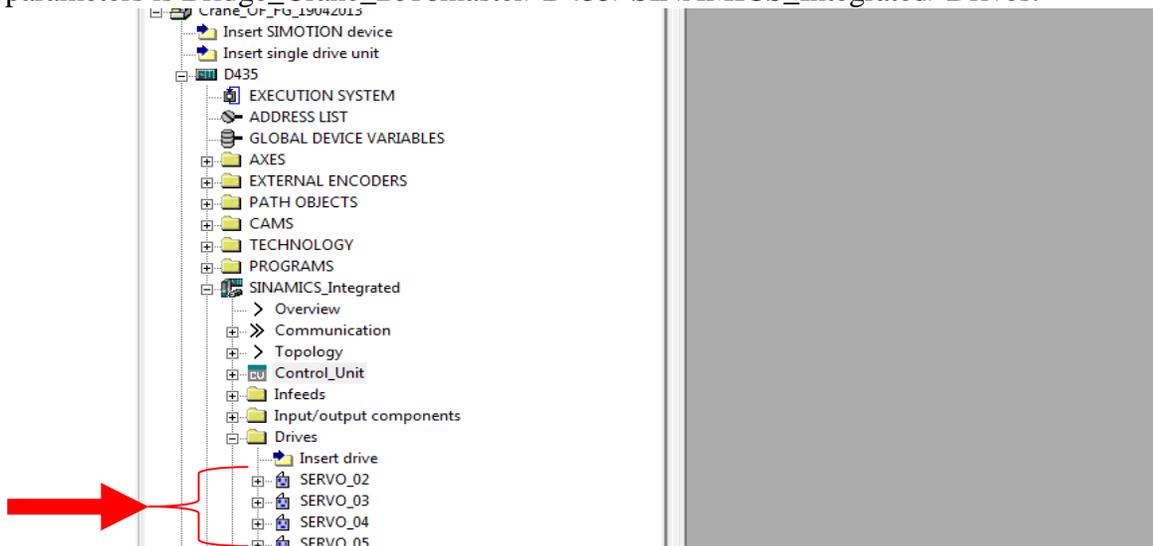
## **Lab Procedure:**

### Executing the Velocity Profiles:

Use the same procedure from Lab 1A to execute the velocity profiles. Design the appropriate “Pulse” velocity profile. Recall that even though you want the crane to produce a pulse in velocity, due to inertia and actuator limits, the actual velocity will resemble a trapezoid.

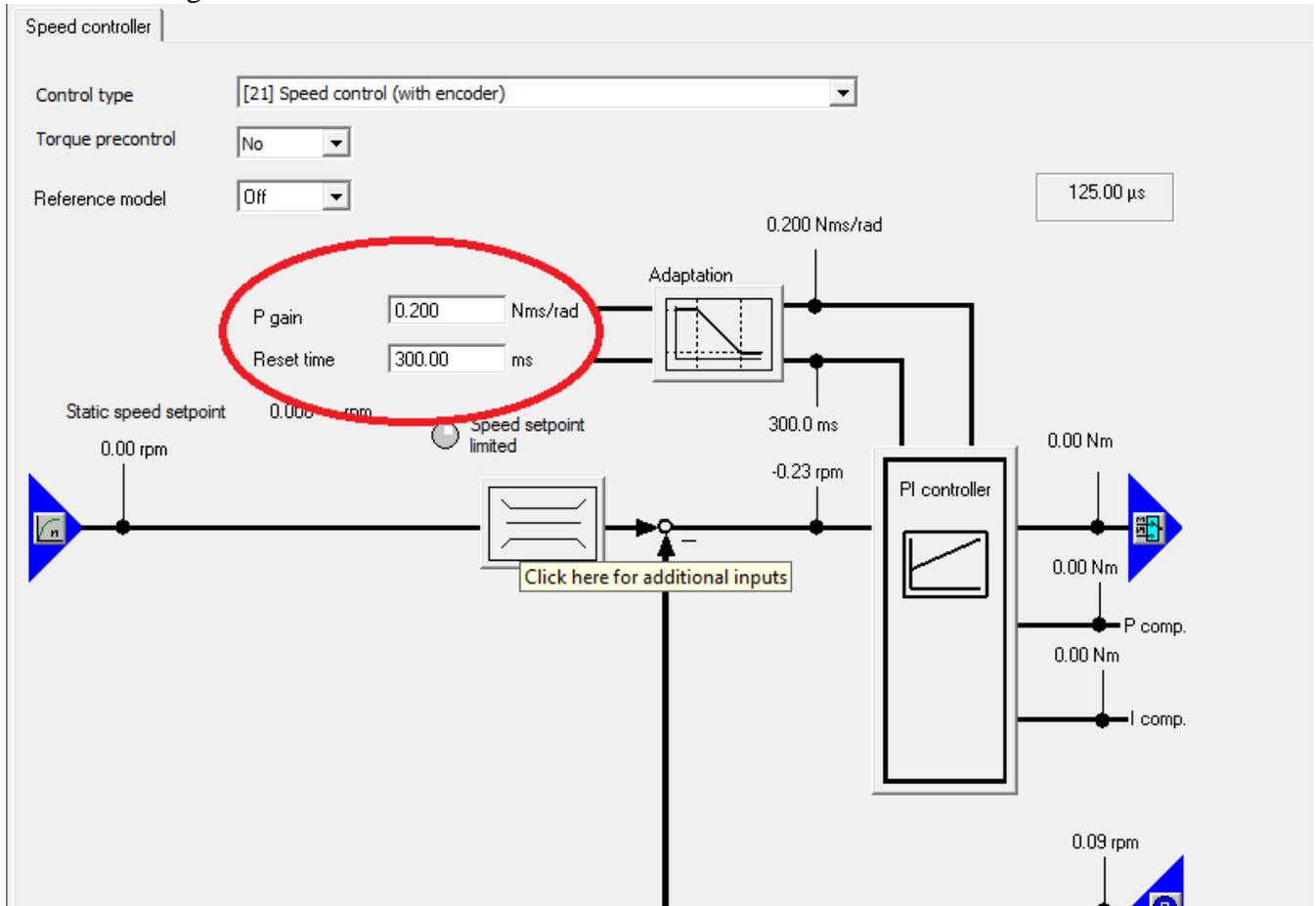
### Modifying P and I Gains:

