

ME6404 - Fall 2009

Lab 3

I. Input Shaping on the Portable Bridge Crane

Background:

In previous labs we examined point-to-point motion by commanding the crane to follow a trapezoidal velocity profile. Through the proper selection of PI gains, the trolley and bridge were able to follow such a trajectory. However, the payload usually had large oscillations at the end of the motion. The only way to decrease such oscillations was to use very low gains. But with low gains, the system had large amounts of error and could no longer track the desired trajectory. Furthermore, using low gains yielded a slow crane response. The question we wish to answer is: can we move the crane quickly while at the same time minimize residual oscillations?

In class we have seen that input shaping can be used to eliminate swing in systems with oscillating modes. If input-shaped commands are implemented on the crane, then we are free to increase the system gains to reduce the tracking error. Therefore, with input shaping we can achieve accurate trajectory following and point-to-point motion without the cost of increased oscillation. In class we have seen that oscillation amplitude is affected by move distance for unshaped commands. Therefore, we must wonder if payload swing is affected by move distance for shaped commands.

In this lab you will observe the benefits of input shaping first hand and do a qualitative comparison between shaped and unshaped point-to-point moves. We will also address how input shaping is affected by variations in move distance and the system frequency.

Objectives:

1. Use input shaping to move a suspended payload in a point-to-point motion with low vibration.
2. Compare the effect of move distance on shaped and unshaped commands.
3. Compare the effect of frequency changes on various input shapers.

Lab Procedure:

In this lab you will only need to use one axis (trolley or bridge – your choice). By now you should be very familiar with the portable bridge crane GUI. You should also know (explained in lab sessions) that when you selected “no shaper stop” and held down a directional button, the controller is convolving the velocity signal (corresponding to the button held down), with the impulse function specified by “no shaper stop”. This convolution results in the trapezoidal velocity profile used extensively in labs 1 and 2.

You will use the same idea for this lab. Figure 1 shows the result of the convolution between a step velocity signal (holding down the button) and the impulse function specified by *NO SHAPER STOP*. This contains two impulses: 100% at time =0, and -100% at time = t_f . The -100% impulse is necessary to bring the crane to a stop. You can see that it generates the familiar trapezoidal velocity profile. You can appreciate that the negative impulse at t_f serves the purpose to move the crane accurately and consistently for a set move distance, when a directional button is held down.

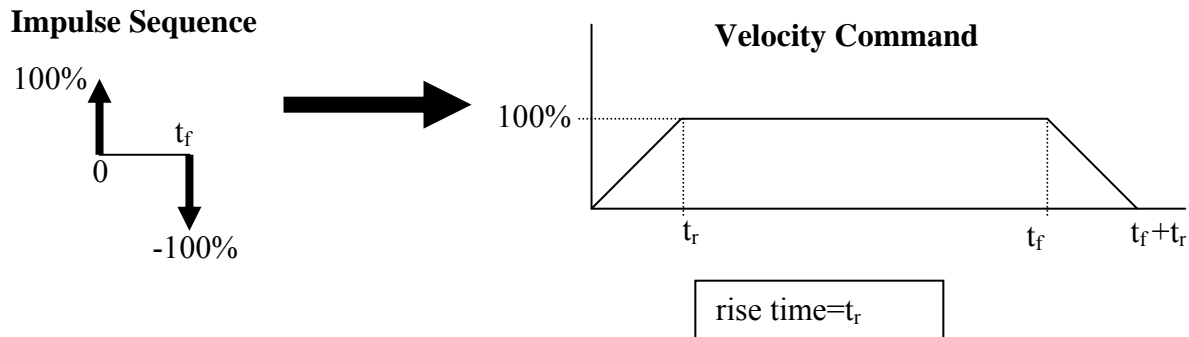


Figure 1: Convolution Result for No Shaper Stop

If we wish to move for roughly the same distance, but now using a shaper, we would do something very similar. Figure 2 shows this idea for the ZV shaper. You should recognize that the ZV shaper (with no damping) contains two 50% impulses, one at time = 0, and the other at time = t_2 . To bring the crane to a stop, we use the same idea of using negated ZV impulses at t_f as shown in Figure 2. A ZV shaper normally contains two impulses, but since we want to bring it to a stop, the total number of impulses is doubled.