1. Before you begin, make sure you have opened the Bridge Crane GUI. There is a shortcut link on the desktop.
2. Click on Simotion Scout shortcut link on the desktop.
3. If the “Bridge\_Crane\_2016master” is not already open, go to Project>Open>... The project you should be using is the “Bridge\_Crane\_2016master” found on storage path C:\Program Files\Siemens\Step7\s7\Bridge3 **IMPORTANT: make sure to have the correct project open under the correct path or else the lab will not work**
4. In the navigational pane, navigate to the drive parameters (they are separate for the bridge, SERVO\_02 and SERVO\_03, and trolley, SERVO\_04) as shown in Figure 5. The path to the drive parameters is Bridge\_Crane\_2016master>D435>SINAMICS\_Integrated>Drives.



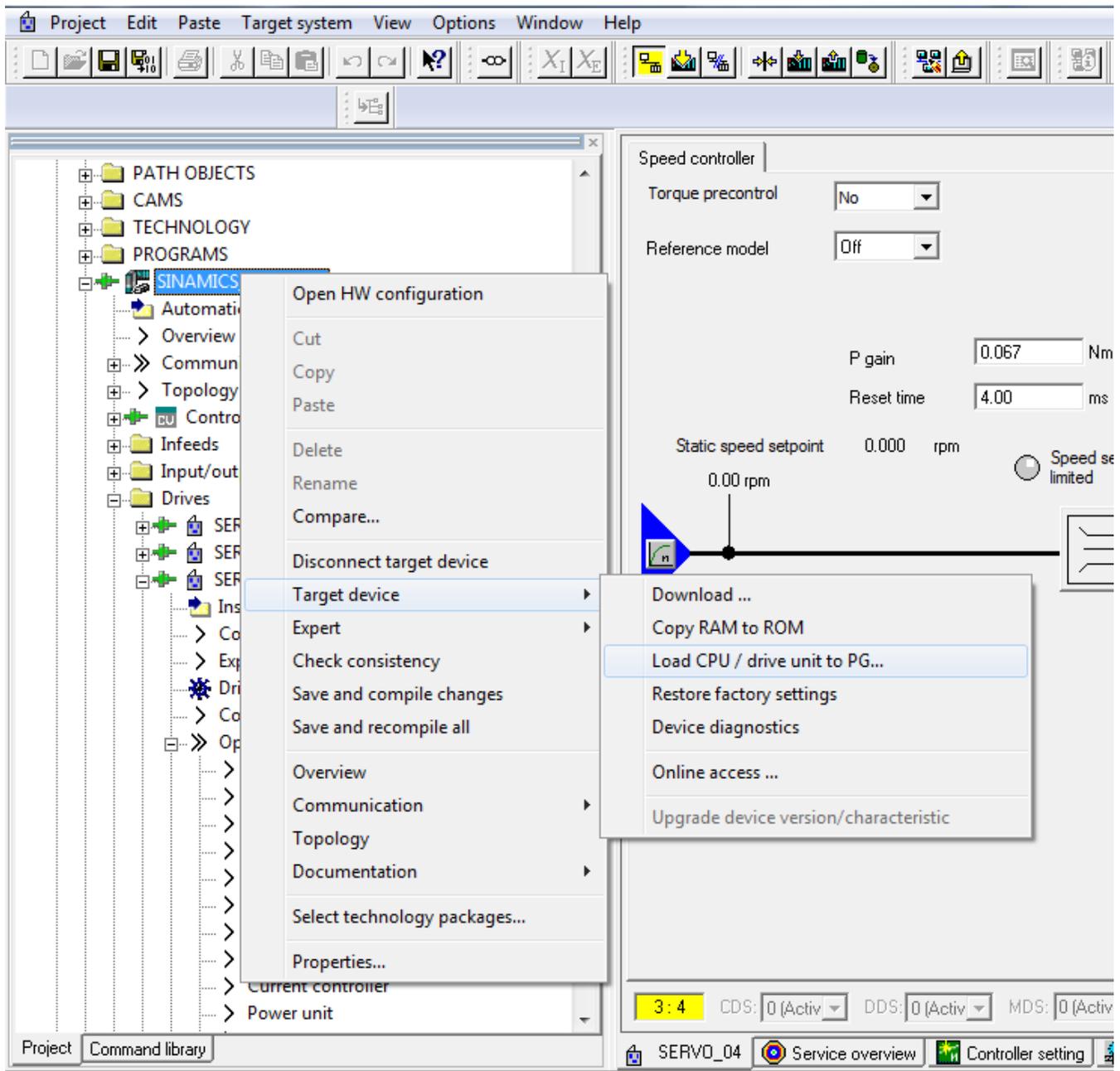
**Figure 5: Simotion Scout**

5. Drill down on the drive parameters for Servos 2, 3 and 4 to Open-loop/closed-loop control and then double click on speed controller to open the Drive Monitor. Motor control gains and reset times are as shown in Figure 6.



**Figure 6: Drive Monitor**

6. **This step is important! Click “Project” in the menu bar and then select Connect to selected target devices option. This allows you to change the gains**
7. The P and I gains are P gain and Reset Time, respectively. Edit them in this window and change them in the PLC by right clicking on SINAMICS\_Integrated>> Target Device>> Load CPU/drive unit to PG. After this is done right clicking on SINAMICS\_Integrated>> Target Device>> Copy RAM to ROM. Now the values should be changed in the PLC. See figure 7 for the proper menu to update.
8. To change the gains for the trolley please update SERVO\_04.



**Figure 7: Procedure to set gains**

9. Reset Time has units in milliseconds and is the **inverse** of the I gain. The lower the value of the Reset time, the higher the integral action, and vice versa. The only exception is when it is set to zero, in which case there will be no integral action.
10. Sometimes, setting aggressive gains will cause the motor to squeak very loudly. This is normal. Calmly set the gains back to a more conservative value.
11. **When you are finished, set the gains back to their default values. Save the gains as you did before and keep the program open for other teams.**

Trolley drive default gains:      **P Gain = 0.067**      **Reset Time = 4ms**

Procedure for Data Collection:

1. Use the same procedure from Lab 1A to record data.
2. Click “**Get Data**” on **Desktop GUI** to update the data file in C:\BridgeCraneData\Download\vba EDIT Process the data as you see fit. Use only the *Actual Velocity*, *Command Velocity*, and *Deflection* columns for this lab.
3. Note that for the velocity data is in mm/s.
4. You will need manually plot the desired velocity profile and overlay on top of the recorded actual velocity data.

*Lab Report (One per Team):*

Present your work and prove that you have met the objectives using **less than 3 pages of text** (not including Figures). Your report should include the following:

Begin with an introduction that briefly describes the goals of the lab. Then, include and explain the results from the two parts of the lab.

Part 1:

1. Compare the desired velocity profile with the actual velocity profile for the various gains tested, in both the bridge and trolley directions. How you present this data is up to you. Think about a fair and meaningful way to compare error (e.g. graphical plots, mean absolute error).
2. Report the optimal PI gains you chose for trajectory tracking and justify them using the reported data. Show the desired trajectory, actual trajectory, and error for these gains. Also discuss any other observations made.

Part 2:

3. Plot and compare the amplitude of the residual payload oscillations for the various gains tested.
4. Report the optimal PI gains you chose for reducing payload oscillation. How do they compare to the optimal PI gains from Part 1? What disadvantages are there in using these gains?
5. What effect did changing the suspension length have on the performance of the gains you have selected? Comment and make observations. Use appropriate plots.
6. What effect did changing the velocity profile have on the performance of the gains you have selected? Comment and make observations. Use appropriate plots.

End the report with a brief conclusion.

**You should think carefully about the plots that you include in your report – these must be neat, clear, non-redundant, and convey the desired message in an efficient manner. Furthermore, in the text, you should comment appropriately on the plots (which must be appropriately placed in the text) and say what is significant about them.**

**The report is due at the beginning of the lab on September 9.**