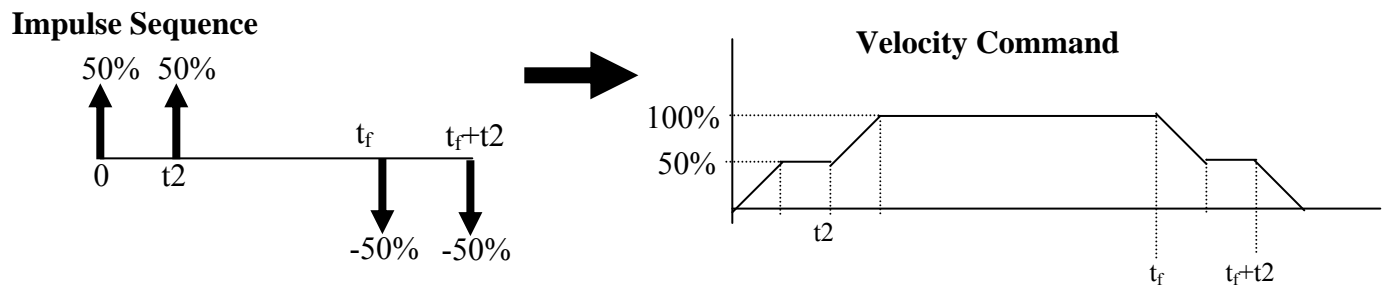


Figure 2: Convolution Result for a ZV Shaper Stop

The process of replicating this on the Portable bridge crane GUI is an extension of what you already know. Figure 3 shows the shaper design interface of the GUI.

- For this lab, you should use only “*NO SHAPER STOP*” and any of the five “*CUSTOM SHAPERS*” available in the drop down menu (A).
- Click “**Show**” (B) to display the shaper.
- You can modify the number of impulses using (D).
- Use (E) to modify the amplitudes of the impulses. Use (F) to modify the times at which those impulses occur. Remember that the first impulse should occur at time = 0. Also remember that to bring the crane to a stop, the last n impulses on and after t_f should be the negated versions of the first n impulses before t_f .
- The graphical representation will reflect the shaper that you have designed. When you are ready, save (C) your shaper into memory, and then in the main window select the appropriate shaper from the drop down box and click on the green button next to it to activate it.

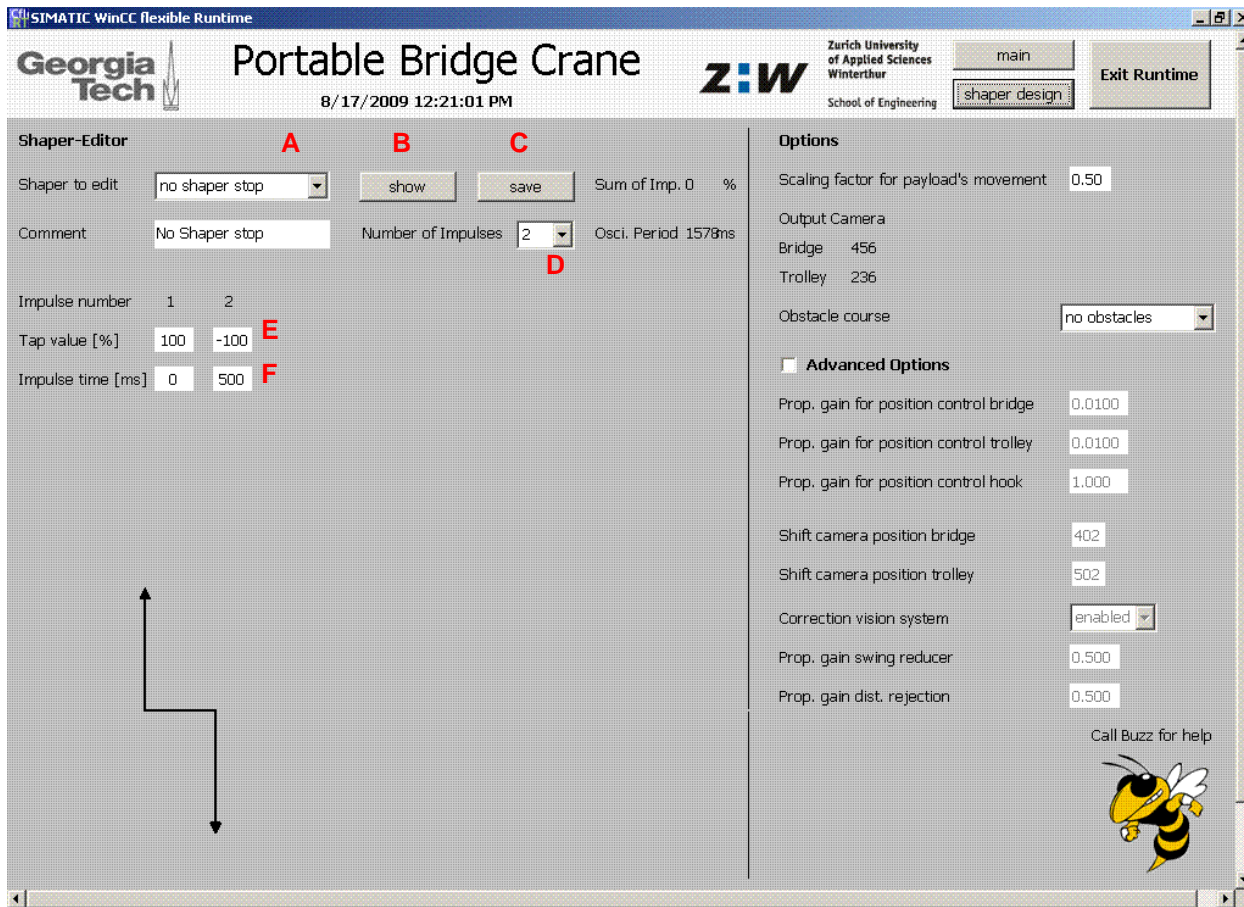


Figure 3: Shaper Design Interface

Lab Tasks:

Part A:

Compare the effect of move distances on input shaping

1. Move the crane three different distances using $t_f = 900\text{ms}$, 1200ms , and 1800ms . Use *NO SHAPER STOP*, with the crane moving at 100% speed. The cable length should be **0.8m**.
2. Repeat step 1 using a *ZV Shaper of your own design* that you think will best minimize the amplitude of residual oscillation. You may wish to account for damping. Use one of the “**Custom Shapers**” selections available in the drop down menu to design your shaper. The cable length should be **0.8m**.

Part B:

Compare the robustness of input shaping under frequency variation

1. Move the crane using one move distance, use $t_f = 1500\text{ms}$. Do this for cable lengths **0.8m and 1.2m**. Use *NO SHAPER STOP*.
2. Repeat step 1 using a *ZV Shaper of your own design* that you think will best minimize the COMBINED amplitude of residual oscillation for BOTH CABLE LENGTHS (calculate this with $\text{max_amp_L1} + \text{max_amp_L2}$). You may wish to account for damping. Again, move for

the same distance twice, using cable lengths **0.8 and 1.2m**. Use one of the “**Custom Shapers**” selections available in the drop down menu to design your shaper.

3. Repeat step 1 using a different shaper (UMZV, EI, ZVD, ZVDD, etc) of your own choosing and design that you think will best minimize the COMBINED amplitude of residual oscillation for BOTH CABLE LENGTHS (calculate this with $\text{max_amp_L1} + \text{max_amp_L2}$). You may wish to account for damping. Again, move for the same distance twice, using cable lengths **0.8 and 1.2m**. Use one of the “**Custom Shapers**” selections available in the drop down menu to design your shaper.

II. Control of the Mobile Boom Crane

Background:

So far in Lab 3, you have designed input-shapers for the portable bridge crane. In this part, you will design a ZV-shaper for the mobile boom crane. What makes this different than shaping the bridge crane is the use of the slewing motion of the boom crane. This motion is rotational and unlike the trolley and bridge axes studies before, causes payload oscillation in both the radial (x) and the tangential (y) directions. Due to the rotation, centripetal forces will be introduced to the equation of motion, making the dynamics of the system nonlinear and more complicated.

In this part, you will observe the benefits of input shaping first hand and do a comparison between shaped and unshaped point-to-point moves for rotational motion.

Objectives:

1. Use input shaping to move a suspended payload in a point-to-point rotational motion with low vibration. Compare the effectiveness of unshaped and ZV-shaped commands.
2. Quantitatively analyze the effectiveness of input-shaping on the slewing motion.
3. Familiarize yourself with mobile boom crane controls.

Note:

Detailed operational instructions on the mobile boom crane can be found in the Appendix. Make sure you are familiar with the Mobile Boom Crane before you start this part of Lab 3.

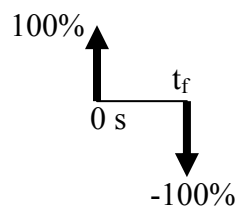
Lab Procedure:

You will only be moving the slewing axis. To perform the various trials you will need to change the command and upload it to the PLC. The values you will be entering create an impulse sequence that the PLC convolves with the button input. Similar to the portable bridge crane, we want to force the slewing base to move for a time, t_f , and then stop while the slewing button is held down (even if the button is held down longer than t_f). However, on the mobile boom crane the procedure for doing this is slightly different.

Lab Tasks:

Part A:

Measure the vibration for unshaped slewing using a payload suspension length of **1.2 m**. Use the following impulse sequence:



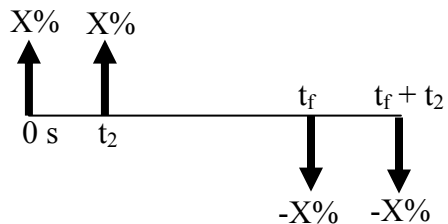
Slew for a time $t_f = 1500$ ms.

- A. Use DB6 (NOSHAPE_STOP) to program this impulse sequence.
 - a. Open SIMATIC Manager from the Desktop.

- b. If you see a blank screen, click on file>open. In the screen that pops open, select the file called BoomCrane_ME6404.
 - c. In the left hand menu, click on the plus signs of the following items in order: BoomCrane_ME6404>SIMATIC300(1)>CPU 317T-2 DP>S7 Program(1)>Blocks.
 - d. From the items on the right side, locate and double click on DB6.
 - e. Click on view>Data View. You can now change the program to your impulse sequence. The first two values should NOT be changed. The third value is t_f , the fourth and fifth values are the impulse percentage values. Note that all times must be entered in milliseconds!
 - f. Once you have programmed your impulse sequence, download it to the PLC by clicking PLC>Download.
 - g. Minimize SIMATIC Manager and proceed.
- B. Select No Shaper on the GUI interface and position the upper cart so that is aligned with the lower cart and the boom is facing the front of the lower cart. You can also manually do this. Press the “Stop” button. Position the upper base to the start position. Press the “Start” button.
 - C. Set the luffing angle to 60 degrees using the Up/Down buttons.
 - D. Set the cable length to 1.2 meters using the Hoist Up/Hoist Down buttons.
 - E. Select No Shape_Stop on the GUI interface.
 - F. Press Record.
 - G. Press and HOLD the Slew CCW button. Hold until 4-5 cycles of the payload swing are completed. Then release the button.
 - H. Press the STOP button.
 - I. Download the data using the Download button.

Part B:

Measure the vibration for ZV-shaped slewing using a payload length of **1.2 m**. Use the following impulse sequence. Note that you have to obtain the value of X (≤ 100) and t_2 (>0) for a ZV-shaper of your own design:



Slew for a time $t_f = 1500$ ms.

- A. Use DB9 (ZV_STOP) to program this impulse sequence
 - a. Follow the same procedure as part 1 but use DB9.
 - b. In Data View, the first two values should NOT be changed again. The third value is t_2 , the fourth value is t_f , and the fifth value is $t_f + t_2$. The last four values are the impulse percentage values. Note that all times must be entered in milliseconds!
 - c. Don't forget to download the updated DB9 into the PLC.
- B. Select No Shaper on the GUI interface and position the upper cart so that is aligned with the lower cart and the boom is facing the front of the lower cart. You can also manually do this. Press the “Stop” button. Position the upper base to the start position. Press the “Start” button.

- C. Set the luffing angle to 60 degrees using the Up/Down buttons.
- D. Set the cable length to 1.2 meters using the Hoist Up/Hoist Down buttons.
- E. Select ZV_Stop on the GUI interface.
- F. Press Record.
- G. Press and HOLD the Slew CCW button. Hold until 4-5 cycles of the payload swing are completed. Then release the button.
- H. Press the STOP button.
- I. Download the data using the Download button.

Lab Report (One per team):

Portable bridge crane:

Part A:

Quantitatively compare the residual oscillations of no shaping with ZV shaping for all distances.

Explain any trends in the data and make reasonable conclusions. You MUST JUSTIFY and EXPLAIN your design for the ZV shaper. Include appropriate and relevant plots.

Part B:

Quantitatively compare the residual oscillations of no shaping with ZV shaping for all cable lengths.

Explain any trends in the data and make reasonable conclusions. You MUST JUSTIFY and EXPLAIN your selection and design of the ZV and other-shaper that you used. Include appropriate and relevant plots.

Mobile Boom crane:

Quantitatively compare the residual oscillations of no shaping with ZV shaping. Explain any trends in the data and make reasonable conclusions. You MUST JUSTIFY and EXPLAIN your design for the ZV shaper. Include appropriate and relevant plots.

The total report should be **less than 3 pages of text**. Put all of the supporting figures at the end of the report, referring to them in the text in sequential order - Figure 1, Figure 2, etc.

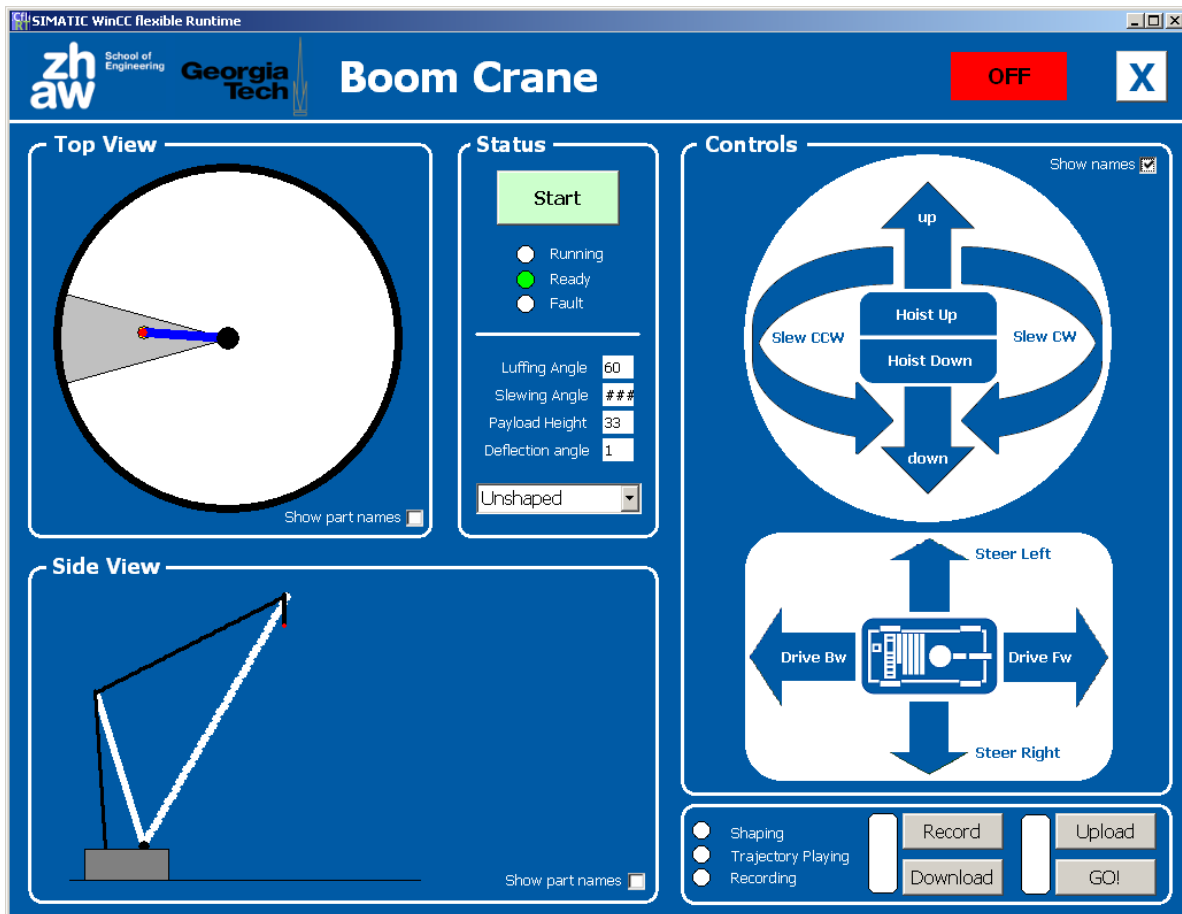
You should think carefully about the plots that you include in your report – these must be neat, clear, and convey the desired message in an efficient manner. Furthermore, in the text, you should comment appropriately on the plots and say what is significant about them.

Appendix

Boom Crane Operation

Starting the WinCC Boom Crane GUI:

Open the control GUI by double clicking “Boom Crane_ ME6404” on the desktop. You will see the GUI shown below.



Basic Crane Operation:

1. In the middle box labeled Status is the “Start” button. **Push the “Start” button** to turn on the power. Notice that the indicator below this button has moved from “Ready” to “Running,” the “Start” button has changed to “Stop,” and the red “OFF” button in the top right has changed to a green “ON” button. If you ever need to execute an emergency stop, push the “Stop” button.
2. Beneath the “Start/Stop” button is the “Shaper” selection box. **Select Unshaped.** In future labs you may need to select various Input Shapers (e.g. ZV, ZVD, etc.) using this menu.
3. The crane is controlled using the directional buttons on right side of the screen. “Hoist Up” and “Hoist Down” will raise and lower the payload. “Slew CW” and “Slew CCW” will rotate the upper base of the crane clockwise and counter-clockwise, respectively. “Up” and “Down” will luff the boom upward and downward. “Drive Fw” and “Drive Bw” will move the crane forward and backward. “Steer Left” and “Steer Right” will steer the front wheels of the crane

left and right. **Experiment with moving the crane now.** DO NOT use the Drive or Steer buttons as there is not enough room in the lab.

4. As you move the crane notice that the top and side views on the left hand side of the GUI show real-time animations of the crane's configuration. The yellow circle is the tip of the boom; the red dot is the payload's location.
5. As you move the crane, also notice the position information indicated at the bottom of the Status box. This shows the luffing angle, the slewing angle, the payload height, and the deflection angle.

IMPORTANT:

There are software limits set for all three axes of motion; however, DO NOT attempt to luff below 30 degrees or above 70 degrees. DO NOT slew beyond 90 degrees in the CW or CCW directions. Also notice that luffing the boom results in a change in payload height. If the payload height reaches limits at the top or bottom (or if any of the other limits are hit) the GUI will not allow further motion unless it is in the opposite direction.

Record and Play Buttons:

1. In the bottom right of the screen are the "Record/Download" and "Upload/Go!" buttons.
2. The "Play" button is used to automate the crane. A series of velocity set-points can be created in specific *.csv files and uploaded to the crane using the "Upload" button. The set-points can be played back automatically using the "Go!" button.
3. The "Record" button will be used in every lab. It is used to record the position data of the crane and payload.
4. **Push the "record" button now.** You will notice that the recording light turns on. After the recording time has reached its limit, it will automatically stop. The sampling rate is 40 ms. You can manually stop the recording before it reaches the limit by pushing the recording button again. **Push the record button now to stop recording.**
5. After you finish recording, the data must be downloaded to the computer. This is accomplished by pushing the "Download" button. A total of 6 channels are downloaded. Each set of data is placed in a specific file in the following location: D:\Download\vba. The file names are Input1 through input6. Note that if the download is completed, the indicator to the left of the "Download" button will remain a solid green color